TMOS

2021
Annual Report

Contents

Centre

Message from the Director

2021 marks the first year of TMOS, and it was full of excitement and challenges. The COVID-19 pandemic placed several big challenges in front of us, affecting the recruitment of new staff and the networking between the existing TMOS members. However, the year also offered new opportunities to easily connect with colleagues and connect across continents with industries from all-over the world. These include large companies like Schott in Germany, Northup Grumman and L3-Harris in the USA.

> “The Centre is well positioned in the field, being the world’s largest research effort to develop and translate this cutting-edge science and technology.

Worldwide, the field of meta-optics has experienced a huge growth with more than 2500 articles containing the word metasurface or metamaterials published during the year. Importantly, we saw a large take up of the technology by industry. We have seen over 40 companies worldwide listing metamaterials technology in their portfolio. Many large companies, such as Apple and Google have also shown their interest in meta-optics by hiring graduates trained in the field, not to mention the bold renaming of Facebook to Meta, inspired by the development of augmented reality (AR) hardware and software.

The Centre is well positioned in the field, being the world’s largest research effort to develop and translate this cutting-edge science and technology. This leadership position of TMOS was further enhanced by winning an international research training group (IRTG) with our international partner, Friedrich Schiller University of Jena. The IRTG, called Meta Active, was granted in 2021 and contributed €5 million into the joint activities in the field.

Despite the difficulties with the pandemic, we managed to recruit a great group of students and postdocs. In 2021, the TMOS team included 15 new postdoctoral researchers and 11 new PhD students. I am very proud that the targeted women recruitment round resulted in a great boost of the gender diversity of the Centre, with the RMIT node reaching 50-50 equity. It is a great outcome, however, it is important for all of us to continue these efforts and propagate them through the entire team. These aspirations are now documented in the TMOS Strategic and Implementation Plan, which further describes our Research, Translation, Education, Mentoring, and Outreach vision.

TMOS delivered a fantastic research output, with total of 87 publications in refereed journals. A number of these were published in top-ranked journals, including publications in Nature, Nature Materials, Nature Photonics, Nature Communications and others. Important examples of our publications were featured in a number of media releases. These include the demonstration of tunable infrared LEDs for detection of various gaseous compounds; the identification of carbon as the source of single photon emission in hBN; the application of metasurfaces for phase contrast imaging; and semiconductor metasurface applications in novel ultra-thin night-vision technologies.

I would also like to congratulate our members who received important awards and career recognition this year. Special congratulations go to:

- Chief Investigator Prof. Jagadish, who was appointed as the President of the Australian Academy of Science.
- Chief Investigator Prof. Madhu Bhaskaran for her appointment as the co-leader of Women in STEMM Australia.

Finally, I would like to reflect on the mental health of all of the TMOS members. The pandemic lockdowns have had an enormous impact on many of us. With the new year of TMOS, we are looking at repairing some of the issues. We are aiming to introduce a number of in-person meetings to energise our interactions within the Centre and create an environment of intellect and innovation. We hope to extend our inspiration to reach people outside of TMOS including outreach events at schools and general public.

2021 was a challenging but invaluable year for us, and I look forward to 2022 offering even more opportunities.

Professor 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 WiFi, 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

DISCOVERY

Foster research at the highest international level.

INNOVATION

Nurture a culture of technology innovation.

COLLABORATION

Create a culture of inclusion, diversity, equity and access.

EDUCATION

Prepare outstanding young innovators as future leaders for decades to come.

ENGAGEMENT

Engage with global and Australian industries to translate the research into innovative technologies in transport, health, security, defence, agriculture, entertainment and education with enomous benefit to society and economic growth.

Message from Ian Chubb, Chairman of the Centre Advisory Board

Research scientists have a responsibility to the public – without the contribution the public makes to the support of our research much of it would not happen. Why should they fund it, or fund it better, if we don't take the time to explain what we do, carefully, professionally and persistently?

We work to understand better the natural and physical world we live in, so that the benefits of that knowledge can be distributed throughout our community. The benefits will take multiple forms: knowing more about our world all the way to products and services that will make life better for most people. To fulfil that responsibility, we should be the best we can be. But we cannot simply focus on our own narrow interests alone. We must ensure that we are communicating effectively and widely.

As scientists, we should see the communication of our work as just as important as the work itself.

Public expenditure is about priorities. At its best, it means selecting what will benefit the community most. Sadly, that is not always the case. To see sensible decisions realized, we need to convince the public that science is important to the future, and that scientific evidence should inform relevant public policy. It is only when the community-at-large, or in focus groups, start talking about research, and after that talk reaches the ears of decision-makers, that governments will invest more in research.

Good communication is about discipline. Disciplined thinking means staying on message and adjusting it to the audience. Highly technical explanations may be appropriate for the scientific peer group, but are an ineffective way of communicating more broadly to the audiences that need to hear what we have to say.

It is not 'dumbing things down' by taking the time to explain our work to the people who make a substantial contribution to its cost – our community. We need them to be aware of what their support goes to, and what the implications are of where we are taking our part of the scientific endeavour. Sooner or later they will have to choose between options, and the better we communicate the more likely our community will make good choices.

I understand how frustrating it can be, as a scientist, to feel that nobody is listening. I encourage all researchers, especially those who are early in their career, not to give up. Take every opportunity you have to get the message out. It may feel like your voice is small, but when a thousand voices all sing the same song, people pay attention. By taking those opportunities now, you start a conversation that can be carried on throughout the journey.

TMOS, the ARC Centre of Excellence for Transformative Meta-Optical Systems, is still in its early days. Its research is still young. I encourage all of its team to focus on communication early, to ask themselves how the world will learn of the work they are doing, and to move forward with a commitment to communication – for the public good, and for the good of research.

Emeritus Professor Ian Chubb AC FAA FTSE
Chairman of the Centre Advisory Board

Message from the International Scientific Advisory Committee

Curiosity driven research, fundamental *and* applied is crucial if humanity is to create new knowledge and make new advancements in technology. It is also vulnerable to external pressures, which create a focus on deliverables and lead young researchers to play it safe. Given the length of funding it has been given, TMOS is uniquely positioned to champion this type of research.

History is full of examples of important inventions that came out of curiosity-driven research. In 1970, Willard Boyle and George E Smith wanted to create a new memory device using metal-oxide-semiconductor (MOS) capacitors. They started with a basic design and then followed their line of enquiry to create the CCD sensor; a device which revolutionized our understanding of the universe and as the first semiconductor image sensor was the beginning of the digital photography revolution. I won its inventors a Nobel prize for Physics. The best results come from curiosity-driven research. However, current pressures in academia have a stifling effect on innovation, even by the most promising young scientists.

One such pressure is the Hirsch Index or h-index, a commonly used metric that measures productivity by scholarly output. Tying career advancement to a 'publish or perish' mentality pressures people into playing it safe. A scientist will not explore a new field or take a risk if they are overly focused on publication.

Instead, they will do the next obvious, though sometimes important, thing in their field, knowing that the results will generate research papers they can publish in high-impact journals.

Take for example the story of Frederick Sanger, an English biochemist who twice won the Nobel Prize for Chemistry. Sanger worked on the structure of proteins in insulin, and was integral to the sequencing of DNA. His contributions to scientific research are invaluable, with clear benefits to the community.

Sidney Brenner, a Nobel Laureate, in his obituary of Sanger said "A Fred Sanger would not survive today's world of science. With continuous reporting and appraisals, some committee would note that he published little of import between insulin in 1952 and his first paper on RNA sequencing in 1967 with another long gap until DNA sequencing in 1977. He would be labeled as unproductive, and his modest personal support would be denied. We no longer have a culture that allows individuals to embark on long-term—and what would be considered today extremely risky—projects".

A second pressure on curiosity driven research is the duration of funding. Here, TMOS has an advantage over other institutions which it must capitalise on. Typically, research funding is for two, or three years. There is pressure to produce deliverables at the end of the funding. Those deliverables may be industry partnerships that bring money into the institution, or research papers published in high impact journals. In turn, that creates pressure on researchers to keep their scope narrow, and play it safe with shorter -term research projects. If we continue down this trajectory of favouring translational research over curiosity driven research, both will dry up. Translational research relies on curiosity research as its foundation, that might lead to a new technology. We must champion the ability of researchers to ask what is possible, without worrying whether it is immediately useful. It is up to institutions like TMOS to push back on the culture of linking academic advancement to such things as H-Index and impact factor, and of privileging funding for proposal focused primarily on technology impacts. . The Centre's seven-year funding model offers a unique advantage in allowing its researchers to engage in curiosity-driven research. I believe it is our responsibility as scientists to capitalise on that opportunity. It can be difficult for research centres to push back on government pressure. However, they may be the only ones who can.

Prof. Federico Capasso
Chairman of the International Scientific Advisory Committee

2021 Key Moments

14 JAN 2021	CI Ann Roberts announced as new SPIE Fellow
3 MAR 2021	First IDEA meeting
9 MAR 2021	First Infrastructure committee meeting
15 APR 2021	First ILC Committee meeting
27 APR 2021	First Education & Colloquium meeting
10 MAY 2021	iRTG 2675 announcement
16 MAY 2021	International Day of Light TMOS Competition
25 MAY 2021	IDEA Framework approved
22 JUN 2021	CI Ann Roberts awarded Alan Walsh Medal
28 JUN 2021	Intersectionality Walk
29 JUN 2021	TMOS Strategy and Implementation Plan approved
1 JUL 2021	CI Lan Fu appointed as IEEE Photonics Distinguished Lecturer
29–30 JUL 2021	TMOS Student & ECR Conference
5 AUG 2021	First Outreach meeting
18 AUG 2021	Fizzics Science Week show
25 AUG 2021	E-Challenge launches + workshop program
20–22 SEP 2021	Early Career Women in STEMM workshop
28 SEP 2021	First ECR Committee meeting
2 OCT 2021	CI Francesca Iacopi announced as IEEE EDS Distinguished Lecturer
25 NOV 2021	CI Chennupati Jagadish announced as President of Australian Academy of Sciences
2 DEC 2021	CI Madhu Bhaskaran announced as Co-Chair of Women in STEMM Australia
7 DEC 2021	First research program manager appointments

Action Items for 2022

THEME 1 – GENERATE

- Optimising cavity design, transparent contacts, and fabrication challenges.
- Development of micro-ring cavities and lasers.
- Develop the theoretical approaches for PT symmetry-based control of gain and loss.
- Explore the effect of high-quality factor resonances on the frequency conversion and develop new materials platforms for enhancing efficiency.
- Continue towards improvement of brightness and purity and integration with nanophotonic elements.
- Develop nonlinear metasurfaces for generation of quantum-entangled photon-pairs.

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THEME 2 – MANIPULATE

- All-optical spectral classification using diffractive neural networks. Develop working principle of standalone diffractive neural network for multi-biomarker classification in sensing/point of care applications.
- Embedded graphene metalens for wearable devices.
- Phase change materials for optical applications.
- Fabricate electro-optic metasurface devices based on lithium niobate, and expand functionality to include control of light polarisation.
- Explore metasurface lenses with liquid crystals for making tunable focal length systems.
- Use metamaterial concepts coupled with MEMS to demonstrate a prototype tunable device.
- Complete the modelling effort and establish the design for a proof-of concept prototype of dynamic on-chip inter-waveguide coupling.

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THEME 3 – DETECT

- Material growth and optimisation of III-V nanowire quantum well mid-IR photodetectors.
- Investigation and design optimisation of III-V nanowire quantum well mid-IR photodetectors.
- MCT detector enhanced with self-integrated on-pixel all-dielectric metamaterial resonance (metaMCT-pixel) - design, simulations, growth, fabrication, and characterisation.
- MCT detector with metamaterial resonance enhancing narrow band SWIR performance towards ultimate quantum efficiency (metaMCT-SWIR for QE) - design, simulations, growth, fabrication, and characterisation/testing.
- Design metasurfaces using semi-analytical and numerical optimization for photon state transformations in polarisation and spatial modes.
- Fabricate and characterise metasurfaces for the target wavelengths, including telecommunication range.
- Demonstrate tailored multimodal MIR detection based on subwavelength structures/pixels (polarisation, phase, angle).
- Dynamic detection spectrum tunability via graphene carrier concentration control: explore range.
- Demonstrate broadband nanowire array photodetectors (VIS to SWIR).
- Develop broadband nanowire array-based spectrometers (visible to SWIR).
- IR MCT focal plane array with metamaterial extended field of view (metaMCT-FPA/FOV) and polarimetric capabilities.
- Demonstrate single-pixel nanowire array NIR to SWIR photodetector imaging.

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INDUSTRY LIAISON COMMITTEE

- Position the Centre as a focus of an industry consortium, to forge tangible pathways for blue sky research toward applications.
- Grow long-term engagement with Australian industry through the development of leaders in key sectors.
- Develop and publish education programs on research commercialisation to improve our business development skills.

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INCLUSION DIVERSITY EQUITY AND ACCESS COMMITTEE

- Create a pilot culture survey (to become an annual survey) to understand what is working and receive feedback from the team.
- Establish the Centre wellbeing and family policies.
- Include an IDEA module in the induction package for all Centre members to promote awareness.

Read the report

EDUCATION & COLLOQUIUM COMMITTEE

- Develop induction materials for TMOS HDR students.
- Develop Centre colloquium/seminar program 2022.
- Develop an Education Program based on Centre students' interests and needs delivered regularly through Centre Science Tuesdays.
- Organise the 2nd TMOS ECR/HDR mid-year conference.
- Develop Centre Conference program 2022.
- Organise topical workshop during Centre conference for TMOS HDR students.
- Coordinate travel awards for HDR student exchange to visit PI's labs whenever possible.

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OUTREACH COMMITTEE

- Develop a communications and content strategy that includes all owned, earned, and paid channels.
- Establish an external Centre newsletter that reaches relevant parties with information about the Centre's work.
- Develop a series of classroom activities that teach meta-optics concepts.
- Collaborate with Questacon to develop an optics exhibition.

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EARLY CAREER RESEARCHERS COMMITTEE

- Develop an ECR Committee strategic plan.
- Create an ECR mentoring program and implement a trial.
- Collaborate with the Education Committee to deliver professional and personal development workshops for ECRs.

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INFRASTRUCTURE AND CAPABILITIES COMMITTEE

- Maintain equipment register that lists the experimental and computational infrastructure available in the laboratories of all Chief Investigators (CIs). In addition, we will continue to raise awareness of the existing facilities within the Centre, to facilitate cross node interaction. This will be achieved by a special session at the TMOS Annual Conference.
- Organise meetings at which Centre CIs interested in proposing a LIEF bid will have the opportunity to interest other CIs in joining their proposal. The Committee will furthermore endeavour to facilitate TMOS CIs to participate in bids led by non-TMOS CIs for infrastructure that would be beneficial for Centre activities.
- Schedule quarterly slot for discussion of unmet infrastructure and facilities needs in Centre Executive Committee meetings.
- Schedule quarterly slot for discussion of possibilities of joint submissions to Australian and international facilities in Centre Executive Committee meetings.
- Serve as contact point with ANFF, NCI, and Microscopy Australia

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CENTRE EXECUTIVE COMMITTEE

- Development of our inspiring flagship research goals, with a view of frontier and translational scientific challenges.
- Completion of the Centre's on-boarding process and induction modules.
- Completion of the Centre's Operation Manual and related KPI reporting system.
- Development of the Centre's Succession Plan.
- Consolidate and finalise the Centre's Code of Conduct.

Read the report

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 Engagement Manager:

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People

GROUP LEADERS:


CHIEF INVESTIGATOR IGOR AHARONOVICH


CHIEF INVESTIGATOR MILOS TOTH

RESEARCH FELLOWS:


DR. MEHRAN KIANINIA


DR. TIESHAN YANG


DR. JOHN SCOTT

STUDENTS:


RITIKA RITIKA


OTTO CRANWELL


LESLEY SPENCER

THE TEAMS BEHIND TMOS

Quantum Materials and Nanophotonics – University of Technology Sydney

The Quantum Materials and Nanophotonics Group was started over a few beers in a bar in Newtown. CIs Aharonovich and Toth had been working together for eight years and knew that partnering in a new group would be a lot of fun. They brought in PhD students and post-docs to join the team and, crucially, expanded the group to include members from more than ten different countries, a move that brought with it a diversity of ideas that have become the bedrock of their success.

How did your team transition into meta-optics?

Aharonovich: I met Centre Director Dragomir Neshev at a conference. He introduced me to the concept of meta-optics and I could quickly see how our work in quatum materials and nanophonics could complement the work that he was doing. When he told us that he was proposing a Centre of Excellence for research in the field, we jumped in.

What is the primary objective that your group is working towards? How did you come to this as a goal? What inspired you?

Toth: Our primary objective is to develop a practical, scalable platform for on-chip quantum photonics. We focus on development of new solid state quantum emitters and nanofabrication techniques that underpin this objective. Most of our recent work has been focused on new capabilities in this field enabled by two-dimensional materials.

What has been your group's biggest achievement in the past 12 months? What has excited you over this time?

Aharonovich: We've had some great research successes in the past year; we've discovered some things that no one thought was possible and we published in Nature Materials a couple of times. But the achievement that brings us the most joy was when our two postdocs became faculty members. That is awesome. Unless you work in academia, you might not understand the significance of that. It's a massive step in their careers and we're so proud of them.

What do you enjoy most about working with your group?

Toth: We do cutting-edge research in an environment that is very informal and fun. Our group is the place to work for researchers who are very ambitious and want to enjoy the workplace beyond the excitement associated with breakthrough research projects.

Has your group collaborated with industry? If so, what did that look like?

Toth: Yes, the group has collaborated with industry since its inception. We develop patent-protected nanofabrication technologies, advanced scientific instruments and nanophotonic technologies.

What is the biggest challenge your group has faced? How did you overcome it?

Toth: The biggest challenge is always to attract the best people. We are constantly trying to promote the group online and in person and are always looking out for people with a similar attitude and interest. We have had to adapt our work and recruitment strategies to stay on track in 2020 and 2021.

How different do you think your group is going to look at the end of the Centre's lifetime?

Aharonovich: Our Centre will have no end. Seriously, these collaborations aren't going to stop because the Centre's funding runs out. We will always continue to work together on various projects. The Centre will continue; it will just metamorphe into a different form. In regards to our team, I'm hoping that some will be in academia and others will be leading new startups on quantum meta-optics.

THE TEAMS BEHIND TMOS

Functional Materials and Microsystems Research Group – RMIT University

The Functional Materials and Microsystems Research Group was established in 2010. Initially just a group of two, it has grown significantly in the past 11 years and now is a team of more than 40 researchers. The group's activities range from fundamental research, funded by the ARC, to applied research and commercialisation, funded through CRC programs and numerous industry partners.

GROUP LEADERS:

CHIEF INVESTIGATOR
MADHU BHASKARAN

CHIEF INVESTIGATOR
SHARATH SRIRAM

RESEARCH FELLOWS:

DR. LITTY THEKKEKARA

DR. KRISHNA MURALEEDHARAN NAIR

DR. BEN CUMMING

STUDENTS:

YING ZHI CHEONG

SUVANKAR SEN

Why did your team embrace meta-optics in your research?

Bhaskaran: As an electronics researcher who works on sensors, it was clear that introducing light and meta-optics to the world of sensing opens up a plethora of new applications with enhanced sensitivity and selectivity.

Sriram: Functionality in materials is due to their structure – the order, disorder or presence of missing atoms. The ability to engineer structures, with designed order, enables new applications in optics. Translating our materials science knowledge to applications where one could make lenses thinner than a human hair or devices that enhance human vision were exciting opportunities.

What is the primary objective that your group is working towards? How did you come to this as a goal? What inspired you?

Sriram: As a group of engineers and innovators, our vision has been to go from concept to reality with the end goal of commercialising research in collaboration with industry and design partners. Currently our industry and translation partnerships are focussed on healthcare and aged-care technologies.

What has been your group's biggest achievement in the past 12 months? What has excited you over this time?

Bhaskaran: One of the most exciting things which happened in 2021 (despite extended lockdowns in a pandemic!) was the launch of REMi, in collaboration with our industry partner Sleeptite. REMi is a non-invasive monitoring system designed for residential aged care facilities – an array of mattress sensors which are unfeelable and can provide you with accurate information of a person's presence, position, and posture in bed. This is technology which has gone from being fundamental research to a patent to a commercialisable product in a span of six years.

What do you enjoy most about working with your group?

Sriram: We take great pride in being a vibrant group who collaborate widely (both cross-disciplinary and cross-sector). We celebrate our gender and cultural diversity and benefit from the innovative technologies realized from having diverse voices and perspectives around the table.

Has your group collaborated with industry? If so, what did that look like?

Bhaskaran: We have always focussed on applied technologies and have worked with industry for 10 years now. Clear communication and mutual respect are key as it is for any successful partnership or relationship.

What is the biggest challenge your group has faced? How did you overcome it?

Sriram: There was a period of over two years when our technology was on the brink of being in the valley of death – people saw the possibilities our stretchable sensors could deliver for them but we were unable to lock in any industry partnerships. Being flexible and listening to what the industry and the market wanted helped us overcome it – it is more important to work to find the right answers to their questions rather than push existing solutions towards them.

How different do you think your group is going to look at the end of the Centre's lifetime and after 10 years?

Bhaskaran: I am hopeful of the group incorporating light and meta-optics to create an array of miniaturised devices which will excite industry and the general audience.

GROUP LEADER:

CENTRE DEPUTY DIRECTOR KENNETH CROZIER

RESEARCH FELLOWS:

DR. WENDY LEE

DR. JIAJUN MENG

DR. SIVACARENDRAN BALENDHRAN*

DR. NIMA SEFIDMOOYE AZAR*

STUDENTS:

HENRY TAN

SEYED SALEH MOUSAVI KHALEGHI

BENJAMIN RUSSELL

THE TEAMS BEHIND TMOS

The Crozier Group – University of Melbourne

The Crozier Group initially formed in 2004 at Harvard University. After a decade in the United States, the group moved to the University of Melbourne, where they sit within both the Optical Physics Group and the Electronic and Photonic Systems Group—an indicator of the cross-disciplinary nature of their research.

How did your team transition into meta-optics?

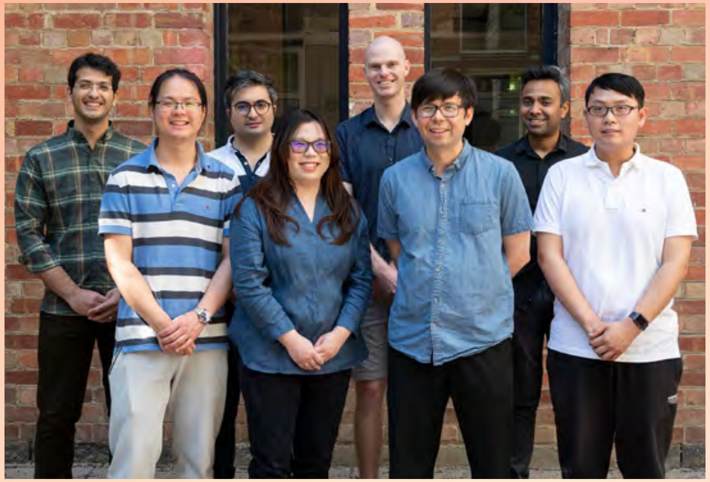
I started working on meta-optics before the term was coined. During my PhD, I investigated techniques for improving optical resolution. I approached this from the electrical engineering perspective of antenna theory, studying what happens when one makes an antenna so small that it resonates at optical frequencies.

What is the primary objective that your group is working towards? How did you come to this as a goal? What inspired you?

My group works at the intersection between optics and nanoscience, with the goal of creating new optical technologies and, along the way, investigating new applied physics. We have adopted this as a goal because of three recent dramatic developments. First, due to advances in top-down (from the computer chip industry) and bottom-up (from the field of chemistry) nanoscience, it is now possible to control materials at the nanoscale, allowing their optical response to be engineered. Second, due to advances in computing power, we can now predict optical properties and design optical devices in a way that was previously unimaginable. Third, there is currently a move toward the miniaturization of optical systems, to allow them to be incorporated into consumer electronic devices, etc. Due to these three reasons, working at this intersection (between optics & nanoscience) is not only possible but also can be used to realise technologies for which there is a real need.

What has been your group's biggest achievement in the past 12 months? What has excited you over this time?

We have devised a method for identifying chemicals based on the integration of a metasurface with an infrared camera and a machine learning algorithm. What is exciting is that the system is very small (e.g. camera weighs less than one gram), so it could be useful for many applications.



What do you enjoy most about working with your group?

Group member alumni have been very successful in their careers, e.g., joining the labs of Nobel Prize winners (lab of Eric Betzig, HHMI), obtaining continuing (tenured) positions as professors at leading universities (e.g., Tel Aviv University, Shanghai Jiaotong University), joining leading labs as research fellows (e.g., MIT, Harvard, NIST), obtaining prestigious fellowships that enabled them to start their own groups (e.g., Rowland Institute) and joining leading companies (e.g., Sony, ASML Brion, Oracle). This has resulted in many opportunities for collaboration, which I enjoy.

Has your group collaborated with industry? If so, what did that look like?

We have had numerous collaborations with industry, including Schlumberger Doll Research, the Advanced Energy Consortium, Zena Technologies, Palette, and Flame Security International. Each of these collaborations was special and unique, and structured to suit the needs of the industrial partner.

What is the biggest challenge your group has faced? How did you overcome it?

Every project brings new challenges that have to be addressed in unique ways. In optical nanotweezers, for example, we found that heating was a major issue, to the absorption that accompanies plasmonic resonance. We addressed this via a “heat sink” approach. In our work on surface-enhanced spectroscopy, we found that quantum mechanical tunneling limits the maximum field enhancement that can be achieved. This is something that needs to be taken into account rather than overcome.

How different do you think your group is going to look at the end of the Centre’s lifetime and in 10 years?

There are so many amazing opportunities for collaboration within TMOS. We have struck up some new collaborations recently, and look forward to our work evolving in new and unexpected ways! In my opinion, much of the potential of meta-optics remains yet to be realised. Meta-optics presents the opportunity for dramatic reductions in C-SWAP metrics (cost, size, weight and power). Yet while many investigations have demonstrated metasurface devices, to use them in real world applications it has been necessary to use them in larger systems. In some sense this defeats the purpose of the metasurface.

I see great opportunities when meta-optics is used in systems with excellent C-SWAP, achieved by miniaturization of all elements. This is a theme we intend to work on over the coming years.

THE TEAMS BEHIND TMOS

Microelectronics Research Group – University of Western Australia

The Microelectronics Research Group was formed more than 30 years ago when Chief Investigator Faraone returned from working in the United States and joined UWA for the opportunity to have a long-term career working in a challenging technical area. Over those decades he has welcomed many PhD students and early career researchers, including CI Martyniuk who joined the group as a PhD student in 2002.

Why did your team embrace meta-optics in your research?

Martyniuk: The marriage of micro-electromechanical systems (MEMS) and metamaterials, or metaMEMS, is a win-win situation and it just makes sense. Tuning of metamaterial response using MEMS is a uniquely suitable and versatile approach for a 'workhorse' technology to achieve actively controlled manipulation of light propagation. AND the best thing is that it came with great people! The potential for collaboration between world-class team of researchers is second to none and we all help each other to realise what currently does not exist and would be great to have. Using MEMS approaches we can add an out-of-the-box degree of freedom to physically move and rearrange meta-optics towards working gadgets that enable novel functionalities previously considered to be beyond the achievable.

What is the primary objective that your group is working towards? How did you come to this as a goal? What inspired you?

Faraone: To develop infrared sensors and imaging array technologies with enhanced performance and/or capabilities. This goal is challenging and in an area that is of national strategic interest.

What has been your group's biggest achievement in the past 12 months? What has excited you over this time?

Faraone: The completion of the Department of Defense (DoD) funded Counter Improvised Threats Grand Challenge project. We successfully integrated optical MEMS as the light manipulating element with Infrared (IR) sensors and delivered a working prototype. This is a new sovereign Australian capability.

GROUP LEADERS:


CHIEF INVESTIGATOR
LORENZO FARAONE


CHIEF INVESTIGATOR
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DR. WENWU PAN


DR. MICHAL
ZAWIERTA


DR. HEMENDRA
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DR. DHIRENDRA
TRIPATHI*

STUDENTS:


SHUBHASHREE
SWAIN*


YAN LIU


DANIEL MORLEY

What do you enjoy most about working with your group?

Martyniuk: We make stuff that works. We realise working miniature MEMS devices that enable novel functionalities previously considered to be beyond the achievable. The integration on a microscale of mechanical or movable parts with integrated electronic opens new avenues for realization of novel devices whose applications are limited only by human ingenuity. It is great to feel the joy that I do working on something so impactful.

Faraone: The infrared technology area that we work in is unique in Australia, is technologically challenging, and has an impact in a wide and diverse range of industry sectors.

Has your group collaborated with industry? If so, what did that look like?

Martyniuk: Our industrial collaboration has ranged from direct industrial contracts, to collaborative research projects co-funded by the ARC and the DoD

What is the biggest challenge your group has faced? How did you overcome it?

Martyniuk: Our group is focused on developing industry-relevant technologies that are at the leading-edge, and in a very high-cost and rapidly developing research area. Thus, it is inherently high-cost and requires a continual upgrading of facilities and equipment, which is an on-going challenge.

How different do you think your group is going to look at the end of the Centre's lifetime and after 10 years?

Faraone: Hopefully, not very different from what it is now. We have a great team and we're working on exciting projects. There are always new opportunities to tackle and we're lucky that we're given those opportunities. If we can still be solving problems 10 years in the future, we'll be happy.

GROUP LEADER:

CHIEF INVESTIGATOR
FRANCESCA IACOPI

RESEARCH FELLOWS:

DR. AISWARYA
PRADEEPKUMAR

DR. IRYNA
KHODASEVYCH

STUDENTS:

PATRICK
RUFANGURA

DAVID KATZMAREK

THE TEAMS BEHIND TMOS

Integrated Nano Systems (INSys) Lab – University of Technolgy Sydney

The Integrated Nano Systems (INSys) Lab was formed a decade ago when Chief Investigator Iacopi started her Future Fellowship. When she moved to UTS five years ago, the group fomalised into The Integrated Nano Systems (INSys) Lab, which still has several members from the original group working together.

How did your group transition into meta-optics?

My background is more in electronics than photonics. However, my interest has always been in the miniaturization of components. Meta-optics and metasurfaces are the logical continuation of our work, as they enable the miniaturization of optical components and their integration with electronics.

What is the primary objective that your group is working towards? How did you come to this as a goal? What inspired you?

The main objective of my group is demonstrating a high-end application of graphene on silicon that can be scaled-up and fabricated according to silicon manufacturing processes. What motivates us is technological and societal impact.

What do you enjoy most about working in your group?

Our group has a very strong team spirit, and all of our team members are very collegial and helpful colleagues and good friends to each other. In addition, the group is not only geographically diverse, as this is very common these days, but also technically (physicists, chemical and electronic engineers) and gender-diverse – with our two senior members being female and myself as a female group leader, we are exactly 50/50.

Has your group collaborated with industry? If so, what did that look like?

Our group is driven by impact and industrial application. I used to run a large industrial semiconductor R&D team in the past. As an academic, I have continuously worked with the Department of Defence in the USA and the Australian Defense Science and Technology Group (DSTG) and Defence. We periodically collaborate with different industries, from semiconductor materials to equipment suppliers. Working with industry is generally more structured with a lot more reporting and stricter timelines and goals but can be very rewarding.

What is the biggest challenge your group has faced? How did you overcome it?

Early on in the history of our group, we had some unexpected results that seemed to make our technology unusable. We did not sweep the problem under the rug, instead we have worked for several years to identify the exact nature and fundamentals of the issue, which has allowed us to also find a valid solution and create a lot of know-how about the system. Nowadays, we know how to work around the issue, but also, in some applications, we know how to take advantage of it! This greatly enhances the value of our technological platform and intellectual property. As the Latins said, "Per aspera ad astra".

How different do you think your group is going to look at the end of the Centre's lifetime?

By the end of the Centre's lifetime I expect that most of the current people in our group will have moved on to different roles, hopefully quite a few in industry and others to post-doc positions in other labs, and maybe, even to academic positions. In terms of research, I expect that we may become more and more focused on sensing and imaging applications of metasurfaces.

THE TEAMS BEHIND TMOS

Experimental Photonics Group – Australian National University

The Experimental Photonics Group formed naturally in 2008 around the experimental activities of CI Neshev in nanophotonics and plasmonics. It is a highly synergistic group, with several early career researchers and PhD students, some joint with other groups within the Centre. This collaborative approach has allowed the group to expand and deepen its research.

GROUP LEADER:


CENTRE DIRECTOR DRAGOMIR NESHEV

RESEARCH FELLOWS:


DR. ROCIO CAMACHO MORALES


DR. ANDREI KOMAR


DR. BUDDINI KARAWDENIYA


DR. MATTHEW PARRY


DR. TUOMAS HAGGREN

STUDENTS:


RIFAT AHMMED


JINGSHI YAN


MUDASSAR NAUMAN


KHOSRO ZANGENE KAMALI


SHRIDHAR MANJUNATH


MARCUS CAI


ZIWEI YANG


BOHAN LI


SARAH DEAN

Why did your team embrace meta-optics in your research?

I have been fascinated by the nanoworld and how it can deliver unique optical phenomena, not seen elsewhere – the world of meta-optics. When conducting some fundamental research, we realized the enormous potential of nanostructured metamaterials to revolutionise optical technologies. The discussions and interest from several companies confirmed the transformative nature of meta-optics. However, it was clear that a lot more research is needed for meta-optics to reach its full potential.

What is the primary objective that your group is working towards? How did you come to this as a goal? What inspired you?

The objectives of the group are (i) to research the fundamental principles of light-matter interactions in nanostructured materials and (ii) to apply these principles to several real-world applications, including infrared vision, advanced imaging and biosensing.

What has been your group's biggest achievement in the past 12 months?

I have been very excited about the application of nonlinear upconversion of infrared light to visible for infrared imaging. The last 12 months have been particularly rewarding for our group being able to demonstrate such imaging in nonlinear metasurfaces made of GaAs nanocrystals.

What is it that you enjoy most about your group?

We are a multicultural group with people from more than ten different countries. We nurture diversity of ideas and encourage the independent thinking of all our group members. We are driven by curiosity, though we focus on the important scientific problems with the biggest impact on the society.

Has your group collaborated with industry? If so, what did that look like?

We have had two industrial Linkage projects with industry and are constantly seeking applications

of our technologies to practical problems. These projects have been focussed on the demonstration of technology concepts, however, we are looking at extending these to the development of working prototypes. Currently, we are engaging with five different companies from several industry sectors.

What is the biggest challenge your group has faced? How did you overcome it?

When aiming to tackle big challenges, our group has to work with researchers from other fields and disciplines. A big challenge has been to learn to understand such diverse researchers, including medical scientists, chemists and engineers. Overcoming misunderstanding and wrong expectations have been often difficult, however, persistence, patience and kindness are the best ways forward.

How different do you think your group is going to look at the end of the Centre's lifetime and after 10 years?

I am pretty sure that group will be very different at the end of the Centre. I'm confident that the strong bond in the group will continue to exist after the Centre and that together we will be able to solve big challenges in a fast and efficient way.

GROUP LEADER:

CHIEF INVESTIGATOR
ANN ROBERTS

RESEARCH FELLOWS:

DR. WENDY LEE

DR. FARIS SHAHIDAN

DR. LUKAS
WESEMANN

STUDENTS:

SHABAN SULEJMAN

NIKEN PRISCILLA

LAURA OSPINA

THE TEAMS BEHIND TMOS

Team Roberts – University of Melbourne

Chief Investigator Ann Roberts has been an academic at the University of Melbourne since 1990. In that time, she's worked with many national and international collaborators and has supervised a number of PhD students who have then gone on to their own careers in academia and industry. Currently, her team consists of several students and post-docs whose research spans imaging, meta-optics enabled photodetectors, plasmonic colour and the colour and near-infrared signatures of beetles. She also work closely with Dr Tim Davis who is an Honorary Professorial Fellow in the School of Physics here at Melbourne and an AI in TMOS. She will be looking to expand the group and recruiting research fellows and students in 2022.

How did your team transition into meta-optics?

I've been working on what we now call meta-optics for my entire thirty plus year career! My Honours and PhD projects as a student involved investigating sub-wavelength structures that we called 'grids' and 'frequency selective surfaces' back then but these devices would now be referred to as meta-optics. It has been fascinating to see where the field has come from and even more exciting to see where it will go from here!

What is the primary objective that your group is working towards? How did you come to this as a goal? What inspired you?

My team is working toward understanding and utilizing light-matter interactions on the nanoscale for a variety of applications including imaging and microscopy and their integration into novel photodetectors. These combine my long-standing interests in subwavelength optics and imaging.

What has been your group's biggest achievement in the past 12 months? What has excited you over this time?

We have been very excited about some of our recent work in demonstrating the visualisation of phase using metasurfaces. Although we knew theoretically that something should work, it is actually quite amazing to see an image generated by a meta-optical device suddenly appear. We have also been delighted by some of our recent work on structural colour and the connection to the natural world is fascinating.

What do you enjoy most about working with your group?

My group accommodates people with diverse interests and backgrounds. One of the great things about our research program is that it extends from more fundamental theoretical activities, through simulations, nanofabrication and benchtop optical experiments. Members of the group work on projects that span these activities but it does give them an opportunity to tailor their work to their interests and develop a broad range of skills.

Has your group collaborated with industry? If so, what did that look like?

In the past we have collaborated with artwork conservators and are currently working with scientists from the Reserve Bank of Australia. The range of problems that exist outside academia that can be addressed using light is extraordinary and working with industry gives us an opportunity to contribute to solving these.

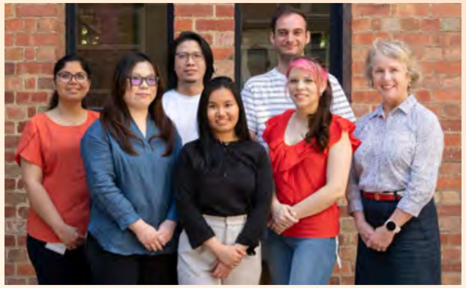
What is the biggest challenge your group has faced? How did you overcome it?

Running an experimental program during a pandemic has been an enormous challenge particularly for the students with tight deadlines. With a (temporary) pivot to theory and modelling, and online meetings we managed to scrape through.

How different do you think your group is going to look at the end of the Centre's lifetime and in 10 years?

I anticipate the group will grow in size while achieving a gender balance that would have been unthinkable even ten years ago. There will also be strong connections with the other nodes within TMOS and movement of staff and students within the Centre.

Based on past experience, members of my team will move into a range of professions. Some of them are working for start-ups (two work at local success story MOGLabs), major research laboratories (e.g. ASTAR in Singapore) and healthcare companies while others have moved into careers in the corporate world and education.



GROUP LEADER:

CHIEF INVESTIGATOR
ILYA SHADRIVOV

RESEARCH FELLOWS:

DR. YANA
IZDEBSKAYA

DR. QUANLONG
YANG

STUDENTS:

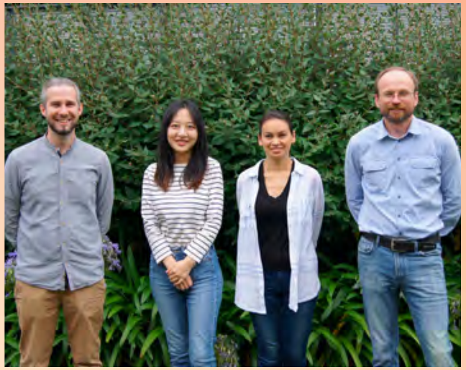
LUYAO WANG

FEDOR KOVALEV

THE TEAMS BEHIND TMOS

Tunable Metasurfaces – Australian National University

The tunable metasurfaces team at ANU began as a partnership between CI Shadrivov and Dr. Yang four years ago. The two had a common interest in tunable metasurfaces, prompting Dr. Yang to visit CI Shadrivov for the last year of his PhD and then to take up a post-doc position. When the Centre became operational, PhD student Luyao Wang joined the team. The team will expand further to include a new student Fedor Kovalev in the beginning of 2022.



Why did your team embrace meta-optics in your research?

The field is so broad that you can always choose to study what you are interested in the most. Meta-optics and metasurfaces will have a wider impact than their names suggest, not only in actual optics, but also in microwave engineering, communications, security etc.

What is the primary objective that your group is working towards? How did you come to this as a goal? What inspired you?

The goal was formulated early when we were at the planning stages of the Centre, when we were putting together the application. We'd been working in the field for some time and had the freedom to ask ourselves "What would be fun to study?" "What is going to have some exciting, useful outcomes?"

What has been your group's biggest achievement in the past 12 months? What has excited you over this time?

2021 was an opportunity for us to set the course for our research. Adjustments needed to be made to be able to run research within a collaborative Centre of Excellence rather than solely within a university department. Once that happened, the research took off. There were some really interesting things to come out of it, but we will talk about it when we publish results in 2022.

What is it that you enjoy the most about your group?

We engage in a wide range of activities, there is a huge choice of research topics both theoretical and experimental. It allows us to follow our passions. I also enjoy the collaborative nature of it. In addition to our expertise and the expertise of the rest of the Centre, we're able to work closely with researchers across Australia and internationally.

What is the biggest challenge your group has faced? How did you overcome it?

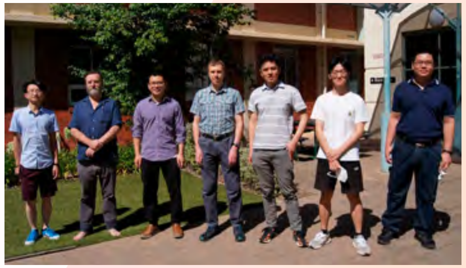
The major challenge so far has been the pandemic, which affected our ability to employ staff and students. It was difficult to get the right people to be able to come to Canberra. Lockdowns also drastically limited our access to the experimental facilities.

How different do you think your group is going to look at the end of the Centre's lifetime and after 10 years?

We aim to grow even a bigger network of researchers world-wide who are graduates and alumni of our group. Some of these people will be academics but I also see our team going on to work in industry, translating our research into tangible real-world products. By the time the Centre draws to a close, we'll have learned a lot, our collaboration with other nodes will have expanded our knowledge and we will discover a new research direction that will be as interesting!

THE TEAMS BEHIND TMOS

Nonlinear and quantum photonics group – Australian National University



GROUP LEADER:

CHIEF INVESTIGATOR ANDREY SUKHORUKOV

RESEARCH FELLOWS:

DR. JINYONG MA

DR. JIHUA ZHANG

STUDENTS:

SHAUN LUNG

NEUTON LI

MARCUS CAI

SARAH DEAN

JUNZE TIAN

The Nonlinear and Quantum Photonics Group started in 2007, when CI Sukhorukov received an Australian Research Council QEII Fellowship. Since then students and junior researchers who have come through the group have since progressed to careers in academia, government, and industry. Most of the current members have joined the group in the past two years and are excited to also be working within TMOS.

Why did your team embrace meta-optics in your research?

This platform offers unprecedented opportunities for manipulating quantum light at nanoscale, which can enable new quantum technologies for imaging, sensing and communications.

What is the primary objective that your group is working towards? How did you come to this as a goal? What inspired you?

We aim to develop new fundamental approaches for tailoring light-matter interaction at micro- and nano-scale. We got inspired by the advances at nanotechnologies, allowing for practical realisation of diverse classical and quantum physical concepts.

What has been your group's biggest achievement in the past 12 months?

We developed a theoretical approach for highly efficient generation of quantum-entangled photons from metasurfaces, and then realized a record enhancement experimentally. This sets a basis for further development of these ultra-compact quantum sources over the coming years.

What do you enjoy most about working in your group?

We have specific expertise in the fundamental aspects of nonlinear and quantum nanophotonics and our team has the ability to apply fundamental theory all the way to experiments and applications.

Has your group collaborated with industry?

We're currently taking part in an ARC Linkage Project with Australian company 'Seeing Machines', which is headquartered in Canberra. The project is developing optical metasurfaces for automotive driver-monitoring systems, to replace bulky optics and improve the functionality.

What is the biggest challenge your group has faced? How did you overcome it?

The incredible hailstorm at the beginning of 2020 shut down the nanofabrication and experimental facilities at ANU. We were shut down again during the COVID lockdowns. Fortunately, our PhD student Neuton Li was able to travel to Melbourne where he undertook training at the Melbourne Centre for Nanofabrication (MCN) and fabricated metasurfaces of excellent quality, which he also personally designed, with only Zoom support from his supervisors.

How different do you think your group is going to look at the end of the Centre's lifetime and after 10 years?

Naturally, there will be new students and early-career researchers. I enjoy working with people at that stage of their careers. We will keep our focus on fundamental research but also aim to strengthen links with practical applications.

GROUP LEADERS:

CHIEF INVESTIGATOR
CHENNUPATI JAGADISH

CHIEF INVESTIGATOR
HOE TAN

CHIEF INVESTIGATOR
LAN FU

RESEARCH FELLOWS:

DR. NAIYIN WANG

DR. TUOMAS
HAGGREN

DR. YI ZHU

DR. ZIYUAN LI

DR. ASIM RIAZ*

DR. JULIE TOURNET*

DR. SIVA KARUTURI*

DR. ZHE LI*

THE TEAMS BEHIND TMOS

Semiconductor Optoelectronics and Nanotechnology Group – Australian National University

The Semiconductor Optoelectronic and Nanotechnology Group was formed in 1993 when CI Chennupati Jagadish received a permanent position at ANU Physics. In the twenty-eight years since, dozens of students have come through the group, earning their PhDs and going on to become academics and professors. CIs Hoe Tan and Lan Fu were two such students, and they have continued to work together for over twenty years, starting well before metasurfaces was a research field.

Why did your team embrace meta-optics in your research?

Jagadish: This happens more by chance. We had been collaborating with Prof. Dragomir's group for many years before TMOS was formed, using our materials for various optics/nonlinear physics related projects. Our work on lasers, LEDs, photodetectors and their integration is highly relevant to meta-optics.

Fu: I have been working in the field of optoelectronic devices (such as lasers/LEDs, Photodetectors and solar cells) and their integration. I see huge opportunities that meta-optics offers to link/enhance those optoelectronic components together to achieve high performance and functional miniaturized photonic systems for many emerging and future technologies.

What is the primary objective that your group is working towards? How did you come to this as a goal? What inspired you?

Fu: My research team's primary objective is to demonstrate high performance optoelectronic devices and their integration with meta-surface for enhanced performance/functionalities. This has been inspired by the surge of new applications/technologies that are in great demand of highly integrated optoelectronic/photonic systems.

Tan: Although our research areas are quite broad, my main interests are in (i) the epitaxial growth of III-V semiconductor nanostructures for optoelectronic device applications and (ii) the use of ion implantation processing of compound semiconductors optoelectronic devices. We try to understand the material physics that underlie the formation of these nanostructures. Once we can control the growth and properties of these nanostructures, we would then use them to make the next generation nano-scale optoelectronic devices that can provide new functionalities, be more efficient and reliable and consume less power.

What has been your group's biggest achievement in the past 12 months? What has excited you over this time?

Tan: The ability to grow nanostructures with pre-determined geometry using selective area epitaxy such as nano-membranes and micro-rings through a systematic and deep understanding of the fundamental mechanism for the formation of these nanostructures. We were able to demonstrate lasing from these micro-rings.

Another area is in hexagonal boron nitride (hBN). Together with CI Prof. I. Aharonovich, we were able to prove conclusively that quantum emission originating from hBN is related to carbon impurities. Our group's contribution is in the epitaxial growth of hBN and the use of ion implantation to incorporate C and generate defects in hBN.

Fu: We have also continued to develop new growth strategies for selective area epitaxy of nanowire arrays based on different material systems. In the past 12 months we have seen a few important device demonstrations including quantum well based nanowire LEDs, photodetectors, as well as dual-band multi-wavelength photodetectors. In the meanwhile, we have also demonstrated through top-down method, the nanowire array based high performance gas sensor, and ultra-sensitive (at single photon level) infrared photodetector.

What is special about your group? Why should other researchers want to work with you?

Jagadish: We are a fairly large group, about 30 members, which is multinational and multicultural with excellent diversity (30% are women). We work very collaboratively and cooperatively in an environment which is respectful and we treat our students as colleagues and encourage them to take leadership in their projects and open doors for them to international collaborators. Science is global and working with leading experts with complementary expertise and facilities allow us to do high impact research of international significance.

Training students and post-doctoral fellows to highest international standards is what motivates us. Working together is fun and having fun is important in life. Many students and post-doctoral fellows are in leading positions in academia, Government and industry. Seeing the success of the group members has been the most satisfying thing for us. Our students and post-docs are our pride and joy.

Has your group collaborated with industry? If so, what did that look like?

Tan: We continually work with industry. Our primary avenues working with them are through supplying bespoke epitaxial wafers and ARC Linkage Projects. We are currently in negotiation with two industry partners to design and fabricate meta-optical devices (in collaboration with CI Neshev) and to develop our catalyst materials from green hydrogen generation.

Working with industry is not only exciting but also provides some satisfaction to a researcher from the perspective that our research effort can actually be used in real life applications.

What is the biggest challenge your group has faced? How did you overcome it?

Fu: Our research is experimentally intensive. The main challenges for us are equipment broken down or lab access interruption beyond anyone's control (such as bushfire smoke, hailstorm damage, or COVID). During such time, we try to encourage our postdocs/PhD students to carry out simulation work, reading more literature and writing papers/theses.

How different do you think your group is going to look at the end of the Centre's lifetime and after 10 years?

Tan: Do I have crystal ball? Although we cannot predict with any accuracy what the group is going to be like in 10 years time, one thing is for certain – forward planning. In 10 years time several of us in the group would have retired or close to retirement and new talent need to be scouted, mentored and nurtured to take over the group. Succession planning is an important part of leadership.

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DR. LILY LI*

DR. MYKHAYLO LYSEVYCH*


DR. OLIVIER LEE CHEONG LEM*

STUDENTS:


ANHA BHAT


ASWANI GOPAKUMAR


FANLU ZHANG


MOHAMMAD RASHIDI


NIKITA GAGRANI


SHIYU WEI


SIBO HUANGLONG


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WEI WEN WONG


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BIKESH GUPTA*


HUYEN PHAM*

ZAHRA AZIMI*


JOSHUA BUTSON*


JOSHUA SOO*

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HARRY ATWATER

Partner Investigator

California Institute of Technology, USA

PROFESSOR
ANDREI FARAON

Partner Investigator

California Institute of Technology, USA

PROFESSOR
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Northwestern University, USA

PROFESSOR
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Partner Investigator

National University of Singapore

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CHENGWEI QIU

Partner Investigator

National University of Singapore

PROFESSOR
WILLIE PADILLA

Partner Investigator

Duke University, USA

PROFESSOR DEMETRIOS
CHRISTODOULIDES

Partner Investigator

University of Central Florida, Orlando, USA

PROFESSOR
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Partner Investigator

The Ohio State University, USA

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Partner Investigator

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MICHAEL JOHNSTON

Partner Investigator

University of Oxford, UK

PROFESSOR
LAURA HERZ

Partner Investigator

University of Oxford, UK

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Partner Investigator

City University of New York, USA

PROFESSOR YESHAIAHU (SHAYA) FAINMAN

Partner Investigator

University of California San Diego, USA

DR. NORBERT HERSCHBACH

Partner Investigator

IEE, Luxembourg

DR. AURELIEN BOTMAN

Partner Investigator

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HELENA BECK

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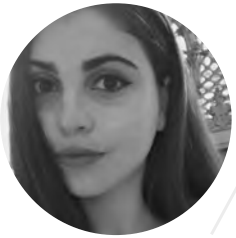
The Australian National University

GREG DENNIS

Inclusion, Diversity, Equity and Access Officer
RMIT University



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RMIT University

KAREN KADER

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University of Western Australia

PETER NOWOTNIK

Inclusion, Diversity Equity, and Access Officer
RMIT University

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The Australian National University

SAMARA THORN

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The Australian National University

Associate Investigators

ASSOCIATE PROFESSOR ARTI AGRAWAL

Associate Investigator

University of Technology Sydney

DR. MONICA ALLEN

Associate Investigator

Air Force Research Laboratory, USA

DR. VICTORIA COLEMAN

Associate Investigator

National Measurement Institute

PROFESSOR ALI JAVEY

Associate Investigator

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ASSISTANT PROFESSOR ARTUR DAVOYAN

Associate Investigator

University of California, Los Angeles, USA

ASSOCIATE PROFESSOR ALEXANDER B. KHANIKAEV

Associate Investigator

City College of New York, USA

PROFESSOR MOHSEN RAHMANI

Associate Investigator

Nottingham Trent University

DR. DAVID A. POWELL

Associate Investigator

The University of New South Wales @CBR

DR. ALEXANDER SOLNTSEV

Associate Investigator

University of Technology Sydney

ASSOCIATE PROFESSOR DANIEL GOMEZ

Associate Investigator

RMIT University

DR. FRANK SETZPFANDT

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Friedrich-Schiller-Universität Jena, Germany

PROFESSOR ANTONIO TRICOLI

Associate Investigator

University of Sydney

ASSOCIATE PROFESSOR YUERUI LU

Associate Investigator

The Australian National University

DR. ZONGYOU YIN

Associate Investigator

The Australian National University

ASSOCIATE PROFESSOR SUMEET WALIA

Associate Investigator

RMIT University

DR. JEFFERY ALLEN

Associate Investigator

Air Force Research Laboratory, USA

DR. RANJITH UNNITHAN

Associate Investigator

The University of Melbourne

PROFESSOR STEPHEN GOULD

Associate Investigator

The Australian National University

PROFESSOR AMPALAVANAPILLAI NIRMALATHAS

Associate Investigator

The University of Melbourne

PROFESSOR THOMAS PERTSC

Associate Investigator

Friedrich Schiller University
Jena, Germany

PROFESSOR ARNAN MITCHELL

Associate Investigator

RMIT University

DR. TIMOTHY DAVIS

Associate Investigator

The University of Melbourne

ASSOCIATE PROFESSOR MARTIN HILL

Associate Investigator

University of Western Australia

PROFESSOR ANDREY MIROSHNICHENKO

Associate Investigator

The University of New South Wales @CBR

ASSOCIATE PROFESSOR JAREK ANTOSZEWSKI

Associate Investigator

The University of Western Australia

DR GILBERTO UMANA-MEMBRENO

Associate Investigator

The University of Western Australia

DR DILUSHA SILVA

Associate Investigator

The University of Western Australia

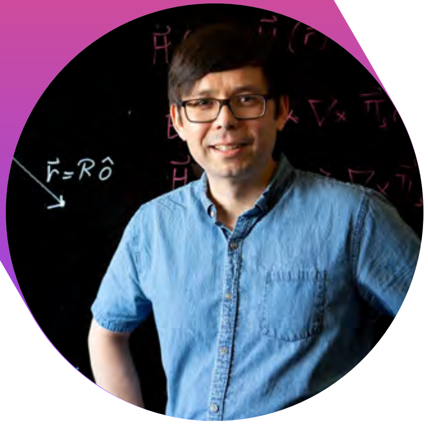
PROFESSOR WEN LEI

Associate Investigator

The University of Western Australia

Research

Message from the Deputy Director



According to Lighting Economic Growth*, the photonics-based industry sector accounts for around A$4.3b of economic activity in Australia and employs nearly 10,000 people in 465 companies. I imagine that many readers would be surprised to learn this. The global photonics industry is sometimes referred to as the "hidden economy", which might stem from it not having a dedicated standard industrial classification (SIC) code, meaning that it is hard to quantify its size. The photonics industry currently creates important employment and wealth in Australia – being similar in size to dairy production – and furthermore presents a welcome opportunity to transition our economy from reliance on minerals to the more environmentally-sustainable growth sector of advanced manufacturing.

At TMOS, we are contributing to the growth of the Australian photonics industry via three key mechanisms.

First, in TMOS we are developing technologies that will be ultimately translated into commercial products by the Australian (and/or international) photonics industry. Centre Chief Investigators have a proven track record in this regard, with their research being found in real-world products. Infrared detector and materials characterisation technologies developed by Centre CIs have been licensed by leading manufacturers. Integrated circuit chips incorporating porous electronics materials developed by one of our Chief Investigators have gone into production. Ion and electron microscopy technologies developed by another Centre CI are found in commercial instruments used all over the world. This tradition is continuing, with new partnerships in technology translation being formed between TMOS CIs and local companies since the Centre inception.

Second, every year TMOS produces a new cohort PhD graduates and early career researchers, trained not only in the science of photonics, but also with experience in leadership and management. This cohort is ideally placed to contribute to the Australian photonics industry workforce. It has been pleasing to see our early "graduating" cohort move into industry and we will follow their career trajectories with some interest!

Third, TMOS represents one of the largest activities in meta-optics research in the world. This represents an unusual resource for the Australian photonics industry, with expertise—all under one roof—that ranges from theory and simulation to materials science, nanofabrication, and optical systems design. Since the Centre's inception, we have seen this bear fruit with new industry partnerships and we look forward to this continuing in the years to come.

The span of the field of photonics is enormous, ranging from basic investigations of the universe to the development of technologies that are enablers of modern computer chips and the Internet. Many of the key milestones in photonics research were carried out at universities. For example, I imagine that you might be reading our report on the Internet. This is enabled by optical fibre communications, which is in turn based on lasers, optical amplifiers, and numerous other technologies. Much of the early work on lasers was performed in universities (notably the conception of the maser – forerunner to the laser – by Charles Townes at Columbia University in 1951 and by others). Similarly, optical amplifiers – which allow the light signals powering the Internet to be boosted so that they can travel long distances – were pioneered at universities (notably by David Payne at Southampton University in the 1980s and by others).

Perhaps you are reading this report on a smart device with face detection. The latter is based on the vertical cavity surface emitting laser (VCSEL), which was pioneered at a university (notably by Kenichi Iga of the Tokyo Institute of Technology in the 1970s and by others). Lastly, it's likely that you are accessing this report by reading it from a screen, i.e., via the human visual system. Perhaps you have had your eyes checked recently via optical coherence tomography, another technology developed at a university (notably by James Fujimoto of the Massachusetts Institute of Technology in the 1990s and by others).

These simple examples illustrate the critical role that university research has played in photonics. However, as noted by Federico Capasso elsewhere in this report, the path from university research to a real-world product is generally not the idealised picture of technology translation that we might imagine. The world would be a very different place without the advances made by photonics, but many of these originated from fundamental research that was driven by curiosity and knowledge discovery rather than by applications. So, while we should continue to strive for research translation in our work, it is critical not to neglect the importance of knowledge discovery-driven basic research.

Professor Kenneth Crozier
Centre Deputy Director

> “
> TMOS represents one of the largest activities in meta-optics research in the world. This represents an unusual resource for the Australian photonics industry, with expertise—all under one roof—that ranges from theory and simulation to materials science, nanofabrication, and optical systems design.

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 WiFi, 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

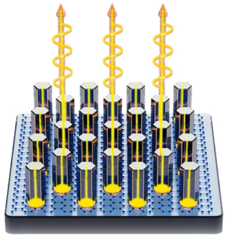
Cater for the exponential growth of image-processing data and emerging exascale problems by developing photonic problem-specific processors.

DETECT

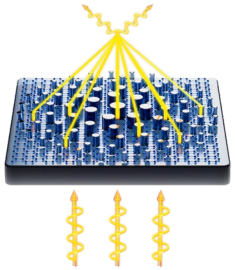
Realise access to currently unavailable optical information by integrating metasurfaces into photodetectors to expand their functionality.

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

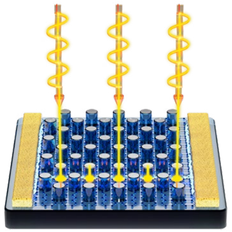
Find out more about our themes on our website



GENERATE



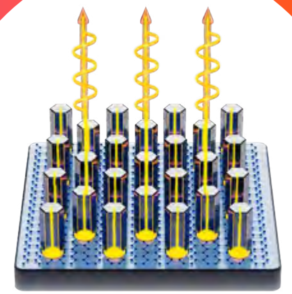
MANIPULATE



DETECT

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 CHENNUPATI JAGADISH
The Australian National University

2021 has indeed been a challenging year with widespread lockdowns in NSW, ACT and Vic. As such many of the labs and facilities were not available to students and researchers for an extended period of time, particularly the MOCVD systems that are used to synthesise the materials. Nevertheless, we continue to perform strongly with many significant results obtained for Theme 1. Our aims for this theme continue to focus on developing novel meta-optical light emitters to be the brightest and most efficient miniaturised classical and quantum light sources.

In nanoscale laser and laser arrays, we have demonstrated for the first time random lasing from semiconductor nanowire arrays with stable and strong 3D localization of the lasing mode. These random lasers offer easy fabrication and can operate over large areas and are attractive in speckle-free imaging and wid-angle viewing.

Using GaAs metasurfaces grown in the non-conventional (110) direction, we were able to achieve highly directional nonlinear up-conversion with the ability control of its forward to backward emission. Such a property allows us demonstrate upconverted IR imaging to the visible wavelength using miniaturised devices, which has prospect in the next generation devices for optical tomography, food and agriculture quality control and night vision, LIDAR and remote sensing. This work has created a lot of interest from industry.

In the area of single photon sources, our work on hexagonal-boron nitride continues to provide further insights into these newly discovered quantum emitters, such as the types of defects/impurity responsible, their coherence properties and the ways to isolate single emitters. These studies lay the foundation for the fabrication of devices for advanced quantum photonic applications.

KEY ACHIEVEMENTS

- Low optical loss contacts towards electrically injected nanowire emitting devices.
- Anderson localisation of light in random nanowire lasers.
- Demonstration of lasing on micro-ring lasers using bottom-up approaches.
- Integration of quantum light sources with a meta optical element.
- Manipulation of quantum light using a meta optical element.

GENERATE

Subprograms

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

1A. NANOSCALE LASERS AND LASER ARRAYS

In the first subprogram, we are continuing to solve the challenges in electrically injected nanowire lasers. We have fabricated n-type ZnO and SnOx transparent contacts on p-type InP nanowires and demonstrated LED action. Absorption loss and conductivity of the transparent contact need to be further improved and also the gain of the nanowires need to be increased. We also developed the technology to embed the nanowire LEDs in a polymer and then peeling them off to demonstrate flexible nanowire LEDs.

3D localisation of light is achieved in InP nanowire random lasers, where lateral confinement is provided by random scattering (2D Anderson localization) while vertical confinement is provided by refractive index contrast. The strong spatial confinement of the modes results in the stable multi-mode operation of random lasers. We also show that the design parameters of the nanowire random lasers such as nanowire density, diameter and the degree of randomness, can affect the lasing threshold, number of lasing modes, Q factor and wavelength resonances of the modes. By changing the excitation geometry, we show that both resonant and non-resonant lasing modes are supported in nanowire random lasers. These large area lasers with facile fabrication provides opportunities for application in the next-generation meta-optical systems.

1B. ADVANCED AND QUANTUM LIGHT SOURCES

In the second subprogram, we investigated several dielectric and semiconductor materials platforms for optical metasurfaces with enhanced nonlinear up-conversion. Using GaAs grown in (110) orientation, we have demonstrated nonlinear up-conversion imaging from IR to visible. The results offer a new approach for infrared imaging with applications in miniaturised ultra-thin night-vision devices.

We have further investigated the applicability of materials with a larger bandgap to avoid re-absorption of the sum-frequency generation wavelength, in particular MoS2 which has a transparency over 720 nm and allows for precision control of emission directionality and LiNbO3 metasurfaces which offer transparency down to the ultraviolet and visible light generation.

We used hexagonal boron nitride as a host of quantum emitters to generate pure quantum light sources on demand. We are able to engineer these emitters on demand, creating arrays of quantum emitters and extend our understanding of their coherent properties.

We developed an approach for enhancing generated rate and spectral brightness of nondegenerate photon pairs in nonlinear metasurfaces by designing multiple bound states in the continuum resonances. Using LiNbO3 thin-film platform, we observed strong enhancement effect combined with low background noise, which will allow us to investigate and control the quantum photon entanglement.

ACTION ITEMS FOR 2022

1. Optimising cavity design, transparent contacts, and fabrication challenges.
2. Development of micro-ring cavities and lasers.
3. Develop the theoretical approaches for PT symmetry-based control of gain and loss.
4. Explore the effect of high-quality factor resonances on the frequency conversion and develop new materials platforms for enhancing efficiency.
5. Continue towards improvement of brightness and purity and integration with nanophotonic elements.
6. Develop nonlinear metasurfaces for generation of quantum-entangled photon-pairs.

GENERATE CASE STUDY

Can a piece of scotch tape stop computer hackers in their tracks? New steps toward quantum communications says 'yes'.

Centre researchers from the University of Technology Sydney have taken the fight to online hackers with a giant leap towards realizing affordable, accessible quantum communications, a technology that would effectively prevent the decryption of online activity. Everything from private social media messaging to banking could become more secure due to new technology created with a humble piece of scotch tape.

Quantum communication is still in its early development and is currently only feasible in very limited fields due to the costs associated with fabricating the required devices. The TMOS researchers have developed new technology that integrates quantum sources and waveguides on chip in a manner that is both affordable and scalable, paving the way for future everyday use.

The development of fully functional quantum communication technologies has previously been hampered by the lack of reliable quantum light sources that can encode and transmit the information.

In a paper published in ACS Photonics, the team describes a new platform to generate these quantum emitters based on hexagonal boron nitride – also known as white graphene. Where current quantum emitters are created using complex methods in expensive clean rooms, these new quantum emitters can be created using $20 worth of white graphene

> "2D materials, like hexagonal boron nitride, are emerging materials for integrated quantum photonics, and are poised to impact the way we design and engineer future optical components for secured communication."
>
> - Professor Igor Aharonovich

SPOTLIGHT

Chi Li

PhD candidate

Chi Li has been a PhD candidate at the University of Technology Sydney since 2018. His research interest is mainly in nanophotonics and optoelectronic devices. He has abundant experience in nanofabrication, confocal microscope system, vacuum deposition system and data analysis by Python. So far, he has published over 30 papers in top journals like Advanced Materials, Advanced Energy Materials, Optica, Nano Letters, Small, etc.

pressed on to a piece of scotch tape.

These 2D materials can be pressed onto a sticky surface such as the scotch tape and exfoliated, which is essentially peeling the top layer off to create a flex. Multiple layers of this flex can then be assembled in a Lego-like style, offering a new bottom up approach as a substitute for 3D systems.

TMOS Chief Investigator Igor Aharonovich says "2D materials, like hexagonal boron nitride, are emerging materials for integrated quantum photonics, and are poised to impact the way we design and engineer future optical components for secured communication."

In addition to this evolution in photon sources, the team have developed a high efficiency on-chip waveguide, a vital component for on-chip optical processing. Lead author, Chi Li says "Low signal levels have been a significant barrier preventing quantum communications from evolving into practical, workable models. We hope that with this new development, quantum comms will become an everyday technology that improves people's lives in new and exciting ways."

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

Integration of hBN Quantum Emitters in Monolithically Fabricated Waveguides

Chi Li, Johannes E. Fröch, Milad Nonahal, Thinh N. Tran, Milos Toth, Sejeong Kim and Igor Aharonovich

Application of hexagonal boron nitride (hBN) in the nanophotonics and quantum technologies has been long sought by researchers wishing to exploit its atomically smooth surface, large bandgap nature, and the way it enhances other materials' properties it's encapsulated to.

The current work describes a novel way of integrating hBN single photon emitters (SPEs) with a monolithic hBN waveguide. This has been demonstrated first by photonic simulations and the results later verified experimentally by fabrication of on-chip hBN waveguides and studying the SPE generation. An optically active defect was embedded in the hBN, which also functioned as the waveguide, which in this work is a slotted one owing to its advantages in SPE generation near the center of the waveguide.

This structure was initially studied using the finite-difference-time-domain (FDTD) method. Three types of configurations namely, monolithic, hybrid and surface with different SPE integrations were tested. Various parameters pertaining to the effectiveness of the coupling to the waveguide such as coupling efficiency (β) and grating efficiency (η) were calculated, with the values varying as a function of the position of the dipole emitter as well as the physical dimensions of the hybrid material.

SPE-integrated monolithic hBN waveguides were fabricated with sticky tape method and EBL to exfoliate hBN flakes and design patterning respectively, among other steps. The room temperature SPEs were identified in the fabricated devices using confocal photoluminescence (PL) mapping. Further characterization confirmed the quantum nature of the hBN emitters.

The zero-phonon line (ZPL) was found at 590 nm, which from previous testing, further confirmed the coupling of emission to waveguide mode. The β was found to be lesser than the simulation value owing to the lower η value and higher waveguide loss due to some errors in nanofabrication. A tapered waveguide, holding distinct advantages for hybrid integration and side collection was realized using the above-mentioned design and fabrication techniques, among others. Various waveguide geometries were designed using Lumerical API automation with potential applications ranging from emission enhancement to narrow-band filtering applications.

In another instance of waveguide used as a beam splitter, well-defined features were obtained post fabrication. Potential future goals encompassing the use of larger crystals for larger devices, improvement of emitter stability and performance improvements by means of electric field or optical pumping have been cited.

Read the full article

GENERATE CASE STUDY

Big step forward in quantum sources for imaging and communications

TMOS researchers have brought forward a miniaturized platform for ubiquitous end-user quantum imaging and free-space communications with the development of a new, smaller than micro-scale method for generating quantum-entangled photon pairs—an important step towards creating integrated quantum devices for future everyday applications ranging from biological imaging to absolutely secure wireless information transmission.

With the advent of quantum technologies including computing and communications relying on complex and bulky systems, we need a new way to generate and transmit quantum states to make unique quantum advances accessible directly in hand-held devices that can be used anywhere, from medical imaging specialists to ordinary people accessing online data.

Quantum capabilities on mobile and other small devices can be facilitated by miniaturised sources of entangled photons. The photons that can illuminate wide regions in space, which is especially important for imaging, are typically created using bulky crystals up to a centimeter size, which are only suited for specialized laboratories and cannot be integrated onto a single chip. Centre researchers are investigating alternative sources of photon generation using metasurfaces, which are ultra-thin films containing millions of intricate nanoscale patterns. Metasurfaces could one day see the integration of quantum technology into devices as small as a mobile phone.

In research published in the SPIE journal *Advanced Photonics* they show that Bound

> “This is an exciting time to be working in optics, because over the last twenty years we have found ways to incorporate a lot of ideas from other fields of physics, such as bound states in the continuum, into optics as well.”
>
> - Dr Matthew Parry

SPOTLIGHT

Matthew Parry

Research Fellow

Matthew Parry is a researcher at the Australian National University. His research interests are in metasurfaces, especially with respect to quantum applications.

States in the Continuum, once considered just a theoretical curiosity, can be used to create extremely strong resonances that not only enhance the number of photons generated by many orders of magnitude, but can shape their properties towards future applications.

Lead author, Matthew Parry, says "This is an exciting time to be working in optics, because over the last twenty years we have found ways to incorporate a lot of ideas from other fields of physics, such as bound states in the continuum, into optics as well. This allows us to engineer metasurfaces and other devices that can do things that were simply unimaginable before. For any application that you can name, if it uses optics then it will be revolutionized by these new advances."

Chief Investigator Andrey Sukhorukov, says "This fundamental research supported by the Australian Research Council Centre of Excellence TMOS sets the new principles for ultimate miniaturization of multiple-photon sources, which shall support practical advances in quantum technologies for Australian industry and general public."

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

Enhanced generation of nondegenerate photon pairs in nonlinear metasurfaces

Matthew Parry, Andrea Mazzanti, Alexander N. Poddubny, Giuseppe Della Valle, Dragomir N. Neshev, Andrey A. Sukhorukov

Enhancement of light-matter interactions via optimally designed Bound State in Continuum (BIC) resonances when coupled with Spontaneous Parametric Down-Conversion (SPDC) enabled entangled photon generation can give rise to ultracompact multi-photon sources at room temperature. Integration of such processes on nonlinear metasurfaces (MSs) effectively open new pathways to quantum communication and free-space communications.

The present work presents a theoretical approach to enhancing photon-pair generations manifold and spectral brightness in nonlinear MSs. The design of the MS (with a D_{2h} symmetry) comprised of a square array of cylinders with two holes which prevent the 90° rotational symmetry. This reduction in global rotational symmetry offers greater freedom in tuning the dispersions from various BICs.

For the resonators, (111) orientation of $Al_{0.18}Ga_{0.82}As$ crystal was considered owing to its robust quadratic nonlinearity and ease in deposition and device fabrication, while providing the highest off-BIC conversion efficiency in the direction of normal propagation. This approach can also be extended to other nonlinear materials like lithium niobate as well. One of the defining features is the nonchanging nature of the photonic-crystal like BIC when subjected to variations in dimensions of the meta-atoms. On shifting the position of the afore-mentioned holes, electric field variations within these two regions were observed, effectively changing the energy of the modes.

In this study, single and two BICs have been studied. For the former, it was found that the SPDC generation was approximately proportional to the product of the maximum intensity of the signal and the idler electric fields inside the resonator. The calculated peak brightness was about 110 Hz/mW over a 1.3 nm bandwidth which was 2×10^3 greater than those of the simulations of an un-patterned film.

The second case consisted of two BICs, where the signal and idler were generated separately, with the occurrence of hyperbolic transverse phase matching. Here, the photon-pair generation was almost two orders of magnitude greater than that of single BIC, with a six-fold enhancement observed. As mentioned before, the hyperbolic phase matching contributed to SPDC enhancement for a wider range of transverse photon wave-vectors as opposed to the narrow range in single BIC near the Γ point. The calculated peak brightness was about 4900 Hz/mW over a 1.2 nm bandwidth which was 10^5 times greater than those of the simulations of an un-patterned nonlinear film.

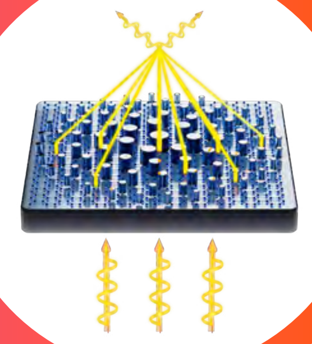
Studies on polarization entanglement showed maximum entanglement for single BIC with Schmidt number K = 2, while for the other case the entanglement could be tuned from full to null by varying the linear polarization of the pump. All these findings can help in realization of quantum light sources for further research and development.

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

This theme aims to develop tunable meta-optics and achieve complex light manipulation for image processing and creating holograms using meta-surfaces. The theme contains several programs which are split into the projects that form the building blocks of the whole research. The first year of any big project is always tumultuous, and the focus in 2021 was on building the team of researchers and students.

We have obtained the first set of results for several projects and we keep adjusting the programs in order to streamline the flow of the research.

One project was to create an all-optical adaptive optics system employing diffractive neural networks and light sensitive meta-optics. The two parts of this were all-optical phase measurement and all-optical phase manipulation. The neural network architecture design is complete with simulations showing excellent ability to predict aberrations at the speed of light. Experimental demonstration is well underway as we create the fabrication recipe for the diffractive neural networks.

Our second project set out to create an all-optical spectral classification system employing diffractive neural networks. A neural network architecture for spectral classification has been created. Simulations are complete and parts of the experimental demonstration is also well underway. This will be followed by testing of the neural networks which will need to be undertaken in collaboration with other nodes.

The third project is aimed at creation of optical metasurfaces tuned by liquid crystals. The liquid crystal platform is a robust and commercially tested platform and it holds a promise for practical applications of metasurfaces. We have performed experiments aimed at establishing the limits of achievable tunability with metasurfaces infiltrated with liquid crystals.

KEY ACHIEVEMENTS

- We have fabricated and tested the metasurfaces infiltrated with liquid crystals, the results are now submitted for publication.
- We have performed a numerical study of the possibility of making tunable structures involving ferroelectric materials.
- We reported a breakthrough in enhancing the utility of phosphorene as a light-active material for versatile photonics and electronics applications without operating in an inert environment.
- We investigated the use of phase change materials to realize tunable metasurfaces Alongside using vanadium dioxide as one of the chosen phase change materials, we have also commenced research on antimony selenide which is a fascinating phase change material in the optical region of the spectrum.

MANIPULATE

Subprograms

2A. DYNAMICALLY TUNABLE METAOPTICS

We are using a variety of approaches for making metasurfaces control light dynamically, essentially creating tuneable metasurfaces with individually controlled pixels that provide large contrast for both the visible and infrared spectrums. We are developing metamaterials concepts for dynamic inter-waveguide coupling and sensing applications.

2B. OPTICAL IMAGE PROCESSING

This includes various light manipulation tasks, including holograms and neuromorphic image processing. We will be processing neuromorphic optical data/image for diffractive neural networks for adaptive optics and biomarker classification.

2C. HOLOGRAPHIC META-OPTICS

This theme is working towards the development of meta-holograms for parallel single photon excitation and collection, including on-demand creation of single photon sources in diamond and manipulation of their emission. It will also be investigating meta-holograms for optical system integration.

ACTION ITEMS FOR 2022

1. All-optical spectral classification using diffractive neural networks. Develop working principle of standalone diffractive neural network for multi-biomarker classification in sensing/ point of care applications
2. Embedded graphene metalens for wearable devices.
3. Phase change materials for optical applications.
4. Fabricate electro-optic metasurface devices based on lithium niobate, and expand functionality to include control of light polarisation.
5. Explore metasurface lenses with liquid crystals for making tunable focal length systems.
6. Use metamaterial concepts coupled with MEMS to demonstrate a prototype tunable device.
7. Complete the modelling effort and establish the design for a proof-of concept prototype of dynamic on-chip inter-waveguide coupling.

MANIPULATE CASE STUDY

Let there be light! New tech to revolutionize night vision

Researchers from The Australian National University (ANU) have developed new technology that allows people to see clearly in the dark, revolutionising night-vision.

The first-of-its-kind thin film, described in a new article published in *Advanced Photonics*, is ultra-compact and one day could work on standard glasses.

The researchers say the new prototype tech, based on nanoscale crystals, could be used for defence, as well as making it safer to drive at night and walking home after dark.

The team also say the work of police and security guards – who regularly employ night vision – will be easier and safer, reducing chronic neck injuries from currently bulk night-vision devices.

“We have made the invisible visible,” lead researcher Dr Rocio Camacho Morales said.

“Our technology is able to transform infrared light, normally invisible to the human eye, and turn this into images people can clearly see – even at distance.

“We’ve made a very thin film, consisting of nanometre-scale crystals, hundreds of times thinner than a human hair, that can be directly applied to glasses and acts as a filter, allowing you to see in the darkness of the night.”

The technology is extremely lightweight, cheap and easy to mass produce, making them accessible to everyday users.

Currently, high-end infrared imaging tech requires cryogenic freezing to work and are costly to produce. This new tech works at room temperatures.

Dragomir Neshev, Director of the ARC Centre for Excellence in Transformative Meta-Optical Systems (TMOS) and ANU Professor in Physics, said the new tech used meta-surfaces, or thin films, to manipulate light in new ways.

“This is the first time anywhere in the world that infrared light has been successfully transformed into visible images in an ultra-thin screen,” Professor Neshev said.

“It’s a really exciting development and one that we know will change the landscape for night vision forever.”

The new tech has been developed by an international team of researchers from TMOS, ANU, Nottingham Trent University, UNSW and European partners.

Professor Mohsen Rahmani, the Leader of the Advanced Optics and Photonics Lab in Nottingham Trent University’s School of Science and Technology, led the development of the nanoscale crystal films.

“We previously demonstrated the potential of individual nanoscale crystals, but to exploit them in our everyday life we had to overcome enormous challenges to arrange the crystals in an array fashion,” he said.

“While this is the first proof-of-concept experiment, we are actively working to further advance the technology.”

> “We have made the invisible visible.”
>
> - Dr Rocio Camacho Morales

SPOTLIGHT

Rocio Camacho-Morales

Research Fellow

Rocio Camacho-Morales is a postdoctoral fellow at Research School of Physics in The Australian National University (ANU). She received her bachelor’s degree in physics at the National Autonomous University of Mexico, her MSc degree from the Ensenada Centre for Scientific Research and Higher Education, Mexico, and her PhD in physics from the ANU. Her research interests focus in the field of nanophotonics, optical metasurfaces, and nonlinear frequency generation.

Infrared upconversion imaging in nonlinear metasurfaces

Rocio Camacho-Morales, Davide Rocco, Lei Xu, Valerio Flavio Gili, Nikolay Dimitrov, Lyubomir Stoyanov, Zhonghua Ma, Andrei Komar, Mykhaylo Lysevych, Fouad Karouta, Alexander A. Dreischuh, Hark Hoe H. Tan, Giuseppe Leo, Costantino De Angelis, Chennupati Jagadish, Andrey E. Miroshnichenko, Mohsen Rahmani, Dragomir N. Neshev

The ability to observe in spectra other than the visible range using convenient tools has been a long-cherished dream in the field of optics. Infrared (IR) imaging holds the key to a multitude of applications, including night vision, autonomous vehicle navigation, optical tomography, food quality monitoring, LIDAR, to name a few. Conventional IR imaging uses low temperature, bulky and expensive optics that limits its widespread usage.

The present work is novel in its scope as it makes use of nanostructured ultrathin metasurfaces (MSs) consisting of nanoantennas (NAs) fabricated on (110) GaAs wafers, that are resonant at all the interacting wavelengths. The use of nonlinear optical processes for upconverting the photon energy offers significant advantages over photodetectors that operate in the IR regime. A parametric second-order non-linear process known as sum-frequency generation (SFG) was observed in the resonant MS. This enabled nonlinear wave-mixing of a short-wave IR (SWIR) signal beam with a near-IR (NIR) pump beam. IR imaging with femtosecond temporal resolution was thus achieved owing to the upconverted emissions in the visible spectrum. GaAs (110) exhibits very prominent quadratic nonlinearities leading to highly directional SHG that makes it a good candidate for IR upconversion.

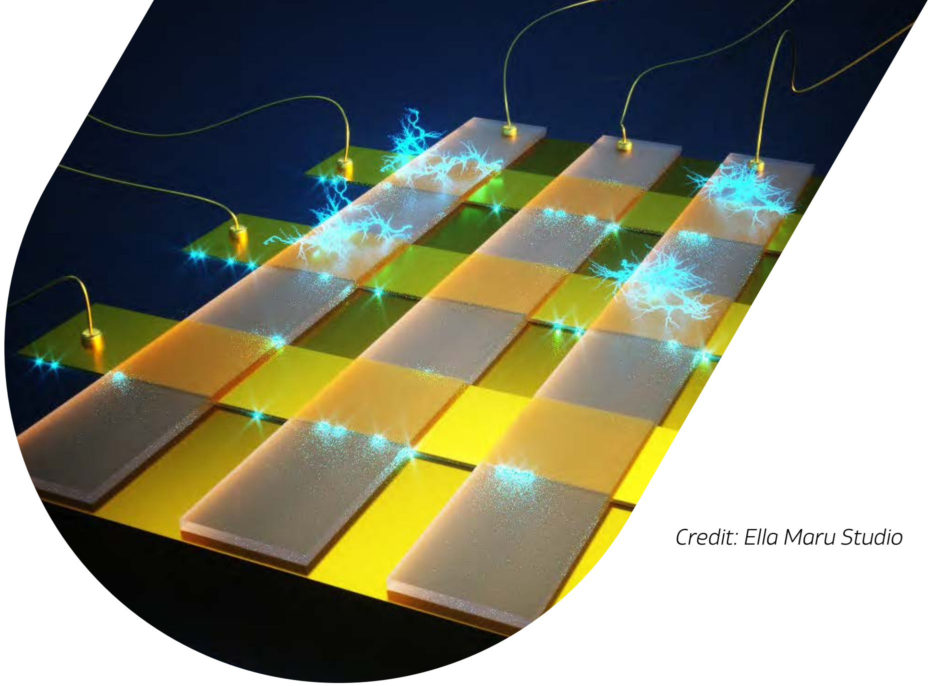
Prior to experiments, numerical simulations were performed in COMSOL Multiphysics to define the resonant properties of the GaAs MSs. The designed metasurface consisted of GaAs NAs embedded within a nondispersive and homogeneous medium (n_m = 1.44), simulated using Floquet boundary conditions to represent an infinite two-dimensional (2D) periodic structure. By tuning the dimension of the NAs, by setting the radius (r) at 225 nm, the periodicity (P) as 750 nm, and fixing the height (h) fixed 400 nm, the forward SFG conversion efficiency, $\eta = PSFG/P_s$ of the designed MS was 1.6×10^{-6} for I_p = 0.78 GW/cm² and I_s = 0.38 GW/cm². This corresponded to the typical pump and source intensity values used in the measurements. The spatial field profile of the pump displayed a huge enhancement of about 2.5 times with respect to the incident field.

For the experimental part, the GaAs MSs were fabricated as per the specifications mentioned above using standard deposition techniques with the arrays defined by electron beam lithography (EBL). Benzocyclobutene (BCB) was used as the immersion medium for the NAs. The emission from the MSs was studied by tuning the pump and signal wavelengths, one at a time. It was found that in both cases, on attaining the maximum at 549 nm, the SFG intensity gradually decreased with the increase of either signal (pump fixed) and pump (signal fixed) wavelengths. During the IR imaging, a signal beam of 1530 nm wavelength was chosen with the pump beam set at 860 nm. The SFG process mixs the pump and signal beams within the GaAs MS, creating upconverted photons that formed a visible image of the target, in this case a Siemens star, captured using a CCD camera. The 400 nm-thick MS based system was robust against thermal noise while operating at room temperature, enabling potential applications in night vision systems, sensors and multi-color imaging.

Read the full article

MANIPULATE CASE STUDY

Switching to the future with smart materials



Credit: Ella Maru Studio

"Turn if off and turn it on again." It's a well-worn strategy of the modern age that works on everything from your computer to your dishwasher to your mobile phone. But as devices get smaller, a new approach for the common switch is required.

> Our developed vanadium dioxide thin-film devices transform from insulator to metal at low electrical input while maintaining a high switching ratio and fast speed, making them promising for future energy-efficient electronic and optoelectronic applications."
>
> - Sumaiya Kabir

Modern switches have become as small as their materials will allow for. Innovation in materials is critical if the miniaturization of electronic and opto-electronic devices is to continue. Vanadium dioxide is a fascinating material which shows the ability to change its phase (from insulator to conductor and vice versa) with application of external stimuli. Centre researchers investigated the use of devices made from vanadium dioxide and found that not only could it transform from an insulator to a conductor, it could do so with less than 5V applied—a key prerequisite for use in small electronic devices.

Miniaturized devices will have applications in many fields, such as consumer electronics, wearables, medical, and optoelectronic devices. Innovative phase change materials can also be used to realize fundamental and novel optical devices.

Lead researcher, Sumaiya Kabir, says "Modern electronic gadgets demand high-speed switching at a low voltage without affecting device performance and lowering power consumption. As reported in *Advanced Electronic Materials*, our developed vanadium dioxide thin-film devices transform from insulator to metal at low electrical input while maintaining a high switching ratio and fast speed, making them promising for future energy-efficient electronic and optoelectronic applications."

TMOS Chief Investigator Professor Madhu Bhaskaran says "By effectively combining smart device architecture with the potential applications of vanadium dioxide, such as in photodetectors, cheap, fast responding and energy efficient optoelectronics can be implemented, thus paving the way for next-generation silicon free devices. The phase of optics is slowly changing!"

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

SPOTLIGHT

Sumaiya Kabir

PhD candidate

Sumaiya Kabir is a PhD candidate in the Functional Materials and Microsystems Research Group, RMIT University, Australia. Her research focuses on the phase change oxide-based thin films. She has developed prototypes such as light sensors, switching devices, and smart window coatings that are promising for improving integration density, speed, and energy-efficiency of next-generation electronics. She has published her work in several top-tier journals and was the finalist of the Young Scientist Research Prize 2021 by the Royal Society of Victoria.

Device Geometry Insights for Efficient Electrically Driven Insulator-to-Metal Transition in Vanadium Dioxide Thin-Films

Sumaiya Kabir, Shruti Nirantar, Mahta Monshipouri, Mei Xian Low, Sumeet Walia, Sharath Sriram, Madhu Bhaskaran

The phase changing nature of vanadium oxide (VO_2) has been extensively studied. It is an insulator at room temperature (RT), but when heated undergoes a phase transition (PT) at ~ 68 °C. This abstract attempts to briefly describe the effect of electrical bias as the trigger for PT. This was achieved by varying the electrode arrangements via three configurations namely, offset, no offset and overlapping. Prior to applying voltages, the resistance of all three devices were in the range of several mega-ohms which upon electrical excitation decreased to several kilo-ohms after insulator-to-metal transition (IMT). From the I-V curves it was observed that overlapping and offset structures required the least and highest amount of trigger voltage, respectively. Though the distance between electrodes was same for no-offset and overlapping structures, the overlapping structure switched at lower voltages, which was explained to be caused by a larger channel length of VO_2 devices being exposed to uniform electric field for these overlapping structures compared to the other geometries.

From the electrical testing it was found that the overlapping architecture gave the best performance, meaning that it required the least amount of electrical bias to trigger the PT. These electrode arrangements minimized the active VO_2 channel areas, thus decreasing the amount of grain boundaries in the path of current flow and nanoscale distance between electrodes obtained to achieve IMT at a lower voltage. Three MIM structures of VO_2 thin-film devices were fabricated with film-thickness of ≈150 nm based on horizontal separation, L and vertical distance, d between top and bottom electrodes to investigate the effect of device structures on IMT with electrical bias. To understand the electric potential distribution and acting electric field for three device configurations, COMSOL was used to perform simulations where the value of relative permittivity of insulator phase VO_2 was 9.0 and VO_2 film conductivity of 10^5 S/m for metallic state.

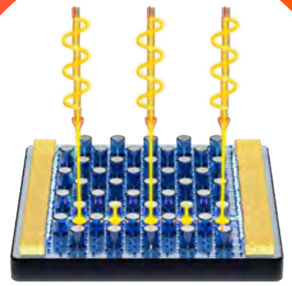
The simulation results confirmed the electric field needed to achieve IMT was of the order of 10^7 V/m, corroborated by earlier experiments. This implied that in electrically driven phase transition in VO_2, electric field is the primary reason for sharp current change or IMT, while Joule heating contributes to the amount of carrier conduction. Thus, variation in device geometry may prove critical for improving integration density, scalability, and lowering power consumption in high speed electronic and optoelectronic devices. These findings are essential in designing and controlling the functional domains of VO_2 for smart, energy-efficient, addressable, and scalable micro/nanoscale devices and sensor applications.

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 LORENZO FARAONE

The University of Western Australia

PROFESSOR ANN ROBERTS

University of Melbourne

With increasing demands on the miniaturisation of portable and other electronic devices for applications ranging from LIDAR through to imaging through bushfire smoke comes requirements for ultra-compact efficient, multimodal optical and infrared detection.

Detectors used for infrared light are critical for defence, medical and other major applications in Industry 4.0. Their relative inefficiency at room temperatures, however, is a major roadblock to miniaturisation and precludes their use in drones and space applications where weight is critical. New approaches to infrared detection using semiconductor nanowires and the integration of subwavelength elements into mercury cadmium telluride detectors will massively lower barriers to their adoption and expand the capacity to extract information from electromagnetic waves.

Action items for 2021 were achieved with the demonstration of new devices and solutions including a novel, compact microspectrometer, enhanced monitoring of optical polarisation with metasurfaces, meta-optics with an asymmetric response to angle of incidence, improved mid-infrared detection with ultra-thin hybrid plasmonic metasurfaces, and enhanced performance and functionality III-V nanowire detectors.

Looking forward, new strategies for quantifying the spectral content of an optical field using tailored metasurfaces and novel algorithms for reconstructing information of interest will be developed. Meta-optics will be used in tandem with ‘off-the-shelf’ photodetectors and, ultimately, monolithically integrated into sensors enabling massive miniaturising of the resulting devices. Furthermore, working with the ‘Manipulate’ research team we will develop devices with a sensitivity that is tunable to different parameters, or permit extraction of multiple dimensions of information from an optical field. These enhanced detectors will be integrated into imaging systems as pixels in focal plane arrays or as a single-pixel, non-imaging detector in ghost imaging systems from the visible through to the mid-infrared.

KEY ACHIEVEMENTS

- Demonstrated dual (vis and NIR) GaAsSb Nanowire Array multiwavelength photodetectors along with their application to RGB colour imaging.
- Demonstrated a InGaAs/InP multi-QW photoconductive photodetector with high room temperature responsivity (14.5 A/W @1550 nm).
- Demonstrated highly uniform multiple QW nanowire growth which is critical for NW-QWIP fabrication
- The hybridization between SPP in graphene and SPhP in SiC was revealed to generate mode splitting and extend the extent of the spectral resonances of graphitized nanowires beyond the Reststrahlen band of SiC.
- Developed a concept of metasurface-assisted ghost imaging for non-local discrimination between a set of polarization objects. The specially designed metasurfaces are incorporated in the imaging system to perform parallel state transformations in general elliptical bases of quantum-entangled or classically-correlated photons. The approach can find applications for real-time and low-light imaging across diverse spectral regions in dynamic environments.
- Demonstrated a device that is able to discriminate between different angles of incidence on a metasurface and applied it to phase contrast imaging of optical wavefields and microscopy of biological cells.
- Demonstrated a compact, lightweight, and robust microspectrometer chip-scale solution based upon doped silicon nanophotonic elements, known as waveguide array (WGA) pixels.

DETECT
Subprograms

The theme supports three broad sub-programs aiming to revolutionise the extraction of information from visible and infrared light. At present IR sensors are bulky, inefficient, and expensive.

3A. ENHANCED IR DETECTION

The first sub-theme is focused on revolutionising detection in the infrared. Through the use of novel nanowire devices and the integration of meta-optics into mercury cadmium telluride technology, the Centre aims to develop compact and efficient near-and mid-infrared detectors.

3B. MULTI-MODE SENSING

The second sub-program involves the integration of meta-optics into sensors ranging from the visible through to the infrared to permit detection of quantum and classical states of light, extracting information from an optical field invisible to conventional detectors. This includes the ability to sense phase and polarisation.

3C. ADVANCED IMAGING

The third sub-program involves integrating these concepts into next-generation imaging systems including focal plane arrays and single-pixel computational imaging systems with the ultimate goal of creating flexible, compact and efficient devices with applications in fields as diverse as defence, transport and biotechnology. By leveraging meta-optics, the resulting integrated systems will be orders of magnitude smaller and lighter and compatible with emerging mobile electronic devices and lightweight platforms such as drones and nanosatellites.

ACTION ITEMS FOR 2022

1. Material growth and optimisation of III-V nanowire quantum well mid-IR photodetectors.
2. Investigation and design optimisation of III-V nanowire quantum well mid-IR photodetectors.
3. MCT detector enhanced with self-integrated on-pixel all-dielectric metamaterial resonance (metaMCT-pixel) – design, simulations, growth, fabrication, and characterisation.
4. MCT detector with metamaterial resonance enhancing narrow band SWIR performance towards ultimate quantum efficiency (metaMCT-SWIR for QE) – design, simulations, growth, fabrication, and characterisation/testing.
5. Design metasurfaces using semi-analytical and numerical optimization for photon state transformations in polarisation and spatial modes.
6. Fabricate and characterise metasurfaces for the target wavelengths, including telecommunication range.
7. Demonstrate tailored multimodal MIR detection based on subwavelength structures/pixels (polarisation, phase, angle).
8. Dynamic detection spectrum tunability via graphene carrier concentration control: explore range.
9. Demonstrate broadband nanowire array photodetectors (VIS to SWIR).
10. Develop broadband nanowire array-based spectrometers (visible to SWIR).
11. MCT focal plane array with metamaterial extended field of view (metaMCT-FPA/FOV) and polarimetric capabilities.
12. Demonstrate single-pixel nanowire array NIR to SWIR photodetector imaging.

DETECT CASE STUDY

Reimagining medical diagnostics in developing countries: meta-optics offers a new way to look inside cells

Developing countries face many challenges in the fight against infectious diseases. One of these is the lack of access to medical diagnostic tools. This is considered a key reason why malaria and tuberculosis are still two of the leading causes of death in sub-Sahara Africa and parts of Asia.

In order to address issue of affordable, accessible medical diagnostic tools, new technologies are needed. That's where nanotechnology comes to the rescue.

The study of biological cells is essential to medical diagnostics, disease detection and prevention. Traditional pathways to 'see' cells, their internal structures and the interaction between different organelles, involve staining the cells with special dyes and using phase contrast imaging. These established techniques deliver a great deal of information, but the coloured dye can kill it. The phase contrast microscopes are bulky and expensive instruments that have optical parts that need maintenance over time, making wide-spread use difficult in low income countries.

Meta-optics aims to miniaturize and condense the current bulky microscopes into something more portable and cost-effective, without affecting the performance. Professor Ann Roberts from the University of Melbourne and her team have designed an array of nanostructures on a conventional microscope coverslip that enable the user to see the transparent biological cells, without staining. Not only does this not harm the cells, it also incorporates the phase contrast microscope's ability to visualize transparent cells without the need for the phase microscope itself— a win on both fronts.

Prof Roberts says, "Our approach has significant potential to become an inexpensive, ultra-compact phase-imaging tool that could be integrated into smartphone camera and other mobile devices to make mobile medical diagnostics broadly available."

Details of this nanophotonics enabled coverslip (NEC) and its ability to visualize micrometer-sized phase components were recently published in Light Science and Applications.

Lead researcher, Dr. Lukas Wesemann says "The next stage of this research will focus on extending the capacity of the nanophotonics enhanced coverslip as an integrated tool for biological imaging. One example of this would be to add the capacity to dynamically adjust the imaging behaviour of the coverslip in order to enable the flexibility needed for its integration into generalized imaging technology."

> "The next stage of this research will focus on extending the capacity of the nanophotonics enhanced coverslip as an integrated tool for biological imaging"
>
> - Professor Ann Roberts

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

SPOTLIGHT

Lukas Wesemann

Postdoctoral Researcher

Lukas is a Postdoctoral Researcher in Meta-Optics at the University of Melbourne node of TMOS. His research focuses on the development of nanophotonic structures for ultra-compact, all-optical image processing including biological phase-imaging. As part of Prof Ann Roberts research group, he recently demonstrated a nanophotonics enhanced coverslip that permits phase-imaging of biological cells and could be integrated in future mobile medical diagnostic equipment.

Nanophotonics enhanced coverslip for phase imaging in biology

Lukas Wesemann, Jon Rickett, Jingchao Song, Jieqiong Lou, Elizabeth Hinde, Timothy J. Davis & Ann Roberts

Real-time visualization of cells, their organelles and interactions are critical to a better understanding of biological processes. Furthermore, the capacity to image live, unstained cells provides information about dynamic cellular processes. The contrast obtainable when viewing unstained cells is, however, poor and phase visualization methods are required.

The current study presents a first-of-its-kind nanophotonics enhanced coverslip (NEC) that generates high-contrast images of pure phase objects on transmission using an ultra-compact device. The team demonstrated that the augmented coverslip significantly enhanced the contrast seen in unstained human cancer cells (HeLa) permitting the visualization of internal structure.

As an established method of imaging, phase contrast microscopy is often described using the optical transfer function (OTF), M(kx) that characterizes the system and relates how the input image is transformed into the output image. The way this is achieved is via conversion of phase differences to intensity contrast via a spatial frequency filter that directly modifies the Fourier transform of the incident image and, hence, the output image which is collected by a camera. Rather than requiring a more bulky optical system to perform this operation, the NEC does this directly on the cover slip onto which cells can be placed.

The NEC structure consisted of a silver grating on a 100 nm thick layer of TiO2 supported by a glass substrate. The grating couples light into and out of the high refractive index layer which behaves as a waveguide and possesses a strong sensitivity to the direction of illumination leading to the sensitivity to spatial frequency. The device was designed and modelled using the finite element method and fabricated using a combination of electron beam lithography, physical vapour deposition and other processes at the Melbourne Centre for Nanofabrication.

Read the full article

DETECT CASE STUDY

Australian research helping self-driving cars get on the road

Centre researchers from the Australian National University have developed a highly sensitive self-powered single photon detector that could be used to make self-driving cars safer and more energy efficient.

> The next step to seeing this technology realized is to optimize the device design to further improve its speed."
>
> - Vidur Raj

A fast, single-photon Light Detection And Ranging (LIDAR) is far more sensitive than other forms of LIDARs, allowing information be to be perceived earlier, and in far more detail, especially in low light or poor visibility conditions. By detecting signals earlier, the AI technology in the driver's seat has more time to make the decisions necessary to prevent an accident. Many previous accidents involving self-driving cars have been a result of the car not being able to identify unexpected objects in a timely manner, such as pedestrians and bicycles.

Until now, single photon detectors have required an external power source or cryogenic cooling, adding to the bulk and weight of the sensor and limiting its applications. These larger, heavier sensors consume more energy, increasing costs and emissions.

In research published in Advanced Materials, the team at TMOS have demonstrated how III-V compound semiconductor nanowires have shown tremendous potential for developing high-speed single photon level detection due to their unique electrical and optical properties, as well as flexibility of device design.

SPOTLIGHT

Dr. Yi Zhu

Research Fellow

Dr. Yi Zhu is currently a postdoctoral fellow of Electronic Material Engineering and TMOS at the Australian National University. He received his bachelor's degree in Material Physics from Tianjin University of Technology in 2014. Then, he continued to achieve his Master and PhD degree at the Australia National University. His research interests include optical and electrical characterizations on advanced materials, and the optoelectronic devices based on low dimensional materials such as 1D nanowires and 2D materials.

SPOTLIGHT

Vidur Raj

PhD candidate

Vidur completed his PhD from the Australian National University and subsequently worked as a postdoc, during which he worked on the fabrication of nanoelectrodes for neuroscience and single-photon detectors. He recently joined the University of Glasgow to work on *"Superconducting single-photon detectors."*

Practical applications extend beyond autonomous vehicles. Even Apple's iPhone now implements LIDAR technology.

Co-lead author on the research, from TMOS, Yi Zhu says, "The future applications of this new device could be almost limitless. We'll see it used in space exploration, medical diagnostics, and quantum computing."

While the technology is still in early stages, the team is confident that it maps out a pathway towards low-cost, high sensitivity, self-powered photodetectors.

Co-lead author, Vidur Raj, says, "the next step to seeing this technology realized is to optimize the device design to further improve its speed. That's where our focus for 2022 will be."

Lead researcher of the project, Professor Lan Fu says, "In the long term, we will leverage our broad research expertise on compound semiconductor nanowire materials and devices to design new detector structures such as single photon avalanche photodiodes and develop chip-scale, multi-pixel arrays for advanced photodetection applications."

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

Self-Powered InP Nanowire Photodetector for Single-Photon Level Detection at Room Temperature

Yi Zhu, Vidur Raj, Ziyuan Li, Hark Hoe Tan, Chennupati Jagadish, Lan Fu

Room temperature (RT), lightweight, and low or no external power consuming single photon detection is a highly attractive area of research with applications ranging from quantum computing, space communications, LIDAR, night vision, military defense, to name a few.

The present work highlights the first of its kind low dimensional III-V compound semiconductor using indium phosphide (InP) nanowires (NWs) as the active material with high sensitivity that is self-powered and non-epitaxially grown.

Inductively coupled plasma (ICP) etching was used to fabricate the NW arrays on a p^+ InP wafer. The p-n junctions were formed by sequential deposition of heavily-doped n-type ZnO and aluminum-doped zinc oxide (AZO) using atomic layer deposition (ALD) that resulted in a radial p-n junction. Thus, the AZO/ZnO shell around the InP NWs and the radial geometry allowed near 100% absorption between 350-850 nm wavelength regime. This design achieved a built-in electric field of more than 10^5 V/cm at no bias with a small depletion width of ~ 40 nm, which enabled sensitive photodetection at even 0 V. The high doping of both the core and shell ensures that the built-in electric field, with or without an external bias remained high, and thus an extremely low dark current.

The photodetector (PD) had an external quantum efficiency (EQE) of nearly 80% over a wide wavelength range, with the EQE as high as 90% in the 500-700 nm region while slightly tapering off in the shorter (350-450 nm) and longer (> 900 nm) wavelength regions due to recombination losses. The photo-response of the device was found to follow well the characteristics of an ideal PD.

Further photocurrent measurements showed a miniscule dark current of 23.7 pA at 0V critical to the device's excellent self-powered photosensitivity at single photon level. A very close correlation observed between the photocurrent and incident light power (α ~ 1.07) further indicates the great device behavior and defect-free material properties. The response time across the entire device was found to be uniform, with the 10-90% rise time of ~ 5.8 ns with a full-width-half-maximum (FWHM) of ~14.9 ns at 0 V under a 522 nm pulsed laser excitation, indicating the potential of the PD to operate in frequency ranges exceeding 600 MHz, a significant step towards ultrafast optical communication, single photon detection (counting), remote sensing and medical diagnostics at RT.

Read the full article

Infrastructure and Capabilities Committee Chair Report

ICC Chair, Professor Kenneth Crozier

The overarching goal of the Infrastructure Committee is to ensure that Centre members have access to the experimental and computational infrastructure needed to achieve the Centre's research aims. There are five mechanisms by which this committee achieves this goal:

1. Hosting equipment register.
2. Coordinating grants to the Linkage Infrastructure Equipment Facilities (LIEF) program of the ARC.
3. Organising regular meetings at which Centre CIs can discuss unmet infrastructure needs.
4. Facilitating submissions to Australian and international government-funded facilities.
5. Serving as a contact point with ANFF, NCI, and Microscopy Australia.

> "Our job is to help every student and researcher realise their ideas by being able to make or measure something. That is something that I have enjoyed about working on the committee."
>
> - Centre Chief Investigator
> Professor Hoe Tan

2021 was a fruitful year for our committee. We made progress in each of these mechanisms. The Centre website hosts an up-to-date equipment register *(mechanism 1)*. We facilitated several submissions to the LIEF program *(mechanism 2)*. In the context of LIEF submissions, we discussed unmet infrastructure needs *(mechanism 3)*. Centre members made submission to Australian and international government-funded facilities *(mechanism 4)*, e.g. the Molecular Foundry of the Lawrence Berkeley National Laboratory (USA) and to the National Computational Infrastructure (NCI). The Infrastructure Committee is indeed in contact with bodies such as ANFF, with for example CI Tan and CI Martyniuk in the leaderships of the ANU and UWA ANFF nodes, respectively *(mechanism 5)*. Similarly, there are strong linkages with Microscopy Australia.

Professor Kenneth Crozier
Infrastructure Committee Chair

Visit the Centre's equipment register

ACTION ITEMS FOR 2022

1. Maintain equipment register that lists the experimental and computational infrastructure available in the laboratories of all Chief Investigators (CIs). In addition, we will continue to raise awareness of the existing facilities within the Centre, to facilitate cross node interaction. This will be achieved by a special session at the TMOS Annual Conference.
2. Organise meetings at which Centre CIs interested in proposing a LIEF bid will have the opportunity to interest other CIs in joining their proposal. The Committee will furthermore endeavour to facilitate TMOS CIs to participate in bids led by non-TMOS CIs for infrastructure that would be beneficial for Centre activities.
3. Schedule quarterly slot for discussion of unmet infrastructure and facilities needs in Centre Executive Committee meetings.
4. Schedule quarterly slot for discussion of possibilities of joint submissions to Australian and international facilities in Centre Executive Committee meetings.
5. Serve as contact point with ANFF, NCI, and Microscopy Australia.

COMMITTEE MEMBERS:

CHAIR: PROFESSOR KEN CROZIER

UOM

PROFESSOR FRANCESCA IACOPI

UTS

ASSOCIATE PROFESSOR MARIUSZ MARTYNIUK

UWA

PROFESSOR HOE TAN

ANU

PROFESSOR SHARATH SRIRAM

RMIT

Engagement & Culture

Industry Liaison Committee Chair Report

Industry Liaison Committee Chair, Professor Francesca Iacopi

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

While the ILC cannot oversee engagement activities, including policies and procedures, nor IP policies on the Centre members as this is a prerogative of the single universities, it facilitates engagement opportunities, tracks engagement within the Centre and plans large-scale translational initiatives using the mechanisms available in the Australian environment (such as CRCs, ARC ITHs and similar opportunities). The ILC has also a formative/educational scope, to be carried out in collaboration with the Education Committee, to ensure that Centre members understand confidentiality, IP protection, rules of engagement between universities and companies, export control and dual-purpose technologies issues, and lately also issues related to foreign arrangements. The ILC role in this context is to promote awareness. As we progress in the Centre lifetime, more and more emphasis will also be put on education around entrepreneurship.

Although 2021 has been a year marked by harsh COVID restrictions, including ban on travel and recurrent lockdown making industry engagement very challenging, the Committee has succeeded in meeting a reasonable number of its goals in 2021:

- The committee members have been secured, including one ECR and one AI representative, and ToR have been developed and formally accepted by TMOS.
- A new industry partner, L3Harris, was brought on board.
- A register of TMOS students updated with the information of IP assignment deed to their respective universities has been developed.
- Training was conducted on current expectations for Australian researchers in terms of compliance with respect to Foreign Arrangements, Influence and Interference (facilitated by David Norman from UWA on 1st June)
- A database was established to track TMOS industry engagement.
- A Translation Plan for the Centre has been developed and agreed upon (see below targets for 2022).

All in all, we are happy with the progress made in this first full year of operations, despite the pandemic challenges. Our plans for 2022 are ambitious. We want to implement a CRM to better manage the Centre's interactions with industry. We will be reaching out to more companies to discuss the ways in which meta-optics could impact their businesses, and we will be continuing to nurture Centre members with an interest in entrepreneurship. 2022 is shaping up to be an exciting and impactful year and we are excited about what is to come.

Professor Francesca Iacopi
ILC Chair

> “Working on the committee, I gained a better understanding of the state of industry-academia collaboration, the importance of protecting intellectual property and creating awareness of existing and future industry-academia networks in order to assist technology transfer from research to commercial products. I also had an opportunity to provide early career researcher perspective on integration and training of graduates for employment and collaboration with industry.”
>
> – Dr. Iryna Khodasevych, ECR Representative, UTS

ACTION ITEMS FOR 2022

- Position the Centre as a focus of an industry consortium, to forge tangible pathways for blue sky research toward applications.
- Grow long-term engagement with Australian industry though the development of leaders in key sectors.
- Develop and publish education programs on research commercialisation to improve our business development skills.

INDUSTRY SEMINARS

- LiDAR for Automotive by Cibby Pulikkaseril, CTO of Baraja, February 2021
- LiDAR for Defense by Dennis Delic, DSTG SA, March 2021
- Multispectral Imaging by Ranjith Unnithan from HortEye, October 2021
- Demystifying Research Translation: Why, When & How by CI Sharath Sriram, RMIT

COMMITTEE MEMBERS:

PROF. FRANCESCA IACOPI

Chief Investigator

UTS (ILC Chair)

PROF. LORENZO FARAONE

Chief Investigator

UWA (ILC Deputy Chair)

PROF. DRAGOMIR NESHEV

Centre Director

ANU

DR. MARY GRAY

Chief Operations Officer

ANU

KAREN JACKSON

IP and Commercialisation Office Representative

ANU

PROF. ANN ROBERTS

Chief Investigator

UOM

PROF. SHARATH SRIRAM

Chief Investigator

RMIT

SAMARA THORN

Engagement Manager

ANU

DR. IRYNA KHODASEVYCH

ECR Representative

UTS

DR. ANDREI KOMAR

ECR Representative

ANU

PROF. DILUSHA SILVA

Associate Investigator

UWA

KAREN KADER

Administraton Assistant

UWA

Early-Career Researcher Committee Report

Early Career Research Committee Chair, Professor Sharath Sriram

The Centre's Early-Career Researcher (ECR) Committee will represent the needs and interests of ECRs in policies and procedures, inform decision making, drive career and professional development initiatives, and interface will the TMOS Executive and sub-committees.

> “In 2021 it was a great pleasure to join the TMOS ECR Committee, get to know the team members and make exciting plans for future. This year, I'm looking forward to seeing the plans in action and to create more opportunities for TMOS ECRs”
>
> – Dr. Tuomas Haggren

The ECR Committee will lead initiatives to support ECRs within the Centre. Core activities include:

- Representing the needs of ECRs in all decision-making processes of the Centre.
- Designing and supporting the implementation of the ECR Mentoring Program.
- Working with the Centre Executive Committee (CEC) to track and achieve key performance indicators related to ECR involvement and engagement.
- Facilitate networking opportunities for ECRs in the Centre and in related disciplines.
- Organising workshops and career/ professional development opportunities for ECRs.
- Liaising with other Centre sub-committees to create opportunities for ECR participation and training.
- Liaising with ECR networks and bodies at the national level in areas of advocacy (for example, the Australian Academy of Science EMCR Forum) or within relevant societies (such as the Australian Institute of Physics or the Australian Optical Society).
- Surveying TMOS ECRs where the need arises.

The ECR Committee was formed in late-2021, with a late start relative to the commencement of the Centre to allow ECRs to settle into their roles. With the initial recruitment completed and ECRs understanding their research landscape, an open nomination process invited ECRs to volunteer to participate in the committee. The committee has a balanced representation across nodes, gender, and ECR career stages. Dr Nima Dehdashtiakhavan was selected as a co-chair of the committee and will report on behalf of the committee to the CEC.

Professor Sharath Sriram
ECR Committee Chair'

ACTION ITEMS FOR 2022

- Develop an ECR Committee strategic plan.
- Create an ECR mentoring program and implement a trial.
- Collaborate with the Education Committee to deliver professional and personal development workshops for ECRs.

COMMITTEE MEMBERS:

PROF SHARATH SRIRAM

RMIT (Chair)

DR. NIMA DEHDASHTIAKHAVAN

UWA (CO Chair)

PROF ILYA SHADRIVOV

ANU (TMOS CI)

MEENA AMIRY

RMIT (Secretary)

DR. TUOMAS HAGGREN

ANU (Member)

DR. JIAJUN MENG

UoM (Member)

DR. KRISHNA MURALEEDHARAN NAIR

RMIT (Member)

DR. IRYNA KHODASEVYCH

UTS (Member)

HDR and ECR representation within the Centre

Representation is key to creating a Centre that meets needs of its higher degree researches (HDRs) and early career researchers (ECRs) and helps to facilitate their career growth. To achieve this, our terms of reference require HDR and ECR representatives on each committee, including the Centre Executive Committee (CEC), which is responsible for strategic operations.

In July at the 2021 student and ECR conference, the CEC called for nominations for student representation. Suvankar Sen, an HDR student from the RMIT node was elected. In August, nominations from each node were sought for the Centre ECR Committee. From that committee, an ECR representative to the CEC, Nima Dehdashtiakhavan, was chosen.

These two representatives are tasked with providing feedback on strategic decisions from the point of view of the groups they represent and acting as a conduit for information flowing to and from the CEC.

> “
>
> I believe it is good opportunity for researchers to take part in a large research initiative steering committee (TMOS) and to be trained as the future leaders and strategists.
>
> The representative will communicate all the aspects of the ECR/HDR from different nodes involved with TMOS to the centre committee. This can range from funding, diversity, scientific, etc. to socio-economic perspective.
>
> My goal is each individual get experience and learn how to communicate the need of subgroup with a hierarchy of the scientific community.”

– Dr. Nima Dehdashtiakhavan, UWA

> “
>
> As much as it is a learning experience, this role gives a glimpse of what a leadership role comprises of, and I am honoured to hold this position.
>
> As an HDR representative, it is my duty to liaise with the Centre HDR cohort and the management team, establish a clear line of communication between them, to promote HDR related policies/initiatives, and most importantly present the students’ interests and ideas across the centre.
>
> Going into 2022, I look forward to facilitating further communication between the HDR candidates, and make new students feel welcome and represented. Another important detail I want to attend to is organising regular meetings for HDR students to get to know other node members better and exchange ideas for collaboration, or just getting to know one another.”

– Suvankar Sen, RMIT

Education & Colloquium Committee Report

Education and Colloquia Committee Co-Chairs, Prof. Lan Fu and Prof. Milos Toth

The Education and Colloquia Committee (ECC) aims to develop a multidisciplinary, dynamic, interactive and collaborative culture fostering new leaders who thrive on 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 HDR students within the Centre, and promote engagement in activities across all nodes to maximise collaboration and networking between teams through:

1. Designing strategies for HDR recruitment in collaboration with node universities.
2. Developing, implementing and monitoring the Centre HDR program.
3. Coordinating the delivery of seminars, workshops, events, and training courses that support the goals of collaboration, education and development in alignment with the IDEA Framework.
4. Coordinating the HDR-Partner Investigator student exchange program.
5. Coordinating the Centre HDR/ECR and annual conferences, including monitoring expenditure and the design of the conference program.
6. Being a forum to support HDR candidates and best practice HDR supervision.

In 2021, the ECC has been formally established with members consisting of CIs, ECRs and HDR from all five nodes. The highlights of our activities include a 2-day online Centre ECR/HDR conference led and organised by TMOS ECRs and HDR students, featuring over 60 participants, 42 ECR/HDR presentations (24 oral/18 poster) and six invited talks; the development of the Centre HDR Program Guidelines to clearly define the administrative and supervisory requirements to foster a multidisciplinary, interactive and collaborative culture; and the formation of two separate working parties to plan for the Centre annual conference framework and coordination of the 2021 Colloquium/Seminar program.

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

> “A vibrant team where new ideas were encouraged and discussed, it has been a wonderful experience for me, both as a student and as the student representative. I look forward to continuing this year as well.”
>
> – Suvankar Sen

ACTION ITEMS FOR 2022

- Develop induction materials for TMOS HDR students.
- Develop Centre colloquium/seminar program 2022.
- Develop an Education Program based on Centre students' interests and needs delivered regularly through Centre Science Tuesdays.
- Oganise the 2nd TMOS ECR/HDR mid-year conference.
- Develop Centre Conference program 2022.
- Organise topical workshop during Centre conference for TMOS HDR students.
- Coordinate travel awards for HDR student exchange to visit PI's labs whenever possible.

COMMITTEE MEMBERS:

**CO-CHAIR:
PROF. LAN FU**

**CO-CHAIR:
PROF. MILOS TOTH**

DR. AISWARYA PRADEEPKUMAR

DR. FARHAD FOROOZANDEH

DR. JINYONG MA

DR. JOHN SCOTT

NIKEN PRISCILLA

SAMARA THORN

SHIYU WEI

SUVANKAR SEN

DR. WENDY LEE

Colloquiums

CENTRE COLLOQUIUM

04-MAR-21 / Dr Dennis Delic

Advanced Single Photon Sensing and Recognition Technologies for Defence Applications

23-APR-21 / Prof. Kishan Dholakia

Shaping the Future of Biomedical Imaging

27-APR-21 / Dr Xuedan Ma

Developing Quantum Photon Sources from Low-dimensional Semiconductor Materials

05-OCT-21 / Prof. Joshua D. Caldwell

Mid-IR to Thz Polaritons: Realizing Novel Materials for Nanophotonics

19-OCT-21 / Prof. Arka Majumdar

Software Defined Optics

22-OCT-21 / Prof. Teri W. Odom

Plasmonic Nanoparticle Lattices as an Expansive Meta-Optics Platform

25-OCT-21 / Dr. Ranjith R Unnithan

Multispectral Image Sensors using Metasurfaces

16-NOV-21 / Prof. Andreas Schell

Hybrid assembly of quantum optical elements

24-NOV-21 / Prof. Suzanne Mohney

Electrical Contacts to Semiconductors: A Microcosm of Materials Science and Engineering

FLEET COLLABORATION

23-APR-21 / Prof. Dragomir Neshev

A new lens – using nanomaterials to transform optical systems

IEEE COLLABORATION

30-SEP-21 / Prof. Francesca Iacopi

Augmenting Silicon Technologies with Graphene: Epitaxial Graphene on Silicon Wafers

21-OCT-21 / Dr Duncan Hickman

An Introduction to Thermal Imaging Systems and Their Applications

25-NOV-21 / Prof. Lan Fu

Quantum wells in Nanowires for Optoelectronic Applications: Materials and Devices

Student Conference Report

Organising committee members, Drs. Wendy Lee & Litty Thekkekara

The 2021 TMOS ECR/Student conference was conducted via a virtual platform (Zoom) due to the COVID-19 lockdowns in Australia. The main aim of this conference was to bring together the next generation of researchers on a single platform to promote networking within the early career researchers (ECRs) and students of the Center. This would enable future inter-node collaborations. It was also designed to boost communication and presentation skills among the ECRs and higher degree research (HDR) students.

> “The 2021 TMOS student/ECR conference was an exciting platform to display our research and network.
>
> – Dr. Buddini Karawdeniya, attendee

The event was hosted over two days and consisted of six keynote talks, 24 ECR/student presentations and 18 posters. In addition, there were two online social activities and, in states with fewer COVID restrictions, local social gatherings of TMOS members. In total, 62 students and ECRs attended.

One of the main challenges that the organising committee encountered was diversity amongst the speakers and the organising committee. The list of speakers was predominantly male while the organising committee consisted mostly of female members. In future years, gender balance needs to be considered in the earlier planning stages of the conference preparation. A set of guidelines for conference planning will help to enhance efficiency and address all issues including diversity and related topics to allow the event to be inclusive. Furthermore, a guideline for the role of local node administrators will avoid confusions in the admin work distribution among the committee members.

The student conference committee learnt a lot from organising this conference. Managing a Zoom webinar, creating programs, allocating speakers and organising local node activities were first-time experiences for many of our committee members.

The attendees expressed that they were pleased to learn what other members of the Centre were working on, and some progressed to contacting each other for scientific discussions after the conference. Despite this, feedback was that having a face-to-face program might have facilitated better communication among the attendees.

The organising committee has suggested conducting regular virtual gatherings for ECRs and students that is conducted without the supervisor in attendance, where topics of the discussion can be determined by the ECR-student committee.

We hope that this conference will continue in the coming years in a face-to-face format for students and ECRs of the Center to foster collaborations through research in a relaxed atmosphere.

Dr. Wendy Lee & Dr. Litty Thekkekara on behalf of the organising committee

> “It was a great honour to be invited to the 2021 TMOS ECR/Student Conference. With this opportunity, I got more familiar with the TMOS Centre by knowing many brilliant ECRs and their work, which I believe will form a strong driving force for the new Centre.
>
> – Dr. Haoran Ren, Speaker

> “The conference was a great experience for me. It gave me an opportunity to understand the research interest and culture in Australia.
>
> – Dr. Krishna M Nair, attendee

AWARDS AND PRIZES

Best paper award for HDRs/Masters/Undergraduates

1. Khosro Zangeneh Kamli, ANU
2. Rifat Ahmed Aoni, ANU
3. Laura Ospina Rozo, UoM

Best paper award for ECRs

1. Michal Zawierta, UWA
2. Buddini Karawdeniya, ANU
3. John Scott, UTS

Social Activity 1 Winners – University of Melbourne

Benjamin Russell, Henry Tan, Shaban Sulejman, Niken Priscilla, Shiva Balendhran

Social Activity 2 Winners

Wendy Lee (UoM), Sarah Dean (ANU), Neuton Li (ANU), Henry Tan (UoM), Laura Ospina Rozo (UoM)

Student Conference Committee

> I congratulate the conference committee on the work they did organising and hosting a conference during difficult pandemic circumstances. It was incredibly challenging yet the end result was a professional, well-run conference they can be proud of.
>
> – Prof. Lan Fu, Education Committee Co-Chair

> I thought the conference was an excellent opportunity for ECR/students to present preliminary work in a welcoming, yet critical, environment. Because the conference is within TMOS, participates were more likely to openly present on-going/preliminary work. This is unique as comments and questions asked during presentations are likely to have a tangible impact to the on-going research.
>
> – Henry Tan, attendee

IDEA Committee Chair Report

IDEA Committee Chair, Professor Madhu Bhaskaran

The Centre aims to deliver scientific innovations in optical science and its applications. To translate research into innovative technologies, we gather outstanding innovators from diverse backgrounds to be future leaders for decades to come. Significant research has shown that diverse teams can develop more innovative ideas. When people from different contexts work together, their unique perspectives lead to greater creativity – and space for productive confrontation. The Centre provides a safe and respectful environment, responding to our community's diverse needs so we can integrate our creative sparks!

> Working on the IDEA committee as a male postdoctoral researcher is a precious experience and opportunity for me. It enables me to think about inclusion, diversity, equality and access during TMOS centre, and respect individual contribution, value different culture, give fair opportunity as well as facilitate access that promotes equity and diversity. It's really important to create IDEA environment to make sure everyone contributes their values for a sustainable research atmosphere and future.
>
> – Dr. Tieshan Yang, UTS Early Career Researcher

International Women's Day 2021

Keeping the individual aspects of IDEA in mind, in 2021 we chose to deliver professional development for all core Centre members through *Symmetra*. Their online gamified short modules allowed members across Australia to take part effortlessly during the pandemic. Six modules were chosen covering topics such as diversity of thought, cultural intelligence, psychological safety and inclusion in meetings. In addition, we developed a workshop program run by Bree Gorman which brought TMOS members together virtually to discuss the content from these modules and allow them to understand further how they can implement their new learnings.

In terms of hitting our 2021 goals, we have:

- Recruited at least 30% women personnel in the Centre.
- Established the IDEA Framework and the Strategic and Implementation Plan.
- Driven IDEA literacy through the online modules.
- Worked towards establishing a Career Respark Program to offer short term positions to people returning to work following a career interruption.

Establishing carer support grants is an action item which has been taken forward to 2022 when we expect more travel and in-person activities to resume.

It has been a packed 2021, during which technology has enabled us to deliver on our IDEA goals across our nodes. We look forward to a 2022, when more face-to-face interactions will be possible to put our learnings into action and to promote a higher sense of belonging among our members.

Professor Madhu Bhaskaran
IDEA Committee Chair

ACTION ITEMS FOR 2022

- Create a pilot culture survey (to become an annual survey) to understand what is working and receive feedback from the team.
- Establish the Centre wellbeing and family policies.
- Indigenous training for all core Centre members.

COMMITTEE MEMBERS:

PROF. MADHU BHASKARAN

Chief Investigator
RMIT (Chair)

PROF. ANN ROBERTS

Chief Investigator
UoM (Deputy Chair)

PROF. DRAGOMIR NESHEV

Centre Director
ANU

DR. MARY GRAY

Chief Operating Officer
ANU

PETER NOWOTNIK

IDEA Officer (2021)
RMIT

GREG DENNIS

IDEA Officer (2022)
RMIT

DR. TIESHAN YANG

ECR Representative
UTS

YAN LIU

HDR Representative
UWA

DR. ZIYUAN LI

ECR Representative
ANU

Outreach Committee Report

Outreach Committee Chair, Professor Igor Aharonovich

One of the exciting things about working in research is the opportunity to share new science with the world. Meta-optics is a field most people outside of university level physics haven't heard of the Science text-books still only feature classical optics. By the time the Centre ends, we want to have made significant advances in educating the wider community about what we do and why.

COVID-19 made that somewhat difficult this year. With most of our nodes in lockdown, in-person school visits were not an option. The work we planned to do with Questacon was paused as the national science education centre closed its doors. 2021 became a year of preparation, getting ready to launch into 2022, when we hope we'll be able to be face to face with the community.

This year, we purchased a significant number of desktop hologram printers and developed a school workshop lesson plan to complement them. These very, very cool machines will enable us to go into schools and teach students the science of holograms, leaving each student with their own hologram to take homes as a reminder of how cool optics is. We've done the same thing with diffraction glasses. We have boxes of them ready to go the moment school visits become feasible.

We've met with Questacon to discuss a potential meta-optics exhibit and a shared program of three days of science communication training for our students and early career researchers. We've also had early

> Being involved with the Outreach Committee has been an incredibly enjoyable experience. We all have a shared vision for popularising science, and I am excited to share with the community what we have planned for next year.
>
> – Neuton Li, HDR Representative, ANU

ACTION ITEMS FOR 2022

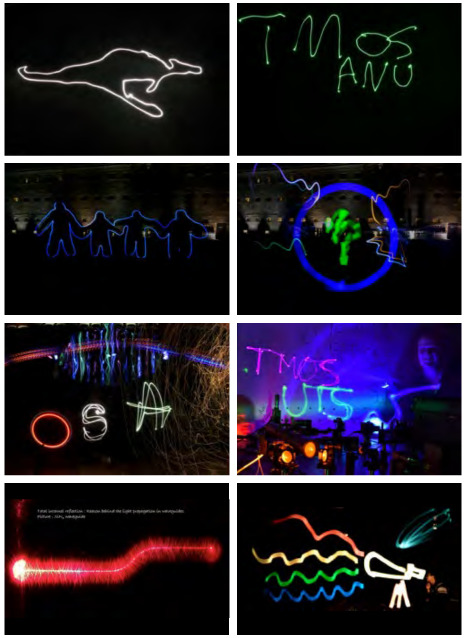
- Develop a communications and content strategy that includes all owned, earned and paid channels.
- Establish an external Centre newsletter that reaches relevant parties with information about the Centre's work.
- Develop a series of classroom activities that teach meta-optics concepts.
- Collaborate with Questacon to develop an optics exhibition.

A screenshot from one of the videos created for RUOK Day

One of the workshops in collaboration with Fizzics Education from Science Week 2021.

talks with professional bodies about developing meta-optics related curriculum materials.

It hasn't all be planning though. Nothing, not even a pandemic, was going to make us miss the International Day of Light with our five nodes duking it out to create the best light painting, an honour that went to our UWA team.



Light painting for the International Day of Light.

Another highlight was Science Week. In collaboration with Fizzics Education, we ran an online optics workshop that attracted viewers from across the globe. At least 1328 people attended, although we know that many of those attendees had more than one person watching the feed. We sent out approximately 800 sets of diffraction glasses to Australian school groups. The workshop consisted of fun optics demonstrations along with tours of the ANU laboratories and a Q&A with Centre researchers Neuton Li, Anha Bhat and Dr Rocio Comacho Morales.

In September, the Outreach and Education committees collaborated to deliver a series of videos for RUOK Day, featuring Centre Director Neshev as he gave advice to Early Career Researchers about navigating conversations with PhD students around mental health in research.

The Outreach Committee is very much looking forward to building on what we've started. 2022 is going to be an exciting year when much of what we're working on comes to fruition.

Igor Aharonovich
Outreach Committee Chair

COMMITTEE MEMBERS:

PROF. IGOR AHARONOVICH
Chief Investigator
UTS (Chair)

A/PROF. MARIUSZ MARTYNIUK
Chief Investigator
UWA (Deputy Chair)

DR. LITTY THEKKEKARA
ECR Representative
RMIT

SAMARA THORN
Engagement Manager
ANU

DR. WENWU PAN
ECR Representative
UWA

DR. WENDY LEE
ECR Representative
UoM

NEUTON LI
HDR Representative
ANU

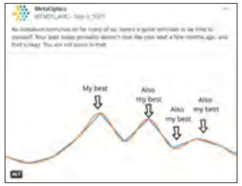
Outreach: Digital Media

Over 2021 our website became the central hub through which people could experience our research, get information about our upcoming seminars and connect with us as potential team members or partners.

Through Twitter and LinkedIn, the Centre became part of a global conversation about meta-optics, research, and the issues that impact us as an academic organization. Oh… and we also had a bit of fun there. Who doesn't love a science meme?

As we head in to 2022 we're looking forward to using digital media to strengthen our community, increase the reach of our research, and position the Centre as a leader in the international meta-optics space.

Samara Thorn
Engagement Manager




MetaOptics

Happy Moon Festival! Usually many of our team would be getting together to celebrate but since we're almost all in lockdown, Chief Investigator @madhu_bhaskaran decided to send the celebration to her team via these delicious moon cakes.

33,176
Website page views

MOST POPULAR PAGE
Centre member profile

8,986
Website visitors

TOP 5 VISITOR COUNTRIES
Australia **(5,633)**
India **(761)**
United States **(532)**
China **(419)**
United Kingdom **(170)**

20
Posts on the TMOS website in 2021

TOP 3 POSTS
1. Nanowire-based devices for THz polarimetry **(192)**
2. Nonlinear and Electro-Optic Metal-Oxides for Sensing and Telecom Devices **(118)**
3. Nanooptics in the electron microscope **(103)**

SOCIAL MEDIA

922 (445 new)
TWITTER FOLLOWERS

735 (398 new)
LINKEDIN FOLLOWERS

33 (22 new)
YOUTUBE SUBSCRIBERS

5
YOUTUBE VIDEOS

1,135
YOUTUBE VIEWS

Governance

Message from the Chief Operations Officer

“

... we have a future and funding to accelerate into, as we implement our ambitious research and operations goals.

I thank all the past and present members of the professional team for their contributions to TMOS in 2021. 2021 was our first full year of operations, during what continues to be a very different world to the one when we were first announced as successful in 2019. We are certainly doing things differently than anticipated. This story is illustrated in our expenditure. When we combine our 2020 expenditure (our ‘establishment year’) with our first year of expenditure (2021) we have spent just 64% of our first-year allocation of ARC funding. This means we have a future and funding to accelerate into, as we implement our ambitious research and operations goals.

In the Professional Team we experienced high staff turnover, as per many other industries. Piotr Nowotnik inaugural IDEA Officer based at RMIT was promoted into a digital content role in the Australian Public Service. Helena Beck our UTS Administration Officer returned to the UK with her husband. Hana Hoblos, RMIT Administration Officer moved onto her dream job as a Research Assistant at Monash. Joshua Cotton, ANU Administration Officer moved to his dream job too (and received two promotions) with international student recruitment at ANU. We also welcomed new team members who all joined in 2021. Karen Kader became officially part of TMOS as the UWA Administration Officer. Galina Shadrivova came on board as our Business Coordinator at ANU. Samara Thorn was recruited as our Engagement Manager at ANU. Kathy Palmer as our UoM Administration Officer. And Greg Dennis joined us on 1 December as our IDEA Officer.

All these changes in how we work, staffing gaps, and new faces have enabled us to review what worked and what we could do better in terms of our professional team structure. Our latest team structure is to be filled by ANZAC Day April 2022 (time to turn the heaters on Canberra).

One of my personal goals is to make all the work that we do accessible to the community, as Centres could really be more like franchises in terms of day-to-day operations. To this end, the TMOS Governance Manual is available to anyone that would like a copy to edit as they please for their own organisation.

We are working on a better way to have this accessible online as part of our 2022 website project, along with our strategic plan, and annual reports. We will also make our Operations Manual and our KPI collection tool (these are partnered to an extent) available to everyone in late 2022. Standard Operations Procedures (SOPs), which will be the core of our Operations Manual, are critical to building scalable business processes (and if it’s good enough for Suneera Madhani – CEO and Founder of Stax – it’s good enough for me). People aligned to our vision and strategy that are empowered to execute it are everything. That’s what all these documents are in support of, and so with that I look forward to pushing ahead into 2022.

Dr Mary Gray
Chief Operations Officer

Governance: CAB and ISAC

CENTRE ADVISORY BOARD:

DR. IAN CHUBB AC FAA

Chair, former Chief Scientist of Australia

PROFESSOR ALEX ZELINSKY AO FAA FTSE

University of Newcastle, founder Seeing Machines

DISTINGUISHED PROFESSOR GENEVIEVE BELL AO FTSE FAHA

Australian National University

DR. GREG CLARK AC

formerly Loral Space and Communications

DR. SIMON POOLE AO FAA FTSE

Cylite Pty Ltd, former Finisar Australia

INTERNATIONAL SCIENTIFIC ADVISORY COMMITTEE:

PROFESSOR FEDERICO CAPASSO

Chair, Harvard University

PROFESSOR HIROSHI AMANO

Nagoya University

PROFESSOR CONNIE CHANG-HASNAIN

UC Berkley

PROFESSOR ZHANG XIANG

University of Hong Kong

DISTINGUISHED PROFESSOR DIN PING TSAI

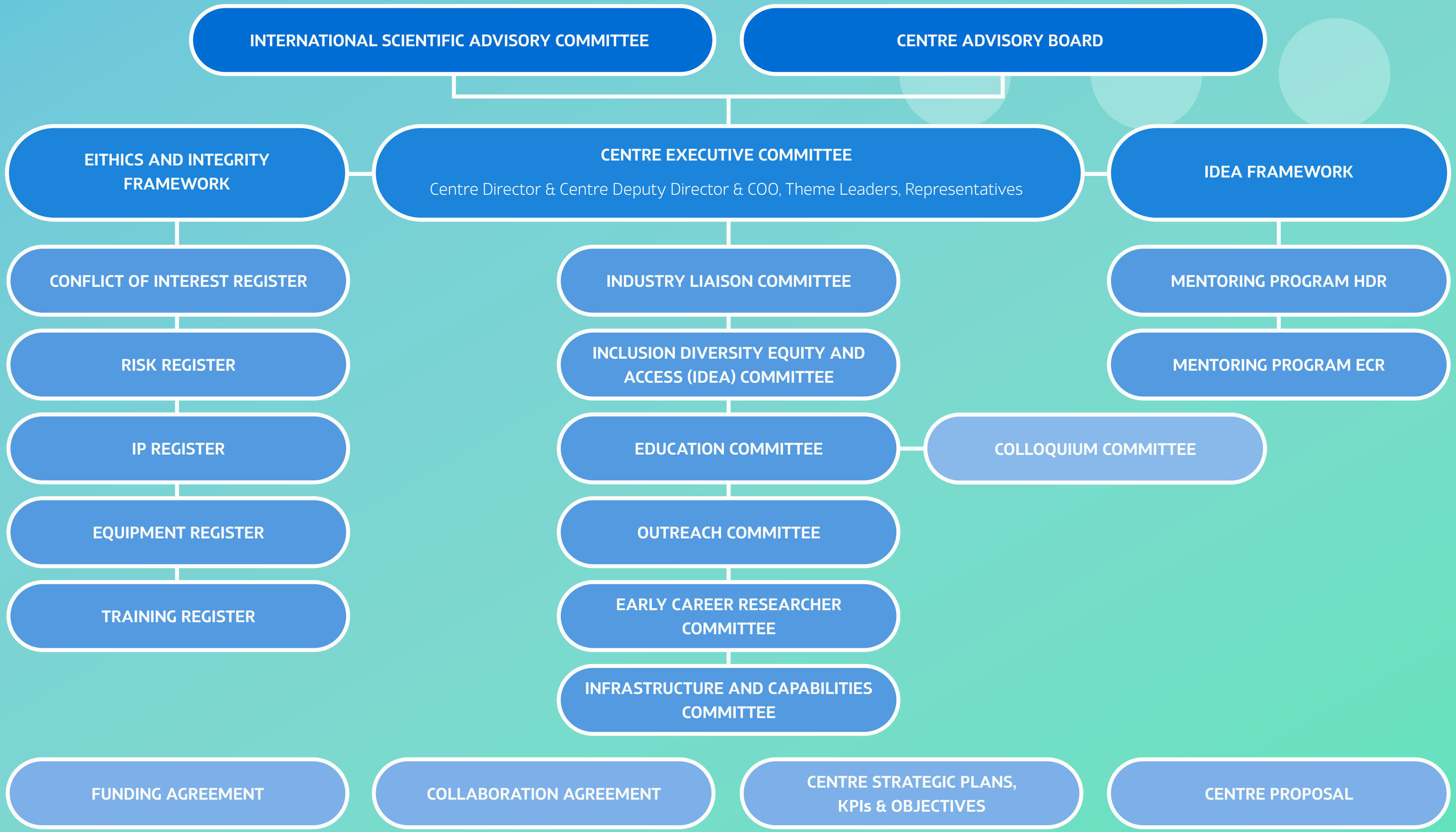
National Taiwan University,

Academia Sinica

PROFESSOR MARK BRONGERSMA

Stanford University

Governance: Structure



INTERNATIONAL SCIENTIFIC ADVISORY COMMITTEE

CENTRE ADVISORY BOARD

EITHICS AND INTEGRITY FRAMEWORK

CENTRE EXECUTIVE COMMITTEE

Centre Director & Centre Deputy Director & COO, Theme Leaders, Representatives

IDEA FRAMEWORK

CONFLICT OF INTEREST REGISTER

RISK REGISTER

IP REGISTER

EQUIPMENT REGISTER

TRAINING REGISTER

INDUSTRY LIAISON COMMITTEE

INCLUSION DIVERSITY EQUITY AND ACCESS (IDEA) COMMITTEE

EDUCATION COMMITTEE

COLLOQUIUM COMMITTEE

OUTREACH COMMITTEE

EARLY CAREER RESEARCHER COMMITTEE

INFRASTRUCTURE AND CAPABILITIES COMMITTEE

MENTORING PROGRAM HDR

MENTORING PROGRAM ECR

FUNDING AGREEMENT

COLLABORATION AGREEMENT

CENTRE STRATEGIC PLANS, KPIs & OBJECTIVES

CENTRE PROPOSAL

Governance: Centre Executive Committee Directorate Report

The Centre Directorate (Prof Dragomir Neshev, Prof Kenneth Crozier and Dr Mary Gray) and the Centre Executive Committee led the Centre operations to continue our excellent record of collaboration and implementation at the highest levels in the Centre. The Directorate met 23 times during the year, an intensive schedule, which however supported us to remain connected, as we were once again unable to meet in person.

We are pleased to report that we have achieved our 2021 Action Items, which were the following:

1. Approve all sub-committee Terms of Reference to complete the Centre Governance Manual.
2. Complete the Centre's Strategic and Implementation plans for non-scientific objectives and KPIs with input from our CAB.
3. Complete the Centre's 3-year Research Plan with input from our ISAC.
4. Appoint our student and early career researcher representatives.
5. Finalise our Partner Investigator and Associate Investigator policies.

Following the approval of our Partner Investigator and Associate Investigator (AI) policies, we reviewed the composition of our AI list, in alignment with our policy and procedure, which makes a clear reference to our IDEA Framework. To this end, we have included more women and more early to mid-career academics in our AI team. We also reviewed the composition of our Centre Advisory Board (CAB) and International Scientific Advisory (ISAC) Committees, with advice and support of their respective Chairs (Prof Ian Chubb and Prof Federico Capasso). We have finalised our ISAC membership for 2022/23 and are continuing to work on the best team for our CAB. We thank our past Associate Investigators, ISAC, and CAB members for their contributions during the application and establishment of our Centre.

During the year, our format of how we connect and meet as a Centre evolved from what we had planned in 2020 (as it should). In addition to our executive meetings, we held 'Science Tuesdays' on alternate fortnights. These online meetings have been a highlight of creativity and excellence in research. Every fortnight we take turns presenting on the different research themes and projects in the Centre, with a focus on ECR and student presentations, and breakout rooms for discussions. We have also used these events to hold a variety of internal seminars, including on research translation and education topics. We will continue to implement this program in 2022. Regarding CEC meetings, we will trial in 2022 a 45 min meeting, with a rotating node update and science project management discussions. While this amounts to weekly meetings for many of us in the Centre, we have found this keeps us together and aligned to our mission.

Critical to our shared vision, is another plan we implemented in 2021 – our Research Program Managers. After an Expression of Interest round, we appointed six ECRs to the role of Research Program Managers. These six ECRs (two women, four men) will support the project management of our research and will be supported to lead and develop our ambitious research program. They are Drs Nima Dehashti, Tuomas Haggren, Yana Izdebskaya, Litty Thekkekara, Jinyong Ma and Hemendra Kala. We are excited to work closely with this group of talented researchers on shaping our research in 2022 and beyond. We also congratulate Mr Suvankar Sen and Dr Nima Dehashti as our elected HDR and ECR representatives.

The Directorate Team

(Centre Director, Professor Dragomir Neshev, Deputy Director, Ken Crozier, Chief Operations Officer, Dr Mary Gray)

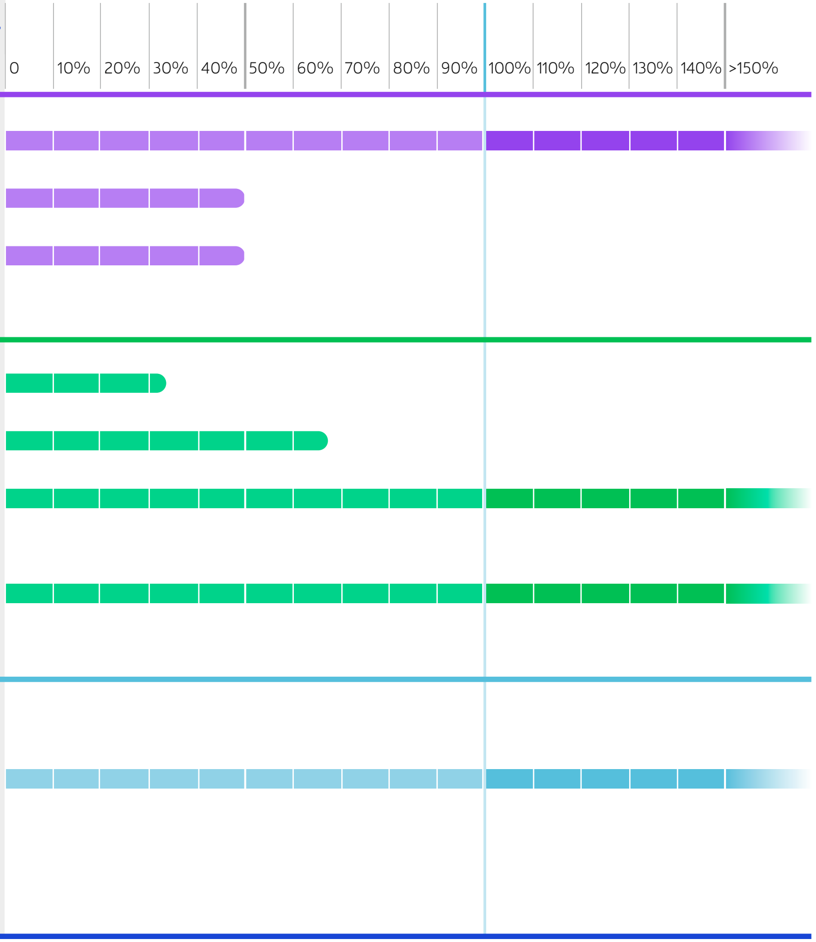
ACTION ITEMS FOR 2022

1. Development of our inspiring flagship research goals, with a view of frontier and translational scientific challenges.
2. Completion of the Centre's on-boarding process and induction modules.
3. Completion of the Centre's Operation Manual and related KPI reporting system.
4. Development of the Centre's Succession Plan.
5. Consolidate and finalise the Centre's Code of Conduct.

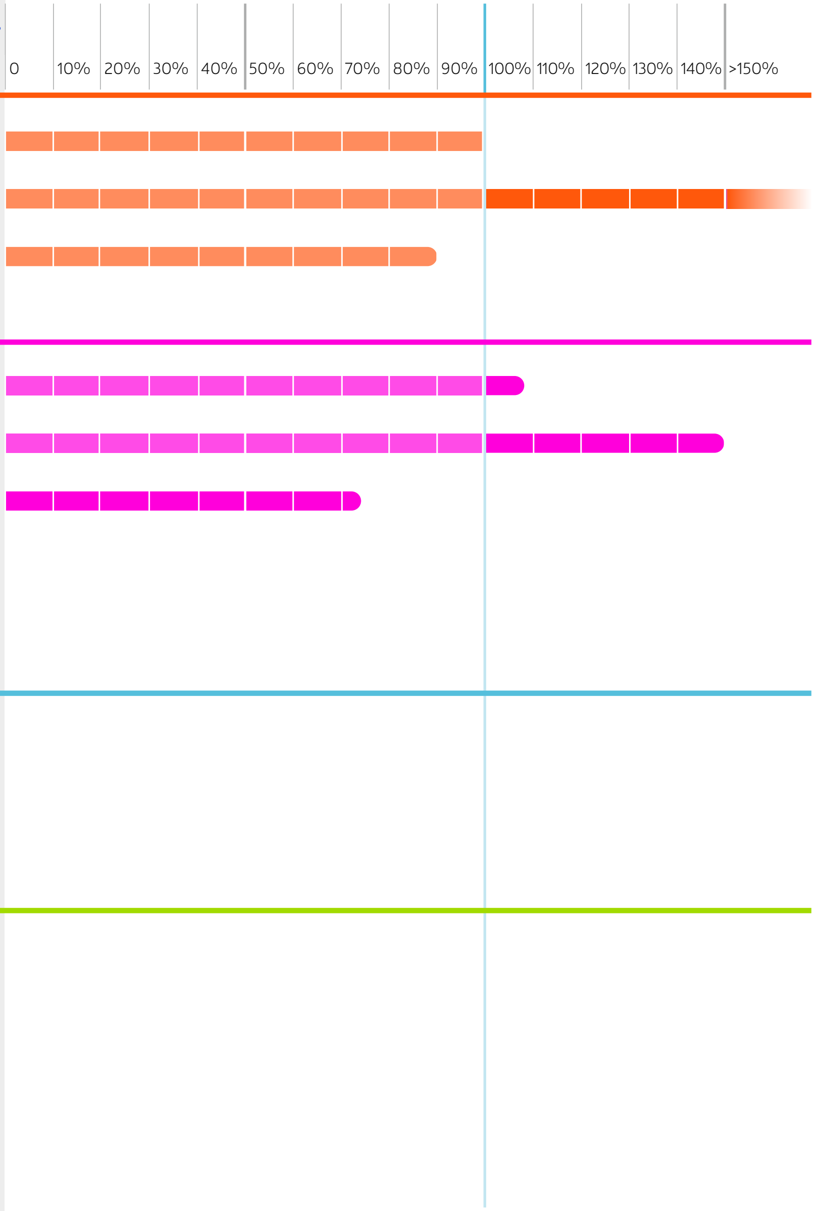
Performance

Key Performance Indicators

Performance Measure		Target Y0 2020	Actual Y0 2020	Target Y1 2021	Actual Y1 2021	Perform. rate 2021
Number of research outputs	Journal articles	15	92	30	87	290%
	Book Chapters	1	1	2	1	50%
	Patents (filing provisional patents and higher)	0	1	2	1	50%
Quality of research outputs	Cross-Node publications	3	2	6	2	33%
	Publications with PIs	2	3	3	2	67%
	High impact publications (in top 10% in the field, e.g. IF>9)	2	17	5	20	400%
	Top-impact publications (in top 3% of the field, e.g. Nature/Science family)	1	10	2	7	350%
Number of workshops/ conferences held/ offered by the Centre	Centre Annual Workshop	0	0	1	0	0%
	Conference Facilitation	1	0	2	4	200%

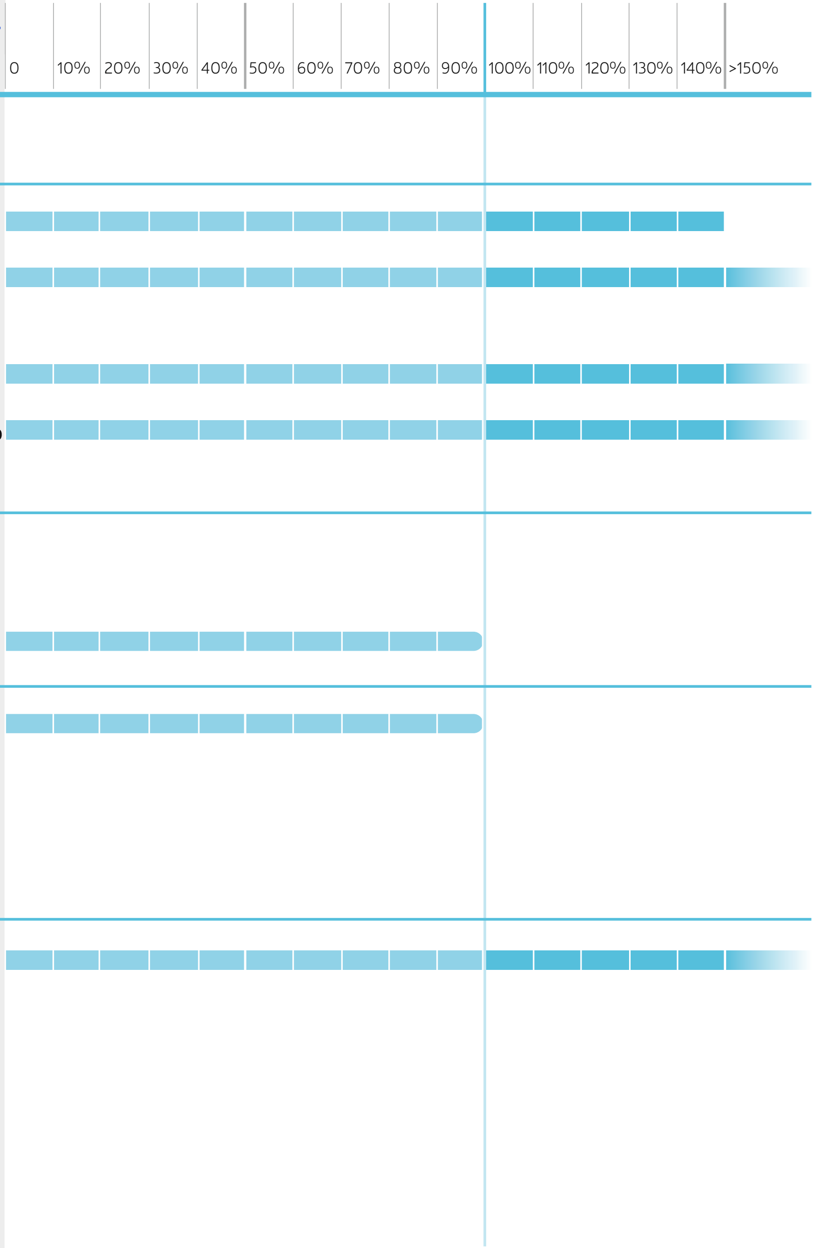


Performance Measure		Target Y0 2020	Actual Y0 2020	Target Y1 2021	Actual Y1 2021	Perform. rate 2021
Number of training courses held/offered by the Centre	Professional Development Courses	1	0	3	3	100%
	Topical workshops and courses	1	0	3	19	633%
	Centre-wide Seminar Program, number of presentations	5	0	20	18	90%
Number of additional researchers working on Centre research	Postdoctoral researchers (new)	6	3	14	15	107%
	Honours and undergraduate students	2	1	4	6	150%
	TMOS HDR Students (PhD and Masters new)	10	0	15	11	73%
	Masters by coursework students (new)	4	0	6	0	0%
	Associate Investigators (new)	3	0	0	0	0%
Number of postgraduate completions	Women HDR completions (percentage of the cohort)	0	0	0	0	N/A
Number of mentoring programs offered by the Centre	Industry Internships (any level longer than 1 month)	0	0	1	0	0%
	PI-Student Exchange Program	0	0	3	0	0%
	Mentors within the Centre	15	0	20	0	0%
	Number of Mentees	10	0	20	0	0%

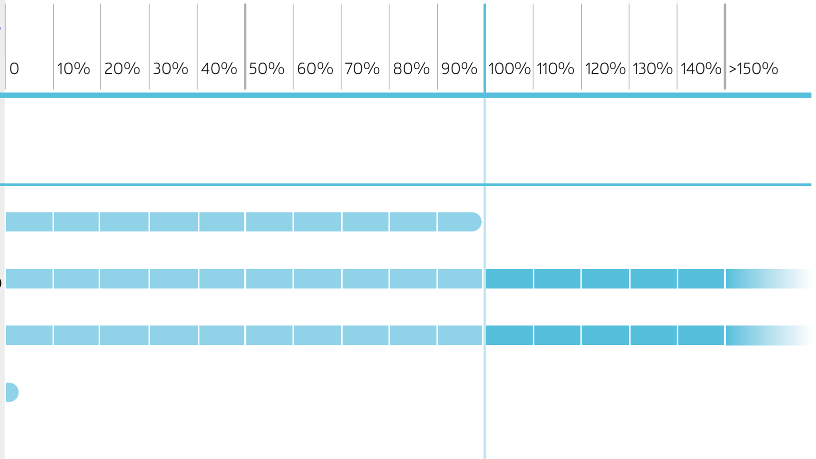


Performance Measure		Target Y0 2020	Actual Y0 2020	Target Y1 2021	Actual Y1 2021	Perform. rate 2021
Number of presentations/ briefings	To the public (Outreach/public engagement events, public lectures)	2	4	5	4	80%
	To government (parliamentarians and department/agencies at both State and Federal level)	0	1	2	0	0%
	To industry/business/end users (documented) incl. DSTG, CSIRO	2	3	3	5	167%
	To non-government organisations	0	1	2	3	150%
	School visits	0	2	5	4	80%
Number of new organisations collaborating with, or involved in, the Centre	Academic collaborations (new)	3	4	3	6	200%
	Industry and end user partnerships (new)	1	4	3	10	333%
Number of female research personnel	Women and diverse gender, % (double the discipline mean)	30	33	30	25	83%

Performance Measure		Target Y0 2020	Actual Y0 2020	Target Y1 2021	Actual Y1 2021	Perform. rate 2021
Centre-specific KPIs						
Research	Plenary talks at international conferences	1	2	2	3	150%
	Keynote and Invited talks at international conferences	10	21	20	41	205%
	Awards and fellowships to CIs, ECRs and AIs	1	11	5	10	200%
	Additional research income secured by Centre staff ('000)	100	4,410	1,000	19,749	1975%
Equity and Diversity	Unconscious bias training, % of Centre personnel (CIs)	100	100	100	0	0%
	Inclusion training, % of Centre personnel	N/A	0	100	100	100%
IP uptake by end-users	Start-up Companies	0	0	0	1	>100%
	IP uptake by end-users	0	0	1	0	0%
	Number of TMOS alumni employed in Industry	0	0	0	0	0%
Education	Associate TMOS HDR students (PhD and Masters, new)	10	16	15	26	173%
	Centre-member attendees at training workshops (total)	30	0	90	0	0%
	Non-Centre member attendees at training workshops	5	0	20	0	0%
	HDRs visiting PIs	0	1	5	0	0%



Performance Measure		Target Y0 2020	Actual Y0 2020	Target Y1 2021	Actual Y1 2021	Perform. rate 2021
Centre-specific KPIs						
Outreach	Media releases	**2**	**2**	**10**	**10**	**100%**
	Media mentions	**2**	**38**	**10**	**170**	**1,700%**
	Twitter followers (new)	**100**	**477**	**100**	**445**	**445%**
	Outreach hours	**100**	**22**	**1,000**	**26**	**2.6%**



Finance

REPORTING PERIOD	2020–2021	2022
INCOME	Actual ($)	Forecast ($)
ARC[A]	10,262,449	5,227,481
Australian National University	1,528,436	731,549
The University of Melbourne	441,572	35,461
RMIT University	379,908	247,466
University of Technology Sydney	687,186	527,385
The University of Western Australia	159,725	159,725
Partners' contributions	10,195	30,000
TOTAL INCOME	**13,459,277**	**6,959,066**

REPORTING PERIOD	2020–2021	2022
EXPENDITURE	Actual ($)	Forecast ($)
Personnel	2,821,642	4,319,791
Equipment	396,462	602,980
Scholars Expenses	314,828	669,303
Travel	30,622	531,574
Other[B]	682,635	805,417
TOTAL EXPENDITURE	**4,246,190**	**6,929,065**
CARRY FORWARD (TOTAL)	**9,213,087**	
CARRY FORWARD TO 2022	**2,762,966**	
CARRY FORWARD TO 2027[C]	**6,450,121**	

REPORTING PERIOD	2020–2021	2022
	Actual ($)	Commitment ($)
IN-KIND		
Australian National University	2,143,035	1,121,068
The University of Melbourne	884,362	391,390
RMIT University	1,149,740	334,870
University of Technology Sydney	741,672	370,836
The University of Western Australia	635,936	317,968
Partners' contributions	691,629	717,181
TOTAL INCOME	**6,246,374**	**3,253,313**

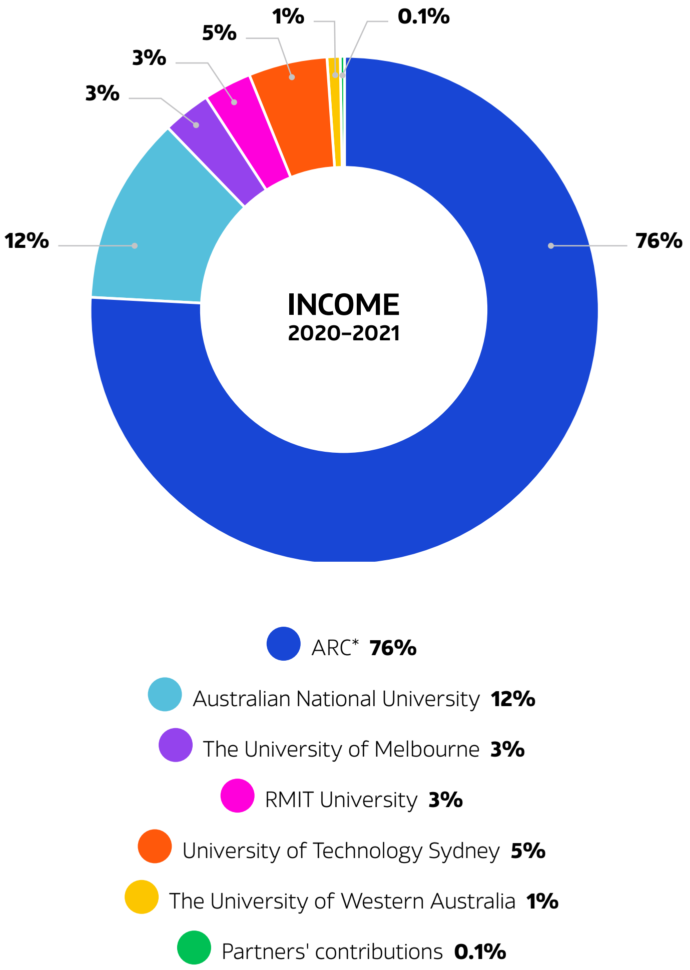
Notes on the Financial Statement:

A) ARC awarded funding for 2020 (inclusive of ARC Establishment Funding $474,813), awarded funding 2021, and indexation (2020, 2021).

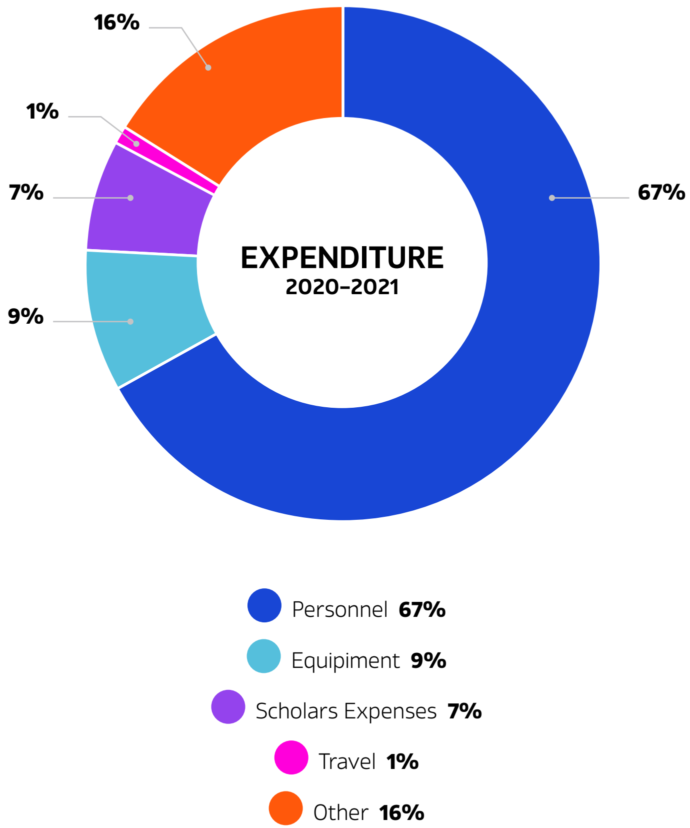
B) Includes materials, repairs and maintenance, branding, outreach, consultancies, recruitment, and administrative support.

C) Unspent balance (2020 awarded funds minus Establishment Funding) is reserved for 2027 (Year 7) Centre operations.

CASH INCOME SOURCES 2020-2021[D]:



EXPENDITURE 2020-2021[E]:



Notes on the Financial Statement:

D) Due to COVID19, less university cash than anticipated was received during 2021 due to an on-going reduction in overall Centre activities, particularly as some universities are providing a portion of their cash as HDR student stipends. We expect that future years will balance this current shortfall.

E) Due to COVID19, overall expenditure was reduced, and the expenditure profile of the Centre was not concordant with the original budget. Travel expenses (1%) were the most severely impacted due to national and global travel restrictions, and the Centre launch and workshop were postponed until 2022.

Publications

BOOK CHAPTERS 2021

1. Fundamental Properties and Power Electronic Device Progress of Gallium Oxide, Chapter 9, https://onlinelibrary.wiley.com/doi/abs/10.1002/9781119529538.ch9
2. Xuanhu Chen, Chennupati Jagadish, Jiandong Ye

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Awards, Honours and Prizes

Awardee Name	Details
Ann Roberts	Australian Institute of Physics Alan Walsh Medal
Ann Roberts	Fellow, SPIE
Ritika Ritika	R F G MacMillan Award University of Technology Sydney
Ritika Ritika	Photonics kit for the B Phot competition (Outreach), Winner B-PHOT Student Chapter
Francesca Iacopi	IEEE EDS Distinguished Lecturer, IEEE EDS
Chennupati Jagadish	President of the Australian Academy of Science
Madhu Bhaskaran	Women’s Agenda Leadership Awards Emerging Leader in STEM, Finalist Women’s Agenda Leadership Awards
Mehran Kianinia	UTS Chancellor’s Postdoctoral Fellowship (CPDRF), 6 September 2021
Andrey Sukhorukov	NCI Grant for the Centre
Dragomir Neshev	Highly Cited Researcher, Web of ScienceTM, Clarivate 2021

Awarded Funding

TMOS Member	Title of Funding Scheme	Project ID	Total Amount (AUD)	Funding Source
Andrey Sukhorukov, Chennupati Jagadish, Dragomir Neshev, Hark Hoe Tan, Ilya Shadrivov, Lan Fu	ITRG – Tailored metasurfaces – generating, programming and detecting light; EURO 5,251,332 granted 7/12/2021 (RBA Forex rate 0.6264)	GRK2675	$8,383,352	Deutsche Forschungsgemeinschaft (German Research Foundation)
Andrey Sukhorukov, Chennupati Jagadish, Dragomir Neshev, Hark Hoe Tan, Ilya Shadrivov, Lan Fu	ITRG – Tailored metasurfaces – generating, programming and detecting light	GRK2675	$450,000	Australian Nationa University cash contributions towards the Project funded by Deutsche Forschungsgemeinschaft (German Research Foundation)
Dragomir Neshev, Kenneth Crozier	UoM share: Efficient infrared-to-visible conversion with an upconverting nanoparticle microlaser	HR001121S0013-ENVision-FP-013	$1,862,954	Defense Advanced Research Projects Agency (DARPA)
Dragomir Neshev, Kenneth Crozier	ANU share: Efficient infrared-to-visible conversion with an upconverting nanoparticle microlaser; USD378,578	HR001121S0013-ENVision-FP-013	$533,208	Defense Advanced Research Projects Agency (DARPA)
Lan Fu	Laser-free on-chip super-resolution microscopy	DP220101417	$495,000	Australian Research Council (ARC); externally led
Madhu Bhaskaran, Sharath Sriram	ARC Research Hub for Connected Sensors for Health	IH210100040	$5,045,163	Australian Research Council (ARC)
Madhu Bhaskaran, Sharath Sriram	Industry contract with nthalmic – Smart wearable patch to resolve chronic dry eye disease		$35,600	Industry contract
Madhu Bhaskaran, Sharath Sriram	DNA nano biosensor for cancer diagnostics (National Foundation for Medical Research and Innovation)		$144,000	State Trustees Australia Foundation and NFMRI
Aiswarya Pradeepkumar	Using Nuclear Techniques to Optimize the Interface Structure and Electronic Properties of Epitaxial Graphene on Silicon for Scalable Optoelectronics		$10,000	AINSE Early Career Researcher Grant (ECRG)

TMOS Member	Title of Funding Scheme	Project ID	Total Amount (AUD)	Funding Source
Francesca Iacopi, Professor Sharath Sriram; Professor Ilya Shadrivov, AI Dr David Powell;	Australian 3D Beam Measurement Platform from Radio Waves to Terahertz Waves	LE220100035	$520,000	Australian Research Council (ARC) LIEF
Lorenzo Faraone	Facility for enabling low thermal budget Si/SiGe technologies	LE220100095	$580,000	Australian Research Council (ARC) LIEF
Kenneth Crozier	Gram-scale IR spectrometer concept for multi-analyte airborne chemical threat		$252,220	DSI-HAC Internal UoM grant
Chennupati Jagadish, Francesca Iacopi, Hark Hoe Tan, Igor Aharonovich	National Facility for Infrared Technologies	LE210100125	$837,000	2021 Linkage: Infrastructure Equipment Facilities – externally led; ARC
Andrey Sukhorukov	Quantum imaging with ultra-thin optical metasurfaces	57559284	$25,000	Universities Australia
Andrey Sukhorukov, Dragomir Neshev	Multi-Spectral and Polarisation Imaging with Ultra-Light Nano-optics for Smarter Satellites	NI210100072	$575,693	Office of National Intelligence (ONI)
TOTAL			**$19,749,190**	

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