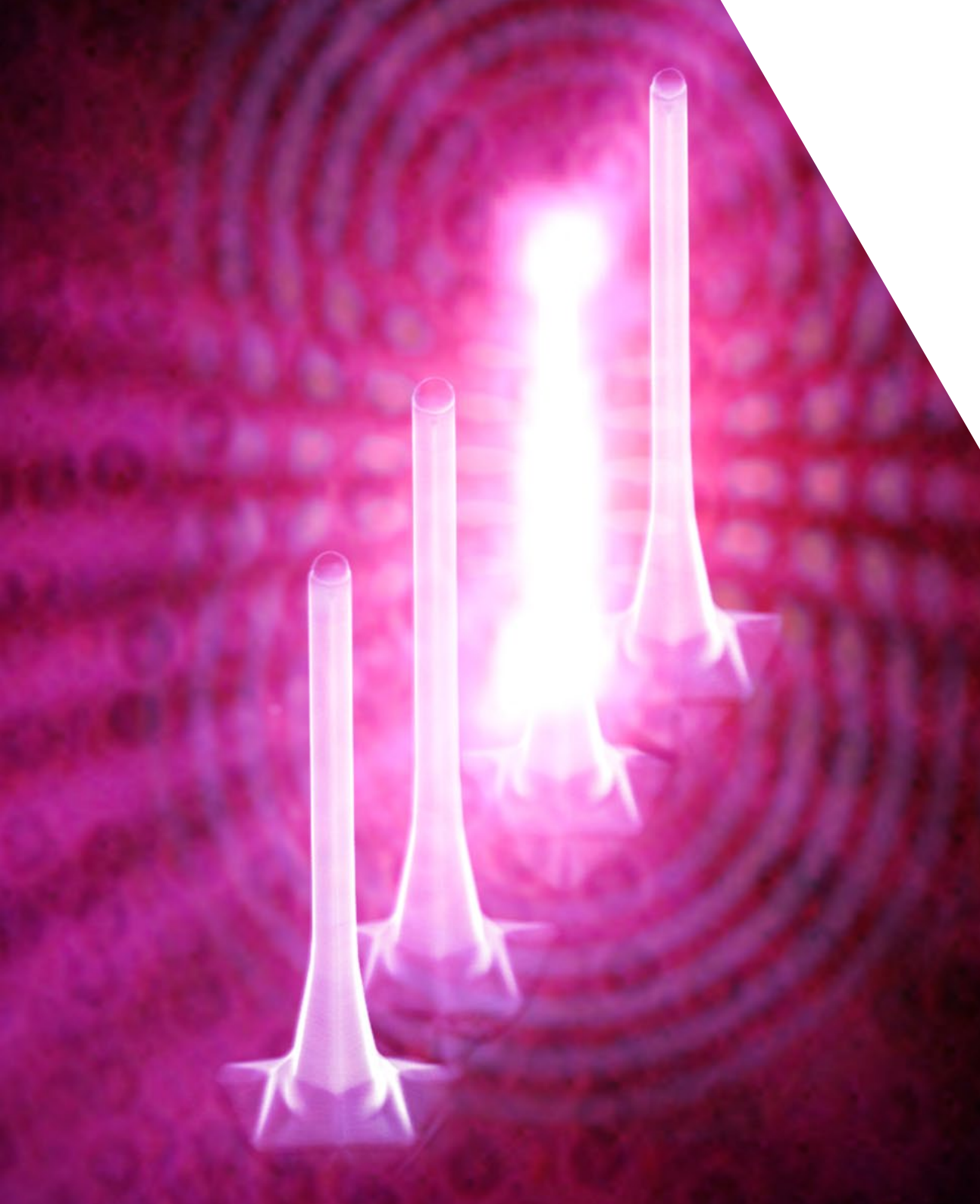


TMOS

2020 Establishment Report

Contents

Centre

Message from the Director

Dear Colleagues and Friends,

2020 was a memorable year for the world marked by significant challenges, especially the COVID-19 pandemic, environmental disasters, and political instability. We took this year as an opportunity to build a strong foundation of trust and community between the Chief Investigators and supporting staff and students.

This report tells the story of the establishment of the Australian Research Council Centre of Excellence for Transformative Meta-Optical Systems (TMOS). The establishment period took longer than anticipated but, having used 2020 to reflect and deeply consider the goals of the Centre, we began strong with an official financial starting date of 1 Jan 2021.

While we are heading into the launch of the Centre, clear and enthusiastic about what we are going to achieve, it is not all opportunity and growth. Indeed, we will be feeling the impact of COVID-19 for years to come, as our team and research plans have been impacted by the international travel restrictions that are in place.

> “The TMOS team has shown incredible enthusiasm for collaboration, cross-fertilisation of ideas and our joint vision for the future.

This does bring home two clear points for us. Firstly, science is international and, by necessity, requires a global effort to solve grand interdisciplinary challenges. Secondly, we need to do more in Australia to build a domestic student base and opportunities for our teams to have fulfilling and impactful careers in Australia.

To this end, part of my intention with this Centre is to actively engage with all aspects of society including industry, government, and the community. We must ensure the work done here is not done in a silo, removed from the world that science serves. We will work closely with a range of industries to gain insight into their needs, which will guide our research.

We will champion the fundamental research, which is the fuel for future innovations. We will support the government in its endeavour to drive jobs and growth through innovation, which is supported by dialogue between academia, government, and industry.

We will also work closely with the community to nurture the next generation of physicists. Success in developing a thriving local optics industry will be limited if we do not develop a pipeline of graduates who can fill these roles. Few people wake up at seventeen years old and suddenly decide to study science, which is why our education and engagement programs are critical.

A commitment to diversity is key to building the resilient education, research, and industry ecosystems we need in Australia. A workplace that is balanced in terms of gender, ethnicity, age, and talents is more creative and productive. Diverse perspectives communicated safely drive new ideas and revolutionary approaches that you would not access otherwise.

It is not enough for me personally to state a commitment to diversity. We need more than

Professor Ilya Shadrivov, Chief Investigator and Professor Dragomir Neshev, Centre Director

words—we need to provide young women, like my daughter, with role models that show them that women belong in this field. Therefore, we cemented Inclusion, Diversity, Equity and Access (IDEA) into the foundation of our organisation. We have a dedicated staff member, an IDEA Committee with funding, and a framework that will underpin our culture as a Centre. In 2020 we took steps to see that framework implemented with a women-only recruitment round for post-docs. There is a long way to go before we achieve equity in this field, but I am determined to relentlessly push for it.

I'd like to end with my personal thanks to everyone involved in getting the Centre up and running—a challenge made more difficult by the COVID-19 restrictions. In particular, I'd like to thank our Chief Operations Officer, Mary Gray, whose dogged tenacity is greatly appreciated. I am so encouraged by the level of engagement of all of our Chief and Partner Investigators. At times, research teams can feel like disparate groups of people linked only by a name. By contrast, the TMOS team has shown incredible enthusiasm for collaboration, cross-fertilisation of ideas and our joint vision for the future. Going into 2021, it gives me great hope for the impact of our Centre and the success that feels sure to follow.

Professor Dragomir Neshev
Centre Director
March, 2021

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 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.

ABOUT OUR LOGO

We are proud to present our Centre logo, as created by IDAHO.

The Centre logo combines a light source (three lines) and an artificial structured surface (dots). The icon demonstrates the concept of meta-optics and forms an arrow, pointing to the future advancement of optical technology that TMOS will enable.

The Centre has a pride colourway, which highlights our commitment to diversity using the colours of the rainbow. The rainbow is a symbol of diversity and the flag of the LGBTQI+ community and, as a happy coincidence, is also used in association with the prism icon by optical-related research and technologies.

Message from the Deputy Vice-Chancellor (Research and Innovation)

On the cusp of the next major industrial revolution—Industry 4.0—it is imperative that Australia maintains its standing as a country that fosters innovation by developing globally competitive future industries across all areas of research and development.

The ARC Centre of Excellence for Transformative Meta-Optical Systems (TMOS), led by The Australian National University, is a global partnership positioning Australia at the forefront of the wave of innovation. It will transform the field of optical physics and engineering with the aim to solve tangible problems, primarily centred around the development of miniaturised, smart, and energy-efficient optics that can keep up with the demand for miniaturisation in personal and mobile applications. These solutions begin with fundamental research into nanophotonics, metaoptics and quantum science.

Optical technologies have largely remained the same for over 2,000 years. TMOS is advancing the status quo by controlling light using nano-structured materials. These optics will be ultra-thin and will integrate light generation, manipulation, and detection into a single system. By engaging with key global and Australian industries, TMOS is establishing the foundation for future translation of its research into innovative technologies that benefit society across diverse sectors including transport, health, security, defence, agriculture, entertainment and education.

The vision of our Centre is to develop the next generation of miniaturised optical systems with capabilities beyond what is conceivable today. Outcomes will underpin future technologies, including real-time holographic displays, artificial vision for autonomous systems, wearable medical devices and ultra-fast light-based WiFi, changing how we live and building national capacity in advanced manufacturing. TMOS is part of a rich innovation ecosystem in Australia, including businesses of all sizes and government, strategically investing in the scientific development underpinning future industry and bringing our research to the point of commercialisation.

Most importantly, TMOS will foster the talent and skills needed for Australia to lead Industry 4.0 by developing home-grown talent, attracting world-leading researchers and entrepreneurs to our shores, and giving the opportunity for Australian businesses to play a fundamental role in our shared future. This talent pool will feed industry, government, and academia, providing a workforce for the burgeoning local optics and photonics ecosystem, which currently comprises more than 10,000 employees in nearly 500 companies—a large but rarely acknowledged industry with enormous scope for growth.

I am delighted to present the first TMOS Annual Report. At ANU, we are looking forward to being part of the ongoing conversation about how government, industry and academia can together develop Australia's capacity and accelerate the translation of fundamental research into commercial opportunities. Together, we have the chance to ensure Australia becomes the go-to destination for expertise and investment in meta-optics.

Professor Keith Nugent
Deputy Vice Chancellor of Research and Innovation, Australian National University

A not-so-long time ago, at a university not-so-far away

The path to establishing a Centre of Excellence is long and requires multiple elements, including breakthrough science, strong international standing of the research, wide representation of this research in Australia, research leaders and significant potential impact on society.

And then it needs for someone to recognise that all the elements are there.

Our story started with an email on 8 September 2017 from Dr Mary Gray "I have put my hand up to coordinate for Science the Australian Research Council (ARC) Centres of Excellence round (CE20) that opens in May next year. Would you be interested?"

That email was the spark. That was when several of the Centre's Chief Investigators got together to look at the elements in front of us to getting a clear picture of the impact of our science.

Then there were the first attempts to communicate our vision to a broader audience. What would engage people? What would excite them as much as we were excited? Our minds quickly turned to a piece of technology that had captured people's imaginations for decades yet was still beyond our reach in the real world.

Holographic projection. It had featured in the 1977 Star Wars movie—and many movies since—and yet forty years later this technology wasn't part of our everyday life, despite the many applications for it. While not everyone is a fan of jedi movies, integrating this technology into the fabric of our society would touch every person in a positive way. Its uses extend beyond science fiction and begins a technological revolution.

Industry 4.0 merges the digital and biological worlds, using *light* to sense and interface humans and machines. Hence, new miniaturised optical technologies with functionalities beyond what is possible to date are required to enable this industry to achieve its full potential. And meta-optics is a concept that could allow this development.

Industries around the world were excited about the prospects, and researchers were embracing this concept. In Australia, we had already pioneered some of the developments and there was a critical mass of scientist core to the field. But it was obvious that there was a bottleneck in the existing development. And the grand challenge of solving it required the development of a multi-disciplinary team with a wide variety of expertise.

Our name was not easy to choose, but TMOS had a great appeal. CMOS (Complementary Metal Oxide Semiconductor) technology revolutionised the nanoelectronics industry and we felt that TMOS paid homage to that work while hopefully being a sign that we, too, could revolutionise industries.

After many long phone calls that stretched into the wee hours, the team charged with developing a solution was formed. In May 2018, we submitted our expression of interest (EoI) to the ARC.

Following a successful EoI process, where only 20 proposals were selected out of about 200,

ANU DVCRI Professor Keith Nugent, Professor Chennupati Jagadish, Professor Dragomir Neshev, Professor Madhu Bhaskaran, Professor Ann Roberts, Professor Ken Crozier, Professor Igor Aharonovich

we put all details together in a full proposal submission. Several Chief Investigators spent long days and nights working. The 610 pages that formed the final document was submitted in December 2018, with the support of Ms Thu Roberts from the ANU research office. Special thanks to the University of Western Australia library in Perth for providing the inspirational environment for writing and collaborating.

The application was followed by an interview at the Australian Research Council. We had to put on nice clothes and communicate the Centre vision and its relevance to Australian society. The interview team was shining, especially Jagadish who radiated excitement and wisdom, convincing the panel that we are a strong team with the knowledge, support, and mentorship for a leadership role in science.

And then we waited.

And waited.

The conference season arrived and many of us were scattered around the world, presenting at conferences and meeting with other researchers. In the backs of our minds, we were all wondering 'when will we get The Call?'

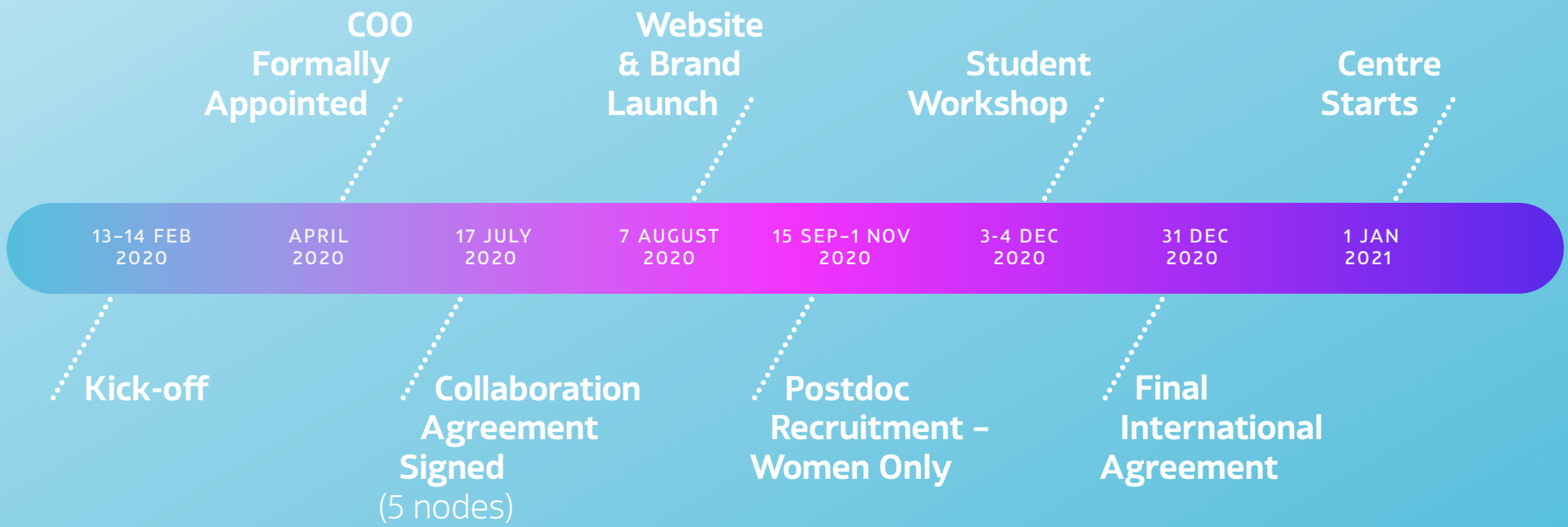
Centre Director Dragomir Neshev was having dinner with research colleagues in what was clearly the noisiest restaurant in Tel Aviv when the phone rang. It was Professor Keith Nugent, the Deputy Vice Chancellor of Research and Innovation at the Australian National University. He had just received a call from ARC. The Centre was funded! It was thrilling. It was also embargoed, which meant he could not tell a soul. Dragomir returned to the dinner table and had to keep quiet despite many curious comments from his colleagues in front of him.

It was a long month before the new Centre was announced and the team were free to discuss it publicly, although plenty of private celebrations were happening. Well before Covid, we were having Zoom champagnes. Before we knew it, it was 2020 and the real work was about to start, which you can read about in the rest of this report.

Read the ARC Announcement

> "Industry 4.0 merges the digital and biological worlds, using light to sense and interface humans and machines. Hence, new miniaturised optical technologies with functionalities beyond what is possible to date are required to enable this industry to achieve its full potential.

2020 Operations



Action Items for 2021

RESEARCH

GENERATE

- 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

MANIPULATE

- Experimentally and theoretically explore the tunability of the metasurfaces with liquid crystals, aiming to achieve practically useful range of parameter tunability
- Study the possibilities to use ferroelectric materials for fast tunable metasurfaces
- Design static holographic metasurfaces
- Fabricate and characterise 3D neuromorphic metastructures
- Investigate the use of phase change materials to realize tunable metasurfaces

DETECT

- Angle sensitive detection with discrimination between positive and negative directions
- Nanostructured silicon photodetector pixels for a fully contained microspectrometer
- Monitoring of optical polarization with metasurface enhancement
- III-V nanowire array/meta surface integration for enhanced performance/ functionality
- Enhanced MIR detection with ultra-thin hybrid plasmonic metasurfaces

INFRASTRUCTURE

- Complete an equipment register that will list the experimental and computational infrastructure available in the laboratories of all Chief Investigators (CIs). This register will be presented on the Centre website and maintained by the committee.
- Organise regular meetings at which Centre members can discuss their infrastructure needs that are currently unmet and develop strategies to fill these gaps.
- Organise meetings to facilitate joint submissions to government-funded capabilities in Australia (e.g., Australian Synchrotron) and overseas.

CULTURE

IDEA

- Recruit at least 30% women personnel in the Centre.
- Establish the IDEA Framework and the Strategic and Implementation Plan.
- Drive IDEA literacy by offering training modules in diversity and inclusion for Centre members.
- Establish the Centre's carer grants scheme.
- Work towards establishing a Career Respark Program to offer short term positions to people returning to work following a career interruption.

ENGAGEMENT

INDUSTRY

- Initiate four opportunities for Centre researchers to engage dialogue with industry,
- Develop a framework of principles and guidelines for Centre IP protection and technology transfer (including Material Transfer Agreements, etc.).
- Develop ethical guidelines and opportunities for engaging with Defence and their subcontracting companies.
- Develop a relationship database covering the areas of research aligned with Centre Themes.
- Together with the Education and Outreach Committee, develop training events and education materials to familiarise Centre members, particularly students and ECRs, in matters of IP, technology transfer, as well as dual-use technologies and other related government and university compliance requirements.

EDUCATION AND OUTREACH

- Design the Education (internal) and Communication and Engagement (external) strategies and implementation plans (2021-2023)
- Establish guidelines for Centre HDR student supervisory panel formation, as well as the formal expectation for their engagement with the Centre training program, academic and outreach activities.
- In collaboration with the Industry Liaison Committee, design and pilot an industry internship program for Centre HDR students.
- Hold three research training events and one career development workshop for Centre students.
- Run two major outreach events at the national level.
- Design three training packages for HDR students and ECRs to deliver at school visits to promote the science of light.

GOVERNANCE

EXECUTIVE

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

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 area 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:

0421 276 272

@TMOS_ARC

@arctmos

connect@tmos.org.au

Culture

IDEA Committee Chair Report

> The IDEA Committee will formulate the IDEA Framework and its Strategy and Implementation Plan with a strong focus on mechanisms to drive inclusion, diversity, equity, and access.

As a Centre, we strongly believe that diversity improves ideas and innovation and leads to better outcomes and productivity. Diversity and fostering a culture of inclusiveness will be a key contributor to the scientific excellence of the Centre. All Centre Australian universities have a Bronze accreditation in the Athena Swan or Science in Australia Gender Equity (SAGE) program.

The IDEA Committee will formulate the IDEA Framework and its Strategy and Implementation Plan with a strong focus on mechanisms to drive inclusion, diversity, equity, and access.

The Centre's leadership considers diversity of all forms to be important. In particular, the Centre will aspire to having 30% women recruited for positions in 2021. This target will build up to an even more ambitious 40% towards the latter half of the Centre's tenure. These are not easy targets to reach considering we span engineering and physics, which have the lowest number of women among STEM sectors—currently less than 20%—and these numbers have held steady over numerous years.

While we could always scout talent internationally, the pandemic and ongoing travel restrictions made it significantly harder to bring over overseas HDR and research talent for our first major recruitment round. A balance will be struck between timely commencement of our Centre activities and the recruitment of suitable personnel with the appropriate skills and the gender diversity that needs to be achieved.

We extend diversity beyond gender to cultural identity, nationality, experience, and perspectives. There is also a focus on inclusion and professional development in the Centre.

As the IDEA Director, I will bring my significant expertise in effecting change in this space as I co-founded the Women Researchers' Network at RMIT University in 2013, have served on the board of directors for Women in STEMM Australia since 2015, and Expert Working Group for the Women in STEM Decadal Plan.

In 2020, we have already made a phenomenal start to IDEA activities by ensuring all Chief Investigators underwent bias training and by carrying out a women-only recruitment round across the nodes for our postdocs to attract the best and the brightest that would enhance diversity in our Centre from the beginning.

The Centre brings opportunities to push the boundaries in science and technology and to build and empower the next generation of scientists. One can invent alone; collaboration leads to innovation; but diverse teams will lead to disruptive innovation. As we work towards disruptive innovations in optics, diversity and inclusion are key pillars in our strategy.

Professor Madhu Bhaskaran
IDEA Director

ACTION ITEMS FOR 2021

1. Recruit at least 30% women personnel in the Centre
2. Establish the IDEA Framework and the Strategic and Implementation Plan
3. Drive IDEA literacy by offering training modules in diversity and inclusion for Centre members
4. Establish the Centre's carer grants scheme
5. Work towards establishing a Career Respark Program to offer short term positions to people returning to work following a career interruption

Diversity: Special Measures Recruitment Round

The Centre is determined to build a diverse and inclusive team. A challenging and obvious place to start is to tackle the underrepresentation of women in STEM research roles. The disproportionate lack of women in these roles is particularly high in senior academic roles. For example, women constitute 41.7% of early career researchers, senior academic roles comprise only 13.9% of women[1]. Women represent approximately 30% of people STEM across all fields. Our Centre spans the disciplines of physics and engineering—two of the lower contributors to gender diversity.

The challenges in this domain are systemic and embedded in our society, beyond the ivory towers of academia. However, as universities are the thought leaders of society, we have a special responsibility to drive positive social change in our workplaces. We need to set our house in order, and this starts with tactics such as special measures recruitment.

Our Centre has a goal of 40% women postdoctoral fellows by 2026.

As a starting point, the Centre decided to begin postdoctoral researcher recruitment with a special measures round (targeting women, women-identifying people, and Indigenous Australians). Previous Centres discovered and communicated to us that if you do not start how you mean to finish, it becomes difficult to change culture as everyone has gone ahead and recruited in their usual way. We had the opportunity to direct what happens when we put special measures in place from the beginning.

We ran women-only ads at four of five university nodes where we could receive exemptions from the various State and Territory equal employment opportunity acts. We advertised all 15 postdoctoral positions at once, with 13 from 15 positions being 'women-only'. Several positions, notably seven at the Australian National University, were also national-only (Australian working rights requirement) due to the COVID-19 employment risk-management strategy. Whilst the ads were open, we also undertook unconscious bias training. All Chief Investigators completed this training in advance of the shortlisting process. The roles were open between 15 of September and 1 November 2020.

Each university had selection panels with cross-node representation and gender balance (at least one woman if there were three members). We had 330 applications during this special measures round, and we recruited four women (the outcome from UWA is pending), with a fifth to be given a position upon completion of her DECRA in 2022 and a potential sixth to be recruited from overseas once the visa and travel exemption processes can be resolved. We consider this an outstanding result and is in addition to two women that we were able to directly appoint with Establishment Funds during 2020. We will be advertising all unfilled positions in 2021, internationally and without reference to gender, though we are planning to continue to attract women.

FURTHER CONSIDERATIONS

All postdoctoral appointments are to be run through our IDEA Committee (in 2020, this was the Centre Directorate Team and the IDEA Chair), so that we have Centre-wide oversight of positions and ads. The goal is to ensure recruitment is done in alignment with Centre policies and procedures. However, the Centre is not in control of universities and their processes. There were extensive delays and different levels of responsiveness from our requests to run women-only ads and have them come out of five universities simultaneously. However, while the recruitment round didn't roll out exactly as planned, it did meet minimum viable standards for what we were trying to achieve. All five Nodes advertised within three weeks of each other (we matched the end dates); four out of five ran women-only ads; and three specified Indigenous Australians. Targeted advertising sites were identified to maximise our chances of attracting quality applicants, with social media also used extensively to market these positions. Matching the end-dates of the ads and creating Centre ads and a Centre-controlled 'jobs' webpage, in addition to the university ads was a simple way around inconsistencies.

Many men applied to the women-only positions (61% of applicants were eligible; most ineligible applicants were men), and even more called to enquire about the roles (and some applied despite being told they should

1 SAGE – STEM https://bit.ly/39sZZ2d

not apply in this round). We also found men applied as 'gender not-specified' to get around systems that bumped them out from applying when they selected 'male' as their gender. Thankfully, we had support from our HR teams to identify the gender of 'unspecified' applicants through querying to remove men from the pool and retain anyone that genuinely identified as neither male nor female in the binary system. This is unfortunate as it took considerable time and resources. We will be prepared for this additional administrative burden in future rounds.

One node wished to advertise an Indigenous-only position, however we were unable to meet the requirements of having an Indigenous member on the selection committee and as a contact person. We found that the Indigenous-identifying members of this university were already over-burdened with such requests. We realised we need to create a meaningful strategy and implementation plan to address this gap in our Centre.

RMIT University also trialled the use of ARTO (Achievement Relative to Opportunity) for the first time in a recruitment round. While this has been used for promotion cycles within the university previously, the use of ARTO allowed applicants to explicitly make a case for any considerations which needed to be made while assessing their track record. These considerations could include career interruptions due to parental leave, immigration, change of positions, moving sectors, and other life circumstances. It was very satisfying to see some applicants opt for this and explain their circumstances, which allowed the panel to assess their track record appropriately.

We directly appointed two women from Establishment Funds, one of which had spent over one year in non-academic employment. We also appointed one man, who had just submitted his PhD. We encourage Chief Investigators, where a woman or person from another underrepresented group is identified, to discuss the application with the Directorate and IDEA Chair in the first instance. If we all agree that the candidate's track-record is sufficient, the Chief Investigators proceed with a direct appointment via their university processes. These appointments, generally less than 12 months, give the candidate the opportunity to develop a more competitive track-record prior to applying for our longer-term positions. Fixed-term direct appointments, particularly where a person has had a career interruption, is a low-risk way to give people opportunities to succeed in a supportive environment.

An overwhelming number of women who have had long breaks and who have struggled to come back to the workforce also applied for Centre positions, and this has given us the thought to create Career Respark positions. The IDEA Committee will work on understanding and establishing these positions through a scheme in 2021-22.

Our universities have '50-50 why not' policies on shortlisting, but often there is limited guidance on techniques that can help us overcome our unconscious biases and put these policies into practice. The training we received as a Centre helped us to develop useful triggers to make what is unseen come to light. For example, we applied our diversity values in the professional staff recruitment space. The technique of the selection panel independently shortlisting men and women *before meeting to create a single shortlist* was very effective in identifying diverse candidates for our administrative roles, which are predominantly undertaken by women in higher education. We will be applying these tactics to the general postdoctoral recruitment round in 2021.

People

Chief Investigators

PROFESSOR DRAGOMIR NESHEV

Centre Director

The Australian National University

Professor Neshev is the Director of the Australian Research Council Centre of Excellence for Transformative Meta-Optical Systems (TMOS). Additionally, he leads the Experimental Photonics Group for the Research School of Physics at the Australian National University. Professor Neshev was one of the founders of the inaugural ANU Grand Challenge "Our Health in Our Hands" (OHIOH) which aims to develop deep personalisation of disease diagnostics and treatment.

PROFESSOR KENNETH CROZIER

Centre Deputy Director

University of Melbourne

Professor Crozier is the Deputy Director of the Australian Research Council Centre of Excellence for Transformative Meta-Optical Systems (TMOS). His research interests are in nano- and micro-optics, with an emphasis on novel nanomaterial-based photodetectors, metasurfaces and optical nanotweezers. Professor Crozier was awarded a Future Fellowship with the Australian Research Council and Innovation Fellowship from VESKI in 2014.

PROFESSOR IGOR AHARONOVICH

Chief Investigator

University of Technology Sydney

Professor Aharonovich's research is focused on exploring single defects in wide bandgap semiconductors for quantum technologies. Specifically, his team was the first to discover single emitters in hexagonal boron nitride and the first to isolate spin defects in this material. Professor Aharonovich received the Pawsey Medal from the Australian Academy of Science (2017) and the David Syme Research Prize (2017).

PROFESSOR MADHU BHASKARAN

Chief Investigator
RMIT University

Professor Bhaskaran's research interests include functional oxide thin films, wearable technologies and conformal devices. In 2017 she was recognised with the Eureka Prize for Outstanding Early Career Researcher. In 2018, she won the Australian Academy of Technology and Engineering's Batterham Medal and the APEC Science Prize for Innovation, Research and Education. She was the 2020 winner of the 40 Under 40 Most Influential Asian-Australians Award in the Science and Medicine category.

PROFESSOR LORENZO FARAONE

Chief Investigator
University of Western Australia

Professor Faraone's areas of research cover Si, GaAs, HgCdTe, AlGaN/GaN and Optical MEMS device physics and modelling, device fabrication technology and reliability, and electrical and physical characterisation of semiconductor materials and device structures. His leadership has been recognised by his Membership to the Order of Australia (AM), and Fellowships of the IEEE (FIEEE), the Australian Academy of Science (FAA), and the Australian Academy of Technological Sciences and Engineering (FTSE).

PROFESSOR LAN FU

Chief Investigator
The Australian National University

Professor Fu's main research interests include III-V compound semiconductor materials and structures grown by metal-organic chemical vapour deposition; as well as design and fabrication of III-V semiconductor based optoelectronic devices, such as lasers/LEDs, photodetectors, solar cells and THz detectors. Professor Fu is a senior member of IEEE, IEEE/Photonics and Electron Devices societies, and Chair of the IEEE Nanotechnology Council Chapters & Regional Activities Committee.

PROFESSOR FRANCESCA IACOPI

Chief Investigator
University of Technology Sydney

Professor Iacopi's research is focussed on the translation of basic scientific advances in nanomaterials and device concepts into integrated technologies. She is known for her influential work in porous dielectrics for interconnects, and, more recently, graphene for on-chip applications. Professor Iacopi received a Global Innovation Award in Washington DC (2014) and was listed among the most innovative engineers by Engineers Australia (2018).

PROFESSOR CHENNUPATI JAGADISH

Chief Investigator
The Australian National University

Professor Jagadish is a Distinguished Professor and his areas of specialisation cover an extremely large range including semiconductor nanotechnology, photonic device integration, and optoelectronic devices as well as many more. Professor Jagadish recently became an International/Foreign Member of the US National Academy of Engineering (2020) as well as a Foreign Fellow of the National Academy of Sciences of India (2020). Professor Jagadish has created an Endowment to support visiting students from developing countries to spend up to 3 months at ANU Physics gaining research experience and developing collaborative linkages.

ASSOCIATE PROFESSOR MARIUSZ MARTYNIUK

Chief Investigator
University of Western Australia

Associate Professor Martyniuk has a strong interest in thin-film materials and thin-film mechanics, as well as their applications in micro-electromechanical systems and optoelectronic devices. In 2008, his research contributions were recognised as a team member of the Inaugural Australian Museum Eureka Prize for Outstanding Science in Support of Defence or National Security.

PROFESSOR ANN ROBERTS

Chief Investigator
University of Melbourne

Professor Roberts has diverse research interests in physical optics and photonics. In particular, she has made significant advances in the computational and experimental study of plasmonic devices, metamaterials and nanoscale antennas. She is a Fellow of the Australian Institute of Physics (and former Victorian Branch Chair), a Member of the Australian Optical Society (and former President), and a fellow of both the Optical Society (OSA) and SPIE.

PROFESSOR ILYA SHADRIVOV

Chief Investigator
The Australian National University

Professor Shadrivov's research includes metamaterials and metasurfaces. He leads Terahertz Spectroscopy and Microwave labs at the Nonlinear Physics Centre. He is a Vice Chair of the OSA 'Spotlight in Optics' and held Future Fellowship from the Australian Research Council as well as being a Fellow of the Optical Society and of the Australian Institute of Physics.

PROFESSOR SHARATH SRIRAM

Chief Investigator
RMIT University

Professor Sriram's passion is to unlock discoveries in materials and devices in order to transform these discoveries into technologies for everyday use, with a particular focus on healthcare. He received the 2016 Australian Museum 3M Eureka Prize for Emerging Leader in Science, and is currently a board member of Science and Technology Australia, and a member of the Australian Research Council College of Experts.

PROFESSOR ANDREY SUKHORUKOV

Chief Investigator
The Australian National University

Professor Sukhorukov's research targets the fundamental aspects of miniaturisation of optical elements down to micro- and nano- scale while achieving advanced functionalities beyond the capabilities of traditional optics. In 2015, Professor Sukhorukov was elected a Fellow of the Optical Society (OSA) for "pioneering contributions to nonlinear and quantum integrated photonics, including frequency conversion and broadband light manipulation in waveguide circuits and metamaterials".

PROFESSOR HARK HOE TAN

Chief Investigator
The Australian National University

Professor Tan's research activities cover both fundamental and applied aspects of semiconductor optoelectronics, with two distinctive contributions in (i) epitaxial growth of III-V semiconductor materials and devices by metal organic chemical vapour deposition (MOCVD) and (ii) ion irradiation of compound semiconductors for optoelectronic applications. In 2019, Professor Tan was elevated to a Fellow of the IEEE "for contributions to compound semiconductor optoelectronic materials and devices".

PROFESSOR MILOS TOTH

Chief Investigator
University of Technology Sydney

Professor Toth's current research is focused on 2D materials and wide bandgap hosts of singe photon emitters. He maintains a long-term industry research partnership with Thermo Fisher Scientific. Professor Toth is the Chair of the Colloquium Committee for the Australian Research Council Centre of Excellence for Transformative Meta-Optical Systems (TMOS).

We acknowledge and thank our former Chief Investigator, Professor Min Gu previously of RMIT university, for his contribution to the establishment of the Centre. He has been instrumental in forming the Centre vision as well as detailing the research program and impact of the Centre. We wish Professor Gu all the best with his new position and look forward to continued collaboration.

Postdoctoral Researchers

The following postdoctoral researchers were employed by the Centre through our Establishment Funding in 2020.

DR YANA IZDEBSKAYA

Research Fellow
The Australian National University

Dr Izdebskaya's research interests include linear and nonlinear wave propagation, singular optics, and physics of liquid crystals for photonics applications. She has demonstrated a three-dimensional control of liquid crystal molecular orientation by applying an external magnetic field. In TMOS, her main research focus on development of dynamically tunable metasurfaces by liquid crystals, with the purpose to enable functional nanosystems with tunable optical properties.

DR AISWARYA PRADEEPKUMAR

Postdoctoral Research Associate
University of Technology Sydney

Dr Pradeepkumar works as a Postdoctoral Research Associate in the Integrated Nanosystems Lab led by Profressor Iacopi in the Faculty of Engineering and IT, UTS. Dr Pradeepkumar's research focuses on dynamically tunable metasurfaces with epitaxial graphene on silicon wafers. She has demonstrated large-scale electronic transport characteristics of epitaxial graphene on silicon, with the purpose to enable functional nanosystems with tunable electronic and optical properties.

DR LUKAS WESEMANN

Postdoctoral Research Fellow
University of Melbourne

Dr Wesemann's research focuses on the development of nanophotonic structures for ultra-compact, all-optical image processing including biological phase-imaging. He has recently demonstrated a nanophotonics enhanced coverslip that permits phase-imaging of biological cells and could be part of future mobile medical diagnostic equipment.

HDR Students

The following students were affiliated with the Centre in 2020.

NIKITA GAGRANI
HDR Student
Australian National University

SHIYU WEI
HDR Student
Australian National University

ZAHRA AZIMI
HDR Student
Australian National University

ASWANI GOPAKUMAR
HDR Student
Australian National University

SHUBHASHREE SWAIN
HDR Student
University of Western Australia

YAN LIU
HDR Student
University of Western Australia

SUMAIYA KABIR
HDR Student
RMIT University

MARCUS CAI
HDR Student
Australian National University

NEUTON LI
HDR Student
Australian National University

MATTHEW PARRY
HDR Student
Australian National University

SHAUN LUNG
HDR Student
Australian National University

SONACHAND ADHIKARI
HDR Student
Australian National University

FANLU ZHANG
HDR Student
Australian National University

MOHAMMAD RASHID
HDR Student
Australian National University

WEI WONG
HDR Student
Australian National University

JORDAN MCMAHON
HDR Student
Australian National University

PARSHWA MANGLE
HDR Student
Australian National University

HENRY TAN
HDR Student
Australian National University

JIAJUN MENG
HDR Student
Australian National University

NIMA AZAR
HDR Student
Australian National University

BENJAMIN RUSSELL
HDR Student
Australian National University

PATRICK RUFANGURA
HDR Student
Australian National University

DAVID KATZMAREK
HDR Student
Australian National University

Partner Investigators

PROFESSOR HARRY ATWATER

Partner Investigator
California Institute of Technology, USA

Professor Atwater is a Howard Hughes Professor and Professor of Applied Physics and Materials Science at the California Institute of Technology. Since 2014 he is the editor-in-chief of the journal ACS Photonics, published by the American Chemical Society. His research interests focus around two interwoven research themes: photovoltaics and solar energy; and plasmonics and optical metamaterials.

PROFESSOR ANDREI FARAON

Partner Investigator
California Institute of Technology, USA

Professor Faraon is a Professor of Applied Physics and Electrical Engineering at the California Institute of Technology. His research interests are in solid state quantum optics and nano-photonics. Applications include quantum information processing, on-chip optical signal processing at ultra-low power levels, energy efficient sensors, bio-photonics.

PROFESSOR TERI ODOM

Partner Investigator
Northwestern University, USA

Professor Odom is the Chair of the Chemistry Department, Charles E. and Emma H. Morrison Professor of Chemistry, and a Professor of Materials Science and Engineering at Northwestern University. Research in Odom's group focus on controlling materials at 100 nm scale and investigating their size and shape-dependent properties.

PROFESSOR ISABELLE STAUDE

Partner Investigator

Friedrich Schiller University of Jena, Germany

Professor Staude studied physics at the University of Konstanz, and subsequently received her PhD from the Karlsruhe Institute of Technology, Germany, in 2011. For her postdoctoral fellowship, she moved to the Nonlinear Physics Centre, Australian National University, Canberra, Australia, where she coordinated the experimental activities on optical nanoantennas and served the nanoplasmonics stream in the Australian Centre of Excellence CUDOS as deputy project leader. She received an Emmy-Noether Grant from the German research Foundation and the Hertha Sponer Prize 2017 from the German Physical Society.

PROFESSOR ANDREW WEE

Partner Investigator

National University of Singapore

Professor Wee is Professor of Physics, and Vice President (University and Global Relations) at the National University of Singapore. His research interests include scanning tunnelling microscopy (STM) and synchrotron radiation studies of the molecule-substrate interface, graphene and 2D materials, and related device studies. He is an Associate Editor of ACS Nano, and on the Editorial Boards of several other journals. He holds a BA (Honours) and MA in Physics from the University of Cambridge, and DPhil from the University of Oxford.

ASSOCIATE PROFESSOR CHENGWEI QIU

Partner Investigator

National University of Singapore

Professor Qiu received his B.Eng. and PhD in 2003 and 2007, respectively. He was a Postdoctoral Fellow at Physics Department in MIT till the end of 2009. From 1st Jan 2018, he was promoted to Dean's Chair Professor in Faculty of Engineering, NUS. He is currently Associate Editor for Photonics Research, Editor-in-Chief for eLight, and Associate Editor of PhotoniX. His research is known for the structured light for beam manipulation and nanoparticle manipulation.

PROFESSOR WILLIE PADILLA

Partner Investigator

Duke University, USA

Professor Padilla has been in the metamaterials field since 2000, when he co-authored the first paper on negative index materials with Smith. Padilla is particularly well known for his work at terahertz (THz) frequencies, as well as in the area of active and dynamically controlled metamaterials. Padilla's recent interests include tailoring the emissivity of objects with metamaterial coatings, and the use of active metamaterial arrays as components in THz and infrared imaging systems.

PROFESSOR DEMETRIOS CHRISTODOULIDES

Partner Investigator

University of Central Florida, Orlando, USA

Professor Christodoulides received his PhD from Johns Hopkins University in 1986 and he subsequently joined Bellcore as a post-doctoral fellow at Murray Hill. Between 1988 and 2002 he was with the faculty of the Department of Electrical Engineering at Lehigh University. His research interests include linear and nonlinear optical beam interactions, synthetic optical materials, optical solitons, and quantum electronics. He has authored and co-authored more than 450 papers.

PROFESSOR SANJAY KRISHNA

Partner Investigator

The Ohio State University, USA

Professor Krishna is the George R Smith Professor of Engineering in the ECE department at the Ohio State University. He received his M.S. in Electrical Engineering in 1999 and PhD in Applied Physics in 2001 from the University of Michigan. His group is involved in the development of next generation infrared detectors, arrays and imagers. His achievements include Gold Medal from IIT Madras, Ralph Power Junior Faculty Award, IEEE Outstanding Engineering Award, the NAMBE Young Investigator Award, IEEE-NTC, SPIE Early Career Achievement Award and the ISCS Young Scientist Award.

DR HANNAH JOYCE

Partner Investigator
University of Cambridge, UK

Dr Joyce is a scientist, and a lecturer at the Department of Engineering at the University of Cambridge. Her research specialises in the development of new nanomaterials for applications in optoelectronics and energy harvesting. She obtained her PhD in physics from the Australian National University in 2010, where her research focused on the growth and characterisation of III-V semiconductor nanowires for applications in optoelectronic devices. She is currently a reader in low-dimensional electronics at the University of Cambridge, and her research group studies the development of new nanomaterials, such as nanowires, for applications in photonic and electronic devices.

PROFESSOR MICHAEL JOHNSTON

Partner Investigator
University of Oxford, UK

Professor Johnston is a THz Photonics Group Leader. His research focuses on semiconductor nanowires, terahertz photonic technologies and vapour deposited perovskite materials for photovoltaic applications. Professor Johnston obtained his PhD working on the topic of "quantum well infrared photodetectors" at the University of New South Wales in 2000. He is currently Professor of Physics at the department of Physics at the Oxford University, UK.

PROFESSOR LAURA HERZ

Partner Investigator
University of Oxford, UK

Professor Herz is a Professor of Physics at the University of Oxford. She works on femtosecond spectroscopy for the analysis of semiconductor materials. She worked for two years as an exchange student at University of New South Wales and subsequently joined the University of Cambridge for her doctoral studies, earning her PhD in 2002. Professor Herz is an expert in perovskite semiconductors and has researched the origins of the high charge-carrier mobilities in perovskite materials.

PROFESSOR ANDREA ALÙ

Partner Investigator
City University of New York, USA

Professor Alù is the founding director of the Photonics Initiative at the CUNY Advanced Science Research Center, Einstein Professor of Physics at the CUNY Graduate Center, and Professor of Electrical Engineering at The City College of New York. Previously he was the Temple Foundation Endowed professor at the University of Texas at Austin. He is a co-inventor of three inventions in various stages of the patent process which are novel waveguides, scattering devices, optical circuits, optical circuit elements, and a cloaked sensor device.

PROFESSOR YESHAIAHU (SHAYA) FAINMAN

Partner Investigator
University of California San Diego, USA

Professor Fainman joined the faculty at UCSD in July 1990 following a faculty appointment at the University of Michigan. Current research interests in his group include the investigation of artificial dielectric properties of nanostructures; polarization selective computer generated holograms and their applications for image processing, transparent photonic switching fabric and networks, and packaging optoelectronic devices and systems; programmable diffractive optical elements; 3-D holographic optical storage; nonconventional 3-D imaging and displays; quantum cryptography for photonic network security and privacy.

DR NORBERT HERSCHBACH

Partner Investigator
IEE, Luxembourg

Dr Herschbach is an industrial researcher with more than 15 years of experience in optical experiments. His expertise was gained through his work in five quantum optics laboratories around Europe, where he has performed experiments on laser cooling and trapping of atoms and ions investigating cold atomic collisions, photoassociation spectroscopy and developing a new ion trap design for advanced optical frequency standards. During the last nine years, he has worked at IEE S.A., Luxembourg, where he has acquired valuable industrial R&D experience in optics and three-dimensional imaging for sensing systems, dedicated to the markets of automotive safety, building management and security.

DR AURELIEN BOTMAN

Partner Investigator
Thermo Fisher Scientific, USA

Dr Botman received his MSc. and BA in Natural Sciences from the University of Cambridge (UK) in 2005. He obtained his PhD on the topic of electron beam induced deposition in 2009 from the Technische Universiteit Delft (The Netherlands), while performing research at Philips Research Laboratories in Eindhoven and subsequently at FEI in Acht. He currently leads a research group at Thermo Fisher as R&D Manager, leading a team of scientists in charged particle microscopy, developing instrumentation, application workflows, and microanalysis techniques.

We acknowledge and thank our former Partner Investigators, Dr Marcus Straw and Dr Chad Rue of Thermo Fisher Scientific, Professor Cun-Zheng Ning of Tsinghua University and Arizona State University, and Associate Professor Jin Liu of Sun Yat-Sen University, for their contributions to the establishment of the Centre.

Professional Team

DR MARY GRAY

Chief Operations Officer
The Australian National University

Mary studied a PhD in human genetics at the University of Otago, New Zealand, graduating in 2013. Also, in 2013, she managed the Dementia Australia Research Foundation, based in Canberra, before commencing her research management career at ANU in 2014.

HELENA BECK

Centre Administrator
University of Technology Sydney

Helena has been working within the UTS Faculty of Science for more than a year after moving from the Faculty of Arts and Social Science. She supports two Centres and is excited to join us at the start of the journey.

JOSHUA COTTON

(commences 15 February 2021)

Centre Administrator
The Australian National University

Joshua is fluent in Spanish and French and has a triple Bachelor of Laws, Psychological Science, and Business as well as professional experience in administration and international student marketing within the Higher Education sector.

HANA HOBLOS

(commences 19 January 2021)

Centre Administrator
RMIT University

Hana is the administrative officer for the RMIT Node, involved in event scheduling and management, financial and KPI reporting, and general executive support, as well as guidance and support to RMIT staff and students undertaking research within the RMIT Functional Materials and Microsystems Research Group.

KAREN KADER

Centre Administrator (acting)
University of Western Australia

Karen is a dedicated administrative officer with over 20 years of experience providing administrative support in the academic environment.

PETER NOWOTNIK

(commences 18 January 2021)

Inclusion, Diversity Equity, and Access Officer
RMIT University

Before joining the Centre, Peter worked at RMIT's Centre for People, Organisation and Work since 2018 and has expertise in IT and adult education.

GALINA SHADRIVOVA

(commences 1 February 2021)

Business Coordinator

The Australian National University

Galina studied Economics and IT in Russia. She changed her career focus after coming to Australia 19 years ago and became a professional accountant and finance specialist. Galina worked as an Accounting Practice Manager before joining ANU in 2017.

SAMARA THORN

(commences 3 March 2021)

Engagement Manager

The Australian National University

Samara has a background in P-12 science education as well as marketing and communications in the not-for-profit sector. She specialises in content and digital marketing.

Associate Investigators

Strong international collaboration is prominent in our Centre, with our Associate Investigators (AI) coming from fifteen different organisations across three continents.

However, we recognise the need for further action in addressing under-representation of women in our ranks. Therefore, we aim to provide sustainable strategies for leadership development for women, including mentoring, training, and targeted recruitment.

Our current proportion of women investigators in our AI group leaves room for improvement. To a large extent, it is reflective of historical and current inequity and exemplifies the requirement for continuous action to improve gender equity across research institutions.

Gender issues are often nested in long-term social mindsets. Change is a sum of numerous localised efforts:

- Developing strategies for mentoring and training.
- Encouraging all individuals to participate in parental leave, carer leave, and flexible work arrangements.
- Supporting all individuals to return to work after parental or carer leave.
- Providing flexible work facilities for all individuals with caring responsibilities.
- Developing strategies for promoting recruitment, retention, and progression of women in research.
- Developing procedures and training for workplaces that are free from bias, discrimination, and harassment.

Active effort to create work environments free from bias and discrimination will lead to more diverse and inclusive research teams, and more excellent research.

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
University of California, Berkeley, USA

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

DR MOHSEN RAHMANI

Associate Investigator

The Australian National 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

Associate Investigator

Friedrich-Schiller-Universität Jena, Germany

PROFESSOR ANTONIO TRICOLI

Associate Investigator

The Australian National University

ASSOCIATE PROFESSOR YUERUI LU

Associate Investigator

The Australian National University

DR ZONGYOU YIN

Associate Investigator

The Australian National University

DR 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

Research

Message from the Deputy Director

> We are delighted to be partnering with the best and the brightest from all corners of the globe...

Optics research has a long and distinguished history in Australia. We aim to add a new and exciting chapter to this legacy, not just through our scientific results, but also by nurturing students and early career researchers who are our future. We are delighted to be partnering with the best and the brightest from all corners of the globe to achieve our vision.

The year 2020 was a busy and productive time for the Centre. Like everyone else, the global pandemic required us to adapt, moving to the use of teleconferencing rather than in-person meetings. Despite these challenges, the Centre designed and put in place all the processes needed for its key goals of research, education, outreach, and diversity.

The most memorable highlight for 2020 for me was the Student and Early Career Researcher (ECR) event, held online in December 2020. The program included 38 poster presentations, 27 talks made by students and ECRs, and nine talks made by the Chief Investigators. In addition, the two talks from companies Baraja and Liquid Instruments provided students and ECRs with much insight into future career paths. By the end of the two-day program, I was left with a notebook full of new ideas and the knowledge that enthusiastic collaborators were just a Zoom call away.

I was also delighted to see much work in print with contributions from our Chief Investigators and Partner Investigators in 2020, with highlights as follows.

Regarding the "Generate" theme, there was a study in Nature Materials (Nov 2020). There has been much interest in single photon emitters from hexagonal boron nitride recently, yet their nature was never really understood. This study showed direct evidence that visible single photon emission was carbon related. This will undoubtedly be important for future applications.

In the "Manipulate" theme was an unusual type of colour hologram metasurface published in Advanced Functional Materials (vol. 30, 1906415 (2020)). Holograms record optical wavefronts but usually look unintelligible under diffuse ambient light. Here a metasurface was shown in which a hologram was encoded into a colour printed image. The printed image could be directly viewed under white light illumination, while a low-crosstalk colour holographic image can be seen when the device is illuminated with red, green, and blue lasers. A very promising science advancement indeed.

Lastly, of relevance to the "Detect" theme, there was a terahertz study in Science (vol. 368, 510 (2020)). There is currently much interest in this spectral range due to applications that include security screening and medical imaging. Conventional terahertz systems are usually sensitive to just one of the polarization states of light. However, it was shown that indium phosphide nanowires could be used to record the full polarization state of terahertz pulses. This is an exciting development.

The year 2021 will undoubtedly bring more scientific achievements for our Centre. We look forward to describing these in future reports. In the meantime, we extend our best wishes to everyone in our shared challenge of the global pandemic.

Professor Kenneth Crozier
Centre Deputy Director
January 2021

Research Overview

Australian Research Council Centre of Excellence for Transformative Meta-Optical Systems (TMOS) will develop miniaturised optical systems for the next generation advance in technology.

The term meta-optics comes from the Greek word μετά, meaning 'beyond', which is to take optics beyond its established principles and technologies. Many of the principles of optics have remained unchanged since the invention of the lens in early civilisation.

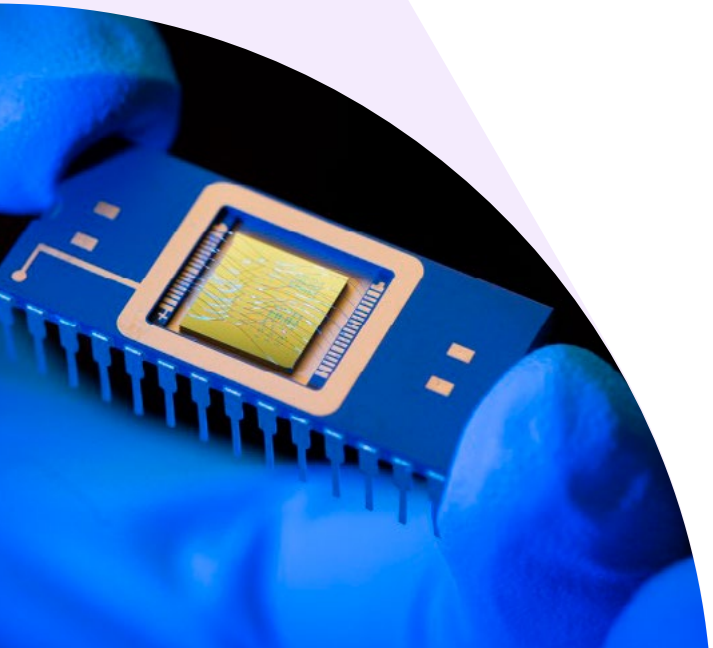
Although those ancient principles underpinned technologies such as telescopes and cameras, they are now the limiting factor in ever-shrinking devices and the capabilities needed in machine-to-machine and human-to-machine communication in Industry 4.0. As we harnessed the power of the electron for transistors and electronics, we must now harness the power of the photon for the optical revolution.

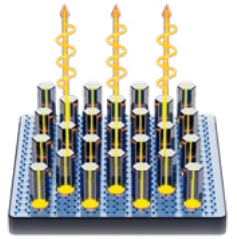
Our challenge is how to generate, manipulate (distribute) and detect light for the creation of optical devices that are extraordinarily compact, lightweight and intelligent. Meta-optics research aims to overcome this challenge with the use of nanotechnology.

By harnessing the disruptive concept of meta-optics, the Centre will overcome complex challenges in light generation, manipulation and detection at the nanoscale. Our research will underpin future technologies, including real-time holographic displays, artificial vision for autonomous systems to see the invisible and ultra-fast light-based WiFi.

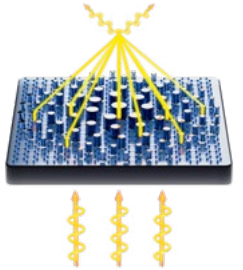
Our Centre has three Research Themes – Generate, Manipulate and Detect.

Find out more about our themes on our website

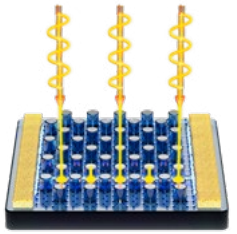




GENERATE



MANIPULATE

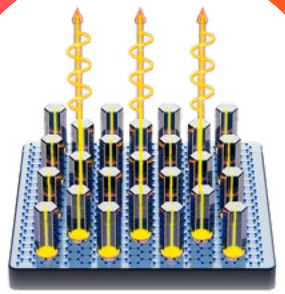


DETECT

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

To do this requires a fundamentally new concepts and approach to light sources. Metasurfaces provide the opportunity to revolutionise this technology. By engineering arrays of nanoscale emitters to interact with metasurfaces or forming the metasurfaces themselves, they can be collectively and dynamically driven to emit light with the properties they are designed for. As these arrays of emitters are nanoscale in size, they would require less power to operate and can be fabricated using current integrated circuits technology.

These nanoscale light sources, integrated onto an electronic chip can be used in a range of technology products. For example they could make dynamic holograms (such as those seen in Star Wars® movies) which is largely in the realm of science fiction a reality, or they could be combined with indoor LED lighting technology for the next generation ultra-high speed wireless optical networking technology (LiFi), or quantum light sources for secure optical communications and on-chip quantum information processing.

GENERATE will focus on the science of light interaction with matter at the nanoscale and developing meta-optical light emitters. Generate is composed of several sub-programs: (i) nanoscale lasing meta-optics—

exploring nanowires and atomically thin (2D) materials as gain medium, (ii) deterministic generation of quantum light sources with high purity based on single defects in 2D materials, (iii) new design of III-V nanowires for flexible and tunable LEDs. Together, we will discover the brightest and most efficient miniaturised classical and quantum light sources.

ACTION ITEMS FOR 2021

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

FURTHER READING

Identifying carbon as the source of visible single-photon emission from hexagonal boron nitride, N. Mendelson, D. Chugh, J.R. Reimers, T.S. Cheng, A. Gottscholl, H. Long, C.J. Mellor, A. Zettl, V. Dyakonov, P.H. Beton, S.V. Novikov, C. Jagadish, H.H. Tan, M.J. Ford, M. Toth, C. Bradac and I. Aharonovich, Nature Materials, (2020).

https://doi.org/10.1038/s41563-020-00850-y

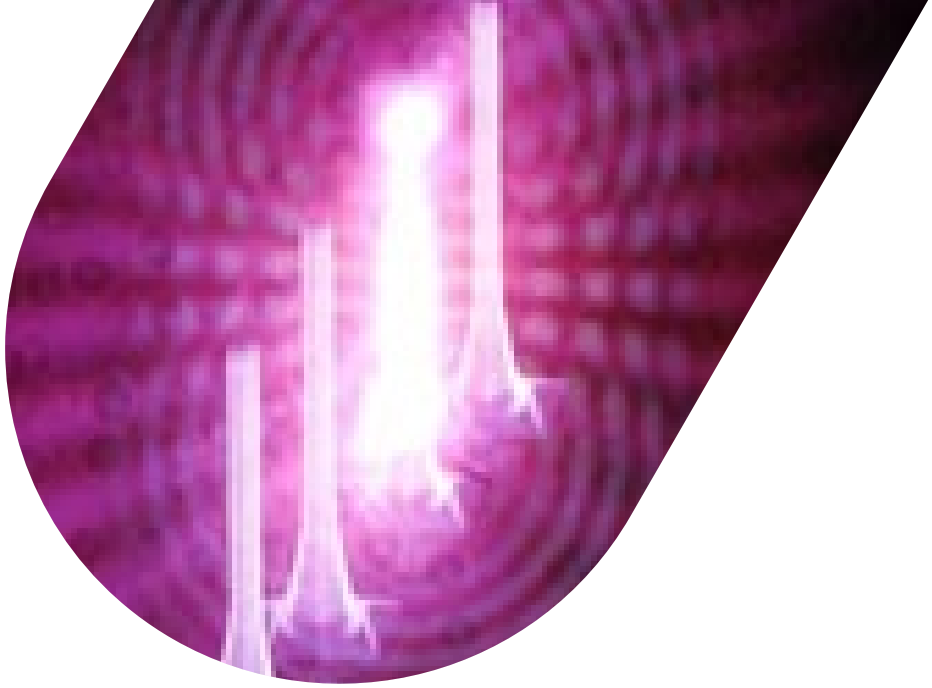
Lasing from InP nanowire photonic crystals on InP substrate, C.W. Tu, M. Franzl, Q. Gao, H.H. Tan, C. Jagadish, H. Schmitzer and H.P. Wagner, Advanced Optical Materials 2001745 (2020).

https://doi.org/10.1002/adom.202001745

Highly uniform InGaAs/InP quantum well nanowire array-based light emitting diodes, I. Yang, S. Kim, M. Niihori, A. Alabadla, Z. Li, M.N. Lockery, D.-Y. Choi, I. Aharonovich, J. Wong-Leung, H.H. Tan, C. Jagadish and L. Fu, Nano Energy 71, 104576 (2020).

https://doi.org/10.1016/j.nanoen.2020.104576

Nanowires as a light source for meta-optics



The work of Chennupati Jagadish and his group, including Professors Hoe Tan and Lan Fu, has broad implications for the research field and for the various research programs of the Centre. Nanowire lasers could be used as coherent light sources for meta-optics applications and developing compact holograms. Nanowire LEDs can be used for LiFi applications.

> In short, nanowires and nanostructures have a great potential for developing next generation photonics technologies."
>
> - Professor Chennupati Jagadish, Centre Chief Investigator

"Our demonstration of the first GaAs nanowire laser has created lot of excitement in the community, globally. Our nanowires have also allowed our collaborators at Oxford and Strathclyde to develop polarization sensitive THz detectors. Furthermore, the broader semiconductor materials and technology developed in our group have the potential to contribute to all three research pillars of TMOS - light generation, manipulation and detection."

So far, the nanowire lasers developed by the group are optically pumped. For practical applications, electrically injected nanowire lasers will need to be developed. This is a challenging task due to the use of metal contacts to inject current but the metals themselves absorb the light generated, thereby causing high optical losses.

"We are currently developing different strategies to overcome this problem such as using non-metallic contacts, different architectures and injection designs. Small lasers and LEDs will find applications in mobile phones for facial recognition, holographic displays and LiFi to augment WiFi for communications. We are also using nanowires for neuroscience applications and photoelectrochemical water splitting to generate hydrogen as a clean, storable and transportable energy source."

SPOTLIGHT

Chennupati Jagadish

Centre Chief Investigator

Professor Chennupati Jagadish came from very humble beginnings in India. He grew up without electricity, studying in front of a kerosene lamp. This experience had a profound effect on him and sparked his interest in light and light-based technologies.

"I initially wanted to be an engineer but couldn't get enrolled into an engineering degree after I finished my year 12. I ended up majoring in physics and developed engineering skills later in life. In hindsight, this path I have taken has given me the opportunity to develop into a more well-rounded person. Now I am accepted as a physicist, materials scientist and an electronics engineer."

He came to The Australian National University (ANU) in 1990 as a postdoctoral fellow. For the last 30 years Jagadish has been leading a group working on developing nano-lasers, nano-LEDs, photodetectors and solar cells. The group's expertise in materials enables them to obtain an in-depth understanding

RELATED WORKS

- Optically pumped room-temperature GaAs nanowire lasers, Nature Photonics, 17 November 2013

https://doi.org/10.1038/nphoton.2013.303

- Three-dimensional cross-nanowire networks recover full terahertz state, Science, 1 May 2020

https://doi.org/10.1126/science.abb0924

- Identifying carbon as the source of visible single-photon emission from hexagonal boron nitride, Nature Materials, 2 November 2020

https://doi.org/10.1038/s41563-020-00850-y

- Failures are pathways to success, presentation by Professor Chennupati Jagadish, 28 April 2020

https://www.youtube.com/watch?v=vXw0vye4w8A

of the properties of these nanowires to synthesise excellent nanowires with near-perfect crystal quality, which is important to develop novel devices.

Recently, Jagadish and his team began collaborating with Professor Yuri Kivshar and Professor Dragomir Neshev, both at ANU, on nonlinear optical properties for nano-antennas made from GaAs structures. From this collaboration the Centre was eventually born.

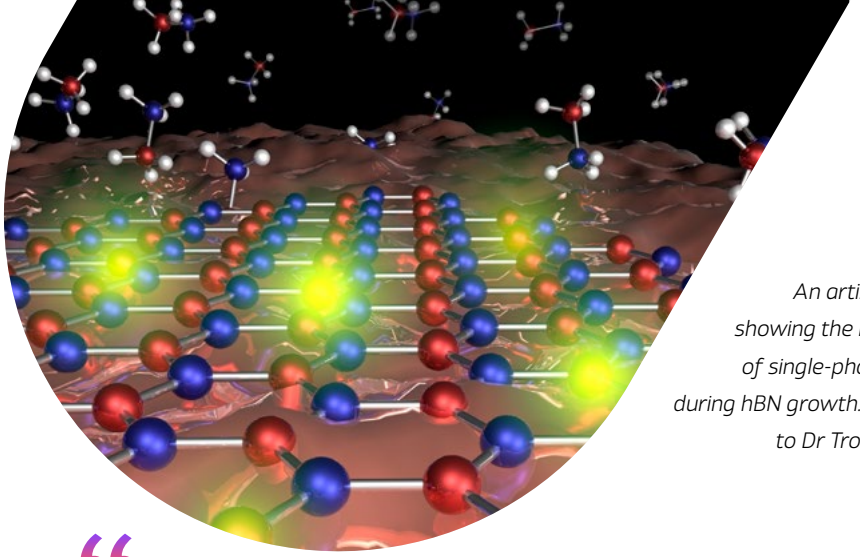
"Our collaboration has been highly fruitful, resulting in a number of joint papers and co-supervision of students and co-mentoring of early career researchers. It's incredibly satisfying to see this work evolve into the Centre, the purpose of which reaches beyond advancement in the field of metasurfaces to the development of a strong, vibrant scientific community."

Jagadish's leadership in the Centre has already opened opportunities to collaborate with the Chief Investigators, Partner Investigators and Associate Investigators. For example, they have already published a joint paper in Nature Materials with Professor Igor Aharonovich' s group at the University of Technology Sydney on single photon sources in hBN and the role of carbon in the emission.

In his free time, Jagadish listens to western and Indian classical music, visits art galleries and watches Indian classical dance.

GENERATE CASE STUDY

Atomically thin single photon sources for quantum information



An artist impression showing the incorporation of single-photon emitters during hBN growth. Image credit to Dr Trong Toan Tran.

Centre Chief Investigator Igor Aharonovich and his team at the University of Technology Sydney specialise in single-photon sources: quantum sources which emit a single particle of light, or a photon, at a time. With these sources, they can generate, encode, and distribute quantum information. One of the systems that the group works with is called "white graphene" or hexagonal boron nitride (hBN): a two-dimensional material with defects that can act as a source of single photons. However, a lack of knowledge about the defect structure has hindered the progress of utilising hBN for scalable quantum technologies.

"We have been able to introduce selective defects in the material, specifically carbon atoms, which can be integrated into hBN during the growth process, or after growth, and in both cases, we were able to definitively link the incorporation of these carbon atoms to the observation of single-photon emission. Thereby, we proved for the first time that the single-photon sources in hBN are carbon-based defects."

Aharonovich and his group were also able to demonstrate for the first time at room temperature that these hBN defects are spin carrying defects, an important property for many quantum applications.

While single photon emitters in hexagonal boron nitride are still a relatively new quantum light source, now that more is known about the nature of the system, the Centre can rapidly accelerate its development from research curiosity to a technologically relevant platform. The ability to reliably fabricate these quantum sources will enable further fundamental studies on their properties and performance and enable us to address inherent challenges more quickly, such as reducing electrical fluctuation in the material, which degrades performance. These fundamental inquires will allow us to identify emerging technological opportunities in which the system can outperform alternatives.

"Given our new insight, we are excited to further study the system as a source of non-classical light emission for quantum technologies."

"Our results resolve a long-standing debate about the origin of single emitters at the visible range in hBN and will be key to the deterministic engineering of these defects for quantum photonic devices."

- Noah Mendelson, PhD student

SPOTLIGHT

Noah Mendelson

PhD student

Noah Mendelson was enthralled by the revolutionary potential of quantum computers and the progress of quantum technologies involving solid state defects. Since arriving at UTS, Noah studied single-photon sources in hexagonal boron nitride and worked towards advancing it into a mature and technologically relevant platform.

"I first became aware of research with the quantum information sciences and the immense potential of these technologies when reading a 2013 article in Scientific American titled 'Beyond the Quantum Horizon.'"

In 2015, Mendelson started to read more about quantum technologies involving solid-state defects, and when he was looking for the

RELATED WORKS

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https://doi.org/10.1038/s41563-020-00850-y

- TMOS Science news: Single-photon emitters: a breakthrough discovery

https://tmos.org.au/single-photon-emitters-a-breakthrough-discovery/

best place to do his PhD, he came across the recent discoveries from the groups of Professor Igor Aharonovich and Professor Milos Toth about a two-dimensional solid-state quantum system, and knew immediately that UTS was where he wanted to do his research.

Despite only having recently formed, the Centre has already been crucial to Mendelson's work. "I became aware of some of the exceptionally cool research taking place in the labs of many of the TMOS member groups and how well it aligned with our work. When TMOS started to come together it became clear how much we could achieve while working towards common aims."

The collaboration resulted in their most recent work on discovering the structural nature responsible for single-photon emission from hBN. "Without collaboration with TMOS members at Australian National University over the last 12-15 months, our most recent work on discovering the source of visible single-photon emission from hBN would not have been possible.

"When we decided to tackle such a difficult problem, it was clear that definitive answers would require working with people across the community towards this goal. All of our collaborators played an indispensable role in realizing the desired outcomes. I am excited about the next couple years working with such a talented group of researchers.

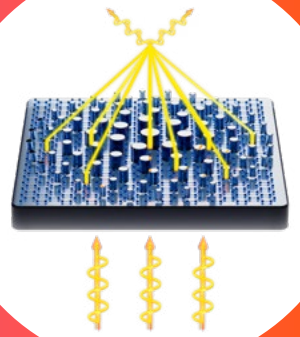
Noah has a diverse research background with expertise in materials science, nanophotonics, nanofabrication, and chemistry. He obtained his master's degree at the University of California San Diego, before finding a PhD position at the University of Technology Sydney.

Outside of the lab he can often be found conversing with both friends and strangers often about science and politics. He also enjoys travelling, camping, sports, and music.

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

Research Theme 2 (RT2) comprises two related sub-themes. The development of novel holographic meta-optics for holographic displays and image processing will be a key research component of this theme. The dynamic reconfigurability of meta-optical elements and making them robust to fabrication and structural deformation will also be key challenges to tackle under this theme. Hologram is just one of the commonly used examples, however with metasurfaces we will be able to control many, if not all, properties of light. Beyond that, we aim to enhance the sensitivity of optical properties of metasurfaces to an external stimulus. The results will benefit not only the manipulation of light but also the development of metasurfaces for interaction with materials to create efficient light sources and optical sensing applications.

The aim for the coming years is to start from the very basic concepts of tunable metasurfaces and develop them to the stage of practical devices. We will explore the design concepts for meta-optics as well as various material platforms. In particular, the Centre team has capabilities to develop novel materials with unique properties that can be tailored for use in metasurfaces.

Metasurfaces enable much stronger tunability and reconfigurability than any natural non-structured material. This makes meta-optics a promising candidate for future flat devices that will dynamically control the wavelength, amplitude, phase, and polarisation of light. These capabilities are essential, for example, for holographic displays and remote imaging. We will build on team expertise in tunable

metamaterials and metasurfaces and aim to enhance the sensitivity of optical properties of metasurfaces to an external stimulus. The results will benefit not only the manipulation of light, but also the development of metasurfaces for optical sensing applications.

The main practical parameters of tunable meta-optics are the modulation contrast and speed. There is often a trade-off between them. The team will explore approaches and designs that have either extremely strong but possibly slow modulation, as well as fast changing metasurfaces that might not have strong modulation. We will proceed with several tunability approaches, including micro-electromechanical systems, liquid crystals, electro-optic, strain, and charge injection in doped metal-oxides or semiconductors. The Centre will explore these and identify which are most suitable to different applications. In tandem with concepts from other research themes, the Manipulate team will target applications in LIDAR, LiFi, and holographic displays. This theme will thus progress in three parallel directions that address different applications but are based on similar design principles and physical understanding.

ACTION ITEMS FOR 2021

1. Experimentally and theoretically explore the tunability of the metasurfaces with liquid crystals, aiming to achieve practically useful range of parameter tunability
2. Study the possibilities to use ferroelectric materials for fast tunable metasurfaces
3. Design static holographic metasurfaces
4. Fabricate and characterise 3D neuromorphic metastructures
5. Investigate the use of phase change materials to realize tunable metasurfaces

FURTHER READING

Ilya Shadrivov and Dragomir Neshev, Tunable Metamaterials

https://doi.org/10.1142/9789813228696_0009

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Sumaiya Kabir, Shruti Nirantar, Liangchen Zhu, Cuong Ton-That, Shubhendra Kumar Jain, Aminuddin Bin Ahmad Kayani, Billy J.Murdoch, Sharath Sriram, Sumeet Walia, Madhu Bhaskaran, "Phase change vanadium dioxide light sensors" Applied Materials Today 21 100833 (2020)

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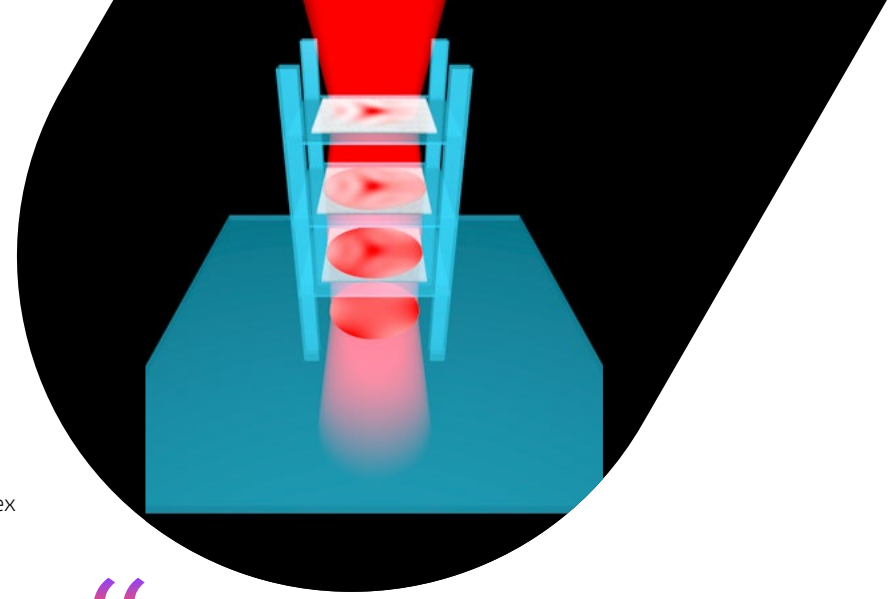
Holographic neural networks



The human brain has an incredible ability to solve complex problems without being programmed with any problem-specific rules. By mimicking the functions of the brain using computer programming, we have been able to create artificial intelligence. However, the processing requirements of traditional artificial intelligence systems is colossal.

Ben Cumming and his team at RMIT's Laboratory of Artificial-Intelligence Nanophotonics are exploring a new field of research that examines how light and photons mimic the immense processing power of the human brain and its holographic systems.

"Can photons perform the same processing but at the speed of light and without any energy requirements? I am excited by the implications an answer to that question might have."

Moving forward, this research focus has the potential to impact both the research field and the various research programs of the Centre. The early demonstration of these holographic systems was performed using the rapid prototyping capability of 3D Nano-Printing, but improvements can be made with Centre expertise.

"We demonstrated that diffractive holograms could be 3D nano-printed at optical wavelengths, mimicking the weighting behavior of the human brain to solve complex tasks such as image classification. However, control of phase with 3D nano-printing is difficult, and more precision control of phase offered by the Centre's metaoptics fabrication capability may well enhance performance."

Dr Cumming also believes there are gains to be made in the technology by expanding the features of the brain mimicked by the holographic neural networks.

"Another key feature of the brain's processing power is activation, and for optics this requires nonlinearity. I'm excited to explore how the nonlinear optical tools and expertise of the Centre may provide a solution to this important neural network behavior in holographic neural networks."

Beyond research, Dr Cumming is eyeing off broader impact. The technology has the potential to impact critical high speed vision systems requiring rapid measurement and classification of scene information.

"Imagine self-driving vehicles that can detect hazards at the speed of light. Imagine vast arrays of ground-based telescopes immune to atmospheric interference. Imagine real time cellular diagnosis available to surgeons."

> "Imagine the power of information processing at the universal speed limit: light speed."
>
> - Ben Cumming, Research Fellow

SPOTLIGHT

Ben Cumming

Research Fellow

From an early age, Ben was keen to explore how the world worked—a passion that meant the sacrifice of many household items. That curiosity led him to pursue a career in science, engineering, and ultimately photonics.

"I remember browsing university course descriptions in high school and stumbling upon a science degree in photonics offered by Swinburne University of Technology. From that moment, I was hooked on the possibilities and benefits of information processing with light and made it my mission to be accepted into that course. Seventeen years later and I'm engrossed as ever, enjoying my research and the opportunity to benefit and teach others."

Ben's studies ultimately led to a doctorate degree in science from Swinburne University's

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https://doi.org/10.1038/s41377-021-00483-z

- Direct determination of aberration functions in microscopy by an artificial neural network, Optics Express, 28 April 2020

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Centre for Micro Photonics, and to a postdoctoral position within the former ARC Centre of Excellence CUDOS (The Centre of Excellence for Utlra-high bandwidth Devices for Optical Systems). His role, alongside research, included higher degree research candidate supervision and project leadership responsibilities, such as the management of research milestones and collaborations.

Dr Cumming's previous collaborations and networks have already opened opportunities to collaborate within the Centre. His work with former Chief Investigator Professor Gu has led to the publication of a joint paper in Light: Science and Applications on a demonstration of optical holographic neural networks. His 3D Nano-Printing software is also in use by Centre members at the University of Technology Sydney.

Making metasurfaces tunable

One of the key strengths of metasurfaces is the potential for a single device to replace multiple static devices. To achieve this, metasurfaces will need to be tunable, with changing properties as external stimuli are applied, such as voltage, temperature, magnetic or electric fields. Centre Chief Investigator Professor Ilya Shadrivov is leading a team to investigate methods to achieve the degree of tunabilty needed for practical applications. Such tunable optical elements will be a central part of many optical systems, including dynamic holograms or optical signal modulators.

One potential method for achieving tunability of metasurfaces is to integrate them with liquid crystals. While liquid crystals are a well-studied area and their application is common in modern-day devices, there has been limited success integrating them with nanostructures.

The team will be studying how liquid crystals interact with the various different types of elements that form metasurfaces. A key focus will be understanding how liquid crystal molecules behave near nanostructures, and how strongly they can tune the response of metasurfaces and individual elements. This will be a major step towards our aim to fully manipulate optical waves to achieve the desired results.

"If we have a surface with fully controllable amplitude and phase, then we will have a working 3D hologram. Such a device will be able to perform an almost arbitrary manipulation of beams of light."

> "At lot of what we're trying people say can't be done. I'm looking forward to making the impossible possible."
>
> - Ilya Shadrivov, Chief Investigator

SPOTLIGHT

Ilya Shadrivov

Chief Investigator

For Ilya Shadrivov, there is a poignant duality working in the field of metasurfaces—it emerged just as he was beginning his career in research at The Australian National University. As he was preparing to start his PhD, he did a review of left-handed materials. Given there were only seven or eight papers on the topic, it wasn't an arduous task and the topic even seemed too simple.

The benefit of dedicating himself to this field while it was in its infancy was that he experienced the full breadth of research.

"The science was so new that the field was full of arguments and controversies between scientists. It was total immersion in the rawest form of research."

In the two decades since, Shadrivov has become a pioneer in the field. When the call for Centres of Excellence proposals was sent out by ARC, he went to Neshev and asked, "Shall we apply?" It was clear they shared the same vision for the Centre, and together with other Chief Investigators they worked to establish it.

He is excited both by the Centre's long-term funding, enabling him to take on a different

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https://doi.org/10.1364/OPTICA.6.000169

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https://doi.org/10.1103/PhysRevX.8.031077

type of project, and the Centre's collaborative nature.

"It joins so many researchers with complementary expertise, and I feel that I have access to a great pool of knowledge and experience. Some of the activities that we are planning will involve teams from all the different nodes. That's an extraordinary way to operate."

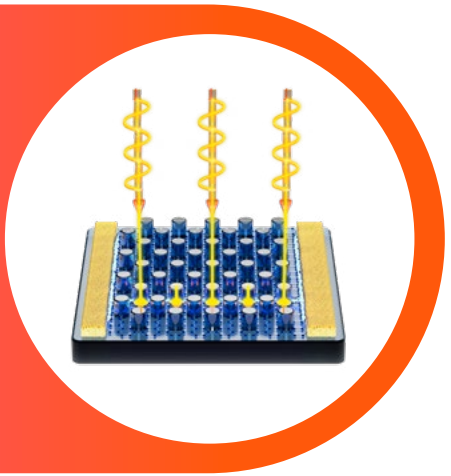
Shadrivov is the recipient of the 2016 Pawsey Medal from the Australian Academy of Science and Geoff Opatt prize from the Australian Optical Society and is a Fellow of the Optical Society and the Australian Institute of Physics.

His main research areas include metamaterials in various frequency ranges, from microwaves to Terahertz and Optics. He leads Terahertz spectroscopy and microwave labs at the Nonlinear Physics Centre. His downtime is split between his diverse hobbies of woodworking, scuba diving, photography and bee keeping.

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:

LORENZO FARAONE
The University of Western Australia

ANN ROBERTS
University of Melbourne

Detectors of infrared light are critical for environment, defence, medical and other major applications. However, their current inefficiency at room temperature is a major roadblock to miniaturisation as these detectors remain bulky. This precludes their use in drones, for example in bushfire detection and rescue, or space applications, such as observation, where weight is a critical design consideration. New approaches to infrared detection using semiconductor nanowires and the integration of subwavelength elements into a mercury cadmium telluride detector will massively lower barriers to the application of infrared detection technology.

Beyond infrared, meta-optical devices provide a means to extract information from electromagnetic waves from the visible through to the short- and long-wave infrared regions of the spectrum. This includes new strategies for quantifying the spectral content of an optical field using tailored metasurfaces and novel algorithms for reconstructing information of interest. The approach extends to determining the angle of incidence of an incident wave, determining its polarisation state and/or its classical or quantum mode content.

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 Theme, the team 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.

The ultimate goal of the Detect Theme is to develop a suite of imaging and non-imaging detectors that can independently, or in tandem, sense different properties of light. 2021 will be focused on developing meta-optical elements that will permit discrimination of different properties of light, designing nanostructures that will enhance the sensitivity of Mercury Cadmium Telluride detectors and developing novel nanowire photodetectors. There will also be emerging demonstrations of metasurface-integrated photodetectors and designs for new approaches.

ACTION ITEMS FOR 2021

1. Angle sensitive detection with discrimination between positive and negative directions
2. Nanostructured photodetector pixels for a fully contained microspectrometer
3. Monitoring of optical polarization with metasurface enhancement
4. III-V nanowire array/meta surface integration for enhanced performance/functionality
5. Enhanced MIR detection with ultra-thin hybrid plasmonic metasurfaces

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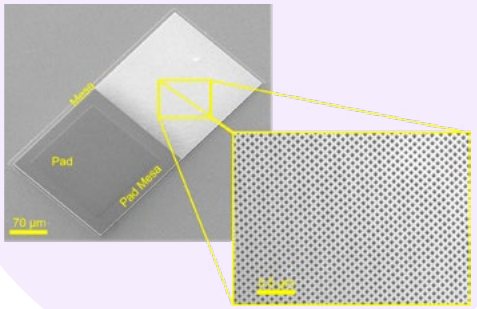
Developing a Fishnet Microspectrometer



The field of structural colour nanophotonic microspectrometers is still in its infancy, with only a few examples currently found in the literature. The spectral information from such a microspectrometer is very useful in security, agricultural, environmental health and safety applications as well as for colour matching or chemical sensing. Centre Deputy Director Ken Crozier and his team at the University of Melbourne are introducing a new class of nanophotonics-enabled devices for efficient sensing and monitoring applications. It's focused on the development of very lightweight and low-cost devices.

"Current spectroscopy solutions are built around lab-based spectrometers either using a Michaelson Interferometer FTIR or diffraction grating and sensor array. These systems weigh anywhere between 1kg-100kg and cost $10k-$100k. They are not portable and are very susceptible to mechanical shocks. We wish to overcome all these limitations by replacing the conventional optics with our own meta-optics systems based upon nanophotonic structures such as metasurface spectral filters or photodetectors with customized responsivity spectra."

By using nanophotonic structures as an alternative to bulky optics, they will develop on-chip spectroscopic systems which increases the device's robustness, while reducing the cost and importantly, the device footprint and weight. This is a great solution for integration into consumer electronics such as smartphones or into unmanned aerial vehicles.

"We have been able to demonstrate a lightweight visible and near-IR microspectrometer chips formed entirely from silicon, without the need for moving mechanical parts, any propagation-distance resolution limits or exotic bandgap engineering of materials. We have also expanded our microspectrometer methods into the mid-wave and long-wave infrared regions of the spectrum, which is useful for chemical detection (in a gas, solid or liquid)."

Collaboration in such a multi-faceted project is vital. "Realms of expertise needed to fulfil our aims here included cutting-edge nanofabrication and optical/electronic characterisation techniques. The microspectrometer also relies on novel machine learning-based signal processing techniques, which we had to develop and apply to our device. With the resources and expertise made available from being part of the Centre, we hope to expand our capabilities and greater outcomes at a faster pace."

Building a microspectrometer is an excellent demonstration of light detection using a meta-optical system, which is a key theme within the Centre that this project contributes to.

> "Engineering structures to manipulate light at the nanoscale is the solution for futuristic light-based applications."
>
> - Jasper Cadusch, Research Fellow

SPOTLIGHT

Jasper Cadusch

Research Fellow

As a young physics student Jasper Cadusch was intrigued to learn about all the amazing possibilities of manipulating light at a nanoscale.

"Being able to develop new ways of using light and carrying out entire photonic experiments—from dreaming up designs, simulating properties, fabricating nanoscale elements and measuring the optical response—is very appealing from a young physics student's perspective."

He then went on to pursue his PhD in nano-optics. "I was very interested to learn that with light, we could engineer things on

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the nanoscale, and by doing so, light could be concentrated into volumes far below the diffraction limit. We can change all its properties in incredible ways, leading to phenomena such as cloaking, phase imaging, interacting with quantum mechanical systems, and particle trapping. It was amazing to me that this could be done in a variety of ways either by chemically synthesising objects such as quantum dots, nanowires, and nanoparticles/rods, or by using the lithographic tools developed during the electronics revolution.

"Working with TMOS will give us the opportunity to tap into an impressive collective knowledge, ultimately speeding up process and allowing us to deliver results faster."

Cadusch obtained his bachelor's degree in physics at the University of Melbourne. Motivated by his interest in light sciences, he pursued his PhD in nano-optics where he studied generation, manipulation and detection of polarized light using novel plasmonic metasurfaces. Upon obtaining his PhD, he joined the Crozier Group as a Research Fellow in 2017.

In outside-of-research life, Jasper enjoys taking a walk with his dog Peggy.

DETECT CASE STUDY

Atomic Force Microscopy on a chip (perhaps even in every smartphone?)

MEMS or Micro-Electro-Mechanical Systems is not only the science and technology, but also the art, of making very small integrated devices or things. The integration on the microscale of mechanical or movable parts with integrated electronic circuits is the basic principle behind the technology, and it opens new avenues for realisation of novel devices whose applications are limited only by human ingenuity. In a nutshell, it is about miniaturisation, or placing a capability that currently requires the area of a fridge or microwave into the 'head of a pin.'

Centre Chief Investigator Mariusz Martyniuk and his team at University of Western Australia are using MEMS to reimagine Atomic Force Microscopy (AFM). Where traditional AFM requires bulky, free-space optics to track the change in position of a sample scanning cantilever, Martyniuk's team replaces this with a miniaturised waveguide to bring light to the cantilever and monitor its position with the ultimate interferometric sensitivity. This miniaturisation reduces costs, increases accuracy, and opens up a range of new applications.

"TMOS-realised metamaterial concepts could be highly complementary when deployed between the MEMS structure and light to enhance and harness the light-matter interaction, further enhancing device performance," says Martyniuk.

> "The ability to harness the interaction of light with physical structures in a fully controlled fashion and in real-time is very well positioned to spark the evolution of new technologies."
>
> - Centre Chief Investigator Professor Mariusz Martyniuk

SPOTLIGHT

Mariusz Martyniuk

Chief Investigator TMOS

Born in Poland, Martyniuk's journey to discover exactly what makes the world work took him to Canada, where he completed his Bachelor and Masters of Science, and then to Perth where he joined UWA to complete his PhD. After gaining experience in industry working as an electronic engineer, he re-entered academia, where his primary areas of interest encompasses thin-film materials and thin-film mechanics, as well as their applications in micro-electromechanical systems and optoelectronic devices.

"MEMS provide a great sand pit to play in. It gives me the ability to continue to learn and figure out how things work. It's highly exciting and satisfying to fully understand the underlying reasons enabling various high- and low-tech gadgets that we often take for granted in everyday life."

Martyniuk finds life as a researcher has opened plenty of opportunities. His team has a research environment that enables him to work hard, play hard, get rewarded and enjoying living—a life that included many hours on 'red-eye' plane trips to the East side of Australia where he was able to network with others in the field, leading him to the newly forming Centre.

"Participation in the Centre opens door to great people! The potential for collaboration between

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https://doi.org/10.1016/j.snb.2018.07.118

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."

As part of his job, Martyniuk manages the Western Australian node of the Australian National Fabrication Facility and in his spare time he plays competitive soccer, despite no longer being considered a 'spring chicken'.

Be it on a sporting field or in academia, by being part of a team with a common goal the opportunities to excel are significantly enhanced and as part of a team effort, Martyniuk's research contributions were recognized by the award of the Inaugural Australian Museum Eureka Prize for Outstanding Science in Support of Defence or National Security in 2008.

Centre Kick-Off Meeting

13-14 FEBRUARY 2020, MANTRA HOTEL, BRISBANE

> It was important to develop a brand that represented the essence of what we do, while also capturing our culture and personality.

The Centre held the formal, inaugural gathering of Chief Investigators in Brisbane, at the end of the 8th International Conference on Nanoscience and Nanotechnology (ICONN 2020).

The Centre Director, Prof Dragomir Neshev, set the scene for the meeting by giving an overview of the Centre vision. "Our Centre is about optics. We receive most of our information from light and light is the main exchange we have with the world. Optics is the growth industry of the future."

Deputy Director, Professor Ken Crozier, noted that "what we are trying to do is foster collaboration in addition to our technical goals and contributions."

Outreach Director and social butterfly, Professor Igor Aharonovich, organised an ice-breaker session to help the team get to know each other more. We have scuba divers, a rock climber, football lovers, gardeners, parents, pet owners, book worms (Harry Potter is the favourite), music lovers and musicians, and artists and art enthusiasts. "It was great to bring everyone together and learn a little more about each other beyond our science mission" said Aharonovich.

They had an afternoon for their research planning homework then reconvened for dinner to talk about science together—their universal topic of interest!

The next morning, the team launched into decision-making about the Centre logo. This was certainly the most contentious debate in the new Centre's history. They were eventually able to resolve their differences over coffee and agreed to a branding direction the team could be proud of for the next seven years.

"It was important to develop a brand that represented the essence of what we do, while also capturing our culture and personality," said Professor Ann Roberts.

As the coffee kicked in, they got into the research planning. Each Chief Investigator presented their ideas in three minutes (including how these contribute to the Centre goals and how they will be collaborative) with three minutes for feedback. They were able to set the foundation for the next few months of detailing our research strategy.

The Chief Investigators were fortunate that the Centre's International Scientific Advisory Committee (ISAC) member, Professor Mark Brongersma of Stanford University, was able to dial in. He shared some key insights and

First step: Dragomir Neshev, Ann Roberts, Ken Crozier; Second step: Francesca Iacopi, Chennupati Jagadish, Madhu Bhaskaran; Third step: Andrey Sukhorukov, Lorenzo Faraone, Hoe Tan; Fourth step: Igor Aharonovich, Milos Toth; Fifth step: Mariusz Martyniuk

suggested a few strategic directions to aim for as we develop a more detailed research plan, and steer toward the implementation of our goals.

"Even though I was not there in person, I did attend the workshop online and felt that the kick-off was worthwhile. It provided us a dedicated time and platform to meet and discuss our research plan and other important issues related to Centre culture and operation."

Professor Lan Fu
Chief Investigator

Infrastructure and Capabilities Committee Chair Report

ICC Chair, Professor Kenneth Crozier

Since its inception in 2004, my research group has made extensive use of nanofabrication facilities and capabilities. Being Chair of the TMOS Infrastructure and Capabilities Committee is important to me for two key reasons. First, I see appropriate infrastructure and capabilities as being critical to the success of the Centre. I am therefore keen to ensure that Centre members have access to these. Second, I am keen to learn about both existing and new infrastructure and capabilities, as these will benefit the students and early career researchers (ECRs) of the Centre.

The overarching goal of the committee is to ensure that Centre members have access to the experimental and computational infrastructure needed to achieve the research aims and objectives of the Centre.

The committee aims to achieve this goal via four mechanisms:

- The committee will be responsible for hosting an equipment register that will list the experimental and computational infrastructure available in the laboratories of all Chief Investigators (CIs). This register is presented on the Centre website.
- The committee will organise regular meetings at which members can discuss their infrastructure needs that are currently unmet. Committee members will endeavour to use their knowledge of infrastructure (both within the Centre and outside the Centre) to assist all Centre members in obtaining access to infrastructure.
- The committee will be responsible for coordinating infrastructure funding and access bids. The committee will facilitate members to participate in bids led by non-Centre members for infrastructure that would be beneficial for Centre activities.
- The committee will organise meetings to facilitate joint submissions to government-funded capabilities in Australia (e.g., Australian Synchrotron) and globally.

The committee will have achieved its goals in the next seven years if there is an increase in the quality and quantity of scientific discoveries arising from our enhanced access to infrastructure and capabilities. We have already made a great start on our register, which is already available on the Centre website https://tmos.org.au/research/capabilities/.

For 2021, I am most excited to see new science being developed based on improvements to infrastructure and capabilities that result from the work of this committee. This will include not only proposals for new infrastructure and capabilities, but also the committee's role in facilitating access to what already exists in Australia and internationally.

Professor Kenneth Crozier
Centre Deputy Director

ACTION ITEMS FOR 2021

1. Complete an equipment register that will list the experimental and computational infrastructure available in the laboratories of all Chief Investigators. This register will be presented on the Centre website and maintained by the committee
2. Organise regular meetings at which Centre members can discuss their infrastructure needs that are currently unmet and develop strategies to fill these gaps
3. Organise meetings to facilitate joint submissions to government-funded capabilities in Australia (e.g., Australian Synchrotron) and overseas

Institutions and Facilities

The Australian National University

ANU is the headquarters of the Centre and is hosted at the Research School of Physics (RSPhys). The ANU node has six Chief Investigators (CIs) (Neshev, Shadrivov, Sukhorukov, Jagadish, Fu and Tan).

RSPhys also hosts the Australian Nano Fabrication Facility (ANFF) ACT Node, part of a broader network established by the Australian Government's National Collaborative Research Infrastructure Strategy (NCRIS) to provide access to micro and nanofabrication equipment, essential to Australia's scientific future.

The fabrication facilities at this node are geared towards epitaxial growth of III-V semiconductors, deposition of various oxide/nitride materials and nano-fabrication of devices based of these materials and structures. It is equipped with state-of the-art tools for material synthesis (such as metal organic chemical vapour deposition, atomic layer deposition, pulsed laser deposition, RF/DC magnetron sputtering), lithography (electron beam lithography, nanoimprint lithography, optical lithography), etching (ICP-RIE, focus ion beam), metallisation (thermal and e-beam evaporation), back-end processes (flip-chip bonding, wire bonding, rapid thermal annealing, hot embossing) and material characterisation (SEM-CL, ellipsometry, focus ion beam).

In addition, all the CIs have established various optical, structural and electrical characterisation facilities for materials and devices. Some of the key instruments include:

- spectroscopy: micro-transmission and Raman spectroscopy, photon-correlation spectroscopy and time-resolved ultra-fast spectroscopy;
- microscopy: photo-luminescence (PL), scanning near-field optical microscopy (SNOM), atomic force microscopy, second-harmonic microscopy, hi-resolution XRD, Hall effect, Deep Level Transient Spectroscopy (DLTS), and Fourier-transform infra-red (FTIR) microscopy;
- facilities for optoelectronic device testing: lasers, LEDs, photodetectors, solar cells.

All the facilities within ANFF ACT node and the CIs labs will be moving into a purpose-built building in in late 2021. The $210M building features:

- a central state-of-the-art cleanroom (715 m²)
- an MOCVD suite (190 m²)
- 22 stable laboratories for optics experiments (1900 m²).

It represents the single largest investment in infrastructure ANU has made since the foundation of RSPhys in 1950.

The Centre's team at ANU also benefits from easy access to a suite of electron microscopy and microanalysis facilities available on campus through Centre for Advanced Microscopy, which is a node of Microscopy Australia.

ANU's MOCVD suite

New ICP machines

Facilities at The University of Technology Sydney

The University of Technology Sydney

UTS is the research home of CIs Aharonovich, Toth and Iacopi. Aharonovich and Toth are based in the School of Mathematical and Physical Sciences, and Iacopi is in the School of Electrical and Data Engineering.

UTS has a range of material growth facilities that include:

- a microwave plasma-enhanced chemical vapour deposition (CVD) diamond reactor
- plasma-free and plasma-assisted tube-furnace CVD systems
- evaporation and sputter deposition systems
- electron beam and optical lithography
- reactive ion etching (RIE) and associated mask aligning
- wire bonding systems
- plasma, ozone, and thermal processing systems.

Scanning and transmission electron microscopy and cathodoluminescence microanalysis is available.

Further capabilities include:

- Ga and plasma-source focussed ion beam systems
- absorption spectroscopy
- Raman spectroscopy
- Ellipsometry
- x-ray diffraction analysis
- scanning probe microscopy.

Within Aharonovich's nanophotonics laboratory there is:

- customised confocal microscopy micro-photoluminescence (PL) setup with single photon detection and analysis capabilities
- nonlinear setup with femtosecond laser
- Hanbury Brown and Twiss (HBT) setup
- polarization-resolved PL setup
- back-focal imaging setup
- a near-field scanning optical microscope (NSOM).

Within Toth's electron/ion beam chemistry laboratory is nano-scale material processing using a broad range of chemical precursor species and electron/ion beam species.

Iacopi's Integrated Nanosystems Lab include:

- electrical and electronic characterisation equipment (4-terminal probestation, Keithley parametric analyser, Hall systems operating at 75-370K)
- spectroscopy analysis equipment (dual laser WiTec confocal Raman microscope/ spectrometer, Nicolet Continuum FT-IR Spectrometer with MIR and NIR configuration and Continuum IR Microscope, both with automated mapping capabilities).

The University of Melbourne

The UoM is the research home of Deputy Director, Kenneth Crozier, and theme leader Ann Roberts. Crozier is both with the School of Physics (in the Faculty of Science) and the Department of Electrical and Electronic Engineering (in the Faculty of Engineering and Information Technology). Roberts is with the School of Physics. Crozier and Roberts both have access to the facilities at the Melbourne Centre for Nanofabrication (MCN, see image).

The MCN is a joint venture between six Victorian universities and the CSIRO. It was developed with significant funding from the Australian Federal Government and the Victorian State Government, as well as its partner institutions. Total infrastructure investment to date has been approximately $50 million. The MCN is the flagship facility within the Australian National Fabrication Facility (ANFF) Victorian node and is also home to the ANFF national headquarters.

Crozier and Roberts also have well-equipped optical laboratories at the University of Melbourne. These include:

- a custom tabletop spectral characterisation set-up (VIS)
- an external quantum efficiency (EQE) testing set-up (Energetiq LDLS, monochromator, custom microscope)
- an FTIR microspectrometer (Perkin Elmer)
- Janis cryostat
- infrared lasers (2.2, 4.5, 8.35 μm)
- an optical trapping microscope
- a probe station (Evergreen) with source measure units (Keithley)
- spatial light modulators
- two supercontinuum lasers with tunable spectral filters
- upright and inverted microscopes including extensive polarisation analysis components.

The Melbourne Centre for Nanofabrication (MCN)

Facilities at The University of Western Australia

RMIT University

RMIT University's Functional Materials and Microsystems Research Group hosts The RMIT node of the Centre. CIs Bhaskaran and Sriram co-lead a team of 40 researchers working to transform discoveries into technologies for electronics, photonics, wearable devices, and healthcare.

The expertise at the RMIT node span materials science and engineering, nanotechnology and surface chemistry, micro- and nano-fabrication, three-dimensional nanoscale printing, stretchable and flexible electronics, and device integration and prototyping.

The group has extensive research infrastructure and facilities. The Micro Nano Research Facility is a $45 million, state-of-the-art cleanroom facility for materials synthesis, device fabrication, and device prototyping that is updated regularly to deliver new capabilities. There are also specialised laboratories for micro/nanoelectronic device characterisation, flexible/stretchable electronics and integration, two-dimensional materials growth, nanoscale fabrication and 3D printing, and prototyping of wearable devices.

The Micro Nano Research Facility at RMIT

The University of Western Australia

UWA and its School of Engineering is the home of CIs Martyniuk and Faraone. Both are members of the Microelectronics Research Group (MRG) which is a well-established, vibrant intellectual environment that is internationally renowned for achievements and capability in infrared science and MEMS technologies. In particular, the translation of technologies into industry is a key feature of the UWA Node.

The group's capabilities in MEMS and IR Technologies Infrared technologies have received important recognition from industrial and government end-users and forms the two flagship capabilities of the Western Australian node of the Australian National Fabrication Facility (ANFF-WA), featured in the 2016 National Research Infrastructure Roadmap. The group hosts its unique, vertically-integrated facilities for fabrication of infrared detectors and imaging focal plane arrays, as well as semiconductor epitaxial growth, and vertically integrated fabrication of MEMS—including thin film deposition and etching, device fabrication, packaging and characterisation.

Importantly, the MRG hosts a Molecular Beam Epitaxy (MBE) facility for the growth of II-VI semiconductors for infrared applications. This is the only facility of its kind in Australia and one of only two such facilities in a university-based environment worldwide.

The system features a series of in-situ tools, such as reflection high-energy electron diffraction (RHEED), ellipsometry, pyrometry and an accuflux meter to allow observations and analysis during growth. This adds a further level of precision and control to the growth process. The in-situ monitoring results combine to provide an extremely effective method to grow high-purity HgCdTe materials, leading to the development of new infrared sensors.

The excellent in-house equipment and expertise has allowed for the full fabrication of high performance infrared focal plane arrays (IR FPA) for the first time in Australia, illustrating the international relevance of ANFF-WA Node.

Engagement

Industry Liaison Committee Chair Report

ILC Chair, Professor Francesca Iacopi

I am a Physicist who has predominantly worked as an engineer, first in industrial R&D and subsequently in academia. I have enthusiastically accepted the role of Chair of Industry Liaison for the Centre as I am a strong advocate for translating fundamental discoveries to useful applications. Throughout my career I have developed the knowledge, skills, and passion for connecting the dots between fundamental science and advanced technologies. Specifically, I have made key contributions to semiconductor technologies in collaboration with companies including Intel, Globalfoundries, IBM, and Panasonic.

The objective of this committee is to support the Centre in creating innovation and ultimately making technological impact. The field of optics is ready for disruption and the specific introduction of meta-optics is very timely. I anticipate substantial impact to originate from Centre research. The successful translation of science into an applied technology is a complex and long process. Translation involves:

- a solid understanding of the basic phenomena one wants to harness
- the appropriate design of a suitable device able to harness such principles
- a thorough engineering of the device and its relation to the larger system, and,
- satisfying requirements for manufacturability and reliability.

Innovation needs input from many players along the innovation chain, including the end-users, and requires familiarity with intellectual property, commercialisation, and technology transfer matters.

To create an environment supportive of innovation, this committee aims to:

1. Bring Centre researchers into closer contact with local and international industry to help identify of technology and market needs, understand industry methods and goals, develop collaborations, and encourage industry career paths for early career researchers.
2. Create a culture that is excited about innovation, literate in the creation and protection of intellectual property, and is knowledgeable on the commercialisation processes.

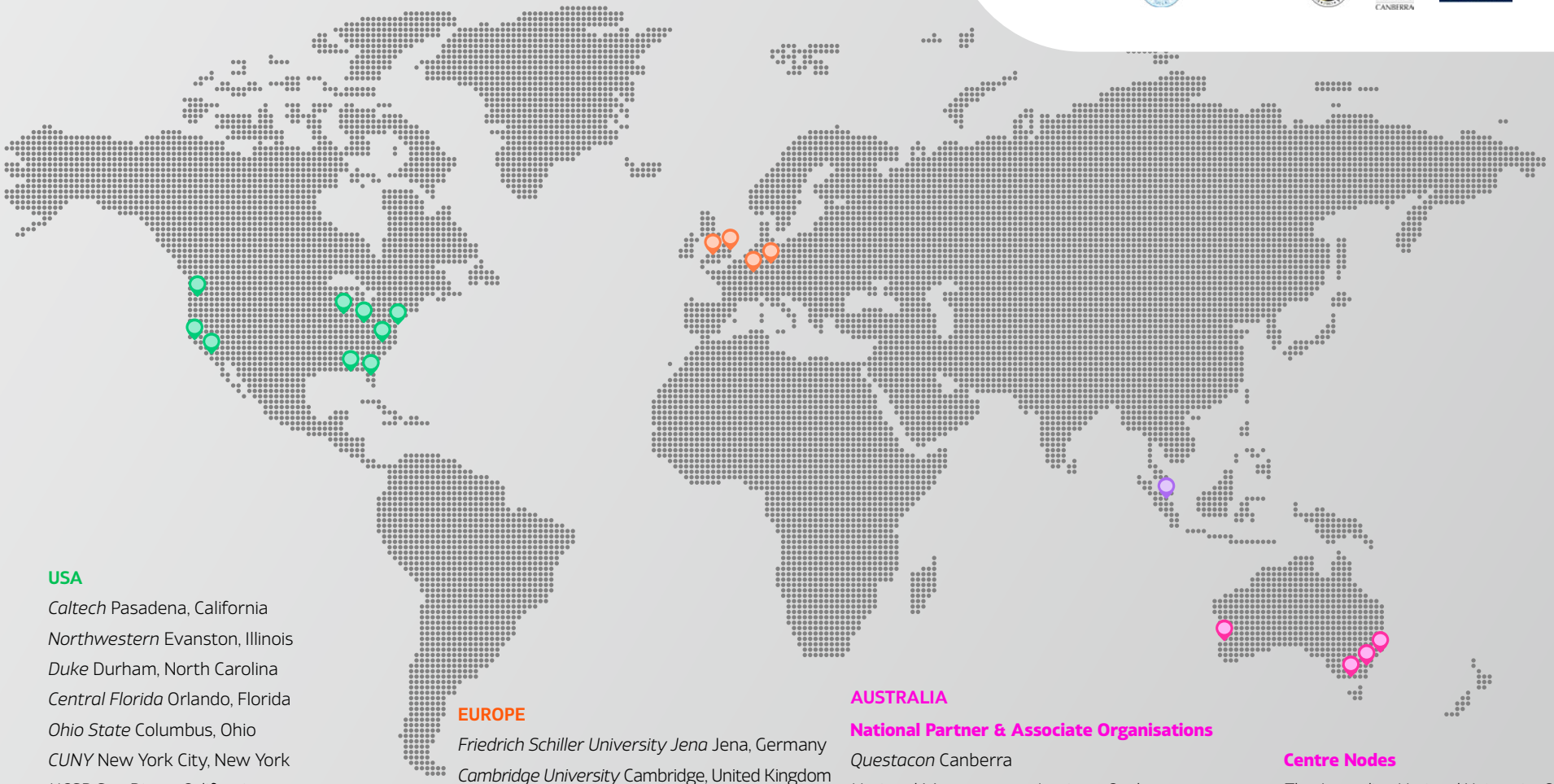
This would enable our students and researchers to maximise research impact and their capability to engage with industry or found their own companies.

> “The field of optics is ready for disruption and the specific introduction of meta-optics is very timely.

ACTION ITEMS FOR 2021

1. Initiate four opportunities for Centre researchers to engage in dialogue with industry
2. Develop a framework of principles and guidelines for Centre IP protection and technology transfer (including Material Transfer Agreements, etc.)
3. Develop ethical guidelines and opportunities for engaging with Defence and their subcontracting companies
4. Develop a relationship database covering the areas of research aligned with Centre Themes
5. Together with the Education and Outreach Committee, develop training events and education materials to familiarise Centre members, particularly students and ECRs, in matters of IP, technology transfer, as well as dual-use technologies and other related government and university compliance requirements

Partnerships and Industry



USA

Caltech Pasadena, California
Northwestern Evanston, Illinois
Duke Durham, North Carolina
Central Florida Orlando, Florida
Ohio State Columbus, Ohio
CUNY New York City, New York
UCSD San Diego, California
Thermo Fisher Scientific Hillsboro, Oregon
AFRL Eglin AFB, Florida
UC Berkley San Francisco, California
UCLA Los Angeles, California

EUROPE

Friedrich Schiller University Jena Jena, Germany
Cambridge University Cambridge, United Kingdom
Oxford University Oxford, United Kingdom
IEE S.A. Contern, Luxembourg

ASIA

National University of Singapore Singapore

AUSTRALIA

National Partner & Associate Organisations

Questacon Canberra
National Measurement Institute Canberra
University of New South Wales Canberra Canberra
Melbourne Centre for Nanofabrication Melbourne
Australian National Fabrication Facility Melbourne
Hort-Eye Melbourne

Centre Nodes

The Australian National University Canberra
University of Melbourne Melbourne
University of Technology Sydney Sydney
University of Western Australia Perth
RMIT University Melbourne

PARTNERSHIPS AND INDUSTRY:

Themo Fisher Scientific

Thermo Fisher Scientific is a North American company serving the international scientific community with instrumentation, consumables, software and beyond. The company is a key partner in our new Centre, but the relationship began over a decade prior.

Chief Investigator Professor Milos Toth has spent most of his research career in partnership with industry, having spent several years as an industry scientist before moving to Australia for a university role.

"The story with Thermo Fisher Scientific actually begins in the 2000s. I was a research scientist for seven years with FEI Company in the USA. In addition to research, I developed Intellectual Property and managed a number of FEI Company–university collaborations. As an early-to-mid career scientist, those experiences beyond the lab helped me to develop my academic career. I wouldn't have predicted it at the time."

In 2011, Milos moved to the University of Technology Sydney (UTS), but not before arranging an on-going collaboration with his former employer.

"We set up a collaboration as part of my move to Sydney. FEI Company contributed cutting-edge equipment for my new lab at UTS and funded a long-term research collaboration. We have been working together ever since and continue to interact weekly."

FEI Company was acquired by Thermo Fisher Scientific in 2017, yet the research collaboration with Milos and his established research group was retained, despite the potential for changes in priorities within a more complex organisation.

"I can say that the relationship has been fruitful for both parties. It is why the partnership continues to last, even if personnel in the company change and during tougher financial times like COVID-19. There is a long-established trust so we can work together on solving real-world technological problems that also generate interesting new science. We have succeeded in selecting projects and deliverables that are highly suitable for an industry—university collaboration. This is reflected in the outcomes, which include not only numerous patents but also papers in top academic journals such as *Physical Review Letters* and *Nature Communications*.

"It's increasingly possible, and I believe ever more essential as an applied university scientist, to have an industry career as part of an academic career. These worlds are complimentary, and we need more bridges between them for our ideas to have impact."

Being part of a Centre is the next evolution for this collaboration. "TMOS will enable a paradigm shift in information technologies based on manipulation of light at the nanoscale. It is not something that can be done by one group or by one company. We need to work together, and the Centre is the massive collaborative platform needed for this type of interaction."

Dr Aurelien Botman of Thermo Fisher Scientific is a Partner Investigator in the Centre and a long-time collaborator of Milos. "The depth of the collaboration and the outcomes of the work is very meaningful. We have trained, developed and supported several students and early career researchers over the years, and this is a special part of working with universities—the next generation part. I'm looking forward to the partnership with Milos within TMOS and exploring the potential of the Centre."

Professor Milos Toth, Dr Michael Lysaght from FEI Company and Professor Matthew Phillips.

> "We need to work together, and the Centre is the massive collaborative platform needed for this type of interaction.

Education and Outreach Committee Co-Chairs Report

Education Chair and Outreach Chair, Professor Lan Fu and Professor Igor Aharonovich

ACTION ITEMS FOR 2021

1. Design the Education (internal) and Communication and Engagement (external) strategies and implementation plans (2021-2023)
2. Establish guidelines for Centre HDR student supervisory panel formation, as well as the formal expectation for their engagement with the Centre training program, academic and outreach activities
3. In collaboration with the Industry Liaison Committee, design and pilot an industry internship program for Centre HDR students
4. Hold three research training events and one career development workshop for Centre students
5. Run two major outreach events at the national level
6. Design three training packages for HDR students and ECRs to deliver at school visits to promote the science of light

The E&O Committee has an internal (Education) and an external (Outreach) component that are combined, as both domains of engagement are deeply inter-dependent. It is chaired by Professor Lan Fu (ANU) and Professor Igor Aharonovich (UTS). Their research is focused on nanophotonics of semiconducting materials, and they both share a passion for education and outreach.

Fu has nearly 20 years' experience in supervising higher degree researchers (HDR), Honours and undergraduate students. She has developed many HDR-related policies, processes, and initiatives at all levels within the university structure and is striving to develop a student-focused culture in the Centre. She will focus on the education portion of the committee's work. Aharonovich will lead the outreach aspect of the committee and is eager to lead the sharing of our progress toward light-based technologies with the Australian public.

Internally, we aim to develop a multidisciplinary, dynamic, interactive and collaborative culture for Centre students and staff. We will develop new leaders who thrive on academic excellence and are equipped with transferable skills to take on any career they choose. Externally, we will develop engagement between our Centre, and its members, with the public – including schools, government and industry.

We will implement this by coordinating an HDR mentoring program, training events, and other education opportunities for Centre students and staff. These include topical workshops on emerging areas within optics, materials, devices and applications, as well as career development workshops on writing, career approaches, and networking.

We will advocate, organise and undertake outreach activities led by the Centre to promote the science of light to the public. We will also collaborate closely with other committees within the Centre to meet our broader engagement goals.

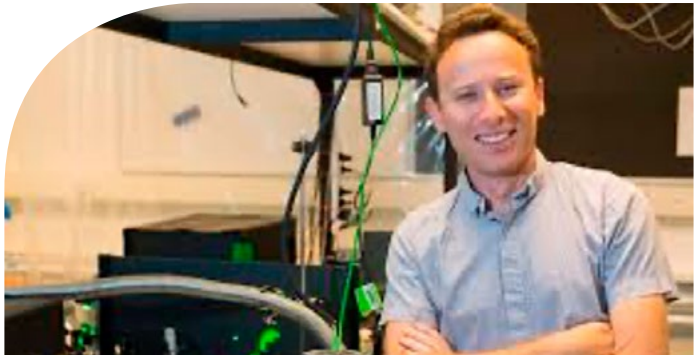
We have an opportunity to establish a unique PhD program in Australia featuring:

- a multidisciplinary PhD
- science communication and outreach training
- industry experience and/or policy engagement
- leadership and/or entrepreneur training.

In the next seven years, we would like to build a student community with the drive and capability to become leaders in academia, industry, government and beyond.

We have an opportunity to influence the Australian school optics curriculum, with a view to build a pipeline for the future photonics workforce.

We aim for the Australian public know what meta-optics is and what it does for them.



Professor Igor Aharonovich and Professor Lan Fu

Education: HDR Recruitment

Higher Degree Research (HDR) students include PhD and research-based Masters students. They are vital for the vibrancy and energy of our Centre and are key players in the hands-on science effort required to reach our research goals. Our students are our culture leaders and the global future workforce. They are critical to our success as a Centre.

As a Centre we cannot directly appoint students as this is done via our five node university's admission processes. So, we opened an 'expression of interest' HDR application round, which was advertised through our network, paid advertising, and our website. We received over eighty applications in our first call, which we carefully assessed.

We interviewed suitable candidates and paired the best potential students with at least one Centre Chief Investigator to enter the admissions process at the applicable universities. Through this recruitment round we identified several students, however, due to the COVID-19 pandemic, our international cohort have largely been unable to enter Australia. There have been a range of issues, from the reduction in international student places with funding by our universities (as places were held for students that had not entered Australia before the borders closed), extensive visa processing delays, and rejections of travel exemptions into Australia. Physics and engineering have relied on international students for the PhD cohort for many years, as small numbers of domestic students continue into postdoctoral studies in our disciplines. We have unfortunately lost several strong international HDR candidates, including several women, due to these global disruptions. This leaves the Centre in a situation where for 2021 and possibly 2022, we have a reduced student cohort.

"There are exceptional students in Australia and worldwide, and we want diverse ideas and expertise applied to every challenge and objective. The Centre undertakes cutting-edge science, which must inspire them, but is an environment focussed on providing high quality education, training, and professional and personal development. Some of this starts with encouraging Australian students to stay engaged in science in school, through to ensuring that there are opportunities for all people to be valued for their postdoctoral education in the physical and engineering sciences." - Professor Sharath Sriram, Early Career Researcher Chair

To achieve our research goals, we will engage the existing students of the Chief Investigators into the research of the Centre, welcome prospective domestic students, and support our prospective international students to arrive in Australia as soon as possible. However, the impact will be felt in our research program as HDR students are the fundamental actors that get things done in any research project. The reduction in HDR students may affect our ability to achieve our diversity goals in the mid-term, in addition to potential delays in our research goals.

We now must consider our strategy and tactics in the face of this challenge, which certainly extends beyond the seven-year lifetime of the Centre as we need to build a more robust education pipeline.

> "I'm very conscious of the long-term impact of the decisions we make today, and how this will impact the whole Centre and beyond. Students are major contributors to the scientific endeavour, so we need to have a clear strategy for engagement and recruitment over a variety of timescales."
>
> - Professor Lan Fu, Education Chair

OUR PLAN:

1. Support our current students to perform research in alignment with the Centre, through tactics such as top-up scholarships and projects appropriate to ensuring their success and timely completion of their degrees.
2. Engage with undergraduate students, such as with research internships, to build a pipeline of domestic Honours and Masters students.
3. Design and advertise attractive student packages to attract larger numbers of the best international students, especially women.
4. Develop our new postdoctoral researchers to be outstanding HDR supervisors so that we can scale up the number of students we can support in the next 18 – 24 months and enhance the skills of our early career researchers, with due consideration of their workload.
5. Engage with students prior to university to build a pipeline for physics and engineering students more broadly beyond the timescale of the Centre.
6. Connect with educators and education agencies to scale-up our impact in growing a physics and engineering-literate and engaged Australia.

Education: Early Career Researcher and Student Retreat

The 2020 Centre Early Career Researcher (ECR) and Student Retreat was a two-day virtual event that was held on December 3–4, with over 90 attendees. The aim of the retreat was to educate each other about our research, our capabilities, our shared interests, and to generate ideas for collaborations within the Centre. All five nodes joined the fun.

The event was organised by ECRs and students under the guidance of Professor Milos Toth (UTS), Chair of the Centre Colloquia Committee (to be formally established in 2021). The committee included Aswani Gopakumar Saraswathyvilasam (ANU), Yan Liu (UWA), Dr Aiswarya Pradeepkumar (UTS), Mehran Kianinia (UTS), Dr Jingshi Yan (ANU), Dr Lukas Wesemann (UoM) and Sumaiya Kabir (RMIT).

"It was a pleasure to work with the organising committee and put together a great event. The quality of the presentations was very high, and the students found the event rewarding—especially the careers forum delivered by Professor Chennupati Jagadish, and external guest speakers Dr Katie Chong and Professor Daniel Shaddock", said Toth.

The event featured 27 oral presentations from Centre ECRs and students, three virtual poster sessions (38 posters), Centre Research Theme presentations delivered by the theme leaders and a career and industry forum. A team of judges was assembled to review all the student and ECR presentations and posters. The poster sessions were sponsored by the iSee VC team, whose platform creates a 3D virtual conference environment. The forum featured academic and industry career development sessions delivered by Professor Chennupati Jagadish from ANU and Dr Katie Chong from Baraja Automotive, as well as a presentation on Software-defined instrumentation by Professor Daniel Shaddock, CEO of Liquid Instruments.

"It was our pleasure to hear the valuable life stories from Jagadish, Katie and Daniel. They showed us unlimited possibilities for developing future careers, especially for when we are experiencing difficulties or at a turning point in our lives. It became a treasure of life to listen to the pride and remedies that they'd learned along their journey," UWA PhD student Yan Liu said.

Following all the presentations and poster sessions, we gathered on the afternoon of the last day to review the judges' scores and announce the overall winners for the presentations and posters, which were assessed together.

"It was an intense and rewarding two days for the whole team. I enjoyed participating as one of the presentation awards judges, even though I am not a physicist. The students and ECRs did an awesome job of presenting their work, which made deciding the winners tough." – Dr Mary Gray, COO.

The Best Presentation Awards were kindly sponsored by John Morris Group.

The best student presentation winners were:

1st Laura Ospina Rozo
(University of Melbourne)

2nd Wei Wen Wong
(Australian National University)

3rd Jingshi Yan
(Australian National University)

The best ECR presentation winners were:

Joint 1st Johannes Fröch
(University of Technology Sydney)

Joint 1st Lukas Wesemann
(University of Melbourne)

Outreach: Digital Media

The Centre formerly launched its website on 7 August 2020, creating a digital home from which to engage with the world. We want to acknowledge the development work and support of Mr Sergei Zyubin in the development of our website, and the contribution of the Chief Investigators Ilya Shadrivov and Andrey Sukhorukov to getting the project underway.

Thanks to Chief Investigator Igor Aharonovich, we grew our Twitter and LinkedIn accounts to build our foundation audience for external engagement as we travelled through 2020.

Connect with us as we transform optical technologies!

35,527

Website views

MOST POPULAR PAGE

Jobs **(6,852)**

8,841

Website visitors

TOP 5 VISITOR COUNTRIES

Australia **(17,330)**
India **(5,430)**
United States **(2,362)**
China **(1,298)**
Germany **(1,087)**

16

Posts on the TMOS website in 2020

TOP 3 POSTS

1. Fifteen Postdoctoral Positions – Open Now! **(392)**
2. Australian Research Council Centre of Excellence for Transformative Meta-Optical Systems – Transforming Technology for Light **(306)**
3. Single-photon emitters: a breakthrough discovery **(146)**

SOCIAL MEDIA

477

TWITTER FOLLOWERS

337

LINKEDIN FOLLOWERS

11

YOUTUBE SUBSCRIBERS

3

YOUTUBE VIDEOS

555

YOUTUBE VIEWS

Outreach: National Science Week 2020

Mr Fröch demonstrating an experiment. Credit: Danny Lam of Fizzics Education

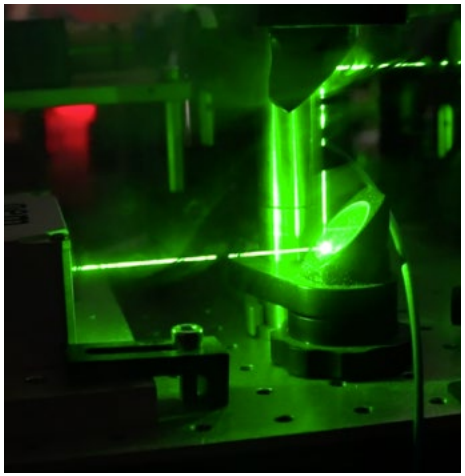
National Science Week is Australia's science celebration that has been running each year since 1997. Due to the COVID-19 pandemic, and the Centre being pre-operational, we decided to run our first event online, sponsored by the Australian National University under the Centre umbrella.

We collaborated with Fizzics Education, Australia's premier science outreach company, to produce our first public event – Light, Lasers and Laboratories.

Fizzics Education Presenter Dr Russell Sandstrom completed his PhD at the University of Technology Sydney (UTS) with Centre Chief Investigator Professor Igor Aharonovich. Sandstrom became a science communication professional in 2018 to share his enjoyment of science with the public. He was the perfect presenter to highlight key physics concepts on the science of light due to his experience in the Aharonovich lab.

"It is honestly the most rewarding job I have ever had," Sandstrom said.

Professor Aharonovich moved to UTS in 2013 after completing his PhD at the University of Melbourne and postdoctoral training at Harvard. Since then, he has mentored and supervised PhD students and new researchers in meta-optics and nanophotonics, including PhD student Mr Johannes Fröch and postdoctoral researcher Dr Sejeong Kim, who both presented in the event, along with Aharonovich.



"I'm proud of all of my former and current students and postdoctoral researchers. One of the great parts of becoming a scientist is sharing what you know and building up those around you to be successful."
– Professor Igor Aharonovich

The event began with a science of light demonstration, led by Dr Russell Sandstrom, a tour of the research laboratories and live demonstration of science in action at UTS by Aharonovich, Kim and Fröch, followed by a facilitated question and answer session with the researchers.

At least 55 registered attendees logged into to the online event, with 34 registered attendees being family or class groups, many of which had primary school aged children. We received positive feedback from the event attendees and aim to build on this small success in 2021.

"Thank you for putting on the great session on Lasers and Light. My 11-year-old daughter really enjoyed the session and was enthralled for its entirety. As a bonus, I am sure it will help with an assignment she has in term four."

"Hi, we attended your workshop light lasers and laboratories. It was awesome, very informative and presented very beautiful way through webinar.... thank you so much."

https://youtu.be/KPPbifJ86Ao

Governance

Message from the Chief Operations Officer

In late 2016, when I was working in a research office at ANU, I instigated an internal report on the ARC Centres of Excellence 2017 round. I met with Dragomir and his team regarding their experience with their unsuccessful, externally led bid. We discussed a range of lessons learned but when it came down to it, it was certainly a question of, 'why not an ANU-led bid next time?' Several months later, I had the fortune to meet Dr Tich-Lam Nguyen of ARC FLEET, as she came to visit ANU to meet with Professor Elena Ostrovskaya to set up their 2017 Centre. I saw a woman in an interesting and senior professional role in university land. At that point, a crazy thought entered my head. I thought, *"I could do that too."* I laughed at myself and got back to reviewing grants...but the idea stuck with me—a true life anecdote of role modelling in action!

Nearly three years later, I found myself actively participating in a different ANU-led ARC Centres of Excellence 2020 bid as the named 'Chief Operations Officer.' It was a rewarding experience being part of the team and named on a major bid, especially as a professional staff member. Unfortunately, our bid was unsuccessful despite our best efforts. However, not long after our bad news, Dragomir reached out to me to ask if I would be interested in helping him establish his Centre, TMOS. At this point I knew I could do it, and I certainly wanted to give it a go! By April 2020 I was officially the Chief Operations Officer for TMOS.

Our establishment period became an establishment year, with numerous unanticipated events (we did not have a risk register then!). To begin the new year, smoke from bushfires impacted the air quality in Canberra, so much so that the University had to close, and we sold out of air purifiers. Later in January a severe hailstorm destroyed research infrastructure, along with our cars, including my 20-year-old Land Rover – RIP Boudica! It took several months for some of the fume hoods in the ANU labs to be made safe and operational. They say these come in threes, so of course next we had the global COVID-19 pandemic and its consequences.

We were lucky here in Canberra. Many of our international partners suffered, and still suffer, greatly during this time, resulting in temporary business closures and a slowdown in administration. Our goal of starting the Centre by 1 July 2020 turned into ether as we could not get our large cohort of partners signed into our Collaboration Agreement due to the new workloads placed on everyone. But we got there in December, thanks to the various professional teams at ANU (especially Marianne, Luca, Marie-Helene, and Sam and her team) and the lawyers and administrators around the world who did what was needed so that we could get started on our ambitious program. Thank you, colleagues, around the world who accommodated our requests and supported us!

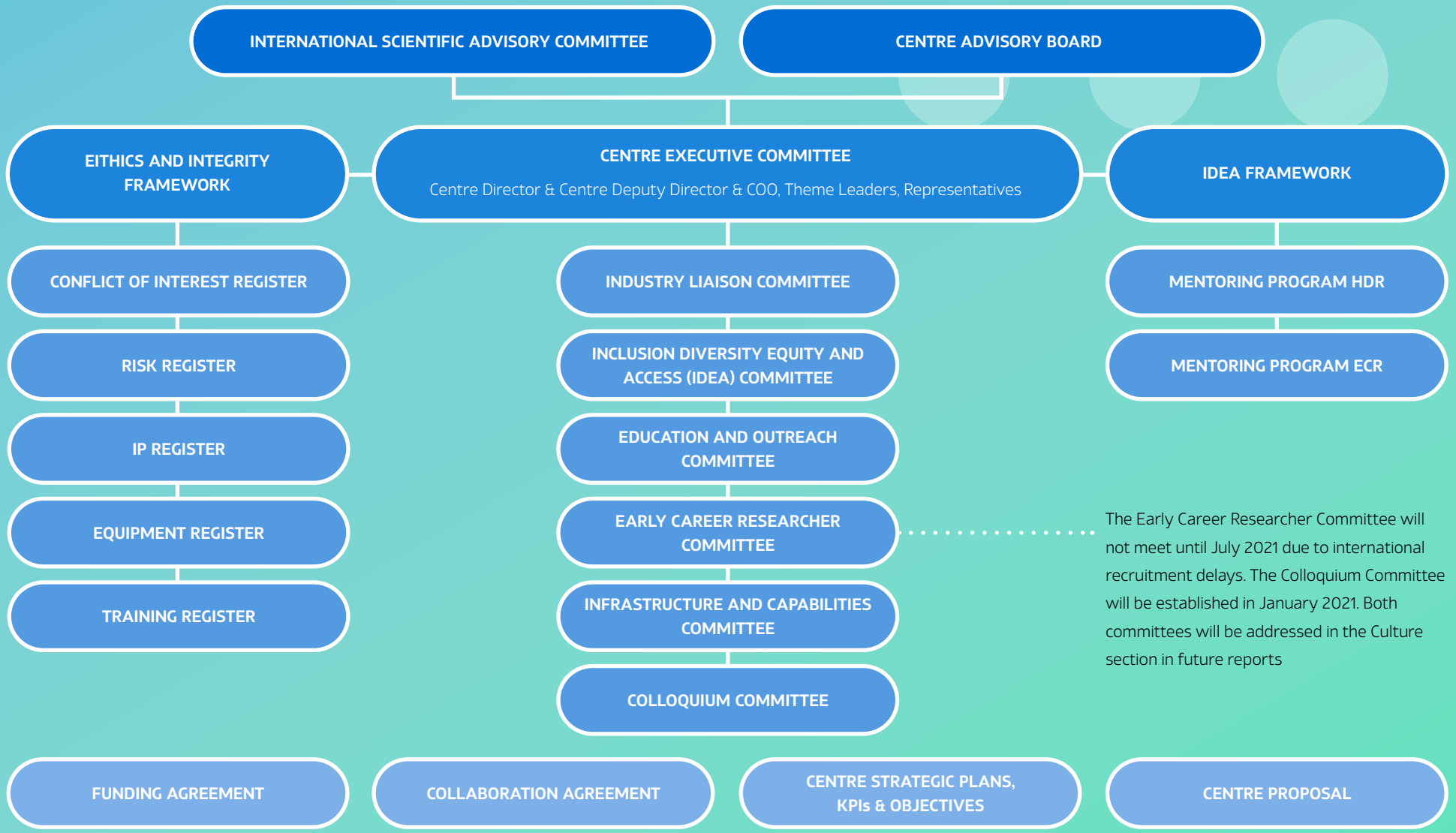
We have a big vision for the Centre. I am excited to facilitate this vision with our professional team, Centre members more broadly, and to grow the relationships with current and future Centre partners. We have built a robust governance structure, designed—and have nearly finished—recruiting our awesome professional team, and we are planning and implementing activities across all domains of the Centre. So much goodness for 2021!

> "We have a big vision for the Centre. I am excited to facilitate this vision... and to grow the relationships with current and future Centre partners.

I aim for our work within the Centre to transform, not only science, but ourselves, our universities, and our colleagues. We have the resources to experiment and create new best-practice methods and the safety of our university bases to take calculated risks for change, such as on IDEA, communication, and impact. I look forward to having the complete professional team come onboard in 2021 and having more of our postdocs and students join us to create a dynamic distributed team of kind, conscious, genius doers!

Dr Mary Gray
Chief Operations Officer

Governance: Structure



The Early Career Researcher Committee will not meet until July 2021 due to international recruitment delays. The Colloquium Committee will be established in January 2021. Both committees will be addressed in the Culture section in future reports

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: Centre Executive Committee Directorate Report

As the Directorate Team of the Centre Executive Committee (CEC), we are very big on integrity and transparency. We see the CEC the platform for this, in alignment of our Centre value of collaboration. We have a 600-page proposal to implement as a team, the core of which is distributed across five Australian universities. Individually within our institutions, we are just small parts of much larger organisations. But together, as a national entity, our Centre is collectively powerful and influential on our institutions and colleagues both locally and internationally. It is therefore imperative that we make a space where we can focus and align ourselves as a single, impactful voice with a shared vision. If our colleagues believe in what we have to say and see and the benefits of our achievements, we will be privileged to play the major role in developing meta-optics as a key Australian research strength and future industry.

The CEC is the decision-making body of the Centre. The Committee will be leading, monitoring, and communicating with the Directorate Team on the planning, implementation, and progress of the Centre's activities including research performance, mentoring, career development, our culture (inclusion – diversity – equity – access), outreach, education, and technology translation. All Centre sub-committees report into the CEC, so that all members stay updated on all activities across our ambitious program. This way, we can maintain our shared vision. Excellent communication and demonstrating leadership values through participation by the senior members of the Centre will enable us to be great role models for our junior members.

The Chief Investigators and the Chief Operations Officer met together nearly every week during 2020, in the lead up to becoming formally operational by 31 December 2021, in what we called 'our pre-executive' meetings. We made these meetings a priority during the disruptions to our regular way of working of the year. We developed our draft Research Plan, the draft Terms of Reference for our committees, tackled draft polices and frameworks, identified our Key Performance Indicators, and embarked on a special measures recruitment round for postdoctoral researchers. Importantly, we created a habit of regular communication on our operations and research issues. Our governance foundations have had input and buy-in from every Chief Investigator. We believe this has set us up for long-term success.

For 2021, we will implement our formal CEC meetings on a fortnightly basis, to discuss operational, governance and risk issues, as well as a brief science update. Although only certain individuals (the Centre Directorate and the Theme Leaders) can formally vote on decisions, all Chief Investigators are expected to actively participate. We will also include a student representative and an early career researcher representative on the committee by July 2021. On the alternate fortnight we will have Theme Meetings, where the theme leaders will host discussions on the science with all Chief Investigators, and others as required. This approach ensures we maintain our great communication habit that we developed in 2020 and provide adequate time for formal CEC matters, and for our science.

We are excited to lead the Centre into 2021 with our excellent team of researchers and professionals.

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

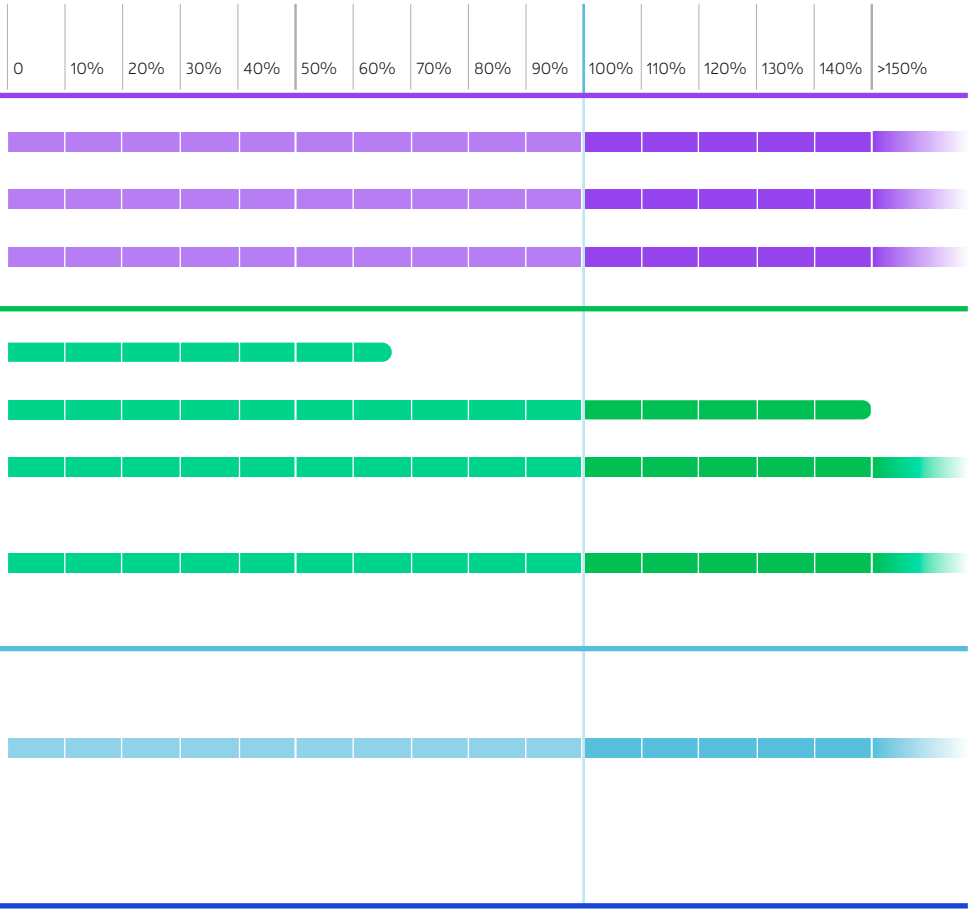
ACTION ITEMS FOR 2021

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

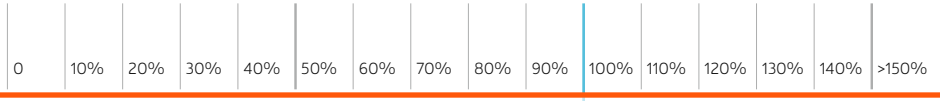
Performance

Key Performance Indicators

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



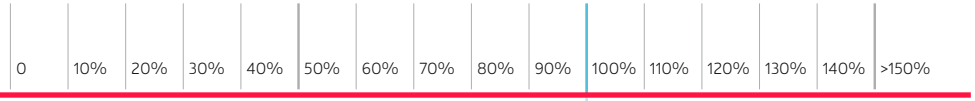
Performance Measure		Target Y0 2020	Actual Y0 2020
Number of training courses held/offered by the Centre	Professional Development Courses	1	0
	Topical workshops and courses	1	0
	Centre-wide Seminar Program, number of presentations	5	0
Number of additional researchers[2] working on Centre research	Postdoctoral researchers (new)	6	3
	Honours and undergraduate students	2	1
	TMOS HDR Students (PhD and Masters new)	10	0
	Masters by coursework students (new)	4	0
	Associate Investigators (new)	3	0
Number of postgraduate completions	Women HDR completions (percentage of the cohort)	0	0
Number of mentoring programs[3] offered by the Centre	Industry Internships (any level longer than 1 month)	0	0
	PI-Student Exchange Program	0	0
	Mentors within the Centre	15	0
	Number of Mentees	10	0



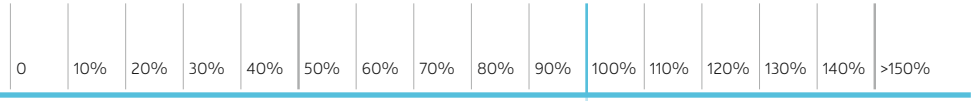
2 We experienced delayed recruitment due to international travel restrictions and an overall delayed start to formal Centre operations due to the COVID-19 pandemic.

3 The HDR and ECR mentoring programs were not implemented, nor were industry internships and the international student exchange program, due to the COVID-19 pandemic.

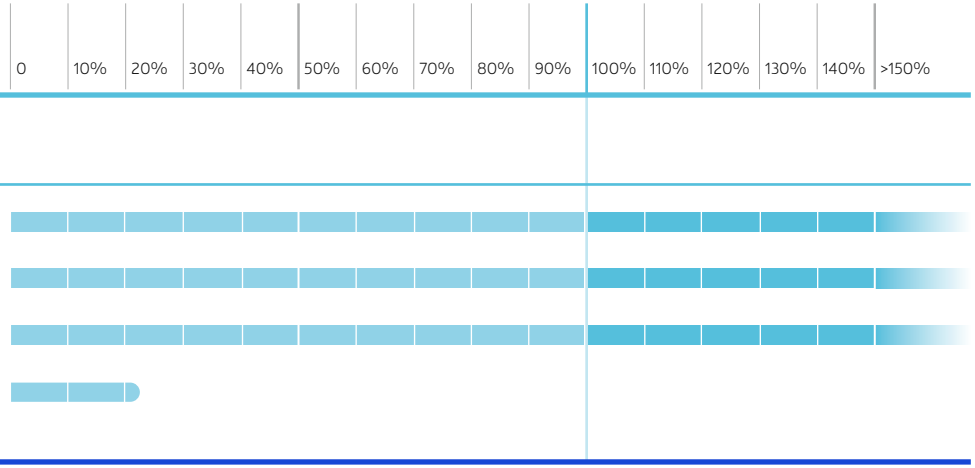
Performance Measure		Target Y0 2020	Actual Y0 2020
Number of presentations/ briefings	To the public (Outreach/public engagement events, public lectures)	2	4
	To government (parliamentarians and department/agencies at both State and Federal level)	0	2
	To industry/business/end users (documented) incl.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



Performance Measure		Target Y0 2020	Actual Y0 2020
Centre-specific KPIs			
Research	Plenary talks at international conferences	1	2
	Keynote and Invited talks at international conferences	10	21
	Awards and fellowships to CIs, ECRs and AIs	1	11
	Additional research income secured by Centre staff ('000)	100	4410.3
Equity and Diversity	Unconscious bias training, % of Centre personnel (CIs)	100	0
	Inclusion training, % of Centre personnel	N/A	0
IP uptake by end-users	Start-up Companies	0	0
	IP uptake by end-users	0	0
	Number of TMOS alumni employed in Industry	0	0
Education	Associate TMOS HDR students (PhD and Masters, new)	10	16
	Centre-member attendees at training workshops (total)	30	0
	Non-Centre member attendees at training workshops	5	0
	HDRs visiting PIs	0	1



Performance Measure		Target Y0 2020	Actual Y0 2020
Centre-specific KPIs			
Outreach	Media releases	2	6
	Media mentions	2	6
	Twitter followers (new)	100	477
	Outreach hours	100	22



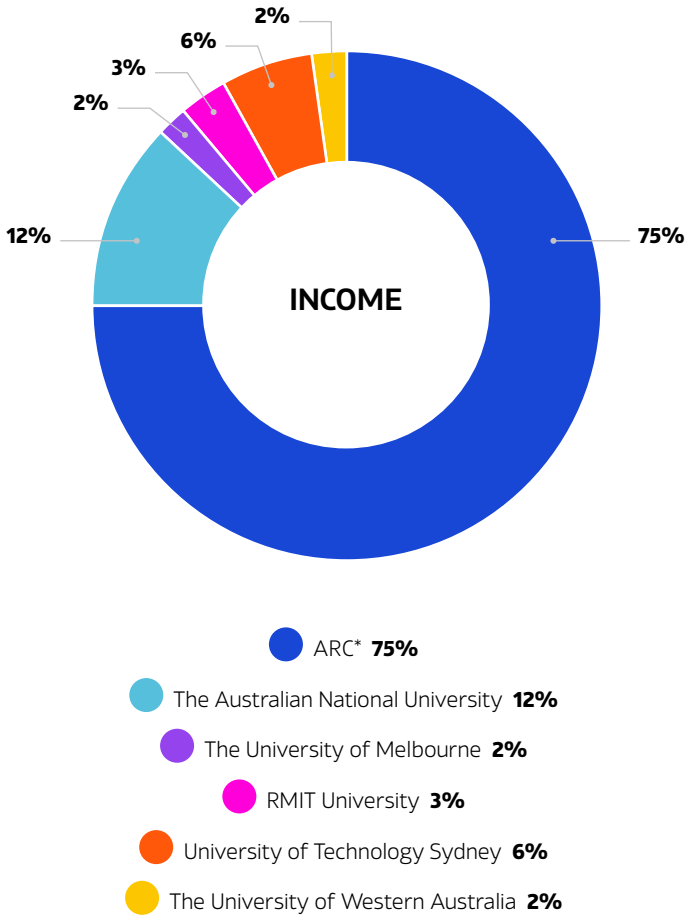
Finance

REPORTING PERIOD	2020	2021
INCOME	Actual ($)	Forecast ($)
ARC*	5,088,022	5,174,427
Australian National University	780,852	740,184
The University of Melbourne	159,011	159,011
RMIT University	195,743	202,793
University of Technology Sydney	404,857	404,857
The University of Western Australia	159,725	159,725
TOTAL INCOME	**6,788,210**	**6,840,997**

REPORTING PERIOD	2020	2021
	Actual ($)	Forecast ($)
Personnel	267,285	3,797,810
Equipment	3,673	763,117
Scholars Expenses	3,446	954,142
Travel	6,125	338,500
Other#	57,559	987,428
TOTAL EXPENDITURE	**338,089**	**6,840,997**
CARRY FORWARD TO 2027	**6,450,121**	

* Includes indexation

Other include Branding, outreach and consultancies, Recruitment expenses, Administrative support



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Awards, Honours and Prizes

TMOS Member	Awards, Honours and Prizes	Awardee
Madhu Bhaskaran	2020 Frederick White Medal	Australian Academy of Science
Madhu Bhaskaran	40 under 40 Most Influential Asian-Australians, Category winner for Science and Medicine	Asian-Australian Leadership Summit
Chennupati Jagadish	Lloyd Rees Memorial Lecture	Australian Academy of Science
Chennupati Jagadish	International/Foreign Member, US National Academy of Engineering, since 2020	US National Academy of Engineering
Chennupati Jagadish	Foreign Fellow, National Academy of Sciences, India	National Academy of Sciences, India
Francesca Iacopi	Elected Member, Board of Governors, Dec 2020	IEEE Electron Devices Society
Hoe Tan	Australia's leading researcher in the field of nanotechnology	The Australian Research Magazine
Ilya Shadrivov	OSA Fellow - class 2021	The Optical Society (OSA)
Igor Aharonovich	OSA Fellow - class 2021	The Optical Society (OSA)
Igor Aharonovich	The Kavli Foundation Early Career Lectureship in Materials Science	Materials Research Society

Awarded Funding

TMOS Member	Title of Funding Scheme	Project ID	Total Amount (AUD)	Funding Source
Kenneth Crozier	Long-wave infrared photodetectors based on nano-optics and two dimensional materials		132,000	Defense Advanced Research Projects Agency (DARPA)
Igor Aharonovich	Interlayer Excitons as quantum emitters in 2D materials		132,000	Asian Office of Aerospace Research and Development (AOARD)
Dragomir Neshev	OPTIcal liMIing and SwiTching with nanoscale photonic structures (OPTIMIST)		162,400	North Atlantic Treaty Organization - Science for Peace and Security (NATO -SPS)
Igor Aharonovich	3D Nanofabrication and Nanocharacterisation facility	LE200100003	400,000	Australian Research Council (ARC)
Hoe Tan	X-Ray Nanolithography Facility: Towards the ultimate resolution	LE200100174	445,000	Australian Research Council (ARC)
Igor Aharonovich	Confidential		>500,000	Confidential
Andrey Sukhorukov	Photonic Chip Integration Facility	LE200100071	535,000	Australian Research Council (ARC)
Francesca Iacopi	Advanced Multifunctional Electro-Opto-Magneto-Mechanical Analysis Platform	LE200100032	600,000	Australian Research Council (ARC)
Francesca Iacopi	Miniature Physiological Sensors and Decoders for Brain-Robot Interaction		1,100,000	Department of Defence Innovation Hub

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