TMOS

2023 ANNUAL REPORT

New discoveries through collaboration

Contents

Centre

Message from the Director

At the ARC Centre of Excellence for Transformative Meta-Optical Systems, 2023 was a year of remarkable achievements. It was a year full of enthusiasm to excel in our collaboration activities without the constraints of Zoom and lockdowns.

Collaborations lie at the heart of a Centre of Excellence, serving as its lifeblood and its driving force for innovation and success. Within TMOS, expert engineers, physicists and entrepreneurs converge to push boundaries and achieve research excellence. Our collaborations foster a dynamic intellectual environment with diverse perspectives, flourishing ideas, and shared knowledge. In the TMOS 2023 annual report, we feature the power of collaboration that allows us to transcend individual capabilities in research, education, equity, outreach, and translation.

A TEAM OF HIGH ACHIEVERS

I am honoured to lead the accomplished TMOS team. This year, the team's research has yielded 119 publications in major refereed journals, including prestigious titles such as Nature Photonics, Nature Nanotechnology, Advanced Materials, Nature Communications, and Light Science and Applications. I commend the efforts of our team member and research program manager, Dr. Lukas Wesemann, who has established a new startup company called MLAI Aus, with the goal of empowering AI builders in Australia. I would also like to recognize the outstanding achievements of our team members, who have received major awards in 2023, including Prof. Jagadish (Pravasi Bharatiya Samaan Award, Thomas D. Callinan Award, Fellow of Chinese Academy of Science, and Fellow of Chinese Chemical Society), Prof. Ken Crozier (Fellow Optica and Fellow of SPIE), and Prof. Sharath Sriram (Rotary International Chennai Chapter Young Achiever Award and Innovation Leader Award Finalist).

FOSTERING COLLABORATIONS AND ENGAGEMENTS

Centre-wide events flourished last year. The fortnightly online Centre seminars, Science Tuesdays, are now screened at the node hubs, allowing the students and staff from each node to get together, participate in the seminar, and exchange ideas. In addition, we have enjoyed research theme workshops, an in-person ECR & Student conference at Kioloa and, of course, the annual TMOS Conference, which took place at Tangalooma Island Resort in Queensland. More than 100 people attended the annual conference, which combined team-building and networking activities together with a top-notch scientific and educational program. Many of our international collaborators also joined the TMOS team at this conference. The Centre's achievements were praised by the members of the Centre Advisory Board and the International Scientific Advisory Committee, who also provided constructive feedback for future development.

In 2023, we increased our external engagement as well as cross-node collaborations within the Centre. We released a major update to the TMOS website, which includes excellent educational information about meta-optics and its applications. Additionally, the website provides detailed information about the potential impact of our research on major industry sectors, including defence, space, and the medical sectors. Our

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At TMOS, we are particularly excited to see the interest in our technology in non-traditional disciplines, such as telescope instrumentation, satellite earth observation, and gravitational wave detectors.

translational research has been presented at various research and industry conferences, leading to increased external interest and numerous discovery calls with potential industry partners.

We have also taken a proactive approach to shaping science policies at both national and international levels. Spearheaded by Chief Investigator Prof. Jagadish, President of the Australian Academy of Science, we have made submissions to several government proposals, including the national quantum strategy. We led several professional conferences, such as the In-STEM conference in Melbourne, the 2023 KOALA Student Conference in Canberra, and the 2023 ANZCOP Conference in Canberra. These activities made our Centre a major contributor to the Australian science community.

ADVANCED RESEARCH PROGRAM

The Centre's research program continues to be refined. The Centre's application-driven flagship program has emerged and with it has come increased industry and government engagement as the real-world impact of meta-optics become more tangible. The flagship program focuses on integrated devices using technology that's at a higher technology readiness level. It is not only a path for the translation of our fundamental research, but for further collaboration and higher impact.

INTERNATIONAL DEVELOPMENT OF THE FIELD

Our research development is well-aligned with major international activities. The field is fast-moving, driven by industry needs. In the past year, we have seen the emergence of multiple start-ups, a number of steadily growing companies such as Metalenz continuing to flourish, and investment in the meta-optics industry by major technology players. Major manufacturing powerhouses such as TSMC, UMC, Canon and A*Star have all taken an interest in the field. This industry growth signals a thriving field with a bright future. At TMOS, we are particularly excited to see the interest in our technology from non-traditional disciplines, such as telescope instrumentation, satellite earth observation, and gravitational wave detectors. TMOS is well-positioned to lead this development, and as we consider our future legacy, we will look to where we could have the biggest impact.

ACTIONS AND INITIATIVES FOR 2024

In 2024, we will conduct our mid-term review. During this review, we will take the time to reflect on the Centre's mission and accomplishments. We will assess how we can improve and focus our efforts for the second half of the Centre. We will compare ourselves to international development standards, while also considering the needs of our staff and students at TMOS. We want to ensure that we provide the best support for their career paths. We will enhance our Centre training and provide project management training to our research and flagship managers, as well as key Centre personnel to further advance the translational program of the Centre and maximise its engagement and impact.

I am most excited about what we can achieve in 2024. I am eager to work alongside the TMOS team to ensure that our research is recognized and impactful.

Prof. Dragomir Neshev
Centre Director

OUR VISION

The Australian Research Council Centre of Excellence for Transformative Meta-Optical Systems (TMOS) will develop the next generation of miniaturised optical systems with functionalities beyond what is conceivable today.

By harnessing the disruptive concept of meta-optics, we will overcome complex challenges in light generation, manipulation and detection at the nanoscale. Our research outcomes will underpin future technologies, including real-time holographic displays, artificial vision for autonomous systems to see the invisible, wearable medical devices and ultra-fast light-based Wi-Fi, meeting the evolving demands of Industry 4.0.

OUR MISSION

We will become a trans-disciplinary team of world leaders in science, technology, and engineering to deliver scientific innovations in optical systems.

We will translate research into innovative technologies in transport, health, security, defence, agriculture, entertainment and education with significant benefit to society and economic growth.

We will prepare outstanding innovators from diverse backgrounds to be future leaders for decades to come.

OUR VALUES

COLLABORATION

We work together to make a team culture that is inclusive, values diversity, strives for equity, and accessibility (you get the IDEA!) so that everyone can participate.

EDUCATION

We embrace learning and failing forward, gaining insight from each iteration of our experiments, processes and beyond.

DISCOVERY

We do research at the highest international level as an interdisciplinary team. We make the unknown knowable through the pursuit of fundamental science.

INNOVATION

We have a passion for technology innovation due to the positive impact it has on the world. Our science has a purpose.

ENGAGEMENT

Internally, we connect with each other, celebrating our wins and creating a fun and safe workplace. Externally, we engage with partners and the public to share the joy of science, and to translate our research into novel technologies.

Message from the Centre Advisory Board

TMOS has completed its third full year of operation, and its research and community continue to evolve, working towards a significant impact in its contributions to our global understanding of meta-optics and Australia's future economic prosperity.

As we look ahead, scientists around the country are making the case for increased investment in fundamental scientific research and updates to Australia's National Research Priorities to take us into the future. ARC Centres of Excellence stand as an excellent example of the impact homegrown talent can have.

The ARC Centres of Excellence scheme contributes to Australia's global competitive strength in research and provides a strong example of the necessity of government support for research, broadly.

In 2024, TMOS Chief Investigator Prof. Sharath Sriram will take up the key advocacy role of President of Science and Technology Australia. In his recent address to the National Press Club he stated that Australia's spending on research and development (R&D) as a percentage of GDP has been declining for over a decade, now standing at only 1.6% of GDP, well below the OECD average of 2.7%. We are both calling for significant change so that Australia can maintain a competitive edge in global R&D.

Foundational research underpins all scientific endeavours and has historically led to significant technological, social, and economic benefits. Increased investment in fundamental research allows for the exploration of novel concepts and technologies, leading to ground-breaking innovations.

Failure to increase this investment in research could have dire consequences for the Australian society and leave Australia reliant on other countries for solutions to technology and security challenges.

TMOS is pushing the boundaries of optical science and engineering and is positioned to maximise opportunity in key areas of sovereign capability such as optical communication and sensing.

Collaboration is key to unlocking the full potential of these opportunities. TMOS exemplifies the forward-thinking multidisciplinary research environment that is necessary to address national and global challenges. As TMOS has matured as a research entity, it has taken strides in its strategic engagement to influence policy by using key appointments and formal submissions, such as its submission to the national quantum strategy.

> “TMOS exemplifies the forward-thinking multidisciplinary research environment that is necessary to address national and global challenges.

Chief Investigator Prof. Chennupati Jagadish is another strong advocate for government support of Australian Research. In his capacity as President of the Australian Academy of Science, he noted, “We also want policy makers and governments to intensify their use of expertise to inform decision making. Science should be heard wherever and whenever decisions are made – in our parliaments, boardrooms, courts of law and in the public square.”

The researchers of TMOS have an important role in communicating the impact of the Centre's research. Every effort to communicate their work with the public and each other contributes to a larger conversation that shapes the future, including investment in research. Public investment in science reflects societal priorities. By engaging with the public and policymakers, we can demonstrate how scientific evidence informs decision-making and influences progress.

In 2023, TMOS developed a front facing program to demonstrate its translational value and applications to industry and government. In addition to various submissions to government policy development, including the national quantum strategy, these activities map a pathway to impact which will lay the foundations for a strong legacy.

I urge all members of TMOS to invest in collaboration and communication from the outset. By sharing your discoveries with the world, you can amplify the impact and pave the way for continued investment in science and advancements in innovation and drive meaningful change for years to come.

Ian Chubb AC FAA FTSE

Chairman of the Centre Advisory Board

Message from the International Scientific Advisory Committee

In 2023, I had the honor of celebrating my 20th anniversary at Harvard University. As part of this major career milestone, I was contacted by group members past and present, and it gave me the opportunity to reflect on some of the most significant collaborations of my lifetime.

Supervising PhD students has given me the opportunity to mentor and guide emerging researchers, an element of my career that I deeply cherish. In exchange for my guidance, expertise, and feedback, they have given me fresh perspectives, new ideas, and enthusiastic reminders that what we do is exciting and impactful.

I am grateful that my relationships have continued past my students' time with me. The Capasso Group network of alumni has resulted in research collaborations that have significantly impacted several fields of study. I have also been lucky to continue working alongside some of them.

Nanfang Yu, who was my student and is now a professor at Columbia University City of New York, was one of my earliest collaborators. Before meta-optics was an established field, Jim Anderson, a leading atmospheric chemist, asked me if I had a way to eliminate the bulky lens in front of the quantum cascade laser (QCL) housed in the tight space of a drone searching for methane emissions. That question led Nanfang and I to design a flat contact lens for the QCL. This is what got us started in flat optics!

I also founded Metalenz, a meta-optics related start-up, alongside my student Rob Devlin, who is now the CEO! Talented researchers at the beginning of their careers have opportunities to take fundamental research into real-world impact and I enjoy watching that journey, and supporting it in all the ways I can.

To all the students of TMOS, in this ever-evolving landscape of science and technology, your contributions are valuable. They contribute to the pool of knowledge that will address pressing global issues and enrich the lives of people worldwide.

I urge you to remain steadfast in your pursuit of excellence, to embrace curiosity, and to approach challenges with resilience and determination. Remember that the knowledge and skills you acquire during your time at TMOS are powerful instruments for positive change in the world.

In particular, I want to congratulate all TMOS students who successfully defended their thesis in 2023. As you celebrate this momentous achievement, know that the wider TMOS team, including myself, takes great pride in your academic accomplishments and has every confidence that you will go forth and leave an enduring mark on the world.

Kind regards,

Prof. Federico Capasso, Harvard University
Chair, TMOS International Scientific Advisory Committee

> Talented researchers at the beginning of their careers have opportunities to take fundamental research into real-world impact and I enjoy watching that journey, and supporting it in all the ways I can.

2023 Key Moments

- JAN 2023 — Ken Crozier SPIE Fellow
- JAN 2023 — CI Prof. Jagadish Chennupati receives Pravasi Bharatiya Samman Award from President Droupadi Murmu for his contribution in Science & Technology
- JAN 2023 — TMOS recruitment initiatives included in RMIT Cygnet Award
- FEB 2023 — Student Neuton Li awarded Fulbright Future Scholarship
- MAR 2023 — CIs Lan Fu and Madhu Bhaskaran featured in Cosmos "50 women at the cutting edge of science"
- MAR 2023 — Meta-Active conference
- MAR 2023 — Student Shridhar Manjunath awarded Optics and Photonics Education Scholarship
- MAY 2023 — PI Teri Odom elected member of US National Academy of Sciences
- MAY 2023 — Presentation at Australian Space Summit
- JUN 2023 — TMOS wide women only recruitment policy approved
- JUN 2023 — Shaban Sulejman awarded SPIE Optics and Photonics Education Scholarship
- JUN 2023 — TMOS 2023 ECR/ Student conference
- JUL 2023 — Student/ECR Conference
- JUL 2023 — New website live
- JUL 2023 — Planning Day
- JUL 2023 — Daria Smirnova awarded ARC Future Fellowship
- JUL 2023 — Samara Thorn (Engagement Manager) speaks at Futures Conference
- JUL 2023 — Girls in STEM outreach at the Bendigo Discovery Centre
- AUG 2023 — Regional outreach tour to Warrnambool
- AUG 2023 — Shirty Science – Science Week competition
- SEP 2023 — inSTEM conference
- OCT 2023 — World Mental Health Day celebrations at RMIT Node
- OCT 2023 — Second women only recruitment round
- OCT 2023 — Senior STEM Engagement Program – Bankstown Girls High
- OCT 2023 — New COO
- OCT 2023 — Presentation to Defence Innovation Network
- OCT 2023 — Second round of TMOS research program manager appointments
- OCT 2023 — First TMOS Flagship Program Manager appointments
- NOV 2023 — Sharath Sriram announced as President of Science and Technology Australia (STA)
- NOV 2023 — Lorenzo Faraone elected Fellow of the Australian Institute of Physics
- NOV 2023 — Chennupati Jagadish elected as foreign member of Chinese Academy of Science
- NOV 2023 — Francesca Iopi elected Institute of Electrical and Electronics Engineers (IEEE) Fellow
- NOV 2023 — Dragomir Neshev highly cited researcher list
- NOV 2023 — Presentation and exhibit at the Military Communications and Information Systems (MilCIS) Conference, Canberra
- DEC 2023 — KOALA Conference
- DEC 2023 — ANZCOP/AIP Conference
- DEC 2023 — TMOS Meta Together Conference

Action Items for 2024

THEME 1A – GENERATE

1. Demonstration of a PT symmetric laser
2. Demonstration of coupled nanowire lasers
3. Electrically injected light-emitting metasurface
4. Development of exceptional point and topological lasers

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THEME 1B – GENERATE

1. Couple QD emissions into whispering-gallery modes of the InP micro-ring resonator
2. Enhance the nonlinear emission from 2D materials and study imaging up-conversion in LiNbO3 meta-grating
3. Develop polarization Bell states from InGaP metasurface
4. Integration of meta lens with optical fibres for quantum sensing

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THEME 2 – MANIPULATE

1. Metasurfaces utilising electro-optics
2. Metadevices utilising liquid crystals
3. Extensive characterisation of novel phase change materials
4. Reconfigurable metasurfaces with phase change materials
5. Ultrafast beam modulation
6. Nanowire metasurface integration

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THEME 3A – DETECT

1. Experimental demonstration of short infrared (SWIR) single-pixel imaging using nanomaterial-based photodetector
2. Demonstrate metasurface/ GaAsSb nanowire array single pixel polarisation imaging
3. Fabrication of a hybridised 2x2-superpixel metalens array with an MCT imaging array

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THEME 3B – DETECT

1. Experimental demonstrationof gas sensing using quasi bound mode in the continuum filters integrated with a detector array
2. Demonstrate tunability of graphene in a gated structure
3. Progress experimental demonstration of ghost imaging of transparent objects

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CENTRE EXECUTIVE COMMITTEE

1. Undertake mid-term review led by the Australian Research Council
2. Continue to drive collaborative initiatives, events, and funding to enhance impact
3. Continue to refine the research strategy and goals
4. Continue to focus on succession planning by providing leadership opportunities to all TMOS members, in particular our PhD students and early career researchers

Read the report

INDUSTRY LIAISON COMMITTEE

1. The main priority will be to develop KPIs for the flagship project selection, support and assessment of the projects, including phase-out if not successful or "promotion" outside of the Centre as a fully-fledged Linkage, CRC project with relevant industry or standalone spin-off
2. Support the flagship managers to develop their flagship programs and the linkages to relevant industry as well as facilitate mentoring by our Advisory Committee when sensible
3. Continue the internal and external mapping of existing industry, existing industry relations and mechanisms to engage with industry that is relevant to meta optics for the benefit of the whole Centre

Read the report

EDUCATION AND PROFESSIONAL DEVELOPMENT COMMITTEE

1. Coordinate professional development program based on Centre ECR and HDR's interests and needs, including the colloquium & topical workshop programs
2. Organise the 2024 Centre ECR and student mid-year conference
3. Coordinate and promote the Centre Mentorship Program via Mentorloop platform.
4. Facilitate the Centre conference program

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IDEA COMMITTEE

1. Centre wide professional development on topics not covered before such as neurodiversity
2. Run culture survey
3. Implement Women First Recruitment

Read the report

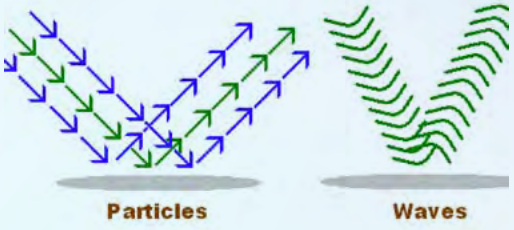
OUTREACH COMMITTEE

1. Establish Senior STEM Engagement Program across all nodes
2. Develop working prototype of Photon Clicker with Partner Organisation Questacon
3. Deliver Science Communication Training across the Centre
4. Review and update demonstrations
5. Develop new connections through education conferences and networking
6. Observe days of interest as platform for public outreach

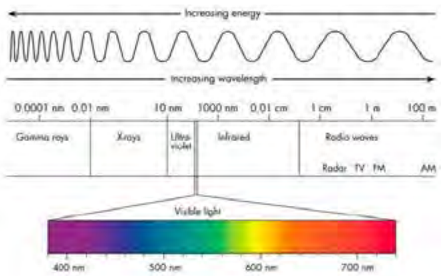
Read the report

What is light?

Light is both a wave and a particle. This is called the Quantum Theory of Light. It can bounce (reflect), bend (refract), and spread out (diffract). It can be absorbed and pass through things. Like other waves, it can interact with itself when it overlaps (interference).



Particles and wave reflected by a mirror

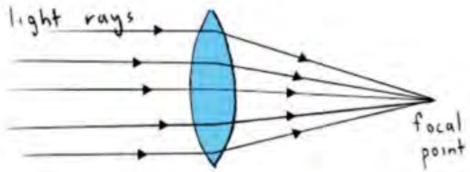


LIGHT = ENERGY

Light energy is a form of electromagnetic radiation. It comprises photons, which are produced when an object's atoms heat up. Light travels in waves. The longer the wave, the more energy it has. Light we can see is just a fraction of the light spectrum (between 450 and 800 nanometers).

WHAT DO WE KNOW ABOUT IT ALREADY?

For thousands of years, optics has revolved around the manipulation of light using a lens. Microscopes, cameras, and even your eyes all have lenses in them. Different shaped lenses created with different materials manipulate light, reflecting, refracting, and transmitting it in different ways.



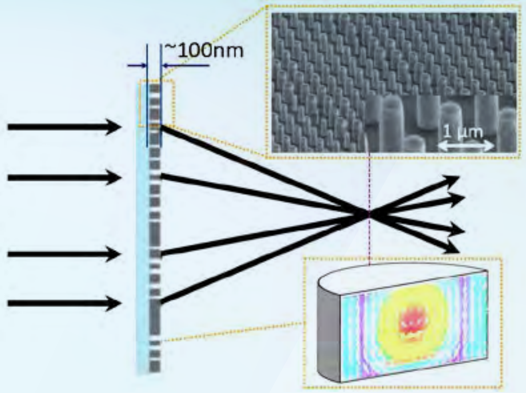
SO, WHERE'S THE PROBLEM?

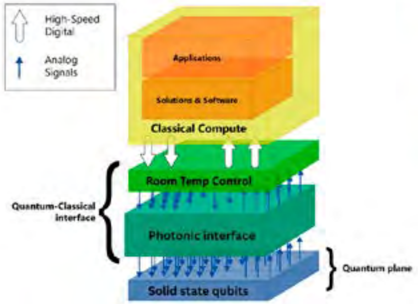
We've gotten pretty good at harnessing traditional optics to do amazing things. Fiber optics use pulses of light to transmit information, bringing us the joy that is the internet. The difficulty is that there is only so far we can push the laws of physics. The nature of light means that we've made lenses as small as they're going to get. There's no going smaller with traditional optics because light simply won't allow it.

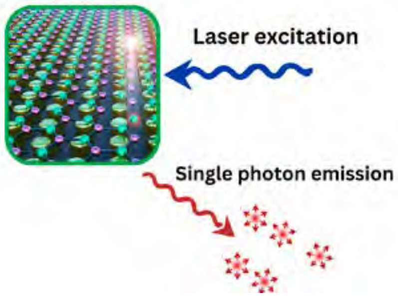
That's where meta-optics comes in...

What is meta-otpics?

Meta-optics (also known as nanophotonics) is the manipulation of light using meta-surfaces. The metasurfaces are millions of nanostructures grouped together. These nanostructures are smaller than light waves. As light passes over them, the structures can manipulate the wave, similar to how a lens does, but at a much, much, much smaller scale.







SO WHY ARE YOU TALKING ABOUT QUANTUM?

Quantum has been the next big thing in computing for a long time. In a nutshell, information is attached to sub-atomic particles and transmitted. This process relies on single photon detection and emission. The development of fully functional quantum communication technologies has been hampered by the lack of reliable quantum light sources that can encode and transmit the information. Where current quantum emitters are created using complex methods in expensive clean rooms and require cryogenic cooling, meta-optics are moving toward mass-produced emitters that work at room temperature, which will be the breakthrough quantum computing needs in order to go mainstream.

WHERE IS META-OPTICS GOING?

Because meta-surfaces are much smaller than traditional optics (only mm in size) they will be less expensive to put on drones and satellites, easier to fit into small devices and cheaper to produce in the same way an electronic chip is now. Holographic displays, night vision, wearable optical sensors, LIDAR, remote sensing and mobile medical diagnostics are just a few of the technologies to be reimagined with meta-optics.

Connect with us

INDUSTRY AND RESEARCHERS

We are interested in connecting with any researchers or potential industry partners that want to explore ways to further our research or apply it to their areas of expertise. If you're interested in having a conversation about ways we might work together, get in touch.

COMMUNITY AND EDUCATORS

The Centre is committed to the development of STEM education in Australia. If you're interested in learning more about how we support science educators through resources or in-school programs, please connect with us.

MEDIA

For all media enquiries, please contact Samara Thorn, TMOS Public Relations Specialist:

0421 276 272

NEWSLETTER

Stay up to date with the latest meta-optics news from across the globe by subscribing to our newsletter.

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@TMOS_MetaOptics

connect@tmos.org.au

Governance

Centre Executive Committee Directorate Report

2023 was an exciting year for TMOS. We made many exciting breakthroughs in the lab. Some were reported in leading scientific journals such as Nature Nanotechnology, Nature Physics, Nature Photonics, and Advanced Materials.

Others were described in outlets held in high esteem by industry. Our PhD students and early career researchers achieved great kudos. Two PhD students, for example, were awarded Fulbright Fellowships to visit the United States of America to carry out collaborative research. We had a positive impact upon science in Australia via our efforts in outreach, with numerous events at schools, libraries, and science museums. We championed inclusion, diversity, equity and access via leading by example in our recruitment practices, in our efforts to foster the careers of those from under-represented groups, and in our efforts to ensure diversity at scientific meetings. We also encouraged a broader conversation amongst the Australian scientific community by organising a major conference on this very topic. We advanced the field of photonics in Australia by taking major roles in the organisation of scientific meetings.

None of this would have been possible without the concerted efforts of TMOS members, led by the Chief Investigators. Collaborative activities like these do not come about spontaneously! How did it all happen? As discussed elsewhere in this report, much of this good work was driven by the TMOS committees. They comprise the Education and Professional Development Committee (EPD), the Inclusion, Diversity, Equity and Accessibility (IDEA) Committee, the Outreach Committee, the Industry Liaison Committee (ILC), and the Infrastructure and Capabilities Committee (ICC). They are the engine room of the Centre. They make things happen. But how to decide what should happen? That's where the Centre Executive Committee (CEC) comes in. The CEC met fortnightly in 2023 to discuss, debate, approve, improve and action TMOS activities. Here, we reflect on 2023, and discuss plans for 2024.

We are pleased to report on our 2023 Action Items:

1. Drive initiatives, events, and funding toward enhancing impact by increasing collaboration between the five nodes of the Centre;
2. Determine the research strategy and goals for the remainder of the Centre;
3. Complete the review of all Centre governance documentation ahead of the mid-term review;
4. Succession plan, inclusive of recruitment measures, to ensure a diverse meta-optics workforce beyond the life of the Centre.

In 2023 TMOS undertook various initiatives to promote collaboration and create the necessary links to build our national and international reputation in the field. By design, our theme leaders, research staff, and students work cooperatively across nodes to advance knowledge. At TMOS' outset, certain CIs had already had a long history of working together. But such individuals were often at the same node. The CEC has therefore been working hard on initiatives aimed at fostering cross-node collaborations. We are proud to have introduced the Cross-Node Exchange Award and the Partner Investigator Exchange Award schemes. These provide seed funding for travel and project costs that demonstrate collaborative approaches to solving new research problems. This seed funding is provided competitively to early career researchers and HDR students to either travel between nodes or to visit an international Partner Investigator. Our "Meta-Together" annual conference is used as a prime opportunity to develop these networks.

TMOS has provided opportunities for early career researchers to lead in this space as Research Program Managers for several years now. This creates an innovative training environment for talented ECRs as they network, coordinate, and report progress across themes as members of the CEC. In 2024 the CEC is investing in the RPMs to undertake a certification course in Project Management to supplement their academic training. This will serve to ensure our research program is cohesive, and also to equip our future workforce with the skills needed to succeed beyond the Centre environment.

The CEC made several changes to its structure in 2023. These changes aimed to provide more leadership opportunities for early career researchers and focused time to discuss research, collaboration, and management issues. The CEC has two streams, the first is the CEC – Research Meeting, of which all Research Program Managers are members. The committee oversees the Cross-Node Travel Award; the Infrastructure and Capabilities Committee; and research strategy and implementation. Importantly, the Research Program Managers have a slot every meeting for quizzing the Chief Investigators, in addition to being able to request agenda items. The CEC – Management Meeting oversees policy implementation and development, plus works on strategies that drive the TMOS operations and community through our non-research committees, for example, recruitment, culture, events, and professional development.

We are proud of our research strategy. It provides a coherent vision of meta-optics research and where TMOS can contribute for maximum impact. It also delineates between basic research (pursued via the Fundamental Research Program) and applied work (pursued via the Flagship Program). For the latter, translation to industry is fostered and overseen by the ILC. For the former, there is strong emphasis on collaborative work as a way of maximising impact. Importantly, the TMOS research program is structured to provide career development opportunities for TMOS early career researchers. This is done by appointing Flagship Program Managers, Research Program Managers and Deputy Research Program Managers. These roles are valuable career development opportunities precisely because of the trust that TMOS has placed in these individuals to guide its research program. Our success rests on their ability to formulate research and to communicate it. These are soft skills that complement the hard skills that one normally develops by doing research. Instilling these skills is one of the objectives of the research program structure, but this program is not the only way that this is achieved in TMOS. One does not need to look hard for other examples such as student-led conferences, outreach, and indeed collaborations. At TMOS, we are not only creating breakthrough science, but we are also building the human infrastructure needed for future advances in this field in Australia. This is our succession plan and will be the real legacy of TMOS.

Ahead of our mid-term review in September 2024, the CEC reviewed and confirmed the TMOS governance policies. This process was invaluable to make sure we are doing what we set out to do and provide flexibility to adjust where things were not working. The CEC views the mid-term review as further opportunity to both showcase the achievements of the Centre, and also take on feedback which will ensure that we are working in the best way possible to drive achieve the objectives of the ARC Centres of Excellence Scheme and TMOS.

In 2024 our focus is squarely on driving forward to create opportunities for our future workforce and to move our research into areas of translational capabilities.

Warmly, the Directorate Team

Professor Dragomir Neshev, Professor Ken Crozier, and Sharyn McFarlane

ACTION ITEMS FOR 2024

1. Undertake mid-term review led by the Australian Research Council
2. Continue to drive collaborative initiatives, events, and funding to enhance impact
3. Continue to refine the research strategy and goals
4. Continue to focus on succession planning by providing leadership opportunities to all TMOS members, in particular our PhD students and early career researchers

Message from the Chief Operations Officer

I joined the ARC Centre of Excellence in Transformative Meta-Optical Systems (TMOS) in October 2023. Building upon the exceptional work of my predecessor, Dr. Mary Gray, I am excited to lead the Centre into the next phase of its journey. Her foresight in governance structures, fostering diversity and inclusivity, and prioritising public engagement has positioned us well for the future.

The September 2024 mid-term review by the ARC is a crucial milestone for TMOS. We are committed to reflecting on our progress and demonstrating the Centre's impact throughout this process. We are building on our strong foundations, and are particularly focused on the following areas:

- Strengthened Research Governance: We have implemented changes to the Centre's decision-making structure, ensuring clear lines of responsibility and enhanced focus and inclusion within the executive committee.
- Enhanced Public Engagement: We have completed a comprehensive communication strategy, including a website refresh, to increase public understanding and industry engagement with our research. This strategy has yielded several discovery calls which are progressing through to more detailed discussions with investors.
- Supporting Our Talent: We are committed to retaining our research talent and fostering a diverse and inclusive work environment. We are also developing strategies to address the challenges faced by postdoctoral researchers due to the pandemic, including providing opportunities for collaboration across nodes and to partnering organisations, and access to mentoring platforms crossing several Centres of Excellence. We remain committed to diversity and inclusion, ensuring that TMOS reflects the richness and excellence of the global research community.

2023 saw the implementation of changes to several of our structures, including refining the structure of the Executive Committee meetings to allow quarantined space for research and management matters. This structure has provided a formal platform for our Research Program Managers to raise research matters directly with the Executive Committee – Research and be part of the decision making process. Likewise, our professional team is encouraged to take part in the Executive Committee – Management so that we all have a shared ownership in decisions that affect the running of the Centre.

We welcome the new Australian National University (ANU) Vice-Chancellor, Professor Genevieve Bell who has previously been engaged with TMOS on designing ethical use of emerging technologies. We also welcome Deputy Vice-Chancellor (Research), Professor Lachlan Blackhall who brings a new and exciting vision for enabling research and innovation impact at ANU. This transition of leadership at the administering organisation brings a renewed commitment to continued support for TMOS and exciting opportunities to work collaboratively to further strengthen our position and achieve even greater success.

> "Together, we will continue to push the boundaries of transformative meta-optics research and create a lasting impact on the research landscape."

I am excited to work with the entire TMOS community as we navigate the next phase of this exciting journey. Together, we will continue to push the boundaries of transformative meta-optics research and create a lasting impact on the research landscape.

Sharyn McFarlane
Chief Operating Officer

Governance: Structure

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AO FAA FTSE

Finisar Australia (Director of New Business Opportunties)

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Chief Investigator

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Partner Investigator

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Partner Investigator

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Partner Investigator

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Partner Investigator

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Partner Investigator

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Partner Investigator

California Institute of Technology, USA

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Partner Investigator

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Partner Investigator

University of Central Florida, Orlando, USA

ASSOCIATE PROFESSOR CHENGWEI QIU

Partner Investigator

National University of Singapore

DR. AURELIEN BOTMAN

Partner Investigator

Thermo Fisher Scientific, USA

Professional Team

SHARYN MCFARLANE

Chief Operating Officer
Australian National University

GALINA SHADRIVOVA

Business Manager
Australian National University

SAMARA THORN

Public Relations Specialist
Australian National University

DR. MARY GRAY

Chief Operating Officer
Australian National University

ELEANOR LUOND

IDEA Officer
RMIT University

CAMILLA GAZZANA

Outreach Officer,
Node Administrator
University of Technology Sydney

KRISZTINA THURZO

Assistant Administrator
Australian National University

KATHY PALMER

Node Administrator
University of Melbourne

KAREN KADER

Node Administrator
University of Western Australia

JULIE ARNOLD

Senior Administrator

Australian National University

EMILY SCHUSTER

Content and Engagement Officer

Australian National University

GREG DENNIS

IDEA Officer

RMIT University

ALINA BRYLEVA

Centre Administrator

Australian National University

Associate Investigators

DR. MONICA ALLEN

Associate Investigator

Air Force Research Laboratory, USA

DR. JEFFERY ALLEN

Associate Investigator

Air Force Research Laboratory, USA

PROFESSOR YUERUI LU

Associate Investigator

The Australian National University

DR. JENNY JIANG

Associate Investigator

The Australian National University

PROFESSOR ALEXANDER KHANIKAEV

Associate Investigator

City College of New York, USA

DR. SEBANIA LIBERTINO

Associate Investigator

Consiglio Nazionale delle Ricerche (CNR) Rome

PROFESSOR THOMAS PERTSCH

Associate Investigator

Friedrich Schiller University Jena, Germany

DR. FRANK SETZPFANDT

Associate Investigator

Friedrich Schiller University Jena, Germany

DR. HAORAN REN

Associate Investigator

Macquarie University

DR. VICTORIA COLEMAN

Associate Investigator

National Measurement Institute

PROFESSOR MOHSEN RAHMANI

Associate Investigator

Nottingham Trent University

PROFESSOR SUMEET WALIA

Associate Investigator

RMIT University

DISTINGUISHED PROFESSOR ARNAN MITCHEL

Associate Investigator

RMIT University

ASSOCIATE PROFESSOR DANIEL GOMEZ

Associate Investigator

RMIT University

DR. ANGELA BARREDA GOMEZ

Associate Investigator

University Carlos III of Madrid

DR. KYLIE DUNNING

Associate Investigator

University of Adelaide

PROFESSOR KISHAN DHOLAKIA

Associate Investigator

University of Adelaide

DR. JIAWEN LI

Associate Investigator

University of Adelaide

PROFESSOR ALI JAVEY

Associate Investigator

University of California, Berkeley

PROFESSOR AMPALAVANAPILLAI (ALIAS 'THAS') NIRMALATHAS

Associate Investigator

University of Melbourne

DR. TIM DAVIS

Associate Investigator

University of Melbourne

DR. SEJEONG KIM

Associate Investigator

University of Melbourne

DR. RANJITH RAJASEKHARAN UNNITHAN

Associate Investigator

University of Melbourne

PROFESSOR CHRISTINA LIM

Associate Investigator

University of Melbourne

PROFESSOR JOEY TALGHADER

Associate Investigator

University of Minnesota

PROFESSOR ANDREY MIROSHNICHENKO

Associate Investigator

University of New South Wales

DR. DAVID POWELL

Associate Investigator

University of New South Wales

PROFESSOR ANTONIO TRICOLI

Associate Investigator

University of Sydney

ASSOCIATE PROFESSOR YANG YANG

Associate Investigator

University of Technology Sydney

ASSOCIATE PROFESSOR ARTI AGRAWAL

Associate Investigator

University of Technology Sydney

PROFESSOR WEN LEI

Associate Investigator

University of Western Australia

ASSOCIATE PROFESSOR MARTIN HILL

Associate Investigator

University of Western Australia

ASSOCIATE PROFESSOR JAREK ANTOSZEWSKI

Associate Investigator

University of Western Australia

DR. GILBERTO UMANA-MEMBRENO

Associate Investigator

University of Western Australia

PROFESSOR DILUSHA SILVA

Associate Investigator

University of Western Australia

Research Staff

DR. ANDREI KOMAR

Associate Postdoctoral Researcher
Australian National University

DR. BUDDINI KARAWDENIYA

Associate Postdoctoral Researcher
Australian National University

DR. CHAOHAO CHEN

Postdoctoral Researcher
Australian National University

DR. DARIA SMIRNOVA

Postdoctoral Researcher
Australian National University

DR. JIHUA ZHANG

Postdoctoral Researcher
Australian National University

DR. JINYONG MA

Postdoctoral Researcher
Australian National University

MS. JOSEPHINE MUNRO

Associate Postdoctoral Researcher
Australian National University

DR. MARIA DEL ROCIO CAMACHO MORALES

Postdoctoral Researcher
Australian National University

DR. MATTHEW PARRY

Associate Postdoctoral Researcher
Australian National University

MR. SONACHAND ADHIKARI

Postdoctoral Researcher
Australian National University

DR. TUOMAS HAGGREN

Postdoctoral Researcher
Australian National University

DR. VLADLEN SHVEDOV

Postdoctoral Researcher
Australian National University

DR. WEI WEN WONG

Postdoctoral Researcher
Australian National University

DR. YANA IZDEBSKAYA

Postdoctoral Researcher
Australian National University

DR. ZHE LI

Postdoctoral Researcher
Australian National University

DR. ZIYUAN LI

Postdoctoral Researcher
Australian National University

DR. KRISHNA MURALEEDHARAN NAIR

Postdoctoral Researcher
RMIT University

DR. LITTY VARGHESE THEKKEKARA

Postdoctoral Researcher
RMIT University

DR. RAJOUR TANYI AKO

Postdoctoral Researcher
RMIT University

MR. JIAJUN MENG

Postdoctoral Researcher
University of Melbourne

DR. LUKAS WESEMANN

Postdoctoral Researcher
University of Melbourne

MR. NIMA SEFIDMOOYE AZAR

Associate Postdoctoral Researcher
University of Melbourne

DR. NITU SYED

Associate Postdoctoral Researcher
University of Melbourne

DR. SIVACARENDRAN BALENDHRAN

Associate Postdoctoral Researcher
University of Melbourne

DR. WENDY LEE

Postdoctoral Researcher

University of Melbourne

DR. AISWARYA PRADEEPKUMAR

Postdoctoral Researcher

University of Technology Sydney

DR. DAVID KATZMAREK

Postdoctoral Researcher

University of Technology Sydney

DR. HOSSEIN ALIJANI

Associate Postdoctoral Researcher

University of Technology Sydney

DR. IRYNA KHODASEVYCH

Postdoctoral Researcher

University of Technology Sydney

DR. JOHN SCOTT

Postdoctoral Researcher

University of Technology Sydney

DR. MEHRAN KIANINIA

Associate Postdoctoral Researcher

University of Technology Sydney

DR. HEMENDRA KALA

Postdoctoral Researcher

University of Western Australia

DR. MICHAL ZAWIERTA

Postdoctoral Researcher

University of Western Australia

DR. NIMA DEHDASHTI

Postdoctoral Researcher

University of Western Australia

DR. WENWU PAN

Postdoctoral Researcher

University of Western Australia

Students

AUSTRALIAN NATIONAL UNIVERSITY

PHD STUDENTS:


ANHA BHAT


ASWANI GOPAKUMAR SARASWATHY VILASAM


DAWEI LIU


ELIZAVETA MELIK-GAYKAZYAN


FEDOR KOVALEV


JINLIANG REN


JOSHUA JORDAAN


KHOSRO ZANGENEH KAMALI


KOSALA DHANAWANSHA


LAURA DANIELA VALENCIA MOLINA


LUYAO WANG


MARCUS CAI


NEUTON LI


PARUL PARUL


RISHABH VASHIST


SARAH DEAN


SHIYU WEI


SHRIDHAR MANJUNATH


SIBO HUANGLONG


SONACHAND ADHIKARI


TONGMIAO FAN


XIAOYING HUANG


YANG YU


YUE BIAN


YUZI SONG


ZIWEI YANG

AUSTRALIAN NATIONAL UNIVERSITY

HONOURS STUDENTS:


YUXIN JIANG


JIA LE LAI


CAITLIN MCMANUS-BARRETT

RMIT UNIVERSITY

PHD STUDENTS:


MINGJIE YANG


NAHIYA MUSHTAQ


SUVANKAR SEN


YING ZHI CHEONG

UNIVERSITY OF MELBOURNE

PHD STUDENTS:


BENJAMIN RUSSELL


HENRY TAN


MARYAM SETAREH


NIKEN PRISCILLA


SEYED SALEH MOUSAVI KHALEGHI


SHABAN SULEJMAN

MASTERS STUDENTS:


PALLAVI PUNJ


LINCOLN CLARK


HAIWEI WANG

UNIVERSITY OF TECHNOLOGY SYDNEY

PHD STUDENTS:

BENJAMIN WHITEFIELD

KARIN YAMAMURA

LESLEY SPENCER

OTTO CRANWELL

RITIKA RITIKA

THINH TRAN

MADELINE HENNESSEY

HONOURS STUDENTS:

SERGEI NEDIC

UNIVERSITY OF WESTERN AUSTRALIA

PHD STUDENTS:

DANIEL MORLEY

OLEG BANNIK

YAN LIU

VISITING STUDENTS

AUSTRALIAN NATIONAL UNIVERSITY:

SANIYA SHINDE

DOMINIK PÖSCHL

MARIUS GRAML

FRIEDRICH SCHILLER UNIVERSITY OF JENA:

SEBASTIAN KLIMMER

MIN JIANG

MAXIMILIAN WEISSFLOG

LUKAS JÄGER

SOFIA UNIVERSITY, ST. KLIMENT OHRIDSKI:

KALOYAN GEORGIEV

INTERVIEW

STUDENT OF THE YEAR 2023: Neuton Li

NEUTON LI

PhD Student

Australian National University

Neuton Li is a PhD student at the Australian National University node of TMOS. He is researching different optimisation techniques for meta-optics to create even more advanced devices for areas such as imaging, optical processing, and non-linear photonics. His current focus is demonstrating non-linear metasurfaces for infrared imaging and exploring avenues for volumetric metamaterials.

What were the collaboration highlights of 2023 for you?

The collaboration highlights of this year include working with Niken Priscilla and Lukas Wesemann from the University of Melbourne to develop new optical image processing metasurfaces. Another highlight is a 6-month research visit to the Faraon Group at Caltech as part of my Fulbright Scholarship to work on volumetric metamaterials.

What challenges did you face in your research? What new or existing relationships helped you through this?

There are numerous roadblocks that I've faced in my research, but my professors always offer helpful guidance. In addition, researchers at other universities, such as Caltech, have helped me with different suggestions for my problems.

What key collaborations have shaped your research and your career?

A key collaboration in my past as an undergraduate was a summer research scholarship at the University of Sydney with Eggleton Group. It was my first taste of research, and I could focus solely on it throughout the summer. I also had a very inspiring advisor in Birgit Stiller and worked with a wonderful PhD student at that time, Atiyeh Zarifi. It was such a memorable experience that I decided to continue in optics and photonics.

When did you first know that you wanted to be a physicist?

Though I've always wanted to be a mathematician, it was only during university that I realised that physics combined my love of mathematics and experimentation.

If you could work with anyone in physics (dead or alive), who would it be and why?

I think it would have to be James Clerk Maxwell because it would just be fascinating to know what he was thinking when writing on electromagnetism in the 19th century.

Where do you think you'll be in five years? How are you going to get there?

I would like to return to Australia after travelling abroad for a while, taking the knowledge and experience that I have gained in that time to advance Australian science.

Do you have any advice for young researchers on how to develop impactful partnerships?

The best advice is to try and make friends with other young researchers at workshops, conferences, and seminars. Having a personal connection makes any future interactions more likely, and potential collaborations to succeed.

INTERVIEW

LEADER OF THE YEAR 2023: Shaban Sulejman

What key collaborations have shaped your research and your career?

I was fortunate to have been involved in various collaborations for my work in 2023. A key example that had a significant impact on me was with the group of TMOS Partner Investigator Prof. Andrea Alu from the City University of New York (CUNY). In October 2022, I visited CUNY and Columbia University to meet with the groups of Prof. Alu and TMOS PI A/Prof. Nanfang Yu, which was made possible by my supervisor Prof. Ann Roberts. While at CUNY, I struck up a collaboration with senior research fellow Dr. Michele Cotrufo (now assistant professor at the University of Rochester). Together, we designed a metasurface capable of tunable image processing through the phase-change material vanadium dioxide, which is currently in review at Nature Communications.

I had the opportunity to travel to CUNY in July 2023 to conduct the experiments for this work with A/Prof. Cotrufo, which was made possible through a TMOS PI exchange award. The vanadium dioxide material was fabricated by the group of TMOS CI Prof. Madhu Bhaskaran at RMIT, thus also creating a cross-node collaboration. The collaboration with CUNY will continue into 2024 as part of my Fulbright scholarship, where I will conduct research at CUNY and also at Columbia University with A/Prof. Nanfang Yu, as well as at the University of Rochester with A/Prof. Michele Cotrufo.

A second key collaboration in 2023 was with Dr. Mikkaela McCormack from Dorevitch Pathology. Dr. McCormack is a leading pathologist who specialises in breast cancer pathology. We worked together to apply the metasurface that I had designed to image human breast cancer tissue. In particular, we focused on distinguishing between cancerous tissue and healthy milk ducts that look similar. These results were part of my PhD work, which has involved other collaborations with Prof. James Hutchison from the ARC Centre of Excellence for Exciton Science to conduct optical measurements on my metasurface, Prof. Gawain McColl from the Florey Institute who provided me with transparent round-worms for my imaging experiments, and the group of Prof. Ravi Shukla at RMIT University who provided me with prostate cancer cells for my imaging experiments. Each of these collaborations have significantly boosted the quality of my PhD and have taught me many different things. It has been a pleasure to work with experts in various fields of work.

What challenges did you face in 2023? What new or existing relationships helped you through this?

The challenges that I faced in 2023 were mostly personal. I faced difficult circumstances due to my dad's health. Therefore, I frequently travelled between Melbourne and my home town of Shepparton in northern Victoria

I enjoy working in research and development roles where I can apply my interests to solve meaningful problems that are prevalent in the community… the impact of providing technology that can potentially contribute to saving the lives of people has a substantial impact on me.

to care for my family and for several hospital visits.

The support, trust and understating of my supervisory panel, primarily Prof. Ann Roberts and Dr. Lukas Wesemann, made balancing my PhD work and caring for my family possible. Them, together with the TMOS community and my personal friends outside of work, all helped me through these challenges.

If you could work with anyone in physics (dead or alive) who would it be and why?

It is a pleasure to work with anyone.

Where do you think you'll be in five years? How are you going to get there?

I enjoy working in research and development roles where I can apply my interests to solve meaningful problems that are prevalent in the community. Through my personal experience in dealing with my dad's health, the impact of providing technology that can potentially contribute to saving the lives of people has a substantial impact on me. I have experienced first-hand the consequences of living in a rural area where certain health services are difficult to attain or only accessible in distant cities.

Getting to these goals in the future will involve patience and resilience. I have had the privilege of being supported by a great network of people and various scholarships that have helped me through to where I am today.

Do you have any advice for young researchers on how to develop impactful partnerships?

I am a young researcher myself and therefore I am still learning every day on the intricacies of the work that we do. However, my approach to developing meaningful relationships, both in and out of work, is through kindness, respect and friendship.

SHABAN SULEJMAN

PhD Student

University of Melbourne

Shaban is doing a PhD degree at the Centre's University of Melbourne node. His research work is focused on the design and application of metasurfaces to image transparent biological samples, such as cancer cells. He aims to develop a portable device that can be used for rapid diagnostic applications.

INTERVIEW

ECR OF THE YEAR 2023: Jinyong Ma

What were the collaboration highlights of 2023 for you?

I have been serving as a TMOS research program manager of Theme 1B: Advanced and Quantum Light Sources over the past two years. Together with Dr. Tuomas Haggren, we successfully organised a cross-node workshop in March 2023 and facilitated cross-node collaborations. I have been also coordinating and presenting the progress of Theme 1B research programs during the TMOS research planning days in 2022-2023.

I was also co-leading the following collaboration research projects:

- *Quantum imaging with metasurfaces:* with Prof. Kenneth Crozier's group at the University of Melbourne on; Manuscript in preparation.
- *Co-writing a review paper "Flat-optics quantum light sources: fundamentals and applications":* with Prof. Igor Aharonovich's and Prof. Milos Toth's group
- *Spectral engineering of photon pairs from metasurfaces:* Dr. Frank Setzpfandt at Friedrich Schiller University Jena on; presented at ANZCOP-AIP Summer Meeting 2023.

What challenges did you face in your research? What new or existing relationships helped you through this?

One of the challenges we faced was in fabricating the required object patterns for quantum imaging. Prof. Kenneth Crozier's group at the University of Melbourne provided invaluable assistance using their advanced fabrication facilities. Special thanks go to Dr. Jiajun Meng who fabricated the objects.

What key collaborations have shaped your research and your career?

Collaborations with Prof. Kenneth Crozier's, Prof. Ann Roberts at University of Melbourne, Prof. Igor Aharonovich's and Prof. Milos Toth's group at UTS, and Dr. Frank Setzpfandt at Jena Friedrich Schiller University Jena shaped my research and career.

When did you first know that you wanted to be a physicist?

My passion for physics was ignited in my childhood.

If you could work with anyone in physics (dead or alive) who would it be and why?

I would like to collaborate with Albert Einstein, because I would like to discuss with him more about whether "God plays dice with the universe" according to state-of-the-art findings about quantum physics.

Where do you think you'll be in five years? How are you going to get there?

In five years, I envision myself as an independent Principal Investigator in the field of quantum nanophotonics. To achieve this, I will improve my supervision and group management skills while actively pursuing grant opportunities and expanding my network within the scientific community.

Do you have any advice for young researchers on how to develop impactful partnerships?

Think beyond their current projects and actively seek collaborations!

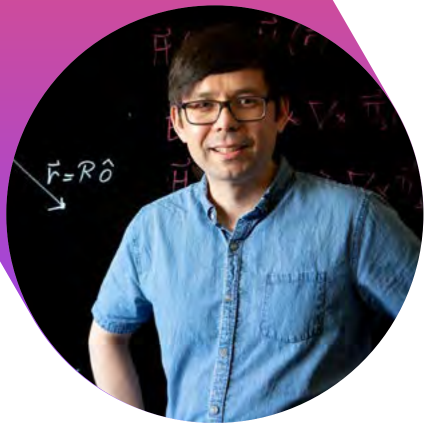
JINYONG MA

Postdoctoral Researcher

Australian National University

Jinyong Ma is currently working on generation of entangled photon pairs from nanostructured nonlinear metasurfaces. He aims to develop ultra-compact photon pair sources with new functionalities for quantum imaging and communication applications.

Research



Message from the Deputy Director

At TMOS, our goals are to develop the next generation of miniaturised optical systems and to lay the foundations for future progress by nurturing future research leaders.

Collaboration is essential to both goals. An individual research group can readily muster the skills necessary to master some aspect of meta-optics, for example developing a new optoelectronic material, or a new meta-optical device, or a new theory. But, the field has advanced to the point where the greatest impact lies in developing meta-optical systems that are fully-functional and perform tasks for end-users. This necessitates project teams with skills that range from theory to materials science, nanofabrication, device physics and optical engineering. We are fortunate to have these skills "under one roof" at TMOS via our personnel and partners. Collaboration also underpins the numerous TMOS outreach and educational programs that are facilitating our aim of fostering the next generation of leaders. There is the saying that "It takes a village to raise a child". This rings true for developing future leaders in TMOS. These individuals need to be not only strong in their own sub-field of meta-optics, but also have broader skills, including in communication and project management. Centre-wide collaboration is again the way to achieve this, enabling Chief Investigators to draw on experience from their own careers and to contribute their strongest suit to the mentoring process.

In 2023, the TMOS governance framework proved itself well up to the task of fostering collaboration. Decisions made by the Centre Executive Committee (CEC) represent the product of collaboration. They are the result of debate and discussion that are inevitably vigorous. In 2023, several initiatives were developed (or maintained) by the CEC to boost collaboration. These include the Cross-Node Exchange Award and the Partner Investigators Exchange Award. An important achievement of the CEC in 2023 was the revision of the Research Program Structure. This was done to enhance collaboration by improving the focus of the research programs and by improving the clarity of the program manager roles. This new approach was codified in the Research Program Governance Policy, which is reviewed every six months to ensure that it remains fit-for-purpose.

Collaboration was also strongly evidenced in the other committees that make up the TMOS governance framework. In the Outreach Committee, for example, staff and students from the five nodes crisscrossed the country to deliver outreach events at venues such as schools and local libraries. The Infrastructure and Capabilities Committee assisted TMOS members find collaborators with infrastructure needed for their fabrication or measurement problem. One of the major goals of the Industry Liaison Committee is to showcase TMOS's capabilities to industry, in the hope that it will lead to collaborations that yield tangible impacts such as new products. The Inclusion, Diversity, Equity and Access (IDEA) Committee has as its central goal the creation of a supportive, creative, and inclusive environment, which is surely central to fostering collaboration at TMOS. The Education and Professional Development Committee aims to develop a culture that fosters future leaders. Two examples come to mind that highlight the importance it places upon collaboration. The higher degree by research (HDR) policy sees that each TMOS HDR student has an external panel member from another TMOS node, thereby embedding possible collaboration into their research programs. The committee also facilitates the annual TMOS Student and Early Career Researcher Conference. This meeting enables those at an early career stage learning to strike up collaborations themselves. Lastly, the Centre Advisory Board (CAB) and International Scientific Advisory Committee (ISAC) provide crucial oversight to TMOS. In 2023, TMOS greatly benefited from their expert guidance via in person meetings at the Australian National University (ANU) in May and at the TMOS Conference in December.

There is the saying "The proof of the pudding is in the eating". One does not need to look hard for evidence of successful TMOS research collaborations in 2023. Three examples are as follows. First, it is well-established that the infrared (IR) portion of the electromagnetic spectrum contains a wealth of information for remote sensing. Traditional IR systems however are too bulky, heavy, costly and power-hungry for many of these applications. In their SPIE Photonics West presentation and accompanying paper (doi: 10.1117/12.2658896), Martyniuk et al describe progress on the realisation of IR filters whose spectral response can be voltage-tuned. These are based on micro-electromechanical systems (MEMS). Martyniuk et al also describe exciting progress that they have made on extending this into the terahertz (THz) frequency band. This is achieved via a collaboration with ANU, who designed metamaterials for this. This project nicely illustrates the benefits of collaboration, with the ANU contributing its expertise in metamaterial theory and modelling, and the University of Western Australia (UWA) its expertise in MEMS. The second example is a collaboration between the University of Technology Sydney (UTS) and the University of Melbourne (UoM). Writing in Optical Materials Express (vol. 13, 1475 (2023)), Khodasevych et al studied an analogue optical computation device comprising graphene-covered silicon carbide gratings. By varying the Fermi level in the graphene, the authors showed that it should be possible to realise a tunable spatial frequency filter and that this could enable an edge detection device for the mid-IR. The third example is a combined effort from ANU and UTS. It is widely accepted that integrated, on-chip lasers are crucial building blocks for next generation photonics chips. These are generally made in a "top down" manner that involves material growth, lithography and etching. This approach has drawbacks related to scalability and reproducibility. In their ACS Nano (vol. 17, 15065 (2023)) paper, Wong et al demonstrated a completely different approach, in which InAsP/InP is directly grown into a ring-like cavity via selective area epitaxy. The devices showed a device efficacy of over 80% and emitted in the telecommunications O-band. The authors write that future work could involve growing microring cavities directly onto Si. Stay tuned for future updates!

In closing, let me convey as Deputy Director my best wishes to all readers for their endeavours in 2024.,

Professor Kenneth Crozier
Centre Deputy Director

Research Overview

Our research excellence in meta-optics enables us to overcome complex scientific and engineering challenges in light generation, manipulation, and detection at the nanoscale. We lead internationally esteemed innovations, inspiring others, and creating positive impacts on society.

Our research outcomes underpin future technologies, including real-time holographic displays, artificial vision for autonomous systems to see the invisible, wearable medical devices and ultra-fast light-based Wi-Fi, meeting the evolving demands of Industry 4.0. The Centre has a visible impact on technology beyond the seven-year timeframe of its research program.

Our Centre has three Research Themes and our goals for each are to:

GENERATE

Prepare for next-generation optical systems by developing miniaturised, energy-efficient laser-light nano-emitters.

MANIPULATE

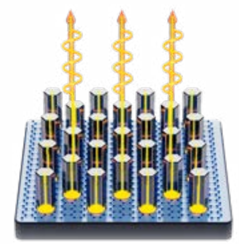
Cater for the exponential growth of image-processing data and emerging exascale problems by developing photonic problem-specific processors.

DETECT

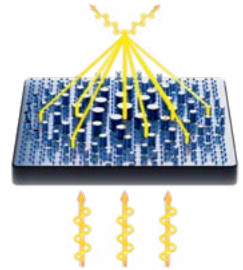
Realise access to currently unavailable optical information by integrating metasurfaces into photodetectors to expand their functionality.

In addition, our research program will provide the Centre with capabilities and infrastructure that supports and expedites research.

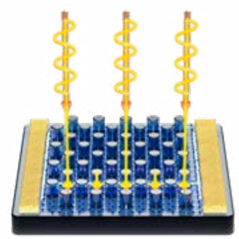
Find out more about our themes on our website



GENERATE



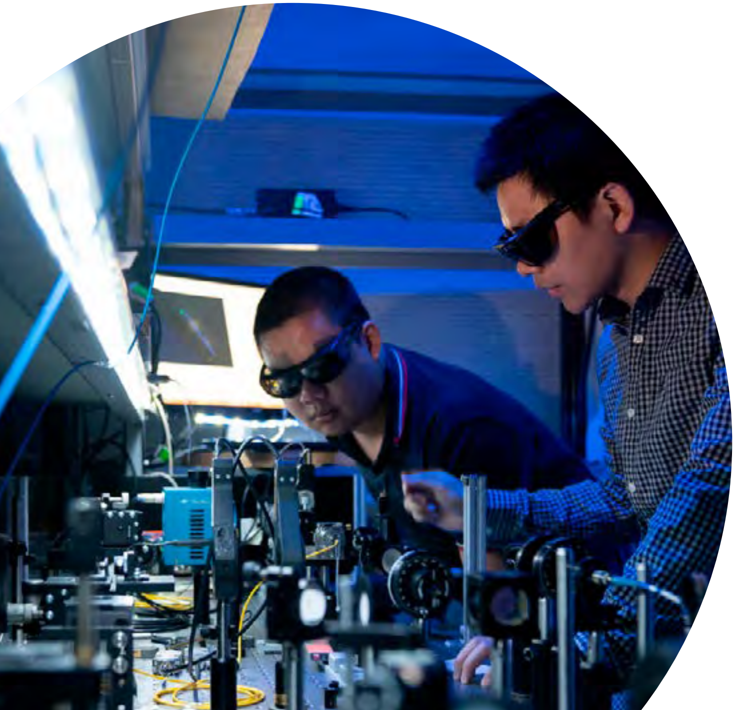
MANIPULATE



DETECT

TMOS Flagship Program

As part of the 2023 restructuring of the Centre's research program, it became clear that some of the Centre's projects were more applied than others. These sat at a higher technology readiness level (TRL) than most of the Centre's program. Some of the projects had patents or were in the process of patent application. Most had working prototypes. All of them were at a point where researchers were seeking industry feedback and investment.



The Centre Executive Committee decided to create three Flagship Programs that would focus on developing specific projects, with the aim to have these projects with end users by the end of the Centre's funding.

The three Flagship Programs chosen were:

- Advanced Quantum Technologies
- Meta Health Sensors
- Enhanced Infrared Vision

In 2024, the Industry Liaison Committee will select 1 – 2 projects related to these flagships and put them through activities designed to identify key market opportunities, develop the research in ways that address these opportunities, and engage in constructive conversations with potential end users. The researchers whose projects are selected will be supported by Flagship Program Managers, the Centre's PR Manager, and the Industry Liaison Committee.

ADVANCED QUANTUM TECHNOLOGIES

The Quantum Flagship projects explore the intersection of quantum technologies and meta-optical systems. With a specific focus on quantum light sources, the goal is to advance secure quantum communication and sensing capabilities. These light sources are coupled into tailored meta-optical systems to achieve higher performance and moisturise quantum devices.

ACTION ITEMS FOR 2024

1. Develop fibre-based quantum sensing with 2D materials.
2. Realisation of electrically driven single-photon source in hBN
3. Develop room temperature quantum emitters in telecom band.

META HEALTH SENSORS

Our Flagship project on Meta-Health focuses on developing miniaturised optical technologies for wearable and portable applications. Using specific wavelengths of light offers enhanced sensitivity and selectivity for key molecules of choice. Capitalising on TMOS technologies, these application-focused projects will deliver outcomes at higher technology levels particularly focused for industry translation and with a key target market of healthcare.

Both technologies will have provisional patents filed.

ACTION ITEMS FOR 2024

1. Optimisation of electronics for InP nanowire-based chemiresistive breath acetone sensing technology
2. Calibration testing for human applications of chemiresistive and optical infrared sensing technology
3. Calibration testing for food/drink applications of optical infrared sensing technology

ENHANCED INFRARED VISION

Light at infrared wavelengths is a crucial source of information for applications including chemical sensing and defence surveillance. Detecting and analysing infrared light is, however, challenging. The "Enhanced Infrared Vision" Flagship Program leverages meta-optics to develop compact and mobile detection technology for the infrared spectral range.

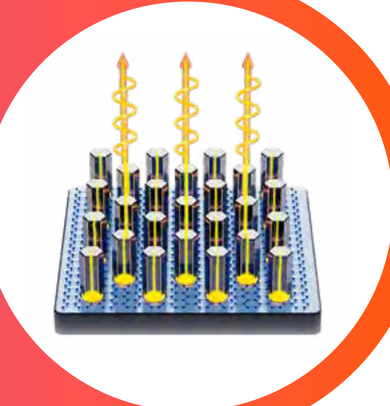
ACTION ITEMS FOR 2024

1. Develop a metasurface enhanced MCT detector array (candidate 1, UWA)
2. Demonstrate IR upconversion using CW laser light (candidate 2, ANU)
3. Demonstrate gas sensing with microspectrometer (candidate 3, UoM)

THEME ONE

Generate

Light emitting diodes (LEDs) and semiconductor lasers are pervasive in our daily lives in applications such as high efficiency low-power lighting, traffic lights, displays, Playstations®, Xboxes® and optical fibre links for the internet. As good and efficient as these devices are now, it is expected that the next-generation optical systems would be integrated onto micro/nano-electronic platforms with added functionalities. As such, miniaturised, highly compact and energy-efficient light sources are needed. To obtain added functionalities, the properties of the emitted beams must also be easily manipulated in terms of colour (frequency), coherence, polarisation, directions and spatial profile.



THEME LEADERS:

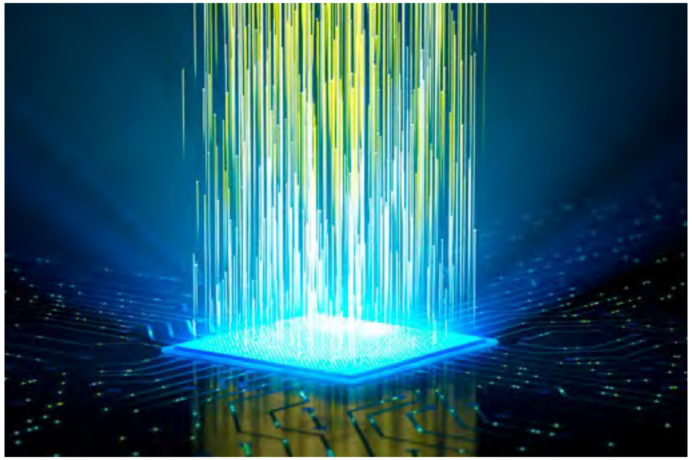
PROFESSOR IGOR AHARONOVICH
University of Technology Sydney

PROFESSOR HOE TAN
The Australian National University

In Theme 1, we continue to explore on all things generate - ranging from material synthesis to device fabrication to demonstration of nanoscale lasers and quantum sources. Our focus remains on developing the brightest and most efficient miniaturised meta-optical light emitters with added functionalities beyond what is possible with conventional means.

The ANU effort in selective area growth of III-V semiconductor micro-rings has resulted in the demonstration of optical coupling between pairs of micro-ring cavities with a highly deterministic and controllable cavity morphology. Furthermore, using the concept of PT symmetry as effective means to enhance lasing mode selectivity, they demonstrated the world first PT-symmetric lasing in bottom-up micro-cavity lasers – a promising step towards the realisation of single-mode, high-brightness on-chip micro-cavity lasers.

The UTS team demonstrated the deterministic fabrication of hBN nanobeam photonic crystal cavities with excellent performance across a broad range of wavelengths from ultraviolet to near-infrared. Their unique position-controlled quantum emitters in hBN provides a promising path to scalable quantum photonics chips. Joint UTS-ANU



effort on incorporating single quantum dots in III-V nanowire arrays has also led to bright and high-purity single photon emitters.

A novel quantum imaging method using photon pairs generated from a nonlinear metasurface was also jointly developed by the ANU and University of Melbourne teams, a testament to a successful the cross-node, cross-theme (1 and 3) effort.

Additionally, the ANU team has developed a novel approach to control the polarisation of photon pairs emitted from a metasurface despite the limitation posed by unstructured crystals. Collaborations with PIs and AIs have also resulted in successful light frequency conversion with enhanced efficiency using 2D materials and its demonstration in upconverted infrared imaging.

COLLABORATIONS:

To further strengthen collaborations, a Theme 1 workshop was organised in March and was attended by researchers and students from ANU, UTS, UoM and RMIT. Several collaborative projects were identified and discussed. 2023 saw the strongest yet collaboration between the ANU and UTS groups. A PhD student from ANU spent about a month at UTS using their Quantum Optics Platform to characterise quantum emitting properties of quantum dot-nanowire samples. Members from UTS also spent several days at ANU to conduct implantation experiments. A joint-ANU/UTS paper was published in 2023 and many more are expected in the forthcoming years. In addition, there were other collaborations in the general area of this theme with PIs, AIs and non-TMOS partners from Friedrich Schiller University Jena, University of Cincinnati, University of Manchester, Monash University and Hebrew University.

ACTION ITEMS FOR 2024

1. Demonstrate electrically injected light-emitting metasurface lasers
2. Development of exceptional point and topological lasers
3. Enhance the nonlinear emission from 2D materials and study imaging up-conversion in $LiNbO_3$ meta-grating.
4. Develop polarization Bell states from InGaP metasurface.
5. Realising electroluminescence from hBN

GENERATE

Subprograms

This theme supports two sub-programs aimed and developing new meta-optical light emitters.

1A. NANOSCALE LASERS AND LASER ARRAYS

Theme 1A aims to create nanolasers and miniaturised light emitters that enable tailorable emission and wavefront. In addition, we aim to create electrical devices for practical applications.

To reach these goals, research in 2023 has included studies on nanoscale light-emitters, control of the lasing modes and upconverting nanolasers for night vision. In the nanolaser building blocks, quantum wells within GaN/AlGaN core/shell nanowires were demonstrated that may be used to create nanoscale UV lasers. In other fabrication studies, an efficient method for creating thin-film semiconductors was demonstrated. By using this method, cost-effective thin-films can be manufactured to create metasurfaces for example for lasing applications.

With practical devices in mind, an electrical injection scheme was developed for microring emitters, and in addition, further structures were simulated to achieve lasing in these emitters. These structures currently researched include quantum wells and improved electrical contact layers. In another study on microrings, controllable lasing mode was achieved by employing the principles of parity-time symmetry in coupled microrings. The particular advantage of bottom-up fabricated microrings is smooth and long facets that increase coupling between the rings. The parity-time-symmetry controlled mode selection enables single-mode lasing at desired wavelengths.

Finally, with night vision application in mind, a theoretical framework was developed for upconverting nanoparticle lasers. Overall, 2023 was productive for Theme 1A with many exciting demonstrations achieved towards the goals and overarching visions of the theme.

ACTION ITEMS 2024

1. Demonstration of a PT symmetric laser
2. Demonstration of coupled nanowire lasers
3. Electrically injected light-emitting metasurface
4. Development of exceptional point and topological lasers

PUBLICATIONS

1. Core-shell GaN-AlGaN nanowires grown by selective area epitaxy
2. Optimization of metasurfaces for lasing with symmetry constraints on the modes
3. Bottom-up-chip-scale-engineering-of-low-threshold-multi-quantum-well-microring-lasers
4. Directional Lasing in Coupled InP Microring Nanowire Systems
5. Strain-engineered-multilayer-epitaxial-lift-off-for-cost-efficient-iii-v-photovoltaics-and-optoelectronics

1B. ADVANCED AND QUANTUM LIGHT SOURCES

This research program aims to develop ultra-compact classical and quantum light sources with novel functionalities for optical imaging, sensing and communication applications. We use metasurfaces, two-dimensional surfaces with nanoscale thickness, for efficient conversion of light colour, emission of quantum light, and generation of spooky photons. In 2023, we have made exceptional achievements through cross-node collaborations and theme workshops. Below are some highlights of our exciting research outcomes.

Efficient conversion of light colour. The ANU team has demonstrated light frequency conversion with enhanced efficiency using 2D materials and achieved infrared imaging by detecting visible light converted from infrared light. This was made possible through the collaboration with PIs from Friedrich Schiller University Jena.

Quantum emitters. The UTS team achieved precise fabrication of quantum nanophotonic components in hBN, such as emitter-cavity systems, offering excellent performance across a wide range of wavelengths. They have also studied spin defects in boron vacancies in hBN and reported on-demand quantum light sources suitable for underwater optical communication. Additionally, joint UTS-ANU collaboration on incorporating single quantum dots in III-V nanowire arrays has also resulted in bright and high-purity single photon emitters.

Generation of spooky photons. The ANU team has developed a new method to control the polarisation of photon pairs emitted from a metasurface, overcoming the limitations of unstructured crystals. Additionally, they collaborated with the University of Melbourne to develop a novel quantum imaging technique using photon pairs from a nonlinear metasurface. This collaboration showcased successful cross-node, cross-theme (1 and 3) efforts.

ACTION ITEMS 2024

1. Couple QD emissions into whispering-gallery modes of the InP micro-ring resonator.
2. Enhance the nonlinear emission from 2D materials and study imaging up-conversion in LiNbO3 meta-grating.
3. Develop polarization Bell states from InGaP metasurface.
4. Integration of meta lens with optical fibres for quantum sensing.

PUBLICATIONS

1. M. Nonahal, J. Horder, A. Gale, L. Ding, C. Li, M. Hennessey, S. T. Ha, M. Toth, and I. Aharonovich, *Deterministic Fabrication of a Coupled Cavity–Emitter System in Hexagonal Boron Nitride,* Nano Lett. **23**, 6645 (2023).
2. A. Gale, D. Scognamiglio, I. Zhigulin, B. Whitefield, M. Kianinia, I. Aharonovich, and M. Toth, *Manipulating the Charge State of Spin Defects in Hexagonal Boron Nitride,* Nano Lett. **23**, 6141 (2023).
3. J. Ma, J. Zhang, Y. Jiang, T. Fan, M. Parry, D. N. Neshev, and A. A. Sukhorukov, *Polarization Engineering of Entangled Photons from a Lithium Niobate Nonlinear Metasurface,* Nano Lett. **23**, 8091 (2023).
4. M. Nonahal, C. Li, H. Ren, L. Spencer, M. Kianinia, M. Toth, and I. Aharonovich, *Engineering Quantum Nanophotonic Components from Hexagonal Boron Nitride,* Laser &Photonics Reviews **17**, 2300019 (2023).
5. Z. Zheng, L. Xu, L. Huang, D. Smirnova, K. Zangeneh Kamali, A. Yousefi, F. Deng, R. Camacho-Morales, C. Ying, A. E. Miroshnichenko, D. N. Neshev and M. Rahmani, *Third-Harmonic Generation and Imaging with Resonant Si Membrane Metasurface,* OEA **6**, 220174 (2023).

GENERATE CASE STUDY

Breakthrough set to push AI and quantum technologies even further

Processing power generally only makes the news when Apple launches its latest iPhone, but researchers from TMOS, the ARC Centre of Excellence for Transformative Meta-Optical Systems have made a breakthrough in the fundamental science that drives processors with the development of on-chip light sources for photonic integrated circuits.

This breakthrough could lead to near-lightspeed communication on your phone, quantum computing power in your hand, as well as highly sophisticated artificial intelligence as your 24/7 know-it-all companion.

For a long time, data transfer was simply the transfer of electrons through copper wires in technology like the telegraph. Later, these same electron-based signals would travel through silicon-based electronic chips within devices such as the computer. The use of light to transmit information instead of electrons was first implemented into fiber optic cables that carried information for relatively long distances before the signals were then converted into electronic ones in devices. Then scientists created the photonic chip, also known as a photonic integrated circuit, which uses photons to transmit and process information. Photonic chips consume much less power and have a smaller footprint than electronic chips. Since information is now processed and transmitted by photons, photonic chips can increase data processing speed and increase data transmission.

But the potential of photonic chips has been limited by the lack of miniaturised light sources that can be built into them. Until now, photonic chips have required bulky external lasers which are then coupled on. The size of these external lasers results in photonic chips with limited integration density, meaning that there's a limit to the number of optical components that can physically fit on a microchip and as a result, the processing power of those chips is limited.

In research published in ACS Nano, TMOS researchers describe a solution to the on-chip light source problem that will significantly increase the integration density of photonic chips and lead to vastly higher processing powers, which will enable emerging technologies such as highly sophisticated AI and quantum computing to operate on smaller devices, such as a mobile phone.

The researchers have grown microring lasers using a bottom-up approach. These microring lasers are only five micrometers in diameter with quantum wells inside each ring. These quantum wells enable the microring lasers to operate at wavelengths suitable for information telecommunications. They can adjust the wavelength of the lasers by controlling the thickness and composition of the quantum well. Each of the 2mm x 2mm

SPOTLIGHT

Wei Wen Wong

Postdoctoral Fellow

Wei Wen Wong received his B. Eng. (Hons) degree in electronics engineering majoring in Nanotechnology from Multimedia University, Selangor, Malaysia, in 2016. From 2016 to 2018, he worked as a Failure Analysis Engineer in Cypress Semiconductor in Malaysia. He obtained his PhD degree at the Australian National University (ANU) in 2022 under the supervision of Professor Hoe Tan and Professor Chennupati Jagadish, working on the selective area epitaxy of III-V micro-ring lasers for optoelectronic applications. He is currently working as a postdoctoral fellow at the Department of Electronic Materials Engineering, Research School of Physics, ANU samples they fabricated contained approximately 1000 microring lasers with fabrication yield exceeding 80%, demonstrating chip-scale manufacturing capability.

Previous attempts at microring lasers for communication purposes used top-down or transfer methods of fabrication, where the microring laser was etched out of a substance, similar to how statues are carved out of marble. These methods created rough surfaces on the quantum wells that made them highly inefficient, and limited the device performance, especially for laser dimensions. The TMOS researchers used a method called selective area-metal organic chemical vapour deposition (SA-MOCVD) to simultaneously 'grow' thousands of highly efficient lasers from the bottom layer up.

Lead author Wei Wen Wong says, "Recent decades have seen an exponential growth in data capacities of photonic chips, however on-chip light sources that enable high integration density of these photonic integrated circuits have remained elusive, primarily due to fabrication challenges. Our method successfully grows quantum wells with excellent crystal quality and morphology that conforms to the microring cavity. Importantly, it does not require any post-growth cavity etching.

"We solve numerous long-standing issues in the community, making this a breakthrough towards the realisation of integrated micro-lasers and the huge step forward in miniaturising devices for data-demanding technologies such as quantum computing."

These microring lasers have a tunable wavelength emission in the telecommunication O-band, which is compatible with the wavelength used by other devices in the data transfer chain, such as 5g cell towers. Importantly, they have an efficacy of over 80% across the device. The impact of this technology will include faster internet speeds, faster computing, and an explosion in the Internet of Things, which requires enormous amounts of data transfer.

The results were underpinned by a rigorous analysis by researchers at The University of Manchester led by Dr. Stephen Church and Dr. Patrick Parkinson, who used an AI algorithm to measure the light output from the thousands of microrings and construct a dataset that shows the consistency of the growth process across the entire chip.

Wong says, "The contribution from the team at Manchester University allows us to demonstrate the high quality of the full sample set, rather than just a few individual examples, which gives an added layer of confidence in the scalability of our fabrication process."

TMOS Chief Investigator Hark Hoe Tan says, "The next steps for this research will be to fabricate these lasers that can be electrically powered and also on silicon wafers as many photonic chips are made on this platform.

For more information about this research, contact connect@tmos.org.au

Bottom-up, Chip-Scale Engineering of Low Threshold, Multi-Quantum-Well Microring Lasers

14TH JULY 2023 IN ACS NANO

Wei Wen Wong, Naiyin Wang, Bryan D. Esser, Stephen A. Church, Li Li, Mark Lockrey, Igor Aharonovich, Patrick Parkinson, Joanne Etheridge, Chennupati Jagadish, and Hark Hoe Tan

Integrated, on-chip lasers are vital building blocks in future optoelectronic and nanophotonic circuitry. Specifically, III–V materials that are of technological relevance have attracted considerable attention. However, traditional microcavity laser fabrication techniques, including top-down etching and bottom-up catalytic growth, often result in undesirable cavity geometries with poor scalability and reproducibility. Here, we utilize the selective area epitaxy method to deterministically engineer thousands of microring lasers on a single chip. Specifically, we realize a catalyst-free, epitaxial growth of a technologically critical material, InAsP/InP, in a ring-like cavity with embedded multi-quantum-well heterostructures. We elucidate a detailed growth mechanism and leverage the capability to deterministically control the adatom diffusion lengths on selected crystal facets to reproducibly achieve ultrasmooth cavity sidewalls. The engineered devices exhibit a tunable emission wavelength in the telecommunication O-band and show low-threshold lasing with over 80% device efficacy across the chip. Our work marks a significant milestone toward the implementation of a fully integrated III–V materials platform for next-generation high-density integrated photonic and optoelectronic circuits.

Read the full article

GENERATE CASE STUDY

Move over diamond. hBN is quantum's new best friend.

Diamond has long been the go-to material for quantum sensing due to its coherent nitrogen-vacancy centres, controllable spin, sensitivity to magnetic fields, and ability to be used at room temperature. With such a suitable material so easy to fabricate and scale, there's been little interest in exploring diamond alternatives. But this GOAT of the quantum world has one Achilles Heel... It's too big. Just as an NFL line-backer is not the best sportsperson to ride in the Kentucky Derby, diamond is not an ideal material when exploring quantum sensors and information processing. When diamonds get too small, the super-stable defect it's renowned for begins to crumble. There is a limit at which diamond becomes useless.

Enter hBN.

hBN has previously been overlooked as a quantum sensor and a platform for quantum information processing. This changed recently when a number of new defects were discovered that are shaping up to be compelling competitors to diamond's nitrogen vacancy centers. Of these the boron vacancy center (a single missing atom in the hBN crystal lattice) has emerged as the most promising to date. It can, however, exist in various charge states and only the -1 charge state is suitable for spin-based applications. The other charge states have, so far, been challenging to detect and study. This was problematic as the charge state can flicker, switching between the –1 and 0 states, making it unstable especially in the types of environments that are typical for quantum devices and sensors.

But as outlined in a paper in Nano Letters, researchers from TMOS, the ARC Centre of Excellence for Transformative Meta-Optical Systems have developed a method to stabilize the –1 state, and a new experimental approach for studying the charge states of defects in hBN using optical excitation and concurrent electron beam irradiation.

Co-lead author Angus Gale says, "This research shows that hBN has the potential to replace diamond as the preferential material for quantum sensing and quantum information processing because we can stabilize the atomic defects that underpin these applications resulting in 2D hBN layers that could be integrated into devices where diamond can't be."

SPOTLIGHT

Angus Gale

PhD Student

Angus Gale completed his B.Sc (Hons) in 2019 at UTS and is finalising his PhD candidature under the supervision of Prof. Milos Toth. His PhD research was focused on the creation and modification of quantum emitters in hexagonal boron nitride (hBN) and diamond. This was achieved using a variety of charged particle microscopy techniques, including focused electron and ion irradiations. During his PhD he developed a novel electron microscopy system, integrating a confocal photoluminescence (PL) setup to a scanning electron microscope (SEM), enabling real-time PL measurements under electron irradiation. The system was utilised to successfully probe charge-switching mechanisms of a spin active defect in hBN. He is currently a research associate at UTS, with research interests including quantum emitter generation, cathodoluminescence (CL), focused ion beams and crystal growth methods for 2D materials.

Co-lead author Dominic Scognamiglio says, "We've characterized this material and discovered unique and very cool properties, but the study of hBN is in its early days. There are no other publications on charge state switching, manipulation or stability of boron vacancies, which is why we're taking the first step in filling this literature gap and understanding this material better."

Chief Investigator Milos Toth says, "The next phase of this research will focus on pump-probe measurements that will allow us to optimize defects in hBN for applications in sensing and integrated quantum photonics."

Quantum sensing is a rapidly advancing field. Quantum sensors promise of better sensitivity and spatial resolution than conventional sensors. Of its many applications, one of the most critical for Industry 4.0 and the further miniaturisation of devices is precise sensing of temperature as well as electric and magnetic fields in microelectronic devices. Being able to sense these is key to controlling them. Thermal management is currently one of the factors limiting furthering the performance of miniaturised devices. Precise quantum sensing at the nanoscale will help prevent overheating of microchips and improve performance and reliability.

Quantum sensing also has significant applications in the medtech sphere, where its ability to detect magnetic nanoparticles and molecules could one day be used as an injectable diagnostic tool that searches for cancer cells, or it could monitor the metabolic processes in cells to track the impact of medical treatments.

In order to study the boron vacancy defects in hBN, the TMOS team created a new experimental setup that integrated a confocal photoluminescent microscope with a scanning electron microscope (SEM). This allowed them to simultaneously manipulate the charge states of boron vacancy defects with the electron beam and electronic micro-circuits, whilst measuring the defect.

Gale says, "The approach is novel in that it allows us to focus the laser onto and image individual defects in hBN, whilst they are manipulated using electronic circuits and using an electron beam. This modification to the microscope is unique; it was incredibly useful and streamlined our workflow significantly."

For more information about this research, contact connect@tmos.org.au

Manipulating the Charge State of Spin Defects in Hexagonal Boron Nitride

NANO LETTERS, JUNE 2023

Angus Gale, Dominic Scognamiglio, Ivan Zhigulin, Benjamin Whitefield, Mehran Kianinia, Igor Aharonovich, Milos Toth

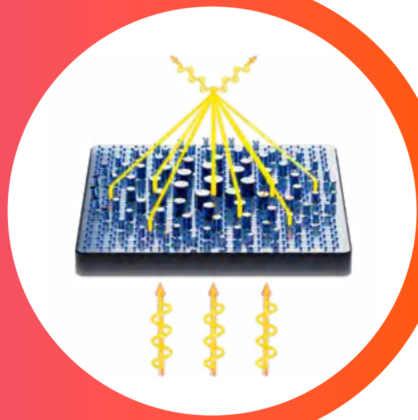
Negatively charged boron vacancies (VB-) in hexagonal boron nitride (hBN) have recently gained interest as spin defects for quantum information processing and quantum sensing by a layered material. However, the boron vacancy can exist in a number of charge states in the hBN lattice, but only the -1 state has spin-dependent photoluminescence and acts as a spin-photon interface. Here, we investigate charge state switching of VB defects under laser and electron beam excitation. We demonstrate deterministic, reversible switching between the -1 and 0 states (VB -⇌VB0 +e-), occurring at rates controlled by excess electrons or holes injected into hBN by a layered heterostructure device. Our work provides a means to monitor and manipulate the VB charge state, and to stabilize the -1 state which is a prerequisite for optical spin manipulation and readout of the defect.

Read the full article

THEME TWO

Manipulate

Vision is a key sense for humans, so it is not surprising that we have so many static pictures and devices around us displaying images. This is being done not only for our entertainment but also for productive purposes. Over the course of human history, the ability to create images evolved from still to the dynamic pictures that we enjoy now in the form of videos, with an ever increasing quality of these images. The limitation of all these visuals is that they only give a flat representation of our volumetric world. In other words, we see 2D images of 3D objects. This limits the usability of these images, as we are not able to see the real depth of the objects or see them from different angles. The desire to show 3D pictures led to the invention of static holograms almost half a century ago. Making dynamic holograms, a true 3D video, is an extremely sought-after ability that will revolutionise many areas of human life, including education, health and entertainment. Artificial surfaces created for manipulating light, or metasurfaces, give us the concept for solving this problem, and this is one of the main motivations behind Research Theme 2 of the Centre.



THEME LEADERS:

PROFESSOR ILYA SHADRIVOV
The Australian National University

PROFESSOR MADHU BHASKARAN
RMIT University

Combining the power of metasurfaces and novel materials allows for control of light in ways that were never before possible. These ultrathin, patterned films, composed of an array of subwavelength nanostructures, can bend, focus, split, and even cloak light, all while being much thinner and more versatile than traditional bulky optical components.

Metasurfaces are made of tiny structures, each much smaller than the wavelength of light they are designed to manipulate. These nanostructures, often made of metals or dielectrics, can be arranged in specific patterns to achieve desired optical effects. By carefully designing the size, shape, and arrangement of the nanostructures, the phase of the light wave can be precisely controlled across the metasurface. This allows for manipulation of the wavefront of the light, leading to effects like focusing, beam steering, and holography.

In TMOS, we also explore the manipulation of light with novel materials such as liquid crystals, electro-optic materials, phase change materials while also utilising novel fabrication techniques to incorporate MEMS technologies. Collaborative research across the nodes enables us to overcome challenges around integration and

fabrication while also allowing us to investigate new trans-disciplinary concepts across physics and engineering. We perform material research to identify those suitable for further creation of tunable structures. These novel materials, apart from the use in meta-optics, can further find applications in wider spectrum of applications.

The field of metasurfaces is still in its early stages, but the potential applications are vast and exciting and offers a promising avenue for creating next-generation optical devices with greater efficiency, adaptability, and functionality.

2023 KEY ACHIEVEMENTS

- Tunable metasurfaces in 3D
- Development of anisotropic electro-optic metasurface devices
- Metasurfaces with phase change materials for optical and sensor applications
- Development of optical waveguide switches

ACTION ITEMS FOR 2024

1. Metasurfaces utilising electro-optics
2. Metadevices utilising liquid crystals
3. Extensive characterisation of novel phase change materials
4. Reconfigurable metasurfaces with phase change materials
5. Ultrafast beam modulation
6. Nanowire metasurface integration

MANIPULATE

Subprograms

2A. DYNAMICALLY TUNABLE METAOPTICS

In Theme 2A, our goals include designing and developing tunable metasurfaces, which offer real-time control over electromagnetic wave interactions at a subwavelength scale. This capability drives innovation across various applications such as tunable metalenses, beam absorbers, splitters, holograms, and sensors. In 2023, we made exceptional progress by exploring new materials and techniques to fabricate and analyse tunable metasurfaces. Specifically, we focused on achieving reconfigurable metasurfaces with amplitude and phase tuning, polarization control, as well as the development of ultra-fast and pixel-size devices aimed at enhancing metasurface performance across a spectrum of applications. Below, we will briefly highlight our recent exciting achievements.

For example, our investigations this year have led to dynamic control of transmitted wave polarization utilizing anisotropic metasurfaces composed of electro-optic materials on a silica substrate. By applying external electric fields to designed Lithium Niobate structures, we achieved ultra-fast polarization modulation, facilitating the rotation of the polarization plane between vertical and horizontal orientations. These advancements lay the foundation for creating tunable filters and multiplexing metasurfaces, enabling precise control over light polarization.

In a collaboration between ANU and the University of Brescia, along with other Italian universities, we pioneered a novel multilayered structure comprising a thin-film VO2 phase change material on top of a gold film and a sapphire substrate. We showed that such a structure can act as a self-activating optical limiter, utilizing light-to-heat conversion for a VO2 phase change and can be used as protection for human eyes and sensitive detectors against high-intensity laser radiation.

Furthermore, we achieved a significant breakthrough in the 3D tunable metasurfaces employing liquid crystals. Introducing a method to dynamically tune dielectric metasurfaces by manipulating liquid crystals in 3D with a magnetic field, we achieved multifunctional operation, allowing for independent control of electric and magnetic resonances. This innovation opens avenues for new tuning capabilities, offering unprecedented flexibility in spectral response and paving the way for novel, multiresponsive metadevices.

Additionally, our exploration into parametric amplification of electromagnetic waves using metasurfaces yielded promising results. Through the design of a variable capacitor-loaded metasurface, we achieved significant amplification of incident electromagnetic waves. Detailed analysis across various operational regimes revealed gains exceeding 10 dB in a single layer of the structure, with control facilitated by parametric modulation.

In summary, our Theme 2A achieved significant progress in tunable metasurfaces and their applications in 2023, offering flexibility and performance across various technological domains.

PUBLICATIONS

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2. A. Tognazzi, M. Gandolfi, B. Li, G. Ambrosio, P. Franceschini, R. Camacho-Morales, A. Carmelo Cino, C. Baratto, D. de Ceglia, D. Neshev, C. De Angelis, Opto-thermal dynamics of thin-film optical limiters based on the VO2 phase transition, Optical Materials Express, 13, 1, 41 (2023).
3. Y. V. Izdebskaya, Z. Yang, V. Shvedov, D. N. Neshev, and I.V. Shadrivov, Three-dimensional (3D) Tuning of Metasurfaces, Nano Letters, 23 (21), 9825-9831 (2023).
4. K. Kamali, L. Xu, N. Gagrani, H. H. Tan, C. Jagadish, A. Miroshnichenko, D. Neshev, M. Rahmani, Electrically programmable solid-state metasurfaces via flash localised heating, Light: Science & Applications, 12,1, 40 (2023).
5. MT Hill, D Silva, M Martyniuk, L Faraone, Sensitivity analysis of a dielectric loaded 1× 2 directional coupler switch based on foundry process optical waveguides, Optical Engineering 62 (8), 087103-087103, (2023).

2B. OPTICAL SENSING

Within the expansive landscape of TMOS theme 2B, our research endeavours are passionately dedicated to confronting and addressing our time's most pressing global challenges. This commitment spans crucial sectors such as healthcare monitoring, environmental sensing for pollutants and global warming, and the all-encompassing oversight of agriculture, food, and air quality, all achieved through the integration of cutting-edge optical technologies.

Our central aspiration propels us toward a pivotal role in shaping the evolution of non-invasive, wearable, and portable sensing devices. Furthermore, we aspire to lead the charge in advancing data transfer mechanisms, drawing upon our profound expertise in circuit design, materials design, and device fabrication techniques. By focusing our concerted efforts on these pivotal domains, our ultimate objective is to deliver groundbreaking solutions to contemporary challenges, actively participating in creating sustainable technologies that positively impact our world's present and future well-being.

In the year 2023, our research was characterised by notable advances in various areas:

Diabetes Monitoring: We delved into diabetes monitoring using nanowire-based breath analysers for non-invasive ketone monitoring and wearable glucose-sensing devices.

Multifunctional Wearable Sensors: Another avenue of exploration involved the development of multifunctional wearable sensors catering to both health and gas monitoring applications.

Flat Optics Integrated Sensing Devices: Our efforts extended to developing and characterising flat optics integrated sensing devices, a frontier with promise for diverse applications.

Phase Change Material-Sb_2Se_3 Thin Film: We explored using phase change materials, particularly Sb_2Se_3 thin films, for non-volatile functional device development within the UV-IR region.

Currently awaiting final submissions or undergoing journal revisions, these works underscore our commitment to pushing the boundaries of knowledge and innovation.

Highlighting notable achievements, Prof. Madhu Bhaskaran's group work at RMIT University resulted in the publication *Adv. Electron. Mater. 2023, 2300705*. This work showcased the development of embedded graphene circuits in flexible mediums and the demonstration of a broadband stretchable flat lens. Applying 3D laser printing techniques in this work allowed for creating these functional structures with only 1/20th of the epidermis layer thickness of human skin. The work demonstrated the potential development of such graphene circuits for soft robotics and functional graphene contact lenses for sensing applications, overcoming the limitations of metallic counterparts while retaining commendable mechanical tuning ability.

Another notable contribution comes from Prof. Dragomir Neshev's group at ANU, focusing on developing optical limiting sensors using Ag/VO_2 phase change material to safeguard our eyes from laser threats. This significant work was published in *IEEE Sensors Letters (2023, 7, 9, 1-3, 3502104)*. The study provides a proof of concept for the optical limiting sensing device's working principle, demonstrating a calculated transmittance drop of 70% when the sensor was exposed to pulsed laser excitation.

As we transition into 2024, a significant milestone has been achieved by initiating the TMOS Meta Health Flagship project. This marks the commencement of a transformative journey to develop functional prototypes for integrated sensors specifically designed to address gas and health monitoring functions. The launch of this flagship initiative underscores our unwavering commitment to translating industrial research into practical applications, laying the foundation for impactful advancements in healthcare and environmental monitoring. This pivotal step reinforces our dedication to contributing innovative solutions that shape the trajectory of our collective future.

JOURNAL PUBLICATIONS

1. L. V. Thekkekara, Y. Z. Cheong, M. A. Rahman, S. Sriram, M. Bhaskaran, 3D Stretchable Devices: Laser-Patterned Electronic and Photonic Structures. *Adv. Electron. Mater.* 2024, 10, 2300705. https://doi.org/10.1002/aelm.202300705
2. C. Baratto et al., "Optical Limiting Sensor Based on Multilayer Optimization of Ag/VO2 Phase Change Material," in *IEEE Sensors Letters*, vol. 7, no. 9, pp. 1-3, Sept. 2023, Art no. 3502104, doi: 10.1109/LSENS.2023.3300801.

MANIPULATE CASE STUDY

TMOS researchers paving the way towards flatter and more energy efficient flat screens

TMOS researchers have developed a proof-of-concept technology that could pave the way for next-generation displays to supersede LCDs and LEDs, enabling screens and electronic devices to become thinner, offer higher resolution and be much more energy efficient.

The team included Centre Director Dragomir Neshev (Australian National University) and Associate Investigators Andrey Miroshnichenko (University of New South Wales) and Mohsen Rahmani (Nottingham Trent University). Their new 'metasurface' technology, detailed in Light: Science & Applications, offers significant benefits over current liquid crystal displays (LCDs).

The metasurfaces are 100 times thinner than liquid crystal cells, offer a tenfold greater resolution and could consume less energy.

Today's screen display market offers an extensive range of choices, each with pros and cons. However, factors including production costs, lifespan and energy consumption have kept LCD technology the most dominant and popular technology for screens such as TV sets and monitors.

Liquid crystal cells are responsible for switching the transmitted light on and off and are constantly lit by a backlight, with polarising filters in the front and behind the pixels, forming a cross-polarised setup. They determine the dimension of pixels – the resolution – and play a significant role in managing the device's power consumption.

The newly engineered metasurface cells, which have tunability and extraordinary light scattering properties, would replace the liquid crystal layer and would not require the polarisers, which are responsible for half of wasted light intensity and energy use in displays.

"Our pixels are made of silicon, which offers a long life span in contrast with organic materials required for other existing alternatives. Moreover, silicon is widely available, CMOS* compatible with mature technology, and cheap to produce," said Professor Andrey Miroshnichenko.

"We hope this development could generate a frontier technology in new flat screen displays, which had a global market value of about $117 billion in 2020."

SPOTLIGHT

Khosro Zangeneh Kamali

Postdoctoral Fellow

Khosro's research journey in nanophotonics started at the Australian National University, where he completed my Master of Engineering in Photonics. He recently graduated with a PhD and is currently a Postdoctoral Fellow at the same institute. His research activities involve extensive fabricating samples, building optical setups for my experiments, and designing my optical systems. Out of interest, he is developing a rigorous coupled-wave analysis (RCWA) code to simulate periodic structures. He received the SPIE Best Paper Award at the AIP Congress 2018 in Perth, Australia. In 2020, he was awarded the SPIE Optics and Photonics Education Scholarship. He has also been fortunate to receive several travel grants to attend various national and international conferences.

Professor Dragomir Neshev said the capability of conventional flat screen displays has reached its peak and is unlikely to significantly improve in the future due to multiple limitations. "Today, there is a quest for fully solid-state flat display technology with a high-resolution and fast refresh rate. We have designed and developed metasurface pixels that can be ideal for the next-generation display."

"Unlike liquid crystals, our pixels do not require polarised lights for functioning, which will halve screens' energy consumption."

Khosro Zangeneh Kamali, a PhD scholar at ANU and the first author of the study said metasurfaces have been proven to exhibit extraordinary optical behaviour. "Inventing an effective way to control metasurfaces is still a subject of heavy research. We have proposed electrically tunable silicon nanostructures, which is a versatile platform for programmable metasurfaces."

"We have paved the way to break a technology barrier by replacing the liquid crystal layer in current displays with a metasurface, enabling us to make affordable flat screens liquid crystal-free," said Prof. Mohsen Rahmani. "The most important metrics of flat panel displays are pixel size and resolution, weight and power consumption. We have addressed each of these with our meta-display concept.

"Most importantly, our new technology can lead to a huge reduction in energy consumption – this is excellent news given the number of monitors and TV sets being used in households and businesses every single day. We believe it is time for LCD and LED displays to be phased out in the same way as former cathode ray tube (CRT) TVs over the past 10 to 20 years."

Dr Lei Xu, a team member from Nottingham Trent University, said: "There is significant room for further improvements by employing artificial intelligence and machine learning techniques to design and realise even smaller, thinner and more efficient metasurface displays."

For more information about this research, please contact connect@tmos.org.au

* CMOS stands for Complementary Metal-Oxide-Semiconductor and is a technology used for constructing integrated circuit (IC) chips, including microprocessors, microcontrollers, memory chips, and other digital logic circuits. CMOS technology is also used for analog circuits such as image sensors (CMOS sensors), data converters, RF circuits (RF CMOS), and highly integrated transceivers for many types of communication.

Electrically programmable solid-state metasurfaces via flash localised heating

LIGHT: SCIENCE & APPLICATIONS, 22ND FEBRUARY 2023

Khosro Zangeneh Kamali, Lei Xu, Nikita Gagrani, Hark Hoe Tan, Chennupati Jagadish, Andrey Miroshnichenko, Dragomir Neshev & Mohsen Rahmani

In the last decades, metasurfaces have attracted much attention because of their extraordinary light-scattering properties. However, their inherently static geometry is an obstacle to many applications where dynamic tunability in their optical behaviour is required. Currently, there is a quest to enable dynamic tuning of metasurface properties, particularly with fast tuning rate, large modulation by small electrical signals, solid state, and programmability across multiple pixels. Here, we demonstrate electrically tunable metasurfaces driven by thermo-optic effect and flash-heating in silicon. We show a 9-fold change in transmission by <5 V biasing voltage and the modulation rise-time of <625 μs. Our device consists of a silicon hole array metasurface encapsulated by transparent conducting oxide as a localised heater. It allows for video frame rate optical switching over multiple pixels that can be electrically programmed. Some of the advantages of the proposed tuning method compared with other methods are the possibility to apply it for modulation in the visible and near-infrared region, large modulation depth, working at transmission regime, exhibiting low optical loss, low input voltage requirement, and operating with higher than video-rate switching speed. The device is furthermore compatible with modern electronic display technologies and could be ideal for personal electronic devices such as flat displays, virtual reality holography and light detection and ranging, where fast, solid-state and transparent optical switches are required.

Read the full article

MANIPULATE CASE STUDY

New breakthrough in 3D stretchable devices fabrication makes robots more human

Despite the many names owners give their robot vacuum cleaners, Dustin Bieber and Optimus Grime being two of our favourites, there's no chance of mistaking these devices as living beings. They can deliver a clean house but not comfort.

As the population ages and robotics becomes more advanced, the prospect of lifelike robots delivering care becomes increasingly likely. Soft robotics use materials that are flexible, deformable, pliant and that mimic skin. Sensors, lenses, and circuits are then embedded within this soft material. In a not-to-distance future, a robot could hold a sick person's hand, simultaneously taking their temperature, heart rhythm, glucose levels etc. all while provide a simulation of human contact and comfort.

But the end goal of soft robotics is not just a Siri with corporeal form performing human-like movements. Soft robotics allows for flexible, wearable sensors as well as minimally invasive surgeries as the material's flexible structures navigate through the body's confined spaces with reduced trauma to the surrounding tissue.

The challenge to widespread adoption of soft robotics in the medical sphere is the durability and longevity of these materials. They stretch and release repeatedly as they are worn or as they moved. This can cause the various layers of the material to pull apart or delaminate. In addition, the circuits and sensors within the material are exposed to air and moisture during the fabrication process, which can cause them to degrade over time.

Researchers at TMOS, the ARC Centre of Excellence for Transformative Meta-Optical Systems, have addressed these challenges with a new fabrication technique that can create stretchable circuits and lenses within a silicone polymer without exposing it to atmospheric conditions and without needing

SPOTLIGHT

Litty Varghese Thekkekara

Postdoctoral Fellow

Litty is an accomplished Science and Engineering professional with expertise in diverse domains, including emerging technologies, research, project management, and science policy. Her research portfolio encompasses various cutting-edge fields, including nano-optics, plasmonics, thin films, 2D materials, spectroscopy, imaging, meta optics, free space optics, sensing and renewable energy and storage technologies. She has a track record of leading impactful research endeavours, managing projects from inception to completion, and ensuring compliance with regulatory standards and industry guidelines

Through fruitful collaborations with internal and external partners, including companies and universities, She has been instrumental in establishing essential processes for device fabrication, characterization, nanofabrication capabilities, supply chain management, and quality control.

Her hands-on experience with advanced techniques, such as 3D laser printing, EBL, FIB, SEM, RIE, AFM, photolithography, and thin-film deposition methods (ALD, PVD, and CVD), as well as nano-characterization expertise underscores her technical proficiency. She takes immense pride in generating high-impact research outputs and influential science policies strategically crucial for both commercial and academic sectors.

the multiple layers that typically fail over time. This flexible polymer with embedded sensors is only 1/20th the thickness of the epidermal layer of human skin, making it an ideal for wearable and implantable devices.

This new fabrication technique uses direct laser writing (DLW) or three-dimensional laser printing to run a highly confined laser along a pre-determined path on a silicone substrate made from combined Polydimethylsiloxane (PDMS) and graphene oxide (GO). This laser interacts with the substrate at specific depths beneath the surface, transforming the GO-PDMS material into reduced GO and carbon-rich PDMS. This carbon-rich material is conductive and, essentially, a circuit is formed within the material without it having been exposed to the atmosphere and without it needed an encapsulating layer.

The researchers also demonstrated the fabrication of stretchable flat graphitized lenses using the same method. These lenses have a broadband focusing capability in the visible region, and present a potential transformation of applications from intraocular lenses for living organisms to compact lens systems in soft robotics.

Lead author Dr. Litty Thekekkera from the Centre's RMIT node says, "Using careful control of carbon doping and with extensive modelling, we have been able to demonstrate not just stretchable electronics but also a stretchable graphitised lens which is tunable with strain and has broadband focusing capability."

TMOS Chief Investigator Madhu Bhaskaran says, "Using a laser to transform the material to create 3D structures is an exciting new way to create next generation optical and electronic devices – it is a a one step process to offer functionality, enhanced stretchability, and encapsulation."

For more information about this research, please contact connect@tmos.org.au

3D Stretchable Devices: Laser-Patterned Electronic and Photonic Structures

ADVANCED ELECTRONIC MATERIALS, 10TH DECEMBER 2023

Litty V Thekkekara, Ying Zhi Cheong, Md. Ataur Rahman, Sharath Sriram, Madhu Bhaskaran

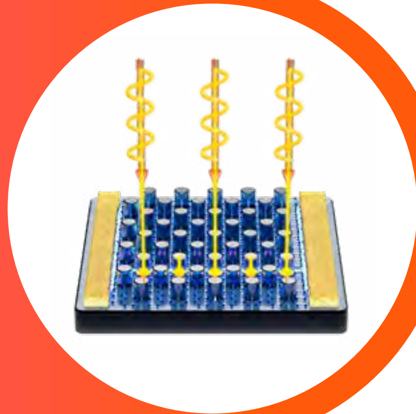
Realizing three-dimensional stretchable structures of functional materials with a minimum footprint on Silicone polymer is highly desirable in soft robotics, stretchable electronics, and photonics. However, material processing on a stretchable substrate requires a sophisticated deposition system with integrated substrate cooling facilities to prevent delamination of materials from the stretchable substrate due to stretching-releasing cycles, and for encapsulating the functional materials. Here, a methodology to address these challenges using in situ graphitization within silicone polymer, referring to transforming the material into graphite-like structures using three-dimensional laser printing is reported. In this case, the graphitization process occurs due to the interaction of the material with a spatially controllable, tightly focused femtosecond laser beam in the confined region within the polymer. Three-dimensional printed embedded, stretchable electrodes and varifocal lenses of thickness 1/20th compared to the epidermis layer thickness of human skin, which can contribute to achieving compact, highly sensitive wearable sensing and imaging systems are demonstrated and characterized. This process will open a new door for forming non-metallic stretchable three-dimensional conductors and photonics with minimum exposure to atmospheric conditions and a pathway to interface with thin films to develop low-dimensional devices. These graphitized three-dimensional structures can make them integral to intelligent skins, e-textiles, and implantable devices.

Read the full article

THEME THREE

Detect

Optical detection is central to modern information acquisition and processing technology. The increasing demands for the miniaturisation of electronic devices requires ultra-compact efficient, multimodal optical and infrared detectors using meta-optics. The Detect Theme will develop devices that will create new opportunities for novel optics in Industry 4.0.



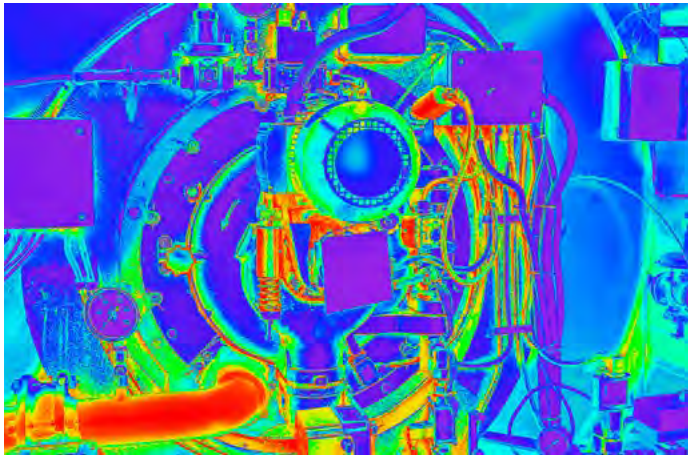
THEME LEADERS:

PROFESSOR ANN ROBERTS
University of Melbourne

PROFESSOR LORENZO FARAONE
The University of Western Australia

Efficient detection in the visible and infrared regions of the spectrum with compact sensors and imaging systems is crucial to address the growing demands for miniaturised mobile electronic platforms. These devices are utilised in various applications, including chemical sensing, three-dimensional imaging, and improving visibility in challenging conditions such as fog and bushfire smoke. Infrared detectors will continue to play an important role in defence, medical, and Industry 4.0 applications, but current challenges lie in their inefficiency at room temperatures, hindering their use in weight-sensitive applications such as drones and space systems. To address this issue and expand their functionality, TMOS is investigating novel semiconductor nanowire devices and their applications to sensing and imaging, along with the integration of metasurfaces and subwavelength structures into mercury cadmium telluride detectors. Additionally, there is a significant demand for optical sensors that can extract information such as polarisation and phase from electromagnetic waves and TMOS is harnessing the power of meta-optics to make this invisible information accessible.

Excellent progress was made on the 2023 action items with most complete, and design and simulations finished in preparation for ongoing work in 2024 for others. Highlights include two new approaches to chemical sensing. Chief Investigator Lan Fu and her team have shown how various nanowire arrays can sense gases such as NO2 and another that can detect acetone which, in human breath, is a marker for diabetic ketoacidosis (DKA), a life-threatening complication of diabetes. This device exhibits an ultra-wide detection range over readings from healthy individuals to those at high-risk of



DKA, and has been incorporated into a handheld testing prototype. Chief Investigator Crozier's group at The University of Melbourne (UoM) also demonstrated the performance of a smart, low-cost, mid-infrared, multi-gas microspectrometer incorporating a metasurface filter and utilising a machine learning algorithm to detect methane, ammonia, CO_2, and methyl-ethyl ketone (MEK). Furthermore, and highlighting the diversity of the theme, Chief InvestigatorSukhorukov's group at ANU have, using a static dielectric metasurface grating with no reconfigurable elements, performed single-shot characterisation of the indistinguishability between two photons in multiple degrees of freedom including time, spectrum, spatial modes, and polarisation.

As TMOS research evolves, metasurfaces will be integrated into new and enhanced detectors, permitting novel functionality that will also enable orders-of-magnitude miniaturisation of devices. Furthermore, with the 'manipulate' theme we will create individual photodetectors and imaging arrays with a sensitivity to different properties of light that can be dynamically tuned or permit extraction of multiple dimensions of information from an optical field at wavelengths ranging from the visible through to the mid-infrared region of the spectrum.

KEY MILESTONES FOR 2024

1. Experimental demonstration of gas sensing using quasi bound mode in the continuum filters integrated with a detector array
2. Experimental demonstration of short infrared (SWIR) single-pixel imaging using nanomaterial-based photodetector
3. Demonstrate metasurface/GaAsSb nanowire array single pixel polarisation imaging
4. Demonstrate tunability of graphene in a gated structure
5. Progress experimental demonstration of ghost imaging of transparent objects 6. Fabrication of a hybridized 2x2-superpixel metalens array with an MCT imaging array

DETECT

Subprograms

3A. ADVANCED IMAGING

The research sub-theme of "enhanced IR detection" endeavours to pioneer the development of next-generation infrared detectors by leveraging novel semiconductor materials, specifically employing III-V compounds like InAs, InGaAs and InP grown by MOCVD and MBE machine into nanowires and quantum wells, operating within shortwave (SW) and midwave (MW) spectral bands. These emerging material systems hold promise for superior responsivity, detectivity, and operational temperature ranges compared to conventional methodologies, which have historically impeded the progress of infrared technologies.

Within the framework of the TMOS initiative, the performance of infrared detectors based on III-V compound technologies, alongside more traditional Mercury-Cadmium-Telluride (HgCdTe) ternary alloys, can be further elevated through integration with meta-materials. This strategic fusion enables the optimization of detector performance by maximizing radiation absorption impinging on the detector surface. Moreover, the amalgamation of meta-materials with infrared detectors facilitates real-time analysis of incoming radiation, unveiling the utilization of concealed properties of light such as polarization and wavelength selectivity. This capability holds profound implications for surveillance, defence and security applications, enabling enhanced target classification and detection capabilities.

Looking ahead to 2024, the research sub-themes of "Enhanced infra-red detection" and "Advanced imaging" will be consolidated due to their closely intertwined objectives, fostering synergistic advancements in the realm of infrared technology.

Researchers at the Australian National University (ANU) have achieved a breakthrough in the fabrication of III-V based nanowire infrared detectors. By refining fabrication techniques, they have successfully produced a small dimension InGaAs nanowire array photodetector measuring 50x50 um, aimed at enhancing the performance of shortwave infrared (SWIR) photodetection. This innovative detector exhibits reduced dark current, enabling the detection of signals at lower power levels and higher temperatures compared to previous iterations. Specifically, the newly fabricated detector demonstrates the capability to detect 6.5 pW of laser power at a wavelength of 1310 nm and a temperature of 323 K, with a 20 MHz repetition rate equivalent to 6 photons per pulse of the laser. Furthermore, enhancements in detector speed are evident, attributed to the reduced detector capacitance. The smaller detector now achieves speeds of up to 15 MHz, a substantial improvement over the previous limit of 5 MHz. This advancement signifies a significant stride forward in the realm of nanowire-based infrared detection technology, promising heightened sensitivity and efficiency in a range of applications.

In a recent advancement, the same research group at the Australian National University (ANU) has achieved a significant milestone by successfully fabricating a high-performance shortwave infrared (SWIR) detector utilizing InGaAs/InP core-shell nanowire technology. This breakthrough entails the fabrication of a 4x4 array of InGaAs/InP nanowire photodetectors, demonstrating exceptional responsivity exceeding 1A/W within the SWIR spectral band spanning from 1000nm to 1600nm. Building upon this achievement, future endeavors will concentrate on the design and fabrication of metasurface-enabled techniques for wavelength demultiplexing, polarization demultiplexing, and orbital angular momentum (OAM) demultiplexing, leveraging the unique capabilities of these detectors to enhance overall performance. This strategic direction promises to unlock new frontiers in infrared detection technology, with potential applications spanning from telecommunications to remote sensing and beyond.

Collaborative efforts between researchers at the Australian National University (ANU) and Professor Hannah J. Joyce's team at the University of Cambridge are advancing the frontier of flexible detector technology through the demonstration of InP nanowire array-based flexible detectors tailored for a myriad of applications, notably including wearable devices. The nanowires, characterized by diameters of approximately 200nm and heights of around 6um, with a pitch size of

0.8um, serve as the fundamental building blocks of these flexible detectors. Leveraging mature epoxy-encapsulation techniques and ultra-microtome technology perfected by the Cambridge group, seamless fabrication of flexible nanowire arrays has been achieved, laying the foundation for subsequent integration into photodetectors. These flexible arrays, once outfitted with appropriate electrical contact layers, are poised to revolutionize the landscape of wearable technology, offering enhanced versatility and adaptability for a diverse range of sensing applications in healthcare, environmental monitoring, and beyond.

Through a collaborative endeavour between the University of Western Australia (UWA) and the Australian National University (ANU), a significant milestone has been achieved in the fabrication of an infrared photodetector optimized for operation within the midwave infrared band (3-5μm), leveraging InGaAs/InP in a Quantum Well Infrared Photodetector (QWIP) structure. This innovative detector, known as the nanowire QWIP (NW-QWIP), has successfully demonstrated normal incidence infrared photodetection, facilitated by the unique radial growth direction of the QW layers. Following meticulous calibration at the TMOS-UWA (The University of Western Australia) node, operating at a temperature of 108 K, the NW-QWIP exhibits a highly sensitive photoresponse within the mid-wavelength infrared spectrum, showcasing peak responsivity and detectivity values of 120 mA/W and 1.3×107 Jones, respectively, at a wavelength of 4.2 μm. This achievement underscores the remarkable performance capabilities of the NW-QWIP, marking a significant advancement in the realm of infrared photodetection technology and holding promise for a wide array of applications spanning from remote sensing to thermal imaging.

ACTION ITEMS 2024

- Experimental demonstration of short infrared (SWIR) single-pixel imaging using nanomaterial-based photodetector
- Demonstrate metasurface/ GaAsSb nanowire array single pixel polarisation imaging
- Fabrication of a hybridised 2x2-superpixel metalens array with an MCT imaging array

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1. Ziyuan Li, Zahra Azimi, Zhe Li, Yang Yu, Longsibo Huang, Weiqi Jin, Hark Hoe Tan, Chennupati Jagadish, Jennifer Wong-Leung, Lan Fu, " InAs nanowire arrays for room-temperature ultra-broadband infrared photodetection," Nanoscale 15 (23), 10033-10041 (2023), https://doi.org/10.1039/d3nr00340j
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6. Yu H, Fu L, Wang R, Memon M, Luo Y, Xiao S, Fu L, Sun H, Highly Responsive Switchable Broadband DUV-NIR Photodetector and Tunable Emitter Enabled by Uniform and Vertically Grown III-V Nanowire on Silicon Substrate for Integrated Photonics, Nano Micro Small (2023)

3B. SEEING THE INVISIBLE WITH NANOTECHNOLOGY

The sub-theme of multimode sensing was focused on enhancing the capability of devices by measuring multiple properties of light. A conventional camera can only record intensity (brightness) information. Other properties of light such as the wavelength (colour), polarisation, angular momentum, and quantum state contain valuable information– which is traditionally only accessible by adding extra components such as filters, polarisers, beamsplitters, complex optics and multiple detectors. Research during 2023 uncovered a swath of meta-optics enabled advanced multimodal sensing, including microspectroscopy, discrimination of polarisation states, and optical image processing.

Spectroscopy is an important tool for identifying unknown compounds with wide-ranging applications in environmental monitoring, for example, air quality and water contamination. Commercially available infrared spectroscopy systems are often large and costly. Researchers at the University of Melbourne continued to improve a next generation microspectrometer design. Having successfully shown the detection of liquids enabled by an array of meta-surface filters and machine-learning algorithms, the researchers extended the capability to demonstrate the detection of gases. In 2024 they will continue to improve the smart, low-cost multi-gas sensing platform.

Optical fibres are the underlying technology for modern telecommunications, with undersea cables carrying 99% of transoceanic data. An inherent physical property that limits the amount of information an optical fibre can transmit is *dispersion*, the spreading out of the signal over large distances through the fibre. Researchers from the Australian National University developed and demonstrated non-trivial metasurfaces for the single-shot discrimination of polarisation state at optical communications wavelengths. Importantly this system does not require multiple sets of bulk optics that are conventionally required for such a measurement.

Optical image processing is a real-time alternative to conventional computational image processing. It is being widely investigated for its ability to reduce the amount of computational power and increase the detection speed. Researchers from the University of Melbourne and the University of Technology Sydney investigated graphene-base nonlocal metasurfaces. The dynamic tunability and the ultra-compact footprint of the design can lead to multimode sensing device miniaturisation at the same time as enabling an order of magnitude increase in data throughput.

At the end of 2023, the restructuring of Theme 3 led to the merging of a few projects from 3C into 3B, and the renaming of 3B from “Multimode Sensing” to “Detection of Hidden Properties”. In 2024 the sub-program will explore fundamental theory and apply research to improve devices using innovative meta-optics to see the hidden properties of light, such as wavelength, polarisation, angular momentum, and quantum/classical states.

ACTION ITEMS 2024

- Experimental demonstration of gas sensing using quasi bound mode in the continuum filters integrated with a detector array
- Demonstrate tunability of graphene in a gated structure
- Progress experimental demonstration of ghost imaging of transparent objects

PUBLICATIONS

1. C. K. Nguyen, P. D. Taylor, A. Zavabeti, H. Alluhaybi, S. Almalki, X. Guo, M. Irfan, M. A. Kobaisi, S. J. Ippolito, M. J. Spencer, S. Balendhran, A. Roberts, T. Daeneke, K. B. Crozier, Y. Sabri, N. Syed, Instant-in-Air Liquid Metal Printed Ultrathin Tin Oxide for High-Performance Ammonia Sensors. Adv. Funct. Mater. 2023, 2309342. https://doi.org/10.1002/adfm.202309342
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3C. DETECTING INFRARED LIGHT FOR IMAGING

The research sub-theme of advanced imaging aims to develop next-generation imaging systems by incorporating emerging technologies such as nanowire infra-red detectors, and harnessing the power of meta-optics to enhance existing HgCdTe based infrared detectors and focal plane arrays with phase and polarization sensitivity. These meta-enhanced detectors and imaging systems will be significantly smaller and lighter compared to state-of-the-art systems, thus allowing large scale integration into mobile electronic devices and lightweight platforms such as drones and nano-satellites.

Going forward, the research sub-themes of "Enhanced infra-red detection" and "Advanced imaging" will be merged together since their objectives are very closely intertwined with each other.

We have also seen the introduction of "flagship projects" that will aim to harness the expertise of researchers across the three main research themes in order to tackle specific real-world challenges. The flagship project for "Advanced IR imaging" will see greater co-operation between the researchers from Detect and Manipulate themes, in order to deliver the next generation of compact, low-power, polarization and phase sensitive infrared imaging systems.

Researchers at UTS and University of Melbourne discovered that graphene covered silicon carbide gratings could be employed as dynamically tunable optical computation and image processing devices, and they have the potential to enable ultrafast high-throughout real-time processing of optical data in compact mid-infrared devices.

Researchers at University of Melbourne also demonstrated real-time, all-optical, object-plane image processing using a commercially available spectral notch filter. Their technique replaces the use of existing methods such as differential interference contrast microscopy which require bulky, expensive, and complex system components. Their research offers a cost-effective method which uses off-the-shelf components to obtain high contrast images of biological cells.

Researchers at ANU have designed two-dimensional InAs nanosheet arrays for use as polarization-sensitive infrared detectors. Their design overcomes the drawbacks of low light absorption, low-polarization sensitivity and stability which are faced by competing technologies such as semiconductor nanowires and opens a new route for the development of high-performance polarization sensitive-photodetectors.

Researchers at ANU also demonstrated broadband light detecting/emitting diodes based on AlGaN nanowires grown directly on silicon substrates. These nanowire-based devices not only eliminate the issues faced in integrating conventional III-V thin film semiconductors on to silicon, but also demonstrate very high responsivity over an extremely wide operational band ranging from deep UV to the near-infrared region of the spectrum. Their dual capability to work as detectors or emitters provides a new avenue for the realization of monolithically integrated Si-photonics systems.

Researchers at UWA have grown HgCdTe thin films on 2D layered transparent mica substrates using Van der Waals (vdW) epitaxial growth. The weak vdW bonding between the HgCdTe and the mica substrate allows the HgCdTe layer to be lifted-off and transferred onto flexible substrates for fabricating curved infra-red imaging arrays in the future.

Researchers at UWA also investigated the use of low-cost GaAs substrates in the molecular beam epitaxial (MBE) growth of HgCdTe for use in high-performance infrared detectors. They found that by incorporating strained CdZnTe/CdTe superlattice-based dislocation layers it was possible to reduce defects and improve surface roughness in the CdTe buffer layers. This will allow for the growth of high-quality HgCdTe on large-area, low cost substrates allowing for widespread integration of cost-effective infra-red detectors and imaging systems.

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DETECT CASE STUDY

Lower cost infrared imaging systems improving your weather forecast

A lot goes into the meteorological surveys that bring you the daily weather forecast. Predicting trends using weather satellites began in the 1950s and the debut infrared imaging observation satellite launched in 1960. These first-ever images of Earth's cloud cover from space played a pioneering role in weather forecasting.

Since then, much has evolved. There's now a heightened demand for precise prediction of localized phenomena, particularly severe weather events such as thunderstorms, strong winds, fog, and hail, which profoundly affect both the economy and public safety worldwide. The emergence of drone-based weather monitoring has emerged as a promising frontier, driven by advancements in drone technology. Equipped with specialized sensors such as infrared sensors, drones are capable of conducting high-resolution, direct temperature measurements, significantly enhancing our ability to forecast and respond effectively to severe weather events.

However, one aspect remains unchanged—the substantial cost associated with equipping weather drones with highly sensitive infrared (IR) imaging systems. This financial barrier limits the widespread deployment of IR-enabled weather drones, consequently restricting the quantity of data available to meteorologists and consequently affecting the quality of trend forecasting.

Traditionally, highly sensitive IR focal plane arrays suitable for meteorology are manufactured from Mercury Cadmium Telluride (MCT) thin film materials, requiring their growth onto a substrate. Conventionally, the preferred substrate has been a semiconductor called Cadmium Zinc Telluride (CZT), as its lattice structure aligns with that of MCT, enabling high-quality epitaxial growth. However, CZT has limitations, being fragile, restricted to small dimensions, and expensive to produce.

SPOTLIGHT

Wenwu Pan

Postdoctoral Research Fellow

Dr. Pan is currently a postdoctoral research fellow for the ARC Centre of Excellence for Transformative Meta-Optical Systems (ARC TMOS) at the University of Western Australia (UWA). His research interests lie in infrared-sensitive materials & devices and their integration with meta-optics for applications in next-generation infrared sensors. Dr. Pan was awarded his PhD in Microelectronics and Solid-state Electronics from Chinese Academy of Sciences (CAS) in 2017. His PhD research was on molecular beam epitaxial (MBE) growth and characterization of III-V optoelectronic materials & devices such as lasers and infrared detectors. Since 26/02/2018, Dr. Pan worked as a full-time research associate/fellow in the Microelectronics Research Group (MRG), the School of Engineering at UWA to continue his research on optoelectronics, particularly II-VI infrared semiconductors and detectors. Dr. Pan has registered on the supervisor panel at UWA and co-supervised two PhD students. Dr. Pan has published more than 50 peer-reviewed papers and 1 book chapter. Most of the papers have been published in well-respected journals of this field, such as Nano research, ASC photonics, Sci. Rep., Appl. Phys. Lett., J. Appl. Phys., etc.

The team at TMOS (Transformative Meta-Optical Systems) from the University of Western Australia has embraced a innovative approach to fabricating MCT infrared detectors. They've developed a buffer layer of Cadmium Telluride incorporating nanostructured dislocation reduction structures, mimicking the lattice structure and material quality of CZT.

This buffer layer can be applied onto more durable and cost-effective substrates such as Silicon (Si) and Gallium Arsenide (GaAs) to serve as an alternative composite substrate, facilitating high-quality growth of MCT.

The result of this approach is a more cost-effective MCT IR detector capable of withstanding environmental stressors more effectively, making it ideal for various applications, including meteorological observations using drones.

Lead author Wenwu Pan says, "to make wide-spread space-based infrared imaging more practical, we need a technology similar to Si-CMOS, which uses large, high-quality substrates for material growth and allows for the production of numerous imaging sensors per wafer through multi-wafer batch processing. The main challenge lies in the significant lattice mismatch between MCT and these alternative substrates, resulting in high density of material defects which are pixel/performance killers. Using a superlattice-based buffer to grow high-quality MCT on large alternative substrates address this problem."

Chief Investigator Lorenzo Faraone says, "Integrating MCT detectors with optical metasurfaces is expected to significantly enhance infrared sensing systems for earth observation and remote sensing, by providing higher performance and sensors with new capabilities such as polarization sensitivity. Integrating metasurfaces with CZT substrates is problematic in comparison to alternative substrates like Si and GaAs. This is because integration necessitates a complex substrate thinning process to couple the metasurface and imaging array. In addition, metasurfaces such as on-pixel-aligned metalens technology enables the use of smaller detector areas, which provides higher performance and/or higher operating temperature. It would have a high industry impact if the combined effects of defect reduction on non-CZT substrates and the integration of a metalens technology results in device performance comparable to or even surpassing that of detectors grown on CZT substrates.

For more information about this research, contact connect@tmos.org.au

Structural properties of MBE-grown CdTe (133)B buffer layers on GaAs (211)B substrates with CdZnTe/CdTe superlattice-based dislocation filtering layers

JOURNAL OF APPLIED PHYSICS, 8TH MAY 2023

Wenwu Pan, Shuo Ma, Xiao Sun, Shimul Kanti Nath, Songqing Zhang, Renjie Gu, Zekai Zhang, Lorenzo Faraone, and Wen Lei

The ever-present demand for high-performance HgCdTe infrared detectors with larger array size and lower cost than currently available technologies based on lattice-matched CdZnTe (211) B substrates has fuelled research into heteroepitaxial growth of HgCdTe and CdTe buffer layers on lattice-mismatched alternative substrates with a (211)B orientation. Driven by the large lattice mismatch, the heteroepitaxial growth of (Hg)CdTe can result in (133) B-orientated material, which, however, has been less explored in comparison to (211)B-oriented growth. Herein, we report on the structural properties of heteroepitaxially grown single-crystal II–VI CdTe (133)B-oriented buffer layers on III–V GaAs (211)B substrates. Azimuthal-dependent x-ray double-crystal rocking curve measurements for the CdTe buffer layers show that the full-width at half-maximum value obtained along the GaAs [111] direction is narrower than that obtained along the GaAs [011] direction, which is presumably related to the in-plane anisotropic structural characteristics of the grown CdTe layers. By incorporating strained CdZnTe/CdTe superlattice-based dislocation filtering layers (DFLs), a significant improvement in material quality has been achieved in (133)B-orientated CdTe buffer layers, including a reduced etch pit density in the low-105 cm-2 range and improved surface roughness. These results indicate that the CdTe (133)B DFL buffer layer process is a feasible approach for growing high-quality CdTe and HgCdTe materials on large-area, low-cost alternative substrates.

Read the full article

DETECT CASE STUDY

New flexible 2D gas sensor soon to be protecting you from toxic ammonia

Your smartwatch could soon save you from more than missed meetings with a new miniaturised ammonia gas sensor in development. The sensor, made from 2D liquid metal and fabricated using a simple, cost-effective technique, could one day be integrated into wearable devices, monitoring your environment for harmful levels of toxins.

Ammonia is an invisible silent threat that can lead to chronic lung conditions and irreversible organ damage when a person is exposed to high levels. Generally, this exposure results from close proximity to high-production agricultural and industrial areas or faulty home appliances. According to industry estimates, 235 million metric tons of ammonia were produced globally in 2019, and that number is projected to rise to approximately 290 million metric tons by 2030.

Researchers from TMOS, the ARC Centre of Excellence for Transformative Meta-Optical Systems, are working to address the dangers of undetected ammonia exposure by developing a gas sensor using atomically thin transparent two-dimensional (2D) tin dioxide film. The material has a thickness of only 2 nanometres which is 50,000 times thinner than a paper. Reducing the thickness to only a few atoms, substantially increasing the flexibility of the material and makes it ideal for integration into wearable devices such as smartwatches and medical patches.

The tin oxide acts as an electric 'nose.' The presence of ammonia in the air changes the electrical resistance of the material. The higher the level of ammonia, the greater the resistance change. As a result, the sensor can differentiate between safe and dangerous levels of the toxin in the surrounding environment.

Current standard ammonia detection is mostly based on advanced approaches like gas chromatography. This is accurate for ammonia measurement, but its use is complicated and requires qualified staff, laborious sampling and preparation, and expensive laboratory equipment. The process is time-consuming and due to the size of the equipment needed, not portable. In addition, the manufacturing of current ammonia detectors often involves expensive and complicated processes to prepare sensitive layers for sensor fabrication.

SPOTLIGHT

Nitu Syed

Postdoctoral Researcher

Nitu Syed is an award-winning research scholar with a demonstrated history of working in academic research, and a PhD in STEM from RMIT University. She has a natural passion for developing innovative engineering solutions using analytical and critical skills, problem-solving skills, stakeholder management, and by managing timelines and available resources. She has demonstrated inspection techniques and procedures to meet quality specs & standards, proven ability to influence and persuade management by accepting accountability and ownership. She has 5+ years of experience in interpreting and executing data-driven solutions to increase efficiency, accuracy, and utility of experimental datasets.

By contrast, the gas sensors developed by the TMOS researchers from the University of Melbourne and RMIT utilised a simple, low-cost liquid metal printing technique to deposit 2D tin dioxide that only requires a single synthesis step without using any toxic solvents, vacuum, and bulky/expensive instruments. Importantly, the fabrication method aligns well with existing silicon industry manufacturing processes, paving the way for easy fabrication adoption for mass production.

Despite its ultra-thin form factor, the 2D sensors are highly sensitive, due to their high surface area-to-volume ratio. The developed sensors demonstrate an unprecedented capability to detect ammonia at ultra-low concentrations (down to parts-per-billion) and outperform conventional sensors in terms of chemical sensitivity, selectivity, and stability showcasing impressive potential for long-term installation. The team demonstrated that engineering materials at the nanoscale can present enormous opportunities in emerging sensing applications. The researchers' peer-reviewed article, "Instant-in-Air Liquid Metal Printed Ultrathin Tin Oxide for High-Performance Ammonia Sensors", is published in Advanced Functional Materials.

Lead corresponding author, McKenzie Fellow Dr Nitu Syed, says, "These novel nanosensors are safer and less tedious than existing techniques for monitoring toxic ammonia gas, and the sensor functions consistently and robustly after months of use. This innovation has far-reaching implications, from enhancing safety in industrial settings where ammonia is used, to enabling non-invasive medical diagnosis through breath analysis."

TMOS Chief Investigator Professor Kenneth Crozier says, "While several applications of the liquid metal-derived 2D oxides have been reported so far, their gas-sensing properties remain largely underexplored despite their cost-effectiveness, scalability, repeatability stability, and suitability for mass-production."

TMOS Chief Investigator Professor Ann Roberts says "This is an exciting development that will underpin progress in the development of low-cost, wearable technologies enabling access to individuals working and living in potentially polluted environments. Ultimately, this can pave the way to improved air quality across the world".

Co-corresponding author, Dr. Ylias Sabri, Senior Lecturer from RMIT, says, "As the world moves away from fossil fuels, green ammonia is predicted to play a central role in the energy transition. While ammonia is already used on vast scales, introducing it into the transportation sector will require the deployment of robust monitoring equipment to ensure safe operation, a task that must keep pace with the development of new fuel sources. This is one key use case for our device, and we're keen to discuss with the industry ways to help it move forward."

For more information about this research, please contact connect@tmos.org.au

New flexible 2D gas sensor soon to be protecting you from toxic ammonia

ADVANCED FUNCTIONAL MATERIALS, 15TH NOVEMBER 2023

Chung Kim Nguyen, Patrick D. Taylor, Ali Zavabeti, Hamidah Alluhaybi, Samira Almalki, Xiangyang Guo, Mehmood Irfan, Mohammad Al Kobaisi, Samuel J. Ippolito, Michelle J.S. Spencer, Sivacarendran Balendhran, Ann Roberts, Torben Daeneke, Kenneth B. Crozier, Ylias Sabri, Nitu Syed

Liquid metal-based printing techniques are emerging as an exemplary platform for harvesting non-layered 2D materials with a thickness down to a few nanometres, leading to an ultra-large surface-area-to-volume ratio that is ideal for sensing applications. In this work, the synthesis of 2D tin dioxide (SnO2) by exfoliating the surface oxide of molten tin is reported which highlights the enhanced sensing capability of the obtained materials to ammonia (NH3) gas is reported. It is demonstrated that amperometric gas sensors based on liquid metal-derived 2D SnO2 nanosheets can achieve excellent NH3 sensing performance at low temperature (150 °C) with and without UV light assistance. Detection over a wide range of NH3 concentrations (5–500 ppm) is observed, revealing a limit of detection at the parts per billion (ppb) level. The 2D SnO2 nanosheets also feature excellent cross-interference performance toward different organic and inorganic gas species, showcasing a high selectivity. Further, ab initio DFT calculations reveal the NH3 adsorption mechanism is dominated by chemisorption with a charge transfer into 2D SnO2 nanosheets. In addition, a proof of concept for prototype flexible ammonia sensors is demonstrated by depositing 2D SnO2 on a polyimide substrate, signifying the high potential of employing liquid metal printed SnO2 for realizing wearable gas sensors.

Read the full article

DETECT CASE STUDY

The Good Fight: Advance in flexible photodetector could improve monitoring of greenhouse gases

There will soon be a new tool to fight global warming with the development of lightweight flexible light sensors that can simultaneously image across a wide spectral range, from the visible to the infrared, with minimal optical components. This makes it perfect for drones and satellites deployed to monitor greenhouse gas emissions.

Conventional cameras use flat sensor arrays and complex optics. These have bulk and weight, complex fabrication processes, and limited spectral ranges. Consequently, monitoring greenhouse emissions using drones and satellites is expensive, given production and operating costs, and the sensors may not detect all gases.

In research published in Advanced Functional Materials, researchers at TMOS outline their work on a new flexible photodetector that can detect visible to long-wave infrared radiation, covering the full spectrum of greenhouse gases without the need for complex optical components. Its production is simple and scalable, reducing costs significantly. It operates at room temperature, removing any need for cryogenic cooling, which is not the case for typical mid-wave infrared cameras.

Lead author, Sivacarendran Balendhran says, “Conventional sensors that have flat arrays require multiple optical components to correct the distortion that occurs around the edges of an image taken with a flat sensor. This increases the size and the weight of the sensor. Flexible photodetectors will enable curved focal plane arrays mimicking the retina of the human eye, allowing you to capture images with a simple lens.

“In addition, current technology requires different types of cameras to cover such a broad spectral range and requires cryogenic cooling in some spectral bands. They usually work with either the infrared spectrum or the visible one. Our detector allows imaging across both, at room temperature.”

In addition to an ultra-broad spectral range and a small footprint, these new flexible photodetectors are more simple and cost effective to make than most traditional technologies. Commercial infrared detectors comprise multiple elements—a sensor and the electronic circuits that convert the infrared signals. The sensors use vanadium oxide (VOx) however, it’s a complex material to grow, requiring temperatures above 450 degrees. The electronic circuits that work in tandem with the sensors are created using large-scale CMOS fabrication, which requires temperatures to be below 200 degrees. In most cases, to satisfy the manufacturing

SPOTLIGHT

Sivacarendran Balendhran

Lecturer

Sivacarendran Balendhran is a Lecturer in Electrical and Electronic Engineering, at the Faculty of Faculty of Engineering and Information Technology, The University of Melbourne. Prior to this, he was a Research Fellow in Nano-optics, DECRA Fellow and a Churchill Fellow. He received his Ph.D. in Electrical and Electronic Engineering in 2013 from RMIT University, with a focus on 2D materials of electronic applications. His research interests include two-dimensional materials, infrared detectors, opto-electronic devices and sensor development.

requirements of both parts, the infrared sensor is suspended from a bridge structure and placed within a vacuum pack. This isolation of the infrared sensor from the circuitry is effective but makes the detector inflexible.

The research team developed a new method for creating the sensors by using VOx nanospheres grown as a powder by researchers at the University of Melbourne and then mixing it with alcohol. This suspension can be dropped onto flexible circuitry at low temperatures, negating the need for a bridge, vacuum pack or complex optics.

Balendhran says, "We've demonstrated the capabilities of our detectors in a curved focal line array. The next step in our research is to manufacture a curved focal plane array."

Chief Investigator Kenneth Crozier says, "Infrared detectors are an essential component in various fields such as telecommunications, imaging, sensing, and surveillance. The integration of IR detectors into flexible platforms offers numerous benefits across various industries, including wearable sensors in the med-tech field, high-performance cameras with increased field of view and sensitivity in defence and security, and lightweight drone-operated sensors for Australia's agritech space. The simple and scalable material synthesis and device fabrication processes make our approach a game-changer for these applications."

For more information about this research, please contact connect@tmos.org.au

Flexible Vanadium Dioxide Photodetectors for Visible to Longwave Infrared Detection at Room Temperature

ADVANCED FUNCTIONAL MATERIALS, 21 JUNE 2023

Sivacarendran Balendhran, Mohammad Taha, Shifan Wang, Wei Yan, Naoki Higashitarumizu, Dingchen Wen, Nima Sefidmooye Azar, James Bullock, Paul Mulvaney, Ali Javey, Kenneth B. Crozier

Flexible optoelectronics is a rapidly growing field, with a wide range of potential applications. From wearable sensors to bendable solar cells, curved displays, and curved focal plane arrays, the possibilities are endless. The criticality of flexible photodetectors for many of these applications is acknowledged, however, devices that are demonstrated thus far are limited in their spectral range. In this study, flexible photodetectors are demonstrated using a VOx nanoparticle ink, with an extremely broad operating wavelength range of 0.4 to 20 μm. This ink is synthesized using a simple and scalable wet-chemical process. These photodetectors operate at room temperature and exhibit minimal variance in performance even when bent at angles of up to 100 ° at a bend radius of 6.4 mm. In addition, rigorous strain testing of 100 bend and release cycles revealed a photoresponse with a standard deviation of only 0.55%. This combination of mechanical flexibility, wide spectral response, and ease of fabrication makes these devices highly desirable for a wide range of applications, including low-cost wearable sensors and hyperspectral imaging systems.

Read the full article

Infrastructure and Capabilities Committee Chair Report

ICC Chair, Professor Kenneth Crozier

The TMOS Infrastructure and Capabilities Committee (ICC) aims to ensure that every TMOS researcher has access to the infrastructure they need. We are pleased to say that the 2023 ICC action items (see 2022 Annual Report) were achieved. New capabilities were added to the equipment register. We raised awareness of existing facilities within TMOS. Bids to the ARC Linkage Infrastructure Equipment Facilities (LIEF) program were supported. We made use of our computing time from the National Computational Infrastructure (NCI). We were also in close contact with Australian National Fabrication Facility (ANFF) .

Our 2024 action items are as follows. 1. Add new infrastructure to the Centre's equipment register. 2. Raise awareness of existing facilities within the Centre to increase cross-node collaboration. 3. Support funding and access bids by TMOS researchers and others whose work is synergistic with Centre activities, such as the ARC LIEF program and NCRIS funding.

One might think that the ICC has a limited role in fostering collaboration. This is far from the case. The ICC, for example, facilitated a month-long visit by Dr Wendy Lee to the Molecular Foundry at the Lawrence Livermore National Laboratory (LBNL) in the United States.

"I interacted with amazing scientists at LBNL. I learned about nanoparticle synthesis, coating processes and cold development in e-beam lithography. I am deeply grateful to the TMOS ICC, the Defence Advanced Research Projects Agency, and the Molecular Foundry User Project scheme. Beyond the lab, there were many memorable moments with the diverse LBNL community, including seeing the charming animals gracing its grounds." – Dr Wendy Lee (formerly TMOS Research Fellow, now Lecturer & Nexus Fellow at University of New South Wales).

Another example of ICC-facilitated collaboration was the visit by Ms. Xiaoying Huang (PhD student, ANU) to the lab of Chief Investigator Igor Aharonovich (UTS).

"My project focuses on the fabrication and characterisation of III-V semiconductor quantum dot-based quantum emitters. At ANU, I developed the processes for growth and fabrication of single InAsP quantum dots in InP nanowire arrays. I took my samples to UTS. I was able to show conclusively that they are truly single photon emitters and that emission wavelength can be tuned from 880 to 1600 nm. Not only did I learn new characterisation skills in advanced quantum optics, but I also made friends with people working in related areas." – Ms Xiaoying Huang

The ICC extends its best wishes to all TMOS members for their experiments and simulations in 2024.

Professor Kenneth Crozier
Infrastructure Committee Chair

ACTION ITEMS FOR 2024

1. Add new infrastructure to the Centre's equipment register.
2. Raise awareness of existing facilities within the Centre to increase cross-node collaboration.
3. Support funding and access bids by TMOS researchers and others whose work is synergistic with Centre activities, such as the ARC LIEF program and NCRIS funding.

COMMITTEE MEMBERS:

PROFESSOR KEN CROZIER

Chief Investigator

UoM (Infrastructure Chair)

ASSOCIATE PROFESSOR MARIUSZ MARTYNIUK

Chief Investigator

UWA

PROFESSOR HOE TAN

Chief Investigator

ANU

PROFESSOR SHARATH SRIRAM

Chief Investigator

RMIT

PROFESSOR FRANCESCA IACOPI

Chief Investigator

UTS

Industry Liaison Committee Chair Report

Industry Liaison Committee Director, Francesca Iacopi

The Industry Liaison Committee (ILC) is facilitating the translation of the scientific work of the Centre in partnership with local and international industry, including Defence and Space Research and Development institutions. The Centre has set very ambitious and challenging goals in this area in order to achieve true technological and societal impact.

The past year has been a year full of changes for the Industry Liaison Committee. First of all, there has been a substantive change in the membership of the Committee, with previous Early Career Researchers phasing out and new joining in (Rocio Camacho from ANU, winner of the 2023 TMOS Industry Liaison Award), as well as a new Associate Investigators (AI) with extensive experience in working with Industry Dr Yang Yang from UTS, and a new representative of the ANU Commercialisation Office, Dr Kelly Farrell. In addition, a growing focus on research translation in the Centre has led to materialising the new "flagship" structure, which will lead the ILC to grow its membership – more on that later. We would like to thank our past members and welcome the new ones and look forward to working with them all as we approach the middle of the Centre's lifetime!

The main strategic achievement in 2023 has been the change of the Centre structure to accommodate for the formation of the TMOS "flagship" program, which is fully focused on the translation of the higher TRL work done within TMOS and is organised by areas (Advanced Quantum Technologies, Meta-health sensors and Enhanced Infrared Vision). Each area has its own flagship manager (an ECR from the Centre), mirroring the structure of the scientific program already in place since the inception of TMOS. The materialisation of the flagship program, one of the projected aims from 2022, represents a key commitment from the Centre to put out our best efforts towards achieving concrete research translation and industry engagement on some of the most promising metasurface-based technologies. The appointed flagship managers will become an integral part of the ILC, where they will get help and mentoring in selecting the flagship projects and bringing them closer to industrial partners and/or graduating them as spin-offs.

Two of the priorities that were set in 2022 regarded the work on mapping Australian Small to Medium Enterprises (SMEs) and larger corporations and making the most out of all funding and ancillary mechanisms available in the Australian landscape. The mapping work is continuously ongoing, also because of the recent changes of some of the government agencies like Defence funding now directed by the new Advanced Strategic Capabilities Accelerator (ASCA) organisation, as well as the establishment of new agencies and capabilities potentially relevant to TMOS, such as the NSW Semiconductor Sector Service Bureau (which I also serve in the Board for) and the Advanced Manufacturing Research Facilities centred in Western Sydney and focusing on advanced packaging. At the same time, the ILC has also initiated the creation of an internal spreadsheet mapping the current status of industry collaborations across the whole of TMOS, which will further facilitate the coordination and future direction of common industry engagement.

Also, throughout the year, industry talks and seminars were offered, including a virtual presentation by Luxottica in September, a worldwide leader in optics products for eyewear with a strong research arm, and the industry forum at ANZCOP 2023 in Canberra in December, both coordinated by our Director Prof. Neshev.

We look forward to achieving an increasing lasting impact in 2024 and beyond - with the recent success by Metalenz in the USA shows us that meta optics is coming of age and TMOS is in a prime position to capitalise on this technology!

Francesca Iacopi
Industry Liaison Director

COMMITTEE MEMBERS:

PROFESSOR FRANCESCA IACOPI

Chief Investigator
UTS (Industry Liaison Director)

PROFESSOR LORENZO FARAONE

Chief Investigator
UWA (Industry Liaison Deputy Director)

PROFESSOR DRAGOMIR NESHEV

Centre Director
ANU

DR. MARY GRAY

Chief Operations Officer
ANU

KAREN JACKSON

Strategic Projects & Partnership
ANU

KAREN KADER

Secretary
UWA

PROFESSOR ANN ROBERTS

Chief Investigator
UoM

PROFESSOR DILUSHA SILVA

Associate Investigator
UWA

PROFESSOR SHARATH SRIRAM

Chief Investigator
RMIT

SAMARA THORN

Engagement Manager
ANU

KELLY FARRELL

Strategic Projects and Partnerships
ANU

YANG YANG

Associate Investigator
UTS

ROCIO CAMACHO MORALES

Postdoctoral Researcher
ANU

ACTION ITEMS FOR 2024

1. The main priority will be to develop KPIs for the flagship project selection, support and assessment of the projects, including phase-out if not successful or "promotion" outside of the Centre as a fully-fledged Linkage, CRC project with relevant industry or standalone spin-off.
2. Support the flagship managers to develop their flagship programs and the linkages to relevant industry as well as facilitate mentoring by our Advisory Committee when sensible.
3. Continue the internal and external mapping of existing industry, existing industry relations and mechanisms to engage with industry that is relevant to meta optics for the benefit of the whole Centre.

Industry Collaboration

Simon Poole, TMOS Advisory Board Member

As TMOS propels forward in its pursuit of groundbreaking research at, it's crucial to underscore the pivotal role industry collaboration plays in translating academic endeavours into real-world applications and successful commercial outcomes. The journey from research to reality hinges on the ability to bridge the gap between academia and industry, and it's a journey I see TMOS approaching with fervour and dedication.

> “To achieve research outcomes of global significance, we must adopt a collaborative approach to research that not only prioritizes requisite skill sets but also nurtures entrepreneurial acumen and a profound understanding of industry dynamics.”

In the realm of transformative technologies, such as meta-optics, the convergence of academic and industrial goals can be intricate, often stretching over a decade from discovery to market. As I noted in my Capability Papers essay, "Leveraging decades of photonics research investment," Australia's photonics research landscape is robust, yet the transformation of this 'deep tech' research into commercially viable products necessitates a concerted effort on an international scale.

To achieve research outcomes of global significance, we must adopt a collaborative approach to research that not only prioritizes requisite skill sets but also nurtures entrepreneurial acumen and a profound understanding of industry dynamics. Collaboration with industry partners is imperative to identify and address pertinent industry challenges and ensure that research discoveries can be developed into tangible solutions that drive economic growth and societal benefit.

If we are to continue to build TMOS's research capability, then we also need to demonstrate the value generated through the commercialisation of ideas, processes and devices developed by the researchers within TMOS. This requires an alignment of research capability and skill-sets with industry needs – not just to solve todays problems, but also to address clearly defined opportunities within a 3-5 year window. To achieve this calls for an interdisciplinary mindset, effective communication, relationship-building prowess, and a keen eye for entrepreneurial opportunities. We live in a globalised market place so establishing strong relationships with potential end-users and industry partners, both locally and internationally is a pre-requisite for success.

TMOS has committed to fostering a collaborative ecosystem that bridges the chasm between fundamental research and industry application. By actively listening to the needs and challenges articulated by our industry partners, and by proactively searching out potential customers and partners across the globe, TMOS can leverage its research to not only address industry needs but also propel Australia to the forefront of the global meta-optics revolution.

To students and researchers of TMOS, I offer the following guidance:

- Cultivate interdisciplinary skills: Embrace diverse perspectives and seek opportunities for cross-disciplinary learning.
- Learn about what an industry needs: Listen to what they're saying, identify the problems that matter most and explore avenues to align your research with their requirements – not just immediate but over the next 3-5 years.
- Master the art of communication: Learn to tell a story around your research – how it started, what it is, and where it's going.
- Be proactive in building meaningful relationships: Engage with industry on their territory e.g. at trade shows (Photonics West, OFC, etc) and seize networking opportunities with people outside of your speciality.
- Think like an entrepreneur: Explore the commercial potential of your research and envision pathways for scaling and market integration.

By embracing these principles, you not only position yourselves for success within TMOS but also equip yourselves to lead the charge in advancing photonic technologies for generations to come. Remember, TMOS stands steadfast in its commitment to supporting your journey every step of the way, offering resources, mentorship, and access to a global network of collaborators.

Simon Poole
TMOS Advisory Board Member

TMOS Cross Node and Partner Investigator Exchange Award

The ARC Centre of Excellence for Transformative Meta-Optical Systems (TMOS) is delivering an ambitious program of research across five Australian Universities. It is also collaborating closely with its international Partner Investigators to further the field of meta-optics globally. To deliver on its research program, it must work collaboratively across all universities and research groups.

Each year, TMOS invites applications from HDR and Early Career Researchers to propose and implement projects of work that require engagement across two or more nodes or with a Partner Organisation. The award is up to $2000 for domestic projects and $4000 for international projects to cover travel and accommodation costs.

In 2023, three new Cross Node and three Partner Investigator Awards were issued. In addition winners of the 2022 awards who were unable to travel in 2022 completed their exchanges.

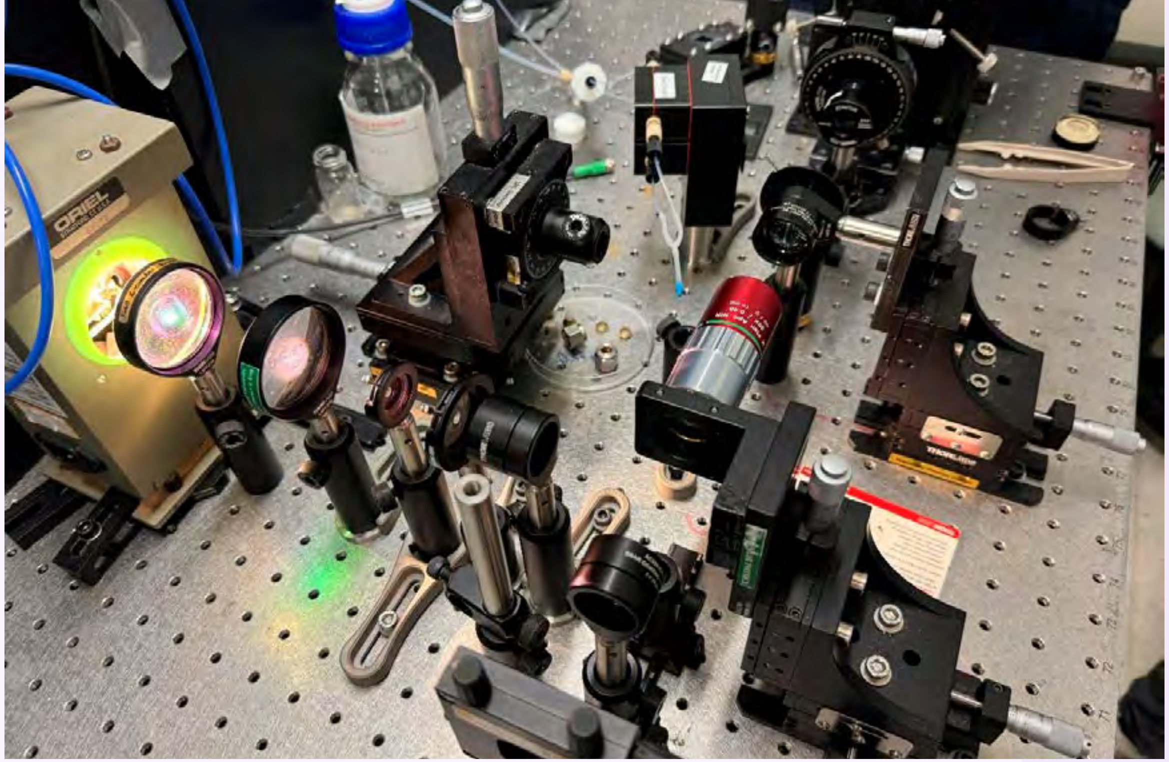
CROSS NODE EXCHANGE AWARD

LUKAS WESEMANN (UNIVERSITY OF MELBOURNE)

Project: Tunable all-optical spatial frequency filters for dynamic real-time image processing

The aim of this project was to realise tunable meta-optical image processing devices for the next generation of integrated photonic systems

Over the past few years, there has been a growing interest in using meta-optical structures for all-optical computation in the spatial domain, specifically for image processing. Unlike traditional methods that digitise analogue optical information for digital processing, nanophotonic devices allow for real-time processing of optical images, which could help with data throughput issues in real-time machine vision applications and make optical imaging technology smaller. Although static image processing devices have been extensively researched, there has been comparatively little focus on developing tunable image processing devices capable of integrating multiple functionalities into a single device. Creating such a device is scientifically challenging but would be crucial for the integration of next-generation optical systems. The collaboration between different groups in this area is expected to result in a joint publication on tunable image processing devices in a peer-reviewed journal. This collaboration will also lay the foundation for ongoing knowledge transfer and follow-up publications in the emerging field of tunable nanophotonics for analogue optical computation.



CROSS NODE EXCHANGE AWARD

LONGSIBO HUANG (AUSTRALIAN NATIONAL UNIVERSITY) VISITED MARIUSZ MARTYNIUK AT UNIVERSITY OF WESTERN AUSTRALIA

Project: Hybrid metasurface-nanowire infrared photodetectors for polarisation imaging

The aim of this project was to fabricate and characterise the hybrid metasurface-GaAsSb nanowire infrared photodetectors for polarisation imaging

This project aims to demonstrate hybrid metasurface-nanowire infrared (IR) photodetectors for polarisation photodetection and imaging. Such nanostructure-based hybrid device architecture will have great potential to outperform current IR photodetector technology in terms of performance, compactness, and cost, with the new functionality of polarisation imaging. Such achievement can enable new opportunities and facilitate real-world deployment of polarization-related devices in various research field, including sensing, imaging, encryption, optical communications, medical science and military uses across Australia.

"My purpose was to pay a visit to the UWA Node and learn how to use/operate the polarization imaging system for my project. We now have a joint paper in progress. To see, learn and interact with others across the TMOS nodes face to face is really important and totally different from the zoom one."

- Sibo Huang

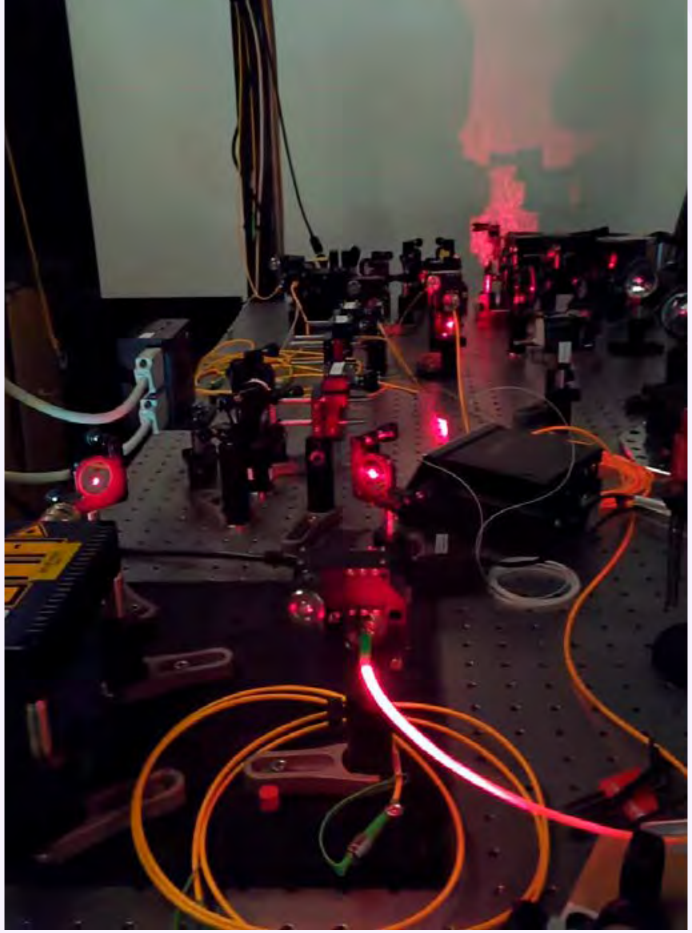
CROSS NODE EXCHANGE AWARD

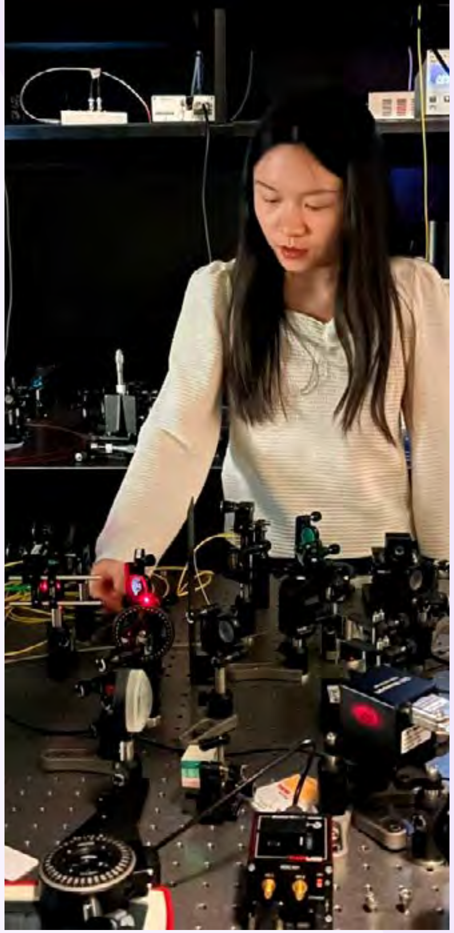
XIAOYING HUANG (AUSTRALIAN NATIONAL UNIVERSITY) VISITED IGOR AHARONOVICH AT UNIVERSITY OF TECHNOLOGY SYDNEY

Project: Growth and characterization of single quantum dots in nano/micro-cavities for single photon emission applications.

This project was designed to directly grow site-control single photon emitter in optical cavities to achieve highly bright, pure and indistinguishable single photon sources.

Semiconductor quantum dot based single photon source have been proved as one of the most highly efficiency single photon sources when they are being incorporated into optical cavities. but currently, most popular strategy is post-cavity fabrication process, which is grow the quantum dots in planar first and then couple them into different optical cavities to increase the quantum extractive efficiency thus the brightness and purity of single photon. However, this process is pretty time consuming and low efficiency. Thus site-control dot in cavity for single photon source application research is particularly attractive. In this project, our goal is to achieve highly bright, pure and indistinguishable quantum dot based single photon sources in cavities directly from one-step growth of selective area epitaxy (SAE) of MOCVD. The successful of this project will not only provide the brightest and efficient miniaturized quantum light sources which addresses the TMOS goal of Theme1, but also benefit to further quantum information application.





“It was my great pleasure to achieve TMOS cross-node exchange award this year. As a result of this visit, We are about to submit a paper with title of ‘Scalable bright and pure single photon sources by droplet epitaxy on InP nanowire arrays.’ My advice to future exchange recipients is to make experimental plans before visiting and discuss with host institution, be active with people you’re working with, and don’t be afraid to ask questions and ask for help when you come with any problems.”

- Xiaoying Huang

PARTNER INVESTIGATOR EXCHANGE AWARD

LUYAO WANG (AUSTRALIAN NATIONAL UNIVERSITY) VISITED MICHAEL JOHNSTON AT OXFORD UNIVERSITY

Project: Active THz Metamaterial

The aim of the project is to design, fabricate and characterize the tuneable performance of engineered materials in the Terahertz (THz) range, which exactly matches with my research topic.

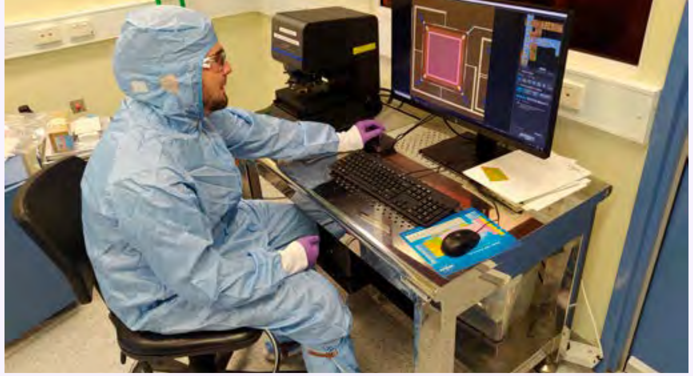
During my studies at ANU, I got an insight into fabrication techniques, facilities, and theoretical training, which has become a confidence for me and an advantage for the ANU team to develop international collaborations. Considering the experimental characterization, Oxford is the most famous in our field all over the world with its well-equipped terahertz laboratory. Therefore, visiting Oxford and combining theoretical calculations and practical experiments will not only greatly stimulate the theoretical development of my Ph.D. research, but also broaden my research horizon in the experimental part.

SHABAN SULEJMAN (UNIVERSITY OF MELBOURNE) VISITED ANDREA ALU AT CITY UNIVERSITY OF NEW YORK

Project: Tunable and non-reciprocal image processing with metasurfaces

The aim of this collaborative research is to design and utilise miniaturised, light-based nanotechnology for image processing applications such as edge detection of objects.

The idea of our work is to design a metasurface that can be thermally tuned and operate only for specific orientations of the device. The scientific benefit of the project is emphasised in the context of the features of our device. Tunability enables the temperature-controlled switching of performance, allowing the device to switch between imaging modalities. On the other hand, non-reciprocity hosts performance only for one-way transmission, which is useful for integration into diodes and other devices. These sort of devices offer an ultra-fast and compact approach that are directly integratable into existing systems, such as portable smart phones.



PARTNER INVESTIGATOR EXCHANGE AWARD

NATALIE ROZMAN (DUKE UNIVERSITY) IS TO VISIT MARIUSZ MARTYNIUK AT UNIVERSITY OF WESTERN AUSTRALIA

Project: MCT Metamaterial for Mid-Infrared Imaging and Detection

The aim of this project is to design, simulate, fabricate, and experimentally characterize a metamaterial mid-IR detector for imaging

We aim to create a metamaterial-based detector that can be used for mid-infrared (IR) imaging. By utilizing sub-wavelength metamaterial absorbers in combination with IR-sensitive materials, we will be able to effectively increase the spatial resolution of the imager. The metamaterial geometry will be studied and optimized through numerical simulation. The device will then be fabricated using nanofabrication techniques and experimentally characterized. The experimental results will be compared to the simulation as a verification and changes to the design may occur at this stage. The simulated and experimental results will be disseminated via a peer-reviewed journal article as well as conference proceedings.

“

I learnt about the full cycle of the metasurface fabrication process and measured the characteristics of some fabricated samples without microelectromechanical systems (MEMS). These samples appeared to be fabricated to the right standard because their transmission characteristics are consistent with the results of my simulations. I also found that the current setup for the measurements isn't perfect since the accuracy of measurements of the transmission characteristics is quite low. I discussed this setup with our collaborators from the UWA and we developed proposals for improving this setup, so we can have better accuracy for our measurements of the complete metasurface structure with MEMS later. We're planning a publication based on the conducted research after the successful fabrication of the metasurface with MEMS and measurements of their characteristics.”

- Fedor Kovlev

CASE STUDY

Translation Collaboration Study: Metalens for Autonomous Industry

Experimental Photonics Group (TMOS ANU), Functional Materials and Microsystems Research Group (TMOS RMIT), Australian National Fabrication Facility (ANFF) Melbourne, Seeing Machines (TMOS Industry Partner)

TMOS researchers collaborated closely with industry partner Seeing Machines to develop a metalens designed to be integrated into the company's driver monitoring systems. Seeing Machines is a global leader in the computer vision systems and is working to minimise road deaths using advanced human data-driven technology to counteract driver distraction and drowsiness.

Seeing Machines has been a collaborator since the Centre's inception, having quickly recognised the benefits flat optics would have to their driver monitoring system. TMOS Centre Director Dragomir Neshev says, "As demands for new automotive technology increase, the space in a car dashboard becomes more valuable. The natural next step for an optics-heavy company like Seeing Machines is to look at the miniaturisation of their work using flat optics. As a bonus, metasurfaces can also provide additional functionality that traditional optics doesn't."

TMOS research fellow Andrei Komar has been a key driver of the collaboration since the beginning of this new project.

Komar says, "Seeing Machines collaborators taught us about automotive standards and processes of industrial certification, the kind of knowledge we lack in academia. This makes our device acceptable for the real-life applications. Seeing Machines also provided us with the requirements for new feature development so that it would be commercially successful. This directed our research in ways that lead to the new scientific knowledge and a successful industrial product."

Komar met weekly with the Seeing Machines team to discuss the latest results and map a path forward. This helped them to keep on track of research novelty and industrial potential.

"The brought knowledge about the automotive industry and we brought the research components, like the scientific idea of how to build a new meta-optical component, theoretical and simulation implementation of the idea, fabrication, and experimental characterisation of every iteration."

The collaboration also included TMOS team members from RMIT and the ANFF. The designed metalens had a large surface area and precise nano-structures. Those two factors required a specialised skillset and advanced machines in order to produce samples. RMIT research fellow Litty Thekkekra possessed the necessary knowledge of large area meta-optical nanofabrication and she worked with the Melbourne ANFF facility to fabricate the intermediate and final samples using their using their state-of-the-art electron beam lithography (EBL) fabrication facility.

The collaborative relationship between Komar and Seeing Machines was so successful that he recently accepted a position with the company to investigate a meta-optical approach for a new element, which will add the features to the element that are impossible when using conventional optics.

"This investigation will likely lead to new collaborative opportunities between Seeing Machines, TMOS and the ANFF," says Komar.

Neshev says, "Watching Andrei move from academia to industry to has been very rewarding. The Centre's purpose extends beyond research. We want to facilitate the quick adoption of meta-optics globally by developing our team to be knowledgeable, critical thinkers with skill sets that are valuable in an industry setting. Andrei's move to Seeing Machines is the perfect example of this."

CASE STUDY

Translation Collaboration Study: The Ketowhistle

Semiconductor Optoelectronics and Nanotechnology Group (TMOS ANU) and Our Health In Our Hands (ANU & ACT Health)

TMOS researchers from Australian National University (ANU) teamed up with engineers, clinicians, and people with lived health experience to transform the management of diabetes. The Ketowhistle is part of the ANU Our Health In Our Hands Grand Challenge Project (OHIOH).

The Ketowhistle, currently in the early stages of development, will be a portable device that measures acetone in the breath. Elevated levels of acetone indicate a potentially life-threatening condition called diabetic ketoacidosis (DKA).

TMOS PhD student Shiyu Wei was at the centre of the collaboration, working with ANU co-supervisors TMOS Chief Investigator Lan Fu from the Research School of Physics and TMOS Associate Investigator Professor Antonio Tricoli from the School of Biomedical Engineering, who is now at the University of Sydney.

Wei says, "We worked for almost 3 years to develop a miniaturized sensor that was sensitive to acetone. The miniaturization of devices using metasurfaces is one of the key TMOS objectives. Once that was done, we collaborated with the School of Biomedical Engineering to create the circuit needed to record the data."

One of the potential applications for the acetone gas sensor is its use in a breath acetone testing device. A wider collaboration was needed to apply the sensor in this manner and develop a prototype device. Professor Chris Nolan, from ANU's School of Medicine, is an expert in diabetes and its management. His work obtaining ethics approvals and overseeing upcoming patient trials, is key to bringing the research to real-work application.

"Currently, we have tested the prototype with simulated breath in the laboratory." Wei says. "We took our own breath and mixed it with controlled amounts of acetone so that we could confirm the sensor's sensitivity and accuracy. The next step is patient trials, and to do that we need to hand the research over to the School of Medicine."

Chief Investigator Lan Fu and her team also worked closely with ANU's Office of Business Engagement and Commercialisation (BEC) to conduct thorough market research as part of a patent application. BEC gathered feedback from potential end users that helped direct Fu's research. Initially, the team had thought the device could be used for the diagnosis of diabetes, but feedback from clinicians revealed that acetone in the breath was too unreliable for diagnosis and blood tests would always be required. The team then adjusted the focus of their industry engagement from diabetes diagnosis to monitoring for DKA.

In addition to diabetes management, BEC identified health enthusiasts who are targeting ketoacidosis for weight loss reasons as a potential second market.

Fu says, "Outside perspectives on the applications for our sensor have been crucial to developing the device and to directing future research. This collaboration between various ANU entities has enabled the work to drive forward at a pace that it may not have had without OHIOH."

As a result of this four-way collaboration, the team have won significant funding for the continued development of the research, including $30k for pilot patient testing from the Australian Centre for Accelerating Diabetes Innovations, which will be performed in collaboration with the School of Medicine, and $20k seed funding from the Australian National Fabrication Facility for further market research.

Wei says, "I am grateful for the opportunity to work with specialists in a variety of fields. It has helped me experience alternative perspectives and to grow as a researcher. I'm looking forward to watching the Ketowhistle device mature and to see it in the hands of the people who need it most."

For more information about this research, contact connect@tmos.org.au

Engagement & Culture

IDEA Committee Chair Report

IDEA Committee Chair, Professor Madhu Bhaskaran

In 2023, we focussed on IDEA training and education for the next generation – this was both for within TMOS as well as for the general Australian scientific community through hosting inSTEM conference.

Our 2023 major IDEA action items included:

- Leadership training for our core Centre members which also includes our Research program managers – this is with a focus on future skills building
- Playing a significant role in the organisation and operations of 2023 inSTEM conference
- Review of IDEA framework

For our IDEA education to all TMOS members, we have been using Symmetra since 2021 – these online modules proved to be a wonderful way to impart knowledge on key topics and enabled TMOS members to access content in their own time. In 2023, we covered six modules on inclusion and bias - *Disability Inclusion, Everyday Inclusion, LGBTIQ Inclusion, Debiasing Techniques, Unconscious Bias 101, and Psychological Safety Behaviours.*

We also held a face to face training session on June 16, 2023 for our leadership team which included our Research Program Managers, on the topic of inclusive leadership training. This was conducted by Dr Kim Hazendonk from Psychology Melbourne and proved to be a great way to bring all of us on the same page about leadership practices.

TMOS played a significant role in organising and conducting inSTEM at Melbourne on September 19-21, 2023. inSTEM is a networking and career development conference for people from marginalised or underrepresented groups in STEM, and their allies. It is an initiative of the STEM-focused ARC Centres of Excellence. The program touched on topics such as impostor syndrome, neurodiversity, and mentoring and welcomed over 150 participants.

In 2023, we also reviewed all of our centre documents including the IDEA framework, recruitment policies and procedure and commenced work on making improvements on the strategic implementation plan. The main takeaways from the reviews which helped streamline the framework and rework the recruitment policy was to add in our new measure of women first recruitment.

When TMOS commenced, we ran a women only recruitment round, this was successful with 5 women being hired. Going forward, we will implement a women first recruitment policy – "All externally advertised TMOS postdoctoral positions are to be women-only advertisements in the first instance, and then general thereafter." This is our chosen way to work towards achieving our KPI of 40% women by 2026.

Other IDEA based activities in 2023 include setting up an IDEA events group. We will run at least 5 IDEA related events throughout the year with each node having an event. So far, we have run an outreach event for International Day of Youth by University of Melbourne, UTS have celebrated R U OK day and RMIT hosted activities for International Mental Health Day.

Our other significant undertaking in 2023 was the submission of our response to the Women in STEM Decadal Plan. This significant undertaking enabled us to map our ideologies and activities to the national plan and cemented our strong commitment to positive change in the sector. The response can be viewed here: TMOS-Decadal-Plan-FINAL-ST.pdf

The IDEA committee will continue to champion the importance of IDEA throughout our centre and the lives of our members. We will continue to encourage and support our members throughout their IDEA journey. We have set out the following action items for 2024:

- Centre wide professional development on topics not covered before such as neurodiversity
- Run culture survey
- Implement Women First Recruitment

Professor Madhu Bhaskaran
IDEA Committee Chair

ACTION ITEMS FOR 2024

- Centre wide professional development on topics not covered before such as neurodiversity
- Run culture survey
- Implement Women First Recruitment

COMMITTEE MEMBERS:

PROFESSOR MADHU BHASKARAN
Chief Investigator
RMIT (Chair)

MARCUS CAI
HDR Representative
ANU

DR. MARY GRAY
Chief Operating Officer
ANU

YAN LIU
PhD Student
UWA

ELIZAVETA MELIK-GAYKAZYAN
PhD Student
ANU

JIAJUN MENG
Postdoctoral Researcher
University of Melbourne

KRISHNA MURALEEDHARAN NAIR
Postdoctoral Researcher
RMIT

PROFESSOR DRAGOMIR NESHEV
Centre Director
ANU

PROFESSOR ANN ROBERTS
Chief Investigator
UoM (Deputy Chair)

KHOSRO ZANGENEH
PhD Student
ANU

BEN WHITEFIELD
PhD Student
UTS

ELEANOR LUOND
IDEA Officer
RMIT

inSTEM 2023

inSTEM, an initiative of the ARC Centres of Excellence, is a networking and career development event for people from marginalised or underrepresented groups in STEM, and their allies. inSTEM aims to provide attendees with an opportunity to develop their identity as a researcher, whilst also creating a community and promoting a sense of belonging among likeminded individuals.

inSTEM offers attendees a safe space where they can meet, make connections, and build relationships with other researchers and research scholars. Attendees will have the opportunity to hear from leading experts on topics and strategies that support career development and progression. We will also discuss how to create change that improves access, supports retention, and champions success in STEM for individuals from marginalised or underrepresented groups.

Networking is a key strategy for career progression, yet numerous studies have shown that women's networks are less powerful than men's and that women seem to be less equipped to leverage the networks they do have when it comes to their career. Further research has found that this is not an issue specific to women but is indicative of the experiences of marginalised groups in general.

TMOS is dedicated to Inclusion Diversity Equity and Access (IDEA) and InSTEM allows our members who are from underrepresented groups the opportunity to attend conference focused on them and their experiences. Giving them practical knowledge and advice to advance their career.

TMOS was part of the organising committee for the first InSTEM in 2022 organised by the Australian Research Council Centre of Excellence for Engineered Quantum Systems (EQUS). Our IDEA Officer was the chair of the planning committee and assisted in the operations of the conference in Brisbane. In 2023 TMOS decided to be the Lead organising Centre of Excellence to show our dedication to the cause. InSTEM is a valuable conference to its attendees, whether they be from underrepresented or marginalised groups or their Allies.

TMOS is the only Centre of Excellence to have a dedicated IDEA officer as IDEA is a core value of our Centre. This puts us in a unique position to have a greater understanding of the difficulties that people from underrepresented or marginalised groups face within the fields of STEM. With TMOS taking the lead this year, we were able to guide the conference into directions and open up to a wider audience.

As lead organisers TMOS had the pleasure of hosting this year's conference at our RMIT node,

> "First of all, thank you for the opportunity to speak today, I had such a great time. I wish I could've attended a conference like this during my PhD, it made me so happy to see so many emerging researchers building community and finding a safe space."
>
> – Dr Naomi Koh Belic 許佳丽 Scientist, Communicator and Educator

Camilla Gazzana and Greg Dennis

"Thank you for organising a wonderful inSTEM 2023 conference. It really stimulated a rethinking in me in comparison to all the other conferences I have attended so far. I congratulate the team for bringing magnificent speakers to the event."

– Dr Litty Thekkekara, Research Fellow with TMOS based at RMIT

with RMIT generously signing on as the Venue sponsor for the event. Our IDEA officer was the chair of the conference as well as the planning committee. As with any conference there was a lot of logistics that needed to be organised and a lot of different stakeholders to manage.

The outcomes of the conference where for people from underrepresented and marginalised groups to come to be able to participate in a networking and careers conference as their true and authentic selves. Quite often at conferences inclusion practices are not including in the organisation therefore people don't feel included, comfortable, or safe in these spaces.

InSTEM aims to give people the opportunity that is afford to everyone else. Allowing people to ask questions that are relevant to their lived experiences. By hearing from people who have similar lived experiences to their own it empowers people to strive to reach their potential. The conference also provided the attendees with tools and resources to thrive in spaces have been historically exclusionary.

The conference also aims to educate and enlighten allies within the STEM fields to do better. To use their power and privilege for good, to support and champion people who are different from themselves.

Key takeaways from the conference are as follows:

- Greater diversity within our panellist and presenters is required. Our program committee contacted numerous presenters from diverse groups unfortunately a lot of these people were unavailable to be part of this year's conference. Beginning to organise the program earlier would allow the organisers to confirm the first-choice presenters.
- From feedback from our attendees this year's conference was an amazing success. The variety of topics and presenters were received exceptionally well however in future conferences it would be ideal to focus on what allies can do. Quite a few of the topics delivered at the conference were aimed at allies however unfortunately the attendance of allies was limited. In the years ahead it is suggested to push for greater attendance from people who are in positions of power.

"inSTEM was a great opportunity to meet and network with an inclusive and diverse group of people within the STEM community. It brought together a wonderful line-up of speakers who were able to share their knowledge and experiences to help us grow and embrace our differences in an often-challenging environment. It makes me proud to work for a Centre of Excellence involved in the organisation and running of such a worthwhile event, and I would strongly recommend this conference to all people involved in STEM.

– Camilla Gazzana Outreach officer TMOS based at UTS

InSTEM 2023 Participants

Outreach Committee Report

Igor Aharonovich, Outreach Director and Camilla Gazzana, Outreach Officer

In the course of 2023, our strong collaboration with Questacon continued, starting with our yearly science communications workshop which we combined with public outreach for International Day of Light (IDL). Facilitated by Patrick Helean and joined by EM Prof. Hans Bachor, this workshop not only helped to welcome our new outreach committee members, but also fine-tuned our science communication skills in a fun and engaging way.

The success with our school workshops program led to Loxton Lutheran Primary School (SA) reaching out to us through their STA Superstars of STEM program, leading to engaging talks with approximately 110 Year 3-6 students, shedding light on STEM careers and fostering a dynamic Q&A session. Furthermore, we shared valuable insights with Year 5 students during their Science class.

Our commitment to school visits expanded to Garran Primary School (ACT), where we participated in their STEM Fest, delving into holograms and diffraction for all Year 5 students. Similarly, students from Grovelands Primary School (WA) learned about holograms and the principles of light behind them. We were also lucky enough to be hosted by Illaroo Rd Public School (NSW) for an entire day, engaging all of their Year 5 and 6 students with our "How-to Holograms" workshop.

Beyond the classroom, our team also participated in meaningful, non-school based outreach events. This included a successful presentation of the “Story of Light” at Footscray Library (VIC), showcasing the evolution of our workshop covering the understanding of light, its applications, and future potential. Utilising laser kits and fog machines, this interactive session garnered enthusiastic responses from visitors, resulting in invitations for us to visit other sister libraries. We were also lucky enough to join in on one of Bendigo Discovery Centre’s (VIC) “Girls in STEM” sessions, with a modified version of our “How-to Holograms” workshop. Some of our female TMOS members shared their experiences and journeys in STEM with the girls, contributing to an inspiring and successful event.

During National Science Week our UWA node hosted a Hologram and 3D printing event, drawing in 71 attendees over two sessions, from culturally and linguistically diverse backgrounds. The event was a resounding success and received funding from the WA Inspiring Australia National Science Week Small Grant initiative.

In a pioneering initiative, we launched the pilot Senior STEM Engagement Program, welcoming a small cohort of senior and gifted students from low-SES Bankstown Girls High School to the UTS node. This program provided a unique opportunity for access to university-grade laboratory equipment and facilities, interactions with TMOS students and leaders and an exposure to the university environment.

As we continue to forge ahead with our outreach efforts, our commitment remains to refining and expanding our programs to make optical physics accessible and inspiring for diverse audiences.

ACTION ITEMS FOR 2024

1. Establish Senior STEM Engagement Program across all nodes
2. Develop working prototype of Photon Clicker with Partner Organisation Questacon
3. Deliver Science Communication Training across the Centre
4. Review and update demonstrations
5. Develop new connections through education conferences and networking
6. Observe days of interest as platform for public outreach

COMMITTEE MEMBERS:

PROFESSOR IGOR AHARONOVICH
Chief Investigator
UTS (Chair)

YING ZHI CHEONG
HDR Representative
RMIT

CAMILLA GAZZANA
Outreach Officer
UTS (Secretariat)

MADELINE HENNESSEY
HDR Representative
UTS

DR. WENDY LEE
ECR Representative
UoM

NEUTON LI
HDR Representative
ANU

A/PROF. MARIUSZ MARTYNIUK
Chief Investigator
UWA

DANIEL MORLEY
HDR Representative
UWA

JINLIANG REN
HDR Representative
ANU

BENJAMIN RUSSELL
HDR Representative
UoM

SUVANKAR SEN
HDR Representative
RMIT

HENRY TAN
HDR Representative
UoM

Senior STEM Engagement Program

2023 was an exciting year for outreach, with the successful launch of the pilot Senior STEM Engagement Program at the UTS node. This not only marks a significant milestone for TMOS, but also opens up a multitude of opportunities for participating schools, students, and the collaborative efforts of TMOS and its host nodes.

Outreach is pivotal in forming relationships with schools and educational systems, bringing TMOS's knowledge and resources to classrooms. The focus of this program has been to increase interest in STEM, particularly physics, among students facing challenges such as low engagement, enthusiasm, and poor teacher support and encouragement. Acknowledging the low numbers of students studying physics at the senior high school level, emphasizes the importance of addressing contributing factors such as school culture, self-perception, and the lack of positive role models in STEM careers.

An integral aspect of the Senior STEM Engagement Program is the focus on groups that are often underrepresented in STEM and in need of additional support, especially those in low socio-economic status (SES) schools, while ensuring they are not financially burdened by this opportunity.

For the high schools involved, this program establishes an exciting partnership with TMOS and its host nodes/universities, offering crucial support for the teaching of senior-level physics. Importantly, it provides access to equipment and materials that are often beyond the budget constraints of these institutions, thereby enriching the educational experience for both educators and students.

Beyond the classroom, students are presented with an opportunity to witness a working university environment and become familiar with the academic setting, humanising the experience to make it a more attainable goal. This exposure goes beyond the conventional school curriculum, offering students a chance to delve into the realms of physics that might otherwise remain inaccessible.

Feedback from teachers involved and students alike are indicative of the pilot's success, with comments highlighting its positive influence. Remarkably, 100% of surveyed students expressed a desire to pursue tertiary education after participating in the program. This resounding affirmation solidifies the program's role in shaping the educational journey of these students, providing not just a learning experience, but inspiration for future endeavours.

The success of the Senior STEM Engagement Program pilot sets the stage for its expansion across all five TMOS nodes in 2024, providing an exciting opportunity to extend its reach to additional disadvantaged schools and students around Australia.

> It was fun and interesting.
>
> – Program Participant

> A lot of new things learned.
>
> – Program Participant

> I found the session very interactive and engaging .
>
> – Program Participant

Science Week Hologram Printing Competition

The Science Week Hologram Printing event was organised at the TMOS Western Australian University. It used the WA University Maker's group for 3D printing experience, seamlessly blending the excitement of the TMOS hologram workshops with the ingenuity of 3D printing technology. Our primary objective was to provide children from pre-primary to high school with an immersive experience, introducing them to fundamental engineering and scientific principles in an engaging and enjoyable manner.

Participants had the unique opportunity to delve into the world of 3D modelling, learning to prepare intricate designs sourced from the internet or crafted by themselves using Tinkercad.

Witnessing their creations materialise through 3D printing was educational and awe-inspiring for all. To cap off this memorable journey, attendees learned how to transform their tangible 3D models into captivating holograms using the materials and processes from our TMOS Outreach Hologram workshop.

The overarching goal of the event was to instil a renewed appreciation for STEM disciplines among the young minds present, and we are delighted to report that this objective was achieved with resounding success. Every child left not only with their personalised 3D model and hologram but also with a spark of curiosity and enthusiasm for science and technology.

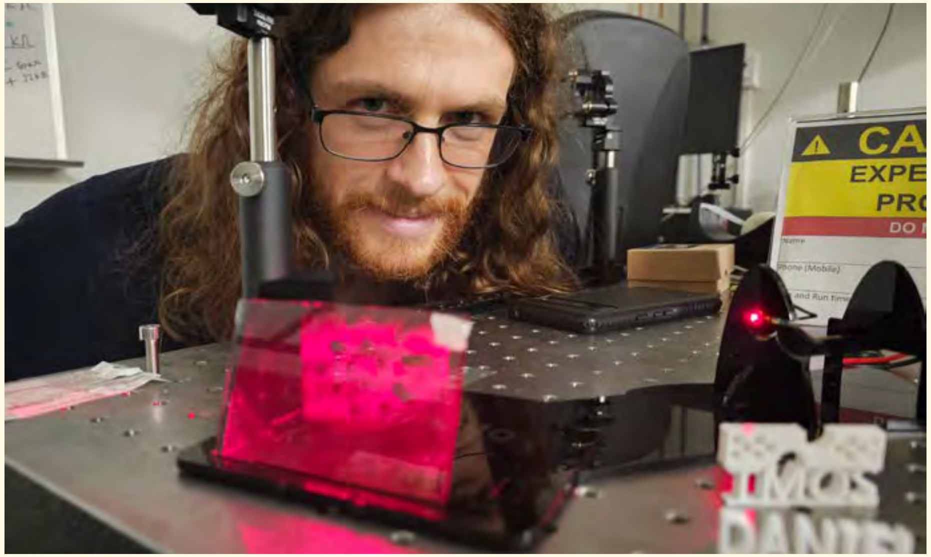
Organising this event was a significant learning experience, marking an initiation into public event planning. The challenges encountered, particularly with the 3D printers at the onset, provided invaluable lessons in adaptability and effective event management. Overcoming these hurdles enhanced the overall resilience of the team and added a layer of satisfaction to the final success.

Furthermore, the event served as a catalyst for collaboration. The camaraderie between the Centre's WA team and the WA Maker's group laid the foundation for future endeavours, fostering an environment where the exchange of ideas and resources can continue to flourish.

In conclusion, the Science Week event is a testament to the transformative power of hands-on learning experiences. Not only did it impact the participants by broadening their understanding of STEM, but it also contributed to the growth and collaboration within our community. I extend my sincere appreciation to all who contributed, and I look forward to future opportunities to inspire and educate through engaging events.

> "The Science Week event is a testament to the transformative power of hands-on learning experiences.

Daniel Morley



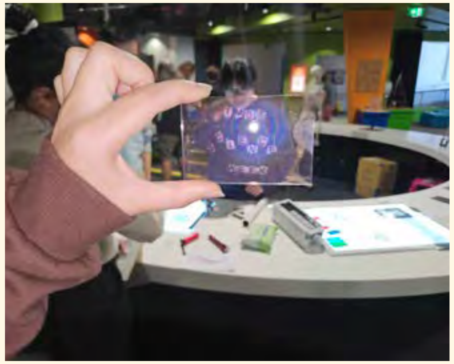
Training with Questacon

IN May 2023 the TMOS Outreach Committee attended an Outreach workshop hosted by Patrick Helean at Canberra's Questacon. The committee listened to presentations by various science communicators, performed a variety of optics demonstrations for the general public and undertook some team bonding activities.

The presentations taught the committee how to effectively communicate science to younger audiences. Professor Hans Bachor suggested suitable physics topics to cover and how to address them in a simple manner. Patrick Helean presented a variety of simple experiments that could be showcased during outreach activities, many of which used "rubbish science" or simple household items. Andrea O'Halloran taught the committee the importance of using an inquiry-based approach when teaching science, to allow the audience to properly engage with the presentation. Joel Barcham had the committee up and moving, taking on the personas of classic archetypes and getting into character for a more exciting way of science communication. These skills were put to the test on the International Day of Light, when the committee performed a range of optics demonstrations to the museum visitors, including playing with polarising filters, prisms and holograms to name a few.

The workshop at Questacon was a fantastic opportunity for the Outreach committee. Their new skills in effective science communication have made them more confident and engaging when presenting, ensuring that upcoming outreach activities will leave a stronger impact on the future generation of young scientists.







Education and Professional Development Committee Chair Report

Education and Professional Development Committee Co-Chairs, Professor Lan Fu and Professor Milos Toth

The Education and Colloquia Committee (ECC) aims to develop a multidisciplinary, dynamic, interactive, and collaborative culture fostering the next generation of leaders who display academic excellence and are equipped with transferable skills to take on any career they choose. The committee strives to provide an outstanding educational experience for the Higher Degree Research (HDR) students within the Centre and to promote engagement in activities across all nodes to maximise collaboration and networking between teams.

The committee:

- designs strategies for HDR recruitments in collaboration with node universities
- develops, implements and monitors the Centre HDR program
- coordinates the delivery of seminars, workshops, events, and training courses that support the goals of collaboration, education and development in alignment with the IDEA Framework
- coordinates the HDR-Partner Investigator student exchange program
- coordinates the Centre HDR/ECR and annual conferences, including monitoring expenditure and the design of the conference program
- is a forum to support HDR candidates and best practice HDR supervision

In 2023, the main activities led and carried out by the EPD committee included:

- organisation of the third mid-year Early Career Researcher (ECR) and student conference. The conference was a 3-day in-person event that was held at the ANU Kioloa Coastal Campus and organised solely by TMOS HDR students and ECRs. It consisted of 6 research skill related workshops, a panel discussion on industry engagement, an IDEA Session on Microaggressions and Cultural differences and a group discussion on workplace feedback. The total number of conference attendees was 34.
- organised and hosted a series of internal seminars as part of the Centre's Science Tuesday program.
- planned and coordinated the 2023 Centre Colloquium program.
- finalise the TMOS HDR student database and establish a quarterly updating mechanism.
- development the program for the 2nd Centre conference and assisted with conference logistics.

Professor Lan Fu and Professor Milos Toth
Education and Colloquia Committee Co-Chairs

ACTION ITEMS FOR 2024

- Coordinate professional development program based on Centre ECR and HDR's interests and needs, including the colloquium & topical workshop programs.
- Organise the 2024 Centre ECR and student mid-year conference.
- Coordinate and promote the Centre Mentorship Program via Mentorloop platform.
- Facilitate the Centre conference program.

COMMITTEE MEMBERS:

PROFESSOR LAN FU
Chief Investigator
ANU (Chair)

PROFESSOR MILOS TOTH
Chief Investigator
UTS (Chair)

SAMARA THORN
ANU (Engagement Manager)

DR. AISWARYA PRADEEPKUMAR
ECR Representative
UTS

DR. JINYONG MA
ECR Representative
ANU

DR. FARHAD FOROOZANDEH
HDR representative
UWA

NIKEN PRISCILLA
HDR representative
UoM

SHIYU WEI
HDR representative
ANU

SUVANKAR SEN
HDR representative
RMIT

KRISZTINA THURZO
ANU (Secretary)

LESLEY SPENCER
HDR representative
UTS

2023 ECR and Student Conference

The 2023 TMOS ECR/Student conference was conducted in person at the Australian National University, Kioloa Campus, from 28 June to 30. The main objective was to bring together the next generation of researchers within TMOS to engage in thought-provoking workshops and to exchange ideas to foster collaborations and networking.

The conference was co-chaired by Shiyu Wei from the Australian National University (ANU) and Dr. Aiswarya Pradeepkumar from the University of Technology Sydney (UTS) with support from members across each node. Dr Iryna Khodasevych, UTS; Dr Hemedra Kala, UWA; Dr Krishna Muraleedhanan, RMIT; Dr Jinyong Ma, ANU; Ms Lesley Spencer, UTS; Mr Farhaad Foroozandeh, UWA.

The event was conducted for 3 days and consisted of 6 workshops, a panel discussion on industry engagement, an IDEA Session on Microaggressions and Cultural differences and a group discussion on workplace feedback.

The committee organized various social activities, including a self-introduction session for the attendees to familiarize themselves with each other, a hike around the Kioloa campus led by Mr. Scott from Kioloa, ANU, camp fire and a trivia session.

The 2023 ECR/Student conference focused on skills development including in simulation, presentation, scientific schematics design, cross-node collaboration, experiments, writing, etc., and promoting new collaborations and building connections among the TMOS students and early career researchers. The diverse range of sessions provided invaluable insights and networking opportunities, promoting the connection and collaboration, which make this experience truly rewarding for both personal and professional growth. Furthermore, the conference committee gained experience in organizing the first in-person ECR/Student conference, deciding the programs, and selecting the workshops and presenters.

> “Attending last year's Student and ECR Conference was truly enriching. The tutorial sessions on nano-electric magnetic simulations of metasurfaces and creating visually appealing schematic figures for publications were engaging and insightful. I'm enthusiastic about integrating these learnings into my ongoing work. The discussions on innovative ideas and feedback for TMOS sparked a Mindstorm of inspiration, fostering a dynamic intellectual exchange. The diverse range of topics and insights shared by experts provided a multi-faceted perspective, enhancing my understanding of research. Eagerly anticipating future conferences for continued learning and collaboration in this vibrant community.
>
> – Wenwu Pan

Events

The 14th Conference on Optics, Atoms, and Laser Applications (KOALA) 2023

EVENT ORGANISERS:

TMOS Students on the KOALA 2023 organising committee: Sarah Dean, Neuton Li, Joshua Jordaan, Marcus Cai, Shridhar Manjunath, Fedor Kovalev

TMOS Staff who greatly assisted us: Galina Shadrivova, Krisztina Thurzo, Samara Thorn, Dragomir Neshev, Mary Gray, Sharyn McFarlane

The Conference on Optics, Atoms, and Laser Applications (KOALA) is an annual student-only conference organised by students at the hosting university. KOALA targets all aspects of lasers, optics and atoms! It is an affordable, inclusive, and supportive conference. There is a focus on academic discourse, with further emphasis on networking for industry careers. KOALA is currently the only prominent Conference in Australia and New Zealand specifically for students in the field of Optics, Atoms, and Laser Applications. This provides an excellent and unique opportunity for students to present their research amongst their peers. It also allows the students organising to gain valuable experience with organising a conference.

For 2023 we had the opportunity to host KOALA at ANU for the 27th Nov to 1st Dec, with 6 of the 8 members of the organising committee also student members of TMOS, allowing us to give KOALA 2023 a bit of a TMOS flair. We also had amazing support from TMOS at every point of the organisation process, both with gold level sponsorship of KOALA and with helping us navigate administrative responsibilities such as anything finance related or contacting industry for our industry night. The support from TMOS staff, and their willingness to answer our conference organisation questions, ensured that KOALA 2023 was an overwhelming success.

KOALA 2023 was attended by a total of 58 students from across Australia, New Zealand, and even a few from Germany, with 16 of these students part of either the ANU or UoM TMOS nodes. With 37 student talks, 20 student posters, 5 plenary speakers, a Social day for casual networking, an industry night attended by several companies, and a 5-person careers panel (including a TMOS representative!), we were able to provide a fulfilling 5 day conference for our student peers in physics. I believe we were able to also highlight the work of TMOS to the other attendees, bringing attention to the field of metaoptics to groups that may have been completely unfamiliar with it.

ANZCOP-AIP Summer Meeting

The ANZCOP-AIP Summer Meeting, held in Canberra over six days in early Dec 2023 (3-8 December), was a huge success for the Australian Physics and Optics community. The meeting was a joint event of the Annual meetings of two professional societies, namely the Australian and New Zealand Optical Society and the Australian Institute of Physics. As a society-run conference, the event relied on volunteers and major research centres in Australia to support it. TMOS led these efforts with the TMOS Director, Prof. Neshev, being one of two co-chairs of the meeting and chair of the ANZCOP. TMOS was a gold sponsor of the event, and our efforts attracted the sponsorship of another four Centres of Excellence in Australia and New Zealand.

The meeting attracted well over 500 delegates, predominantly from Australia, along with guests from the USA, India, New Zealand, Germany, Italy, and China. The conference featured a trade show, a public lecture, and an industry networking night with over 20 Australian companies and government entities. The event also featured the second report on the optics and photonics industry in Australia and New Zealand, presented by the TMOS Advisory Board Member, Simon Poole. Hosted at the Australian National University's new Physics Building; the venue features a spacious auditorium and five additional lecture halls. Highlights of the conference included a Gala dinner at the Old Parliament House, attended by 320 participants. A policy-focused town hall at the Australian Academy of Science, chaired by the TMOS Advisory Board Chair, Prof. Ian Chubb, provided a vivid discussion of the links between science and government.

As a major organising body, TMOS provided the lanyards for the participants. It was fulfilling to see over 500 people wearing the blue-coloured lanyards with the pride flag at the focus of each name tag. Importantly, TMOS organised a focused session on Quantum and Non-Conventional Metaoptics, which was led by three TMOS Research Program Managers, Dr Yana Izdebskaya (ANU), Dr Jinyong Ma (ANU) and Dr Litty Thekkekara (RMIT). This session featured the latest developments in our field and was supported by several international speakers and a large number of contributed and invited talks. TMOS was also a key exhibitor at the trade show (see images below). The TMOS booth featured educational materials, holograms, and most importantly, the products of the TMOS spin-off VIColours, colourful TMOS logos, and other end-user products.

Overall, the ANZCOP-AIP Summer meeting was a great testimony for the important role played by TMOS to build strong and supportive scientific community in Australia as well as to demonstrate the leadership of the Centre at the international scene.

> Overall the conference was one of the best I have attended. The schedule and scientific content was excellent.

TMOS Meta-Together Conference

Between 13 – 15 December, 2023 TMOS members gathered for the second Meta-Together Conference at the stunning Tangalooma Island Resort, Queensland, Australia. We were joined by a 18 of international collaborators, including Partner Investigators and members of our boards. The setting provided an ideal location for collaboration in action, entangling inspiring research discussions with a relaxing tropical island environment.

Kicking off with a planning day, our board members provided constructive feedback on our research progress and structures. The Chief Investigators engaged in a spirited debate about establishing a new Flagship Program, which will set the path to impact through the incubation of translation-ready projects.

The conference began with a moving Welcome to Country on the sands of Moorgumpin (Tangalooma). This was followed by a joyous Welcome Dinner, a moment of celebration and identity as the team came together to mark the start of the conference.

In keeping with our embedded Inclusion, Diversity, Equity and Accessibility (IDEA) policy, TMOS awarded seven IDEA Travel Scholarships. This initiative was a testament to our commitment to inclusivity, ensuring that members with carer responsibilities were able to participate. We were thrilled to see the positive impact this had on enabling their participation, making them feel valued and included.

The program was packed full of engaging scientific content, which gave our EMCRs and students a fantastic opportunity to present to colleagues and international collaborators. Participants are encouraged to create new opportunities, which can be facilitated by the TMOS exchange awards.

The whole TMOS team made the most of an opportunity to meet face to face, share in science, develop collaborative relationships, and celebrate the achievements of colleagues through our own awards night.

Lan Fu, Sharyn McFarlane, and Dragomir Neshev

> The program was amazing. A unique opportunity to do networking and discuss with great researchers about metasurfaces.















Outreach: Digital Media

In 2023, TMOS strengthened its commitment to science communications with the creation of a dedicated Public Relations Manager role. The first task was to develop a thorough marketing and communications strategy that clearly articulated the Centre's business objectives, its primary audiences, and the tactics that would increase awareness of the Centre's research, facilitate new industry collaborations, and recruit new people to the Centre's team.

The Centre's new marketing and communications strategy was built around a customer journey funnel that takes potential collaborators from a new awareness of meta-optics as an industry through a content-based research stage to the point of collaboration.

Highlights of the year's communication output include:

- a new website built using UX principles with a focus on content
- a two-page article in the Australia Inspace Magazine
- presentations at multiple space and defence industry events
- exhibition booths at MilCIS and the Futures Conference
- the launch of the Centre's Discovery Call initiative.

In addition, the Centre launched its Bright Light Coaching program. This coaching program utilises Gallup's Clifton Strengths as a framework for helping early career researchers direct their future paths as well as developing their science communications skills. It is a tailored approach to personal brand building based on the individual's natural talents as well as best-practice communication strategies. The purpose of this coaching program was to ensure that Centre's communication efforts generate impact long after the funding ceases and TMOS as a brand no longer exists.

In 2024, we are looking forward to exploring new communication channels including a TMOS newsletter and Reddit as well as the development of more long-form and multimedia content that addresses key questions about what meta-objects are and what impact it will have on a variety of industries.

Samara Thorn
Public Relations Manager

Below: The Centre's customer journey funnel

Clockwise from Top Left:
TMOS exhibition booth at the MilCIS Conference,
Rocio Camacho Morales speaks at the MilCIS Conference,
Industry profile – engineers,
TMOS exhibition booth at the Futures Conference

"The next frontier in space optics",
Australia Inspace Magazine

34,233
Website page views

MOST POPULAR PAGE
Our Team

7,680
Unique website visitors

TOP 5 VISITOR COUNTRIES
Australia
United States
India
Germany
China

30
Posts on the TMOS website in 2023

TOP 3 POSTS
1. New nanowire sensors are the next step in the internet of things.
2. New flexible 2d gas sensor soon to be protecting you from toxic ammonia.
3. From lightning storm to scholar.

SOCIAL MEDIA

1,712 (394 new)
TWITTER FOLLOWERS

1,578 (409 new)
LINKEDIN FOLLOWERS

44
TIKTOK FOLLOWERS

85 (9 new)
INSTAGRAM FOLLOWERS

105 (21 new)
YOUTUBE SUBSCRIBERS

1
YOUTUBE VIDEOS

1,988
YOUTUBE VIEWS

Performance

Key Performance Indicators

Performance Measure		Target Y0 2020	Actual Y0 2020	Target Y1 2021	Actual Y1 2021	Target 2020 -2021	Actual 2020 -2021	Target Y2 2022	Actual Y2 2022	Target Y3 2023	Actual Y3 2023	Perform. rate 2023
Number of research outputs	Journal articles	15	92	30	87	45	179	65	100	100	119	119%
	Book chapters	1	1	2	1	3	2	3	0	3	3	100%
	Patents (filing provisional patents and higher)	0	1	2	1	2	2	5	2	5	8	160%
Quality of research outputs	Cross-node publications[1]	3	2	6	2	9	4	20	4	20	4	20%
	Publications with PIs[2]	2	3	3	2	5	5	10	4	10	4	40%
	High impact publications (in top 10% in the field, e.g. IF>9)	2	17	5	20	7	37	10	28	25	28	112%
	Top-impact publications (in top 3% of the field, e.g. Nature/ Science family)	1	10	2	7	3	17	3	5	5	9	180%
Number of workshops/ conferences held/offered by the Centre	Centre annual workshop (conference)	0	0	1	0	1	0	1	2	1	1	100%
	Conference facilitation	1	0	2	4	3	4	2	8	2	9	450%

1. The early stages of the center's operation occurred during COVID and established foundational work in nodes. The cost of travel remains prohibitive however several initiatives have been developed to promote further cross node collaboration.
2. The impact of COVID has limited international collaboration. However, we are pleased to report that we have co-authored 36 journal articles with Associate Investigators this year.

Performance Measure		Target Y0 2020	Actual Y0 2020	Target Y1 2021	Actual Y1 2021	Target 2020 -2021	Actual 2020 -2021	Target Y2 2022	Actual Y2 2022	Target Y3 2023	Actual Y3 2023	Perform. rate 2023
Number of training courses held/offered by the Centre	Professional development courses	1	0	3	3	4	3	3	4	3	5	167%
	Topical workshops and courses	1	0	3	19	4	19	3	11	3	8	267%
	Centre-wide Seminar Program, number of presentations	5	0	20	18	25	18	20	21	20	20	100%
Number of additional researchers working on Centre research	Postdoctoral researchers (new)[3]	6	3	14	15	20	18	2	5	6	2	33%
	Honours and undergraduate students (new)[4]	2	1	4	6	6	7	6	1	6	4	67%
	TMOS HDR students (PhD and Masters new)	10	0	15	11	25	11	5	16	10	10	100%
	Masters by coursework students (new)[5]	4	0	6	0	10	0	6	0	6	3	50%
	Associate Investigators (new)[6]	3	0	0	0	3	0	2	1	0	4	>100%
Number of postgraduate completions	Number of postgraduate completions[7]									15	4	27%
	Women HDR completions (percentage of the cohort)	0	0	0	0	0	0	20	31	35	25	71%
Number of mentoring programs offered by the Centre	PI-Student Exchange Program[8]	0	0	3	0	3	0	5	0	6	3	50%
	Mentors within the Centre[9]	15	0	20	0	35	0	20	19	20	13	65%
	Number of mentees[10]	10	0	20	0	30	0	30	21	30	22	73%

3. Several positions were filled with existing TMOS members. As contracts finish, new recruitment opportunities will arise.
4. We have focused on recruiting PhD students as this is a more attractive path to many of our prospective students.
5. We have focused on recruting PhD students as this is a more attractive path to many of our prospective students.
6. We reviewed our AIs annually and have made several new appointments that commence in January 2024.
7. This is the first year for TMOS when the PhD students who were recruited by TMOS at the beginning of the Centre started graduating. Most of the PhD students still have ongoing projects since the normal course usually takes 3.5 years.
8. This program was on pause until mid-2023 due to the rising cost of international travel. However, due to the high costs of travel it was difficult for CIs to commit to matching 50% of the costs of travel, so applications were minimal.
9. Through 2023 we switched from the Centre wide mentoring program to the collaborative mentoring program, which was organised by several CoEs together to provide better opportunities for the members to learn new cross-discipline skills. Due to old mentoring connecting still being active, new ones were forming slightly slower than expected.
10. Through 2023 we switched from the Centre wide mentoring program to the collaborative mentoring program, which was organised by several CoEs together to provide better opportunities for the members to learn new cross-discipline skills. Due to old mentoring connecting still being active, new ones were forming slightly slower than expected.

Performance Measure		Target Y0 2020	Actual Y0 2020	Target Y1 2021	Actual Y1 2021	Target 2020 -2021	Actual 2020 -2021	Target Y2 2022	Actual Y2 2022	Target Y3 2023	Actual Y3 2023	Perform. rate 2023
Number of presentations/ briefings	To the public (Outreach/public engagement events, public lectures)	2	4	5	4	7	8	10	14	15	12	80%
	To government (parliamentarians and department/agencies at both State and Federal level)	0	1	2	0	2	1	3	6	3	7	233%
	To industry/business/end users (documented) incl. DSTG, CSIRO	2	3	3	5	5	8	5	3	10	20	200%
	To non-government organisations	0	1	2	3	2	4	3	6	3	8	267%
	School visits	0	2	5	4	5	6	8	6	8	13	163%
Number of new organisations collaborating with, or involved in, the Centre	Academic collaborations (new)	3	4	3	6	6	10	3	10	3	8	267%
	Industry and end user partnerships (new)	1	4	3	10	4	14	3	7	3	9	300%
Number of female research personnel	Women and diverse gender, % (double the discipline mean)	30	33	30	25	30	29	35	36	35	32	91%

Performance Measure		Target Y0 2020	Actual Y0 2020	Target Y1 2021	Actual Y1 2021	Target 2020 -2021	Actual 2020 -2021	Target Y2 2022	Actual Y2 2022	Target Y3 2023	Actual Y3 2023	Perform. rate 2023
Centre-specific KPIs												
Research		12	34	27	54	39	88	53	67	58	100	
	Plenary talks at international conferences	1	2	2	3	3	5	3	12	3	11	367%
	Keynote and Invited talks at international conferences	10	21	20	41	30	62	40	41	45	63	140%
	Awards and fellowships to CIs, ECRs and AIs	1	11	5	10	6	21	10	14	10	23	230%
	Additional research income secured by Centre staff ('000)	100	4,410	1,000	19,749	1,100	24,159	1,000	5,957	2,000	21,362	1,068%
Equity and Diversity	Leadership Skills Training, % of Centre personnel (CIs)	100	100	100	0	200	100	100	0	100	100	100%
	IDEA Training, % of Centre personnel[11]	N/A	0	100	100	100	100	100	90	100	87	87%
IP uptake by end-users	Start-up companies	0	0	0	1	0	1	0	2	0	3	>100%
	IP uptake by end-users[12]	0	0	1	0	1	0	1	6	2	0	0%
	Number of TMOS alumni employed in industry	0	0	0	0	0	0	0		1	2	200%

11. There was a period of time when the platform had technical problems and TMOS members could not log in to complete studies. However, most of the TMOS members managed to complete compulsory training.
12. We have started several new relationships with end-users but this has not converted to IP-uptake.

Performance Measure		Target Y0 2020	Actual Y0 2020	Target Y1 2021	Actual Y1 2021	Target 2020 -2021	Actual 2020 -2021	Target Y2 2022	Actual Y2 2022	Target Y3 2023	Actual Y3 2023	Perform. rate 2023
Centre-specific KPIs												
Education	Associate TMOS HDR students (PhD and Masters, new)[13]	10	16	15	26	25	42	5	1	10	3	30%
	Centre-member attendees at training workshops (total)	30	0	90	0	120	0	90	129	90	109	121%
	Non-Centre member attendees at training workshops	5	0	20	0	25	0	20	16	20	26	130%
	HDRs visiting PIs[14]	0	1	5	0	5	1	10	3	10	5	50%
Outreach	Media releases	2	2	10	10	12	12	20	13	20	22	110%
	Media mentions	2	38	10	170	12	208	20	20	20	21	105%
	Twitter followers (new)	100	477	100	445	200	922	100	396	100	394	394%
	Outreach hours (Direct contact hours only)	100	22	1,000	26	1,100	48	1,000	59	70	79	113%

13. We have several associated students through MetaActive, which is an international program, not captured by this KPI. Most of them started doing Dual PhD in 2022, so there were only a few more added to the program.
14. This program was on pause until mid-2023 due to the rising cost of international travel.

Finance

INCOME STATEMENT 2023

REPORTING PERIOD	2023	2024
	Actual ($)	Forecast ($)
Opening Balance (total funds)	**11,444,755**	
INCOME		
ARC[1]	5,399,946	5,825,226
Australian National University	427,899	415,988
The University of Melbourne	32,462	159,011
RMIT University	226,699	217,885
University of Technology Sydney	210,000	404,857
The University of Western Australia	159,725	159,725
Consultancies	-	19,580
Government grant/sponsorship	22,400	
TOTAL INCOME	**6,479,130**	**7,202,272**

REPORTING PERIOD	2023	2024
EXPENDITURE	Actual ($)	Forecast ($)
Personnel	3,639,657	4,273,119
Equipment	169,870	437,704
Scholars Expenses	666,630	712,187
Travel	522,924	631,574
Other[2]	1,057,688	1,147,688
TOTAL EXPENDITURE	**6,056,768**	**6,806,327**
CARRY FORWARD (TOTAL)	**11,867,117**	
CARRY FORWARD TO 2024	**5,416,996**	
CARRY FORWARD TO 2027[3]	**6,450,121**	

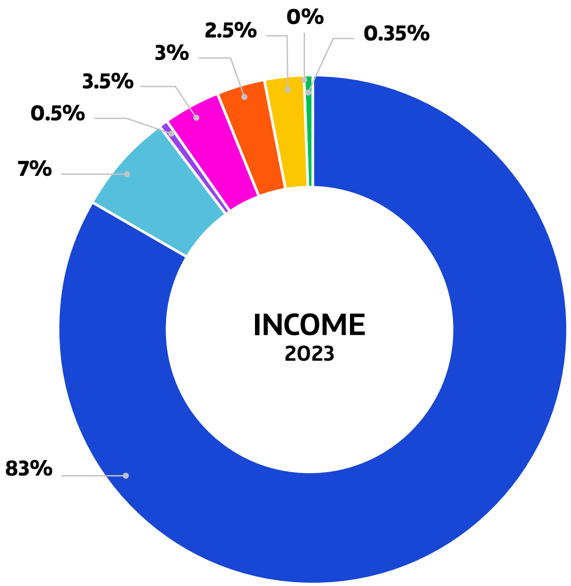
IN-KIND CONTRIBUTIONS 2023

REPORTING PERIOD	2023	2024
	Actual ($)	Commitment ($)
IN-KIND		
Australian National University	1,372,428	1,121,068
The University of Melbourne	734,818	391,390
RMIT University	419,410	334,870
University of Technology Sydney	595,070	370,836
The University of Western Australia	494,693	317,968
Partners' contributions	736,629	736,629
TOTAL IN-KIND CONTRIBUTIONS	**4,353,047**	**3,272,761**

Notes on the Financial Statement:

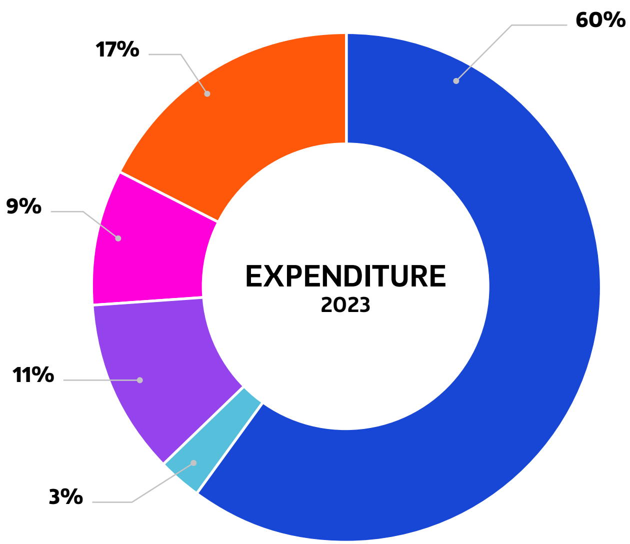
1) includes indexation and 2023 ARC funding
2) incl Materials, R&M, Branding, Outreach, Consultancies, Recruitment, Administrative support, Strategic Initiatives
3) unspent balance from 2020 reserved for 2027 (year 7) operations incl $5,530,785 ARC funds

CASH INCOME SOURCES 2023:



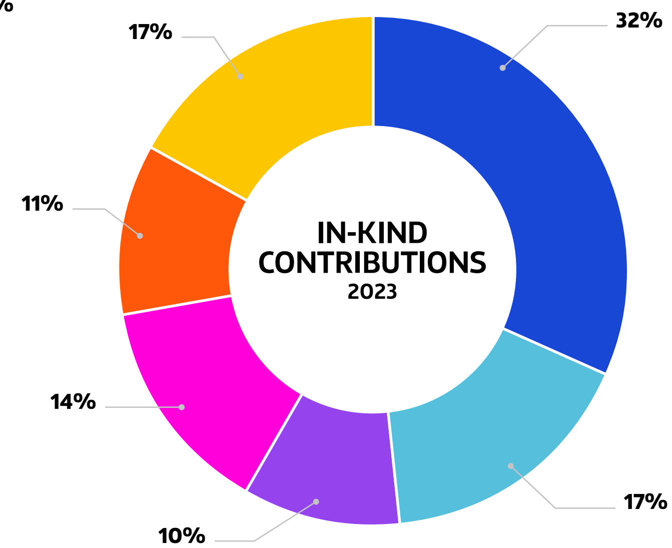
- ARC[1] **83%**
- Australian National University **7%**
- The University of Melbourne **0.5%**
- RMIT University **3.5%**
- University of Technology Sydney **3%**
- The University of Western Australia **2.5%**
- Consultancies **0%**
- Government grant/sponsorship **0.35%**

EXPENDITURE 2023:



- Personnel **60%**
- Equipment **3%**
- Scholars Expenses **11%**
- Travel **9%**
- Other **17%**

IN-KIND CONTRIBUTIONS 2023:



- Australian National University **32%**
- The University of Melbourne **17%**
- RMIT University **10%**
- University of Technology Sydney **14%**
- The University of Western Australia **11%**
- Partners' contributions **17%**

Notes on the Financial Statement:

1) includes indexation and 2023 ARC funding

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Awards, Honours and Prizes

Awardee Name	Details
Chennupati Jagadish	Pravasi Bharatiya Samaan Award 2023 Government of India, Highest Honour for Overseas Indians presented by the President of India, "for contributions to science and technology and education"
Daria Smirnova	Recipient of The Nanophotonics Early Career Award
Neuton Li	Fulbright Future Scholarship (Postgraduate) 2023
Kenneth Crozier	Became Fellow of Optica Citation: For exceptionally broad and novel scientific contributions to the understanding and engineering of light-matter interactions at the nano- and micro-scales
Kenneth Crozier	Fellow of SPIE
Lesley Spencer	Faculty of Science Art Exhibition, Highly Commended
Chennupati Jagadish	Division Awards: Dielectric Science & Technology Division Thomas D. Callinan Award: Semiconductor Nanostructures for Optoelectronics and Energy Applications at the 243rd ECS Meeting with the 18th International Symposium on Solid Oxide Fuel Cells (SOFC-XVIII); May 28-June 2, 2023, at the Hynes Convention Center and Sheraton Boston.
Fedor Kovalev	Vice Chancellor's HDR Travel Grant
Shaban Sulejman	Dr Alan Kenneth Head PhD international research award
Shaban Sulejman	SPIE optics and photonics education scholarship
Madeline Hennessey	AIP Student Poster Network Event pitch - first place (honours category)
Maximilian Weissflog	Travel Grant Student Award from the European Physical Society
Khosro Zangeneh Kamali	Vice-Chancellor's HDR Travel Grants for CLEO Europe 2023
Benjamin Russell	Recipient of a Jean Laby Travel Scholarship to attend
Shiyu Wei	John Carver Seminar Series 2023 – 28 September – winning the The Director's Prize ($500)

Awardee Name	Details
Sharath Sriram	Innovation Leader Award (Finalist)
Sharath Sriram	Rotary International Chennai Chapter Young Achiever Award
Chennupati Jagadish	Honorary Fellow, Chinese Chemical Society
Lan Fu	Appointed as Editorial Board Member of njp Nanophotonics
Lan Fu, Buddini I Karawdeniya, Shiyu Wei	Winner of the Health Technology Innovation Challenge, Australian Centre for Accelerating Diabetes Innovations (ACADI). The pitch on our "Ketowhsitle device for non-invasive breath-based acetone sensing for diabetes monitoring" was an in-person event at Melbourne Connect that took place on 13 November 2023, 4-6PM. with Buddini I Karawdeniya
Chennupati Jagadish	Foreign Member of the Chinese Academy of Sciences
Dragomir Neshev	Clarivate 2023 Highly Cited Researchers
Francesca Iacopi	Institute of Electrical and Electronics Engineers (IEEE) Fellow

Awarded Funding

TMOS Member	Title of Funding Scheme	Project ID	Total Amount (AUD)	Collaborators	Funding Source
Lukas Wesemann	Australia-Germany Joint Research Co-operation Scheme		$ 24,400	Prof. Ann Roberts, Dr. Tim Davis, Prof. Harald Giessen, Dr. Mario Hentschel, PhD students from both nodes to-be-named	Universities Australia in collaboration with the DAAD (German Academic Exchange Service)
Francesca Iacopi	Advanced Prototype Packaging Facility (APPF)		$ 3,000,000	Lead by A/Prof Nathan Langford, UTS	NSW Tech Central Research and Innovation Infrastructure Fund
Dragomir Neshev	European Space Agency (ESA)		$ 215,000	Dragomir Neshev and Vesselin Vassilev	European Space Agency (ESA)
Dragomir Neshev	Sony Europe, B.V.		$ 225,000	Tuomas Haggren, Dragomir Neshev, Hoe Tan, Chennupati Jagadish, Rocio Camacho Morales, Daria Smirnova	Sony Europe, B.V.
Francesca Iacopi	Miniature Physiological Sensors with Integrated Brain Signal Decoders for Brain-Robot Interaction Phase 3 of Defense Innovation Hub funding		$ 3,836,000	Prof.CT Lin, UTS	Commonwealth of Australia, Defence Innovation Hub
Lan Fu	ANFF Gate-1 Funding for market research		$ 20,000		NCRIS
Lan Fu	ANFF-C		$ 20,000		NCRIS
Yana Izdebskaya	2023 ANU Physics Research Equipment Grant		$ 33,170	Vladlen Shvedov	Australian National University
Lan Fu, Buddini I Karawdeniya	ANU Impact Fund		$ 50,000	Shiyu Wei, Lan Fu, Christopher Nolan, Jane Desborough	Australian National University
Lan Fu	Australian National Fabrication Facility (ANFF) Commercialization Gate 1 Fund		$ 20,000		ANFF
Lan Fu	2023 Major Equipment Committee Award (non-research)		$ 111,402		Australian National University

TMOS Member	Title of Funding Scheme	Project ID	Total Amount (AUD)	Collaborators	Funding Source
Buddini I Karawdeniya	ANU Impact Fund		$ 50,000	Shiyu Wei, Lan Fu, Christopher Nolan, Jane Desborough	Australian National University
Mariusz Martyniuk	Dep of Jobs Tourism Science and Innovation, Defence Science Grant 2023-2024		$ 150,000		WA State Govt
Mariusz Martyniuk	ANFF WA node Opex		$ 4,312,000		NCRIS
Mariusz Martyniuk	ANFF WA Node Capex		$ 4,377,000		NCRIS
Hoe Tan	ANFF – ACT		$ 2,942,000		NCRIS
Buddini I Karawdeniya	2023 ACADI Health Tech Innovation Challenge		$ 30,000	Shiyu Wei, Lan Fu, Christopher Nolan, Jane Desborough	Medical Research Future Fund (MRFF)
Daria Smirnova	Australian Research Council Future Fellowship 2023 Round 1	FT230100058	$ 827,020		The Australian Research Council
Kenneth Crozier	Discovery Project (DP) DP240101309	DP240101309	$ 562,507		The Australian Research Council
Milos Toth	Discovery Project (DP) DP240103127	DP240103127	$ 606,238		The Australian Research Council
TOTAL			**$ 21,361,738**		

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