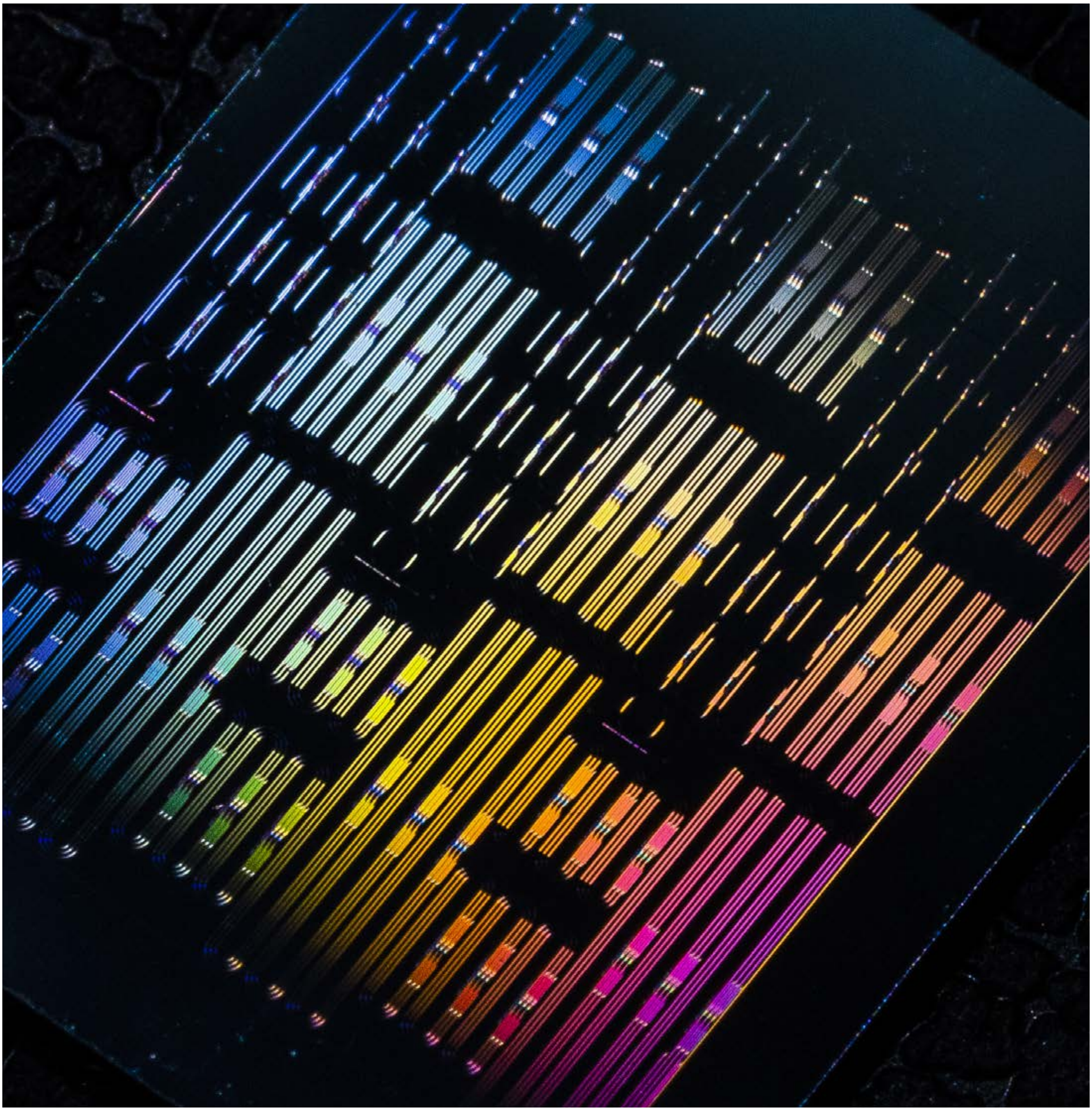

Integrated Photonics and Applications Centre

Annual Report

2022

RMIT UNIVERSITY

InPAC Integrated Photonics and Applications Centre

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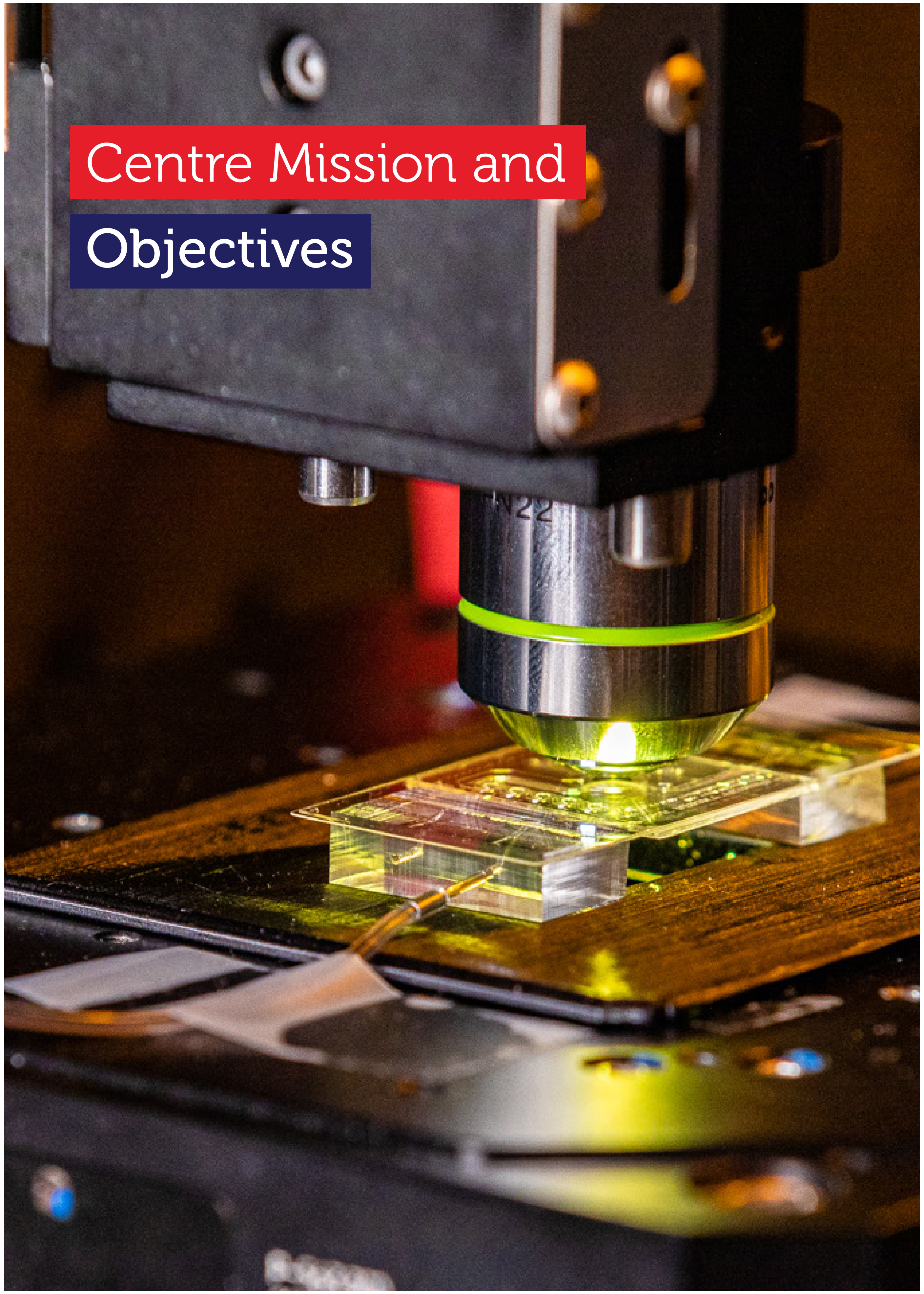
Centre Mission and Objectives



Centre Mission and Objectives

Centre Mission

Our mission is to create impactful integrated photonic technologies. This is achieved by continuous end-user engagement to deeply understand real-world problems. We pioneer breakthrough science in the field of integrated photonics coupled with rapid, systematic and disciplined iterations to deliver a consistent stream of significant outcomes to end users.

Centre Rationale

The rise of ‘big data’, artificial intelligence and the internet of things predicts that the world will be filled with ubiquitous highly integrated objects that can monitor and interact with the world without human interaction. This will create new paradigms for manufacturing and indeed for our way of life. However, to make this vision a reality, we will need new and diverse forms of sensors and technologies to manage the ever-growing volumes of data they will collect. All this will need to happen while maintaining environmental robustness and the low cost that we now take for granted in consumer electronics.

Electronic technologies are excellent for processing digital information but lack the precision and sensitivity to sense subtle features of our analogue world. They also lack the bandwidth to transport this detailed information to central processing hubs. Photonic approaches can provide orders of magnitude more sensitivity and millions of times more bandwidth than electronics can offer.

Integrated photonics is emerging as a technology, which enables photonic components to be integrated directly onto fingernail-sized microchips using the same technology currently used to mass manufacture integrated electronics. Photonic integrated circuits have been the subject of research for decades, but the manufacturing infrastructure and industrial demand has only recently reached the scale and intensity to match the same revolution that integrated electronics had, but in integrated photonics.

Centre Vision

Our vision is for the Integrated Photonics and Applications Centre (InPAC) to be recognised as world leaders in the research and translation of photonic integrated circuit technology. We are determined to be pioneers of fundamental science and cutting-edge technology, but with a commitment and track-record in translating this technology into practical solutions to address real world problems spanning data, defence and biomedical fields.

We believe it is possible to transition from high volume, foundry mass manufacture – the same that has grown the electronics industry for the last 50 years – to advanced manufacture of highly customised solutions using modular building blocks, with easy and dynamic scaling between small and large volumes. Through this approach, we believe we can engage with a much broader range of end-users – especially small, specialised industries in Australia.

Objectives

Research: The Integrated Photonics and Applications Centre (InPAC) will perform world-leading research in photonic integrated circuits for applications in communications, biomedical and defence.

Education and Training: InPAC will inspire, guide and educate the next generation of photonic engineers and scientists to strengthen and shape the Australian photonic community.

Translation: InPAC will create intellectual capital and translate it to benefit the Australian photonic industry, building industrial strength through new jobs and new companies.

Director's Report

Looking back on 2022, I am struck by just how much the Integrated Photonics and Applications Centre (InPAC) has achieved.

The major focus of this year was on the ARC Centre of Excellence in Optical Microcombs for Breakthrough Science (COMBS). In the first quarter we submitted the nearly 1000-page application, and in the second we prepared intensively for the interview. In the third quarter, while we were frantically rebooting a lot of our activities post-COVID, we nervously awaited the outcome from the ARC! By the years end, we finally got the news that we were successful in transforming our research direction for the next decade, handing us a mandate to lead the photonic chip ecosystem in Australia.

In parallel with the COMBS application, we expanded our collaborations with new industry partners, such as Future Fibre Technologies, the SmartCrete Cooperative Research Centre and new collaborations in defence with DSTG. We expanded our international collaborations through the Australia France Network of Doctoral Excellence (AUFRANDE) $15.7M project, supporting more than 60 STEM HDRS students and establishing RMIT as an international leader in industry-focused research education.

Among the many great achievements of the InPAC team, I would like to congratulate Andy Boes who is making great strides setting up independently at The University of Adelaide, and winning his own ARC Discovery Early Career Award (DECRA). I also congratulate Bill Corcoran at Monash University for winning his ARC Future Fellowship – recognising him as Australia's leading researcher in data communications. Both Andy and Bill will join COMBS as Chief Investigators.

When we started InPAC, we dreamed about successes of this scale. It is startling to see how much we have grown and how far we have come such that this is now our reality. This is a testament to the hard work, imagination and dedication of the whole InPAC team.

I believe 2023 will be a year of reflection and planning, to choose our next steps in recalibrating our ambitions for the next decade. I am excited to start on this new phase of InPAC and to find out what we can achieve together!

Distinguished Professor Arnan Mitchell
Director of the Integrated Photonics and Applications Centre (InPAC)

Centre Members

Below is the list of members at the Integrated Photonics and Applications Centre in 2022. New members recruited in 2022 are marked with an asterisk (*) beside their name.

Director

Dist. Prof. Arnan Mitchell

Arnan is responsible for the overall strategy of the Centre and is the initial contact for new collaborations with academics, industry and government.

Media and Communications

Science Communicator

Rachael Vorwerk

Rachael is a science communicator and raises the profile of the Centre, whilst working with the team to make their research accessible to broader audiences such as the public, media, grant funders and industry.

Data Communications Team

Team Leader

Dr. Bill Corcoran

Bill is a researcher in optical communications, focusing on using novel photonic technologies to fix problems in the systems that provide the backbone of the internet.

PhD Student

Caitlin Murray*

Caitlin is investigating novel ways to generate and refine optical frequency combs, to support ultra-high speed communication in a more efficient way, enabling us to keep up with future global internet traffic demand.

PhD Student

Jorge Acosta-Montes*

Jorge is working on ways to put the most data on optical frequency combs in the most efficient ways possible, to reduce the power consumption of the internet while enabling increasing connection speeds.

PhD Student

Park (Chawaphon) Prayoonyong

Chawaphon (Park) is investigating how optical frequency combs can support data communication systems, to reduce costs and the load on current internet infrastructure.

PhD Student

Yisong (Ethan) Xu*

Yisong is looking at ways in which we can make communications to satellites as fast as we can on the ground, by making current multi-terabit internet technologies applicable to space.

PhD Student

Yonghang Sun

Yonghang is investigating ways to clone laser light after travelling over long distances of fibre, which aims to allow for ultra-high data rates in our internet infrastructure, but with lower energy consumption and cost.

Precision Sensing and Defence Team

Team Leader

Dr. Andreas Boes

Andy is using photonic integrated circuits for precision sensing and defence applications (such as inertial positioning sensors), which are created by the simulation and fabrication teams.

Staff

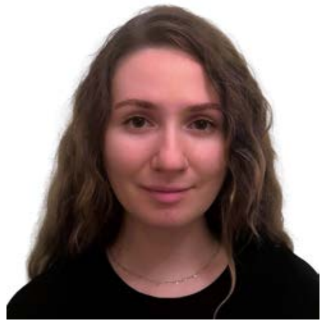
Nicholas Greig

Nicholas designs and simulates the optical components at visible wavelength on silicon nitride platform for the applications of virtual reality.

Staff

Luke Broadley

Luke is working on signal processing techniques to improve the accuracy, size, and cost of optical sensors needed in assessing biological samples, monitoring the structural health of buildings and bridges, and defence applications.



PhD Student (Ecole Centrale de Lyon)

Marina Raevskaia

Marina creates integrated non-linear broadband light sources to make the internet faster, more energy-efficient and capable of carrying larger bandwidths.

PhD Student

Paramjeet Kaur

Paramjeet is creating a photonic integrated photodetector that will make sensors more accurate, compact and cost-effective to be used in driverless cars, infrastructure monitoring and drones.

PhD Student

Rebecca Taube

Rebecca is researching how to integrate optical gyroscopes onto a fingernail-sized chip so they are more suitable from a cost and performance perspective in driverless cars.

Simulation and Design Team

Team Leader

Dr. Thach Nguyen

Thach is responsible for coordinating the simulation and design efforts of the Centre and investigates new theoretical concepts for photonics integrated circuits.

PhD Student (Casual staff)

Hiep Dinh

Hiep designs light-powered components capable of simulating the complex behaviour of crystals, to experiment whether these unique properties could be used for high-speed processing in quantum computing.

PhD Student

Haijin Huang

Haijin is researching how to use more efficient techniques like optical frequency microcombs, to send data faster and more efficiently through existing networks for faster internet speeds.

PhD Student (Ecole Centrale de Lyon)

Kokou Firmin Fiaboe

Kokou designs, fabricates and integrates broadband sources into photonic chips using a lithium niobate platform for environmental monitoring, medical diagnosis and military applications.

PhD Student (Technical University of Denmark)

Lars Emil Gutt*

Lars was investigating the use of photonic chip technology to control the speed of light to increase data transmission speed over a single optical fibre with different colours of light.

PhD Student (Ecole Centrale de Lyon)

Panteha Pedram

Panteha is developing new 2D materials to identify their non-linear optical properties, to integrate them onto chip-based devices to increase data flow across the internet.

Simulation and Design Team

PhD Student (RMIT Vietnam)

Phuong Tang

Phuong is investigating how to develop more compact ways to implement a new type of filter, which is an essential component for a variety of applications including sensing and data communications.

PhD Student

Tasneem Akther

Tasneem is researching more efficient, accessible and less invasive scanning methods using on-chip optical filters that could be used to more accurately read glucose levels or the allergic components of food.

PhD Student (Lanzhou University, China)

Xu Han

Xu investigates devices and circuits on photonic chips that can enable low energy consumption, high speed data transmission using the next generation optical fibres.

Undergraduate intern (Casual staff)

Max Herbold

Max produces computational algorithms and processes that interface with specialised laboratory hardware to ensure the teams' light-powered devices are working as they should be.

Fabrication Team

Team Leader

Dr. Guanghui Ren

Guanghui looks after InPAC's current fabrication platforms and establishes new technologies for application teams and end-users, whist ensuring all InPAC's photonic integrated circuits perform the way the design team intended.

Staff

Rifat Ahmmed Aoni*

Rifat explores the possibility to combine meta-surface structures with photonic integrated circuits for the applications of free-space beam manipulation which can be potentially used in LiDAR systems for autonomous driving.

Fabrication Team

Staff

Dr Armandas Balčytis

Armandas is working on interfacing and packaging microscale integrated photonic circuits for real-world applications, like enhancing the precision of drones used for remote survey of land and infrastructure.

PhD Student (Casual staff)

Aditya Dubey

Aditya's research combines functional optical materials with novel two-dimensional materials to create more compact, sensitive and accurate applications in defence, data communications, and biotechnology.

PhD Student

Jackson Jacob Chakkoria

Jackson is researching wavelength converters that have the potential to meet future high-speed communication needs while minimising energy consumption, cost, and size with the photonic integrated circuit platform.

PhD Student (Ecole Centrale, Lyon)

Marko Perestjuk

Marko is working on trapping mid-infrared light to develop a tiny fingernail-sized photonic chip to make sensors more compact for detecting diseases in our breath, or the quality of the air in our environment.

PhD Student (Ecole Centrale, Lyon)

Mohab Abdalla

Mohab is investigating neuromorphic computing architectures using integrated photonics, aiming towards energy-efficient hardware with faster computational speeds for ever-demanding deep learning applications.

PhD Student

Sonya Palmer

Sonya is looking at how integrated photonic circuits can be used to miniaturise precision measurement tools like quantum sensors for use in satellites in deep space exploration and more accurate mining.

Biomedical Applications Team

Team Leader

Dr. Cesar S. Huertas

Cesar combines photonic biosensors with microfluidic devices to give us more accurate insight into human biology and disease states for more personalised treatments in the future.

Staff

Dr. Crispin Szydzik

Crispin is creating new microfluidics approaches to more accurately filter, sample and sense small amounts of liquid such as blood and saliva for more precise and personalised medical devices.

Staff

Dr. Francisco Lopez

Francisco investigates how to use microfluidics and micromechanics to ensure the seamless integration of all components for more precise biomedical fluid handling, personalised care devices and sensitive sensors.

Visiting Research Fellow

Dr Tetsuya Shimogaki*

Tetsuya is investigating how to make portable medical devices that can easily and rapidly detect viruses and proteins in a small amount of biological sample.

PhD Student

Siew Joo Beh

Siew is using photonic biosensors to create a handheld, compact device that aims to revolutionise how heart attacks are currently diagnosed.

PhD student (Casual staff)

Jorge Lozano Lopez

Jorge is working with optical sensors based on nano-structures and is researching how to improve the sensitivity of sensors by applying signal processing techniques to ensure everyone has access to high quality healthcare.

Biomedical Applications Team

PhD student

Madhuri Edla

Madhuri is researching simpler, faster and more accurate fabrication methods so larger numbers of samples can be analysed at the same time for medical diagnostics.

PhD Student (Ecole Centrale de Lyon)

Syed Harris Hussain

Harris is working on developing an integrated optical-microfluidic biosensing device for real-time analysis of cancer cell biomarkers circulating in the blood.

PhD student (Casual staff)

Paul Michel Lara*

Paul is developing a handheld, real-time device to detect signs of early ovarian cancer by using light-powered biosensing technology.

Masters student

Wei-Che (Wade) Chang*

Wade is a cross-disciplinary researcher with a focus on medicine and microfluidic devices.

Centre Recruitment and Integration

Our focus is on addressing any gaps or imbalances that have been identified within the Centre, including those related to emerging science, technology, and applications, as well as issues pertaining to gender and career stage diversity.

Staff

Our 2022 recruitment strategy focused on finding individuals with:

- relevant research experience in photonic integrated circuits
- Australian citizenship for defence-related projects
- proficiency in IPKISS
- capabilities in chip packaging and interfacing.

We advertised staff positions through online recruitment sites, as well as our Centre's and researchers' social media channels such as LinkedIn and Twitter. We also used the RMIT recruitment webpage and included a link on our InPAC website. Typically, these positions are associated with specific externally funded research projects (e.g., industry, ARC, etc.).

New staff at InPAC are introduced by existing staff during team meetings, receive tours and inductions of labs and facilities to familiarise themselves with ongoing experiments and given fabrication or design training (as required).

Higher Degree by Research (HDR) students

In 2022, our recruitment priorities included finding HDR students with:

- motivation and initiative
- excellence in relevant research related to photonic integrated circuits (PICs)
- Australian citizenship for defence-related projects
- proficiency in IPKISS
- capability and interest in chip packaging and interfacing
- relevant technical backgrounds (not always necessary)
- ability to communicate effectively
- capacity for learning.

Our team at InPAC regularly advertises PhD positions on our website and social media channels (LinkedIn and Twitter) throughout the year. The Director and Team Leaders also share any advertised positions on their LinkedIn and Twitter accounts. We also recruit students who conduct their projects and Masters' with our Centre.

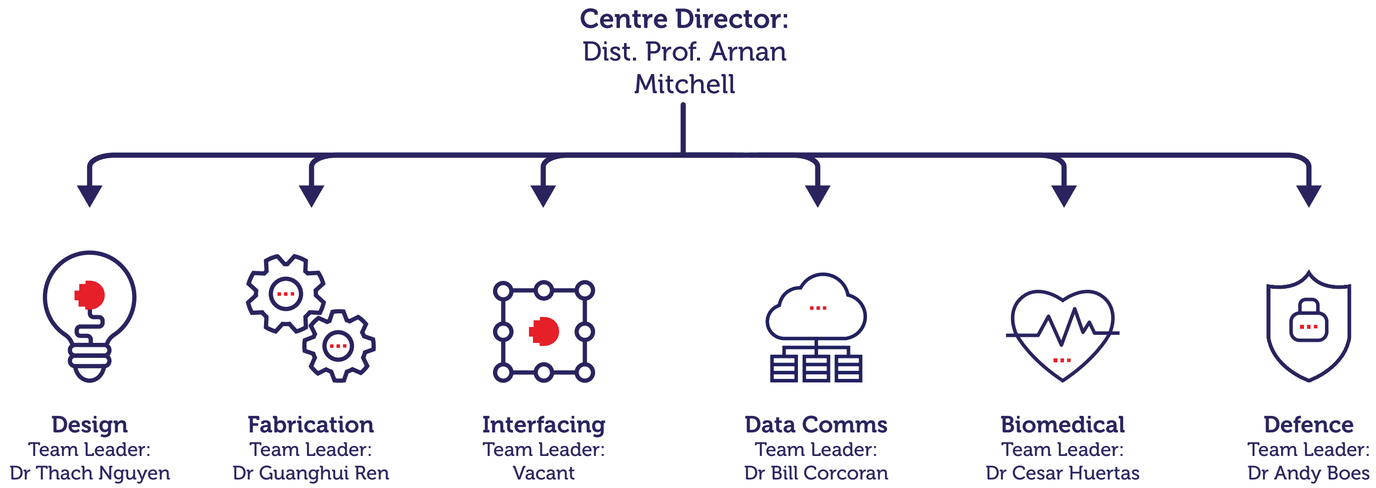
Upon joining InPAC, HDR students are introduced to the team in meetings, given training in fabrication and design as required, provided with lab and facility inductions, and introduced to the scientific discipline to learn skills in critically analysing relevant information for their project. HDR students are also scheduled to present at the InPAC Team Meeting in the lead up to their first milestone, to gain feedback about their research.

Structure and Governance

Organisation structure

InPAC comprises of one Centre Director coordinating six focused teams (Design, Fabrication, Interfacing, Data Communications, Biomedical and Defence), each of which is led by an early or mid-career researcher and includes a cohort of students. A schematic of the personnel organisation structure of InPAC is shown below.

Plans are underway to recruit an Interfacing Team Leader.



Advisory Board

A Centre Advisory Board was planned for 2022, with four members that bring a broad range of experience and background.

This goal was not met, and going forward we will need to align the advisory board for the Centre of Excellence in Optical Microcombs for Breakthrough Science (COMBS) with InPAC.

Advisory Board Recruitment for 2023

We will aim to recruit the following members for the Advisory Board through our own Centre's networks:

- One world leading photonics researcher from Australia, Europe or the USA, which will be sourced through existing collaborations or common research initiatives.
- One industry representative from the biomedical application field, sourced through national industry bodies, such as AusBiotech or BioMelbourne Network.
- One industry representative from the communications application field, which will be sourced through existing industry collaborations of a larger company. Specifically, we will engage with Finisar and Cisco.
- One representative from the application field of defence, which will be sourced using the Australian Industry Defence Network. One member should represent 'prime' contractors (e.g., from a government body like DSTG) and the other member should represent defence small-to-medium enterprises.

InPAC Team Meetings

All InPAC members attend these Team Meetings which were held fortnightly on Wednesdays in 2022. The Team Meetings are not held in slow down periods or public holidays. These Team Meetings include a variety segments:

- **Update presentations** – InPAC team members provide an update about their research.
- **Milestone preparation presentations** – PhD students practice their presentation to gather feedback from the InPAC team before their milestone.
- **Journal Club** – InPAC team members analyse a journal article that is from a top-tier journal that includes cutting edge literature or research related to InPAC. The segment encourages the team to describe other research in a non-technical manner, whilst highlighting its significance to the team.
- **News Article Club** – InPAC team members analyse an article in the news related to STEM and describes why it was a newsworthy science story. This segment builds the teams' science media literacy, while helping them to understand how they might promote their own research in the media.
- **Prizes and Awards overview** – our Centre's Science Communicator Rachael collects the latest prizes and awards and categorises these to PhD students, ECRs and other researchers. These upcoming opportunities are presented during the InPAC team meeting for Centre members to apply for.

InPAC Team Leader Meetings

Five Team Leader meetings were held in 2022, where all Team Leaders and our Director attend these meetings. These meetings included agenda items such as:

- Grant planning
- Strategic planning outlook (i.e. Where we want things to be in three years' time)
- Focusing efforts on uplifting projects
- Equipment requirements
- Strategic PhD and Fellowship recruitment

Report on 2022 Achievements and Activities

Summary of 2022 plans, outcomes, key achievements and Centre impact

Key Achievements and Impact

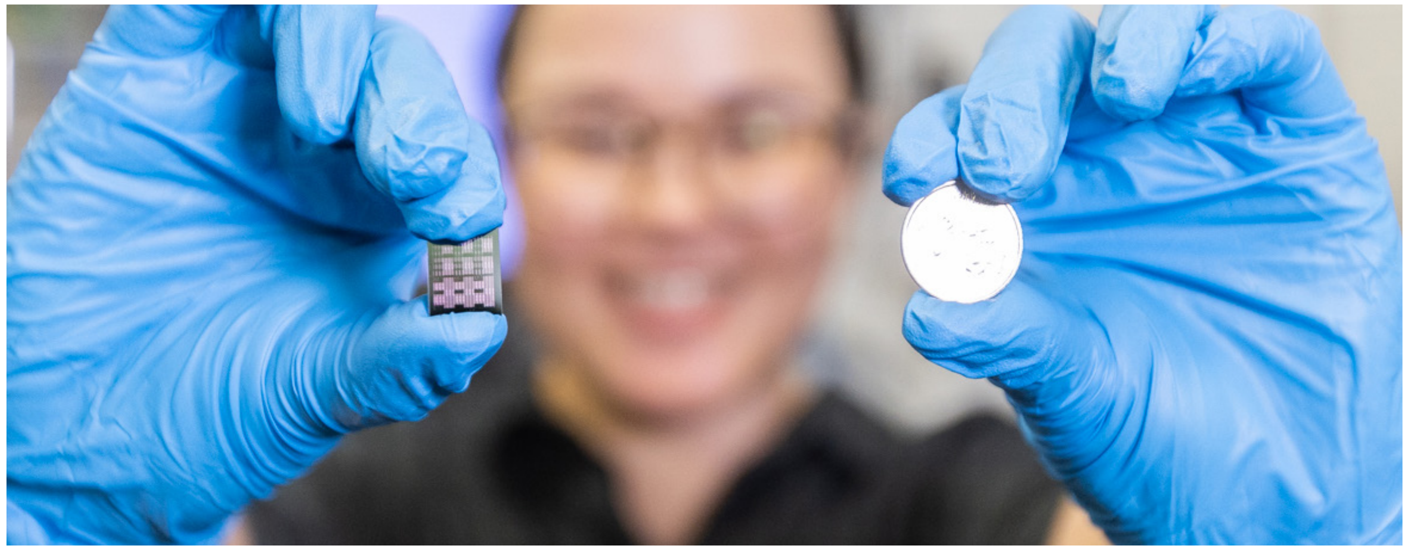
The Centre had many key achievements in 2022, as highlighted below.

Research Excellence

- The Centre members published a total of 29 journal publications, 24 in Q1 journals, 3 in a Q2 journal, 2 uncharacterised; and a book chapter.
- Highly significant, breakthrough research demonstrations were reported in leading journals including *Science, Nature, Nature Electronics, Advanced Optical Materials* and *APL Photonics, Nature Materials*.
- Centre members were recognised for their research excellence by being various ARC funding grants including a DECRA (Discovery Early Career Researcher Award), Future Fellowship and ARC Centre of Excellence.

Research Funding

- InPAC was successful in attracting seven research grants in 2022:
  - **ARC Centre of Excellence in Optical Microcombs for Breakthrough Science valued at $34,958,910** including Arnan Mitchell, Andy Boes, Bill Corcoran to bring optical frequency comb technology – which translates electronic signals into light waves for high precision measurement – out of the lab and into a wide range of real-world applications.
  - **AUFRANDE – Australia-France Network of Doctoral Excellence valued at $11,977,475** including Arnan Mitchell to help educate the next generation of at least 64 STEM researchers.
  - **ARC Future Fellowship valued at $1,207,007** awarded to Bill Corcoran (Monash University) to produce new technologies to help our internet infrastructure keep up with data demands.



- **ARC Discovery Early Career Researcher Award (DECRA) valued at $456,354** to Andy Boes (transferred to University of Adelaide) to make optical frequency combs (the world's most precise ruler) even more accessible at more light wavelengths, like in the visible realm.
- **ARC Linkage Infrastructure, Equipment and Facilities (LIEF) valued at $852,787** awarded to Arnan Mitchell, Bill Corcoran, Andy Boes (among others) to create a Dual-comb Hyperspectral Imaging Facility that will respond to newly emerging global trends towards video rate imaging with precision spectral analysis
- **Innovations Connections with Future Fibre Technology valued at $50,000** to explore using photonic chip technology to improve the performance and minimise the cost of optical fibre intrusion detection technology.
- **Defence Materials Technology Centre (DMTC) project valued at $95,882** to create arrays of tiny sensors to listen for sounds travelling on the wings of aircraft to determine their structural health.

Centre Impact

The Centre has made the following impact in 2022:

- Successfully funded ARC Centre of Excellence in Optical Microcombs for Breakthrough Science (COMBS) to develop ultra-precise measurement devices that could enable high-speed internet, better medical screening technologies and carbon emissions monitoring.
- The Centre held a Veski and Study Melbourne student workshop to promote PhD positions in Melbourne, which led to 68 online registrations.
- Four RMIT news articles sharing the Centre's news – ranging from ovarian cancer awareness week, International Day of Light, HatiSens and the Centre of Excellence – were published and led to news stories in Cosmos, Australian Manufacturing and VICE Media.
- Twenty-nine journal articles and one book chapter were published in total, spanning many high impact journals including Nature, Nature Electronics, Advanced Optical Materials, APL Photonics and Nature Materials.
- Arnan presented his second Distinguished Lecture at RMIT University about how optical microcombs can be used to measure earthquakes, tsunamis or even the planets of distant suns.

Performance Against Targets

Create and maintain a vibrant, collegiate and stimulating intellectual environment in which researchers and research students are mentored, guided and supported to develop their careers.

Our team has fortnightly meetings that include different segments of focus. One element is to talk about prizes for career development. We have regular presentations where students and staff present a research update, and these are timed in the lead up to student milestone presentations to help them to prepare. Another element of these meetings is called 'Journal Club,' which give staff and students the opportunity to analyse the latest academic literature.

As border restrictions have lifted since COVID-19, our students and staff are traveling more to international conferences to share and learn about their field of research. In 2022 a cohort of students and staff attended the 15th Pacific Rim Conference on Lasers and Electro-Optics in Sapporo, Japan. Another cohort attended the 2022 Australian and New Zealand Conference on Optics and Photonics (ANZCOP) in Adelaide, among many other conferences.

Our Centre also heavily focuses on providing students with real-world industry-engaged projects. A part of this is also employing the students to work as Research Assistants on projects that are complementary to their own PhD.

Expectation 1: *Researchers within the Centre actively support, coach and mentor each other and their junior colleagues to achieve success in their research and career goals.*

Each of the teams within the Centre has their own regular set of meetings that they organise. This way Team Leaders have autonomy in finding the right structure to suit their leadership style.

The Centre is set up to enable our teams to engage with industry and advance their academic careers. This includes each team practice writing high profile papers, and applying for grants that are relevant to their end-users' needs. We ensure that the students are participants in this process.

Expectation 2: *Number of female researchers in the Centre increases.*

We are proud of having a 50/50 gender balance in our HDR cohort, and we will continue to maintain that. There are different gender balances in different research disciplines – for example biotechnology has a higher proportion of women compared to data communications.

However, we need to do better at the post-doctoral level, where we currently have seven males and five females. There are several approaches we are taking to bolster this number at the leadership level.

Firstly, we can use the Centre of Excellence funding more proactively to hire five new postdocs. This can help to improve the gender balance at the post-doc level.

Another approach is to recruit mid-career female research leaders as team leaders in InPAC, and help to create roles that are relevant to our Centre. We can use the COMBS (Centre in Optical Microcombs for Breakthrough Science) Centre of Excellence to recruit photonic chip experts in engineering as female-only recruitment. To do this, we need to be using targeted positions for Fellows in ongoing, permanent positions.

Another method is to organise employment positions for recent PhD graduates, to target those who are promising female graduates. This approach worked for a number of female researchers at our Centre in 2021 and 2022.

Another approach is proactively reaching out to female collaborators directly. We have found this approach to also be quite successful.

Provide a high-quality training environment for research candidates that supports the timely completion of their higher degree and the development of a broad professional skill set that ensures they are highly competitive for jobs in their chosen career.

Target 1: Panel of examiner forms submitted at third milestone and approved by SGR prior to all candidate submissions

Target 2: On time completion of milestones and submission of thesis.

Expectation 1: *Organisation of regular meetings.*

As discussed earlier, our team has an InPAC-wide team meeting every fortnight, and each Team Leader organises a separate meeting with their PhD students. Each PhD student routinely presents at the InPAC team meeting in the lead up to a milestone presentation, giving them extra time to obtain feedback. These regular check-ins help students to work to their milestones.

Our goal is for HDR students to achieve their thesis submission within 3.5 years.

Expectation 2: *Workshops and/or seminars of the group.*

For the second year in a row, InPAC hosted a 1.5-day workshop at the beginning of the year to bring all team members together. 2023 was the first time a workshop had happened in-person and included overviews from each theme and discussion time for everyone to meet one another.

Each fortnightly meeting includes different segments, including project updates from staff and students and an analysis of recent journal articles and media articles.

Expectation 3: *Creation of opportunities for HDR students to network including internship opportunities.*

Our team has applied for many grants that explicitly include internships, particularly with changes in the Research Training Scheme program that doubles the funding if an internship is involved. This has also been written into the COMBS Centre of Excellence strategy.

Similarly, we have applied for many industry projects where we have explicitly said the industry partner must include an internship.

The whole philosophy of InPAC involves industry engagement, and most of the HDR students are inadvertently exposed to an industry partnership at some point during their PhD. Industry partners are also brought into our research at InPAC – pulling industry closer to the work students are doing.

Advance research in their specialist areas and develop both a national and international reputation for delivering excellent research outcomes.

Expectation 1: *Keep abreast of changes in the external environment and identify new opportunities both national and international.*

With restrictions lifting, we are encouraging InPAC team members to participate in national and international conferences. In the case that a team member cannot travel, we can overcome this is by engaging with conferences virtually. Another approach has been to analyse our international peers' research in the external environment through the Journal Club segment in our fortnightly InPAC team meetings. This segment allows students and staff to analyse high profile publications and learn who the groups are internationally.

Another key element in developing a national and international reputation in excellent research outcomes is investing in science communication. It is one thing to be excellent in an area of research, but being able to communicate this excellence is vital. To build our national and international reputation, our team invests heavily in a science communicator to share the excellent research our team is conducting. This strategy has led to a pre-existing reputation as world-leaders even before arriving at a conference – a testament to the power of investing in science communication.

Target 1: New international partners/collaborators

After a two-year strategy – particularly during COVID-19 – of being proactive in reaching out to international partners and collaborators, we are now seeing a shift in potential partners reaching out to us. There has been a correlation with this success as the profile and reputation of our Centre has grown.

On top of this positive shift, now that we have the COMBS Centre of Excellence, we have people from around the world wanting to engage with us. This is an exciting opportunity that brings with it the need for strategic decision making to make the most of the enquiries we are getting.

Over the last two years we have laid the groundwork for further international engagements through the Marie Curie COFUND program and ARC Centre of Excellence scheme. This engagement approach is mutually beneficial, so our collaborators get funding out of it to maintain resources, excitement and momentum.
Our team has a lot of external collaborators all around the world (and locally), with connections in Europe, the US and China, to name a few. We have also built a profile in the media which has led to more invited talks at international conferences. A part of this strategy is to make sure that students have a paper in that conference and can be promoted by the invited speaker from InPAC.

Target 2: Increase in publications with international co-authors

Most of our high-profile research is done with high-profile international partners, thanks to our existing networks overseas. Many of our InPAC team are also international, leading to our natural collaboration with international partners. Our aim is to leverage these partnerships with the end-goal of co-publishing a publication.

Through our growing presence on social media and in the media, we are deliberately emphasising our international papers, which then perpetuates further international partnerships.

Target 3: International research income growth of at least 10% per annum

Our focus is to apply for increasingly ambitious programs. For example, we have been scaling the Marie Curie program – starting with ECLAUSION (10 HDRs), scaling to REDI (RMIT European Doctoral Innovators) (44 HDRS) and laying the foundations for another program that is about 50% bigger than this again.

In parallel we are mentoring the next generation to do the same; team leaders and students will win their own grants and we will encourage them to apply for larger and larger funding.

Increase research income.

Expectation 1: *Establish a broad sustainable funding base that grows annually to support the Centre's research and goals.*

Target 1: Minimum 15% growth in total research income annually

The newly awarded Centre of Excellence provides a total of $35M from the ARC, of which RMIT would receive approximately $14M over seven years. This represents a major funding stream in its own right, but will also create a platform for other major initiatives in coming years.

Our strategy at InPAC is to engage with industry starting with short term, modest funding, then quickly scaling to large scale collaborations. Our objective is to have three major projects running in parallel: one starting, one mid-term and one ending. We would classify a major project as about $3M (e.g., CRC-P). We currently have three CRC-Ps in the pipeline.

Increase the quality and number of publications produced by Centre members and research students.

Target 1: At least three journal publications from each HDR candidate targeting Q1 outlets

Target 2: Centre outputs grow by a minimum of 15% per annum

Target 3: 75% of publications in Q1 journals.

***Expectation 1:** Reinforce the culture of targeting high quality outputs*

At the beginning of each students' PhD journey, they work with their supervisors to map out four potential publications. Some students complete more than that, and we will try to extract those papers even after the students finish their PhDs. We also conceive their projects as three separate publications, with a publication plan to align to.

We encourage Postdocs to produce two first author publications a year, while participating in at least two others. We also ask the same of Team Leaders.

As demonstrated in 2022, our team published in Science, and we are ramping up the quality of journals we publish in. Our track record includes successful co-publishing in Nature, Nature Photonics and Nature Communications.

By showing that our team regularly publishes in these top-tier outlets, we are building a reputation and brand which will help us to achieve future publications in these outlets. We are also showing our team members what is possible and providing them a credible pathway to achieving similar levels of publication performance.

Establish, develop and broaden collaborations and partnerships with key external partners to create tangible impact and enhance the research environment of the Centre and build global engagement.

Target 1: 20% increase in industry funding annually

Target 2: New partnerships

Target 3: Evidence of efforts to broaden and strengthen partner relationships

Target 4: New research impact case studies.

We will aim for an increase of 20% in industry funding annually by working with our current clients to identify their problems. For example, a new project with optical communication components manufacturer Finisar began $20,000 project, which may turn into a multi-million-dollar project, pending approval. Our customer acquisition strategy is to always encourage our industry partners to think about projects at a large scale.

We also currently have a $50,000 Innovations Connections project with Future Fibre Technology and a $95,000 project with Defence Materials Technology Centre (DMTC).

The Centre's Science Communicator uses the InPAC website to share our impact case studies which are shared on Twitter and LinkedIn. The lead researchers on each project are also encouraged and trained to share these impact case studies across their LinkedIn and Twitter profiles. Five case studies were developed in 2022 and can be found on the InPAC case studies page and are also used as promotional material during lab and conference visits.

***Expectation 1:** Establishment of a significant multi-party externally funded Research Centre within five years (e.g., ARC Centre of Excellence (lead, or node)*

We currently have an application in its final stages for an ARC Centre of Excellence in Optical Microcombs for Breakthrough Science (COMBS). We have a 9 in 17 chance of this Centre succeeding.

***Expectation 2:** ARC Industrial Transformation Research Hub or Training Centre*

Sumeet Walia has prepared an ARC Industrial Transformation Research Hub in photonic sensors for different applications, of which will find out the result in 2023.

***Expectation 3:** Cooperative Research Centre (lead or key participant)*

In our first year of operation as a Centre in 2020 we were awarded a $2.8 million Cooperative Research Centre Projects (CRC-P) grant with navigation system manufacturer Advanced Navigation. This will end in 2023.

We will begin a project within the SmartCrete CRC in collaboration with civil engineering that aims to use optical fibre sensors – the same that power our internet – for measuring the health of bridges and sea walls.

We have submitted a CRC-P in proposal stage with Finisar in photonic chips for data communications.

We aim to begin the ARC Centre of Excellence in Optical Microcombs for Breakthrough Science (COMBS) in 2023. While this will take some time and focus to set up, this Centre is unashamedly translational and will make use of the CRC and CRC-P schemes. Strategically, InPAC will expect to maintain approximately 3 CRC-P projects in parallel. We will also be active participants in CRCs that can offer pathways to impact for our photonic chip technologies (particularly leveraging optical microcombs). Towards the end of the Centre term, we may explore establishment of a CRC on photonic chip technologies, but this will not be a priority for 2023-2025 and would ideally be the next big Centre ramping up in 2030.

***Expectation 4:** Industry funded research centre.*

Our Biomedical Applications team strategically aims to access funding and support for biomedical research and translation of this research into the biomedical industry. There is a very strong industrial biomedicine and biotechnology ecosystem in Victoria.

Long term, we aim to be recognised as a research centre with unique capabilities for lab-on-a-chip and biomedical integrated devices based on our microfluidic actuation and photonic chip sensors. We will seek NHMRC Development and Medical Research Future Fund support for commercial development of our biosensors and microfluidics devices, but first we need to establish proof of concept demonstrators.

We will use the outcomes of our NHMRC Project grant on ovarian cancer and will seek partnerships with biomedical research institutes around Melbourne. A good example is our partnership with Max Lim at St Vincent's Hospital. We have been awarded $70k seed funding and we will use this to develop a lab-based organoid platform (with a heart and cancer organoid), then treat it with chemotherapies to test the effect it has on the heart. This will form the basis of larger scale research funding later in 2023.

***Expectation 5:** Active monitoring, tracking and recording of research impact and path to impact and the promotion of Centre research impact internally and externally.*

Our Science Communicator, Rachael Vorwerk actively monitors, tracks and records InPAC's impact in a PowerPoint presentation that can be used to demonstrate success in our Annual Reports, case studies and media reporting. She also evaluates the success of the Centre's promotion via an automated monthly Google Analytics email from the RMIT web team about the amount of InPAC website traffic and is constantly trying innovative approaches based on that data.

Using the RMIT Research Centre and Group Report Dashboard, we can track the amount of funding we receive from one year to the next.

New InPAC case studies are housed on the case study webpage – these demonstrate our real-world impact and act as an advertising tool for future partners. They include testimonials from our project partners which is a way to gauge our research impact. Printed versions of these case studies are also disseminated to our laboratory visitors.

We also constantly evaluate engagement of our social media posts across our researchers' and Centre account and adjust accordingly. Our Science Communicator Rachael Vorwerk monitors the success of each post and offers advice to researchers to keep building their profile.

This section compares the Centre outcomes against the expectations set by the STEM College for RMIT Centres.

We'll be looking for an increase of 15% of all our performance measures for 2023.

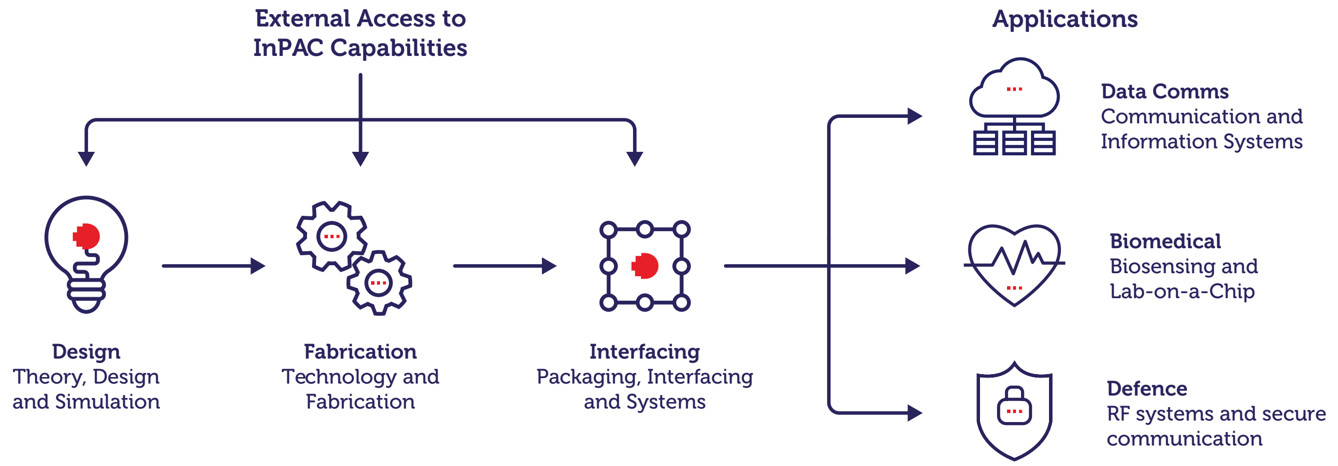
Performance Measure	Target	2020 Outcome	2021 Outcome	2022 Outcome
Research Findings				
Number of research outputs				
Q1 Journal paper	20	28	20	24
Provisional patents	1	1	0	0
Quality of research outputs				
Journal paper with impact factor > 6	5	9	7	13
Post deadline presentations	0	0	0	0
Number of invited talks/papers/keynote lectures given at major international meetings	2	2	5	7
Number and nature of commentaries about the Centre's achievements				
Media releases	1	0	2	4
RMIT articles	1	3	1	4
Research Training and Professional Education				
Number of new HDR students				
PhD	5	5	6	4
Master	0	0	3	2
Number of HDR completions				
PhD	2	1	1	1
Master	0	0	0	1
Number of new postdoctoral researchers recruited	0	1	4	1
Number of Early Career Researchers (within five years of completing PhD)	3	3	7	9
Number of students mentored	15	20	20	29
International, National and Regional Links And Networks				
Number of international visitors and visiting fellows	3	4	0	5
Number of national and international workshops held/organised by the Centre	1	0	0	2
Number of visits to overseas laboratories and facilities	3	0	0	11
End-User Links				
Number of government, industry and business community briefings	3	3	2	4
Currency of information on the Centre's website Number of unique visitors per month	Monthly 100	Monthly 220	Monthly 243	Monthly 359
Number of public talks given by Centre staff	5	2	3	1
National Benefit				
Students in industry	1	1	1	1
Technology transfer	0	0	5	0
Industry/end-user collaboration	0	0	8	4

Key Research Areas

Our team at the Integrated Photonics and Applications Centre is made up of six teams that work with industry and academia to design, prototype and scale-up photonic chips to make new products.

The team has the capability to work with industry and research partners to think of new ideas, create chips, then test them in a real-world environment – all in a matter of weeks.

All our capabilities and expertise are concentrated at the RMIT Melbourne City campus, which enables us to rapidly advance photonic technologies, whilst ensuring this technology can be genuinely useful in the real world.



Steps to Designing an Integrated Photonic Chip

1. Theory

Our team is made up of academics that are constantly testing and publishing research – we draw on this in-house knowledge in every process.

2. Device Simulation

We use the IPKISS design framework to simulate all our chips to ensure all our designs are industry-compliant and scalable to mass manufacture.

3. Design

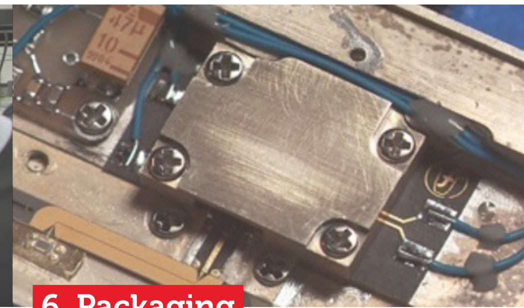
To make any design plug-in in with your existing systems, we draw from our library of tried-and-tested integrated photonics circuit components.

4. Fabrication

This phase involves printing the chips and testing that everything we've created performs in the way it was intended.

5. Characterisation/Testing

Once we have fabricated your chip, we do a number of tests to measure the performance of the chip to make sure it is behaving optimally.



6. Packaging

After the chip is performing optimally, we can create permanent electrical (wire bonding) and optical (fibre) interfaces to connect to any standard circuit boards.

Design and Simulation Team

Our team conducts fundamental research to explore new phenomena to create new components and platforms for the applications and fabrications teams.

The goal of our team is to minimise the number of iterations to achieve the right design the first time, to minimise the time spent on each stage of chip development.

We do this by:

- using a validated library of components and circuits that can be used as building blocks for different technologies
- creating an effective design and simulation framework to ensure different tools are compatible.

Team achievements

- InPAC now uses RMIT Amazon Web Services (AWS) Cloud Supercomputing Hub
    - This has allowed the team to automate data processing in the InPAC lab
- Haijin Huang published a paper in APL Photonics to create a modulator that can save 9 times the amount of power as traditionally done in integrated photonics chips, which also won the Best Paper Award at the 15th Pacific Rim Conference on Lasers and Electro-Optics (CLEO Pacific Rim).

Beyond the constraints of space for more versatile smart devices

To help our smart devices become increasingly smaller, yet more complex, our team at the Integrated Photonics and Applications Centre is exploring how systems can be made to encompass higher dimensions beyond the three we experience as humans.

The challenge

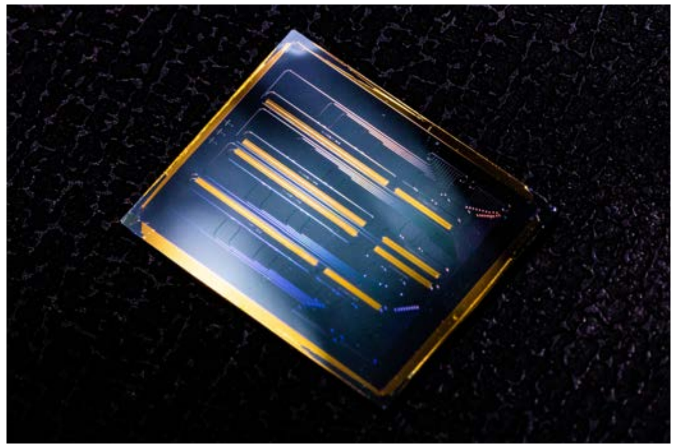
Increasing on-chip interconnectivity and making devices resilient to environmental fluctuations

As our smart devices become more complex yet demand to be smaller by consumers, we need to look for other ways to use materials that could pack information into less.

Currently, the light-powered fingernail-sized chips underpinning our smart devices only operate in two dimensions, as they are arranged on a flat surface along which light particles are routed.

However, theoretical models of higher dimensions – beyond the space and time which we experience as humans – are abundant and offer alternative ways to go from point A to point B. As the number of dimensions increases, greater variety and potential efficiency becomes unlocked.

However, realising these higher dimensions on a chip requires new ways to control light particles.



The microchips often found in our phones (like the chip pictured) exist on a flat surface, so we only have two dimensions to play with from the outset.

Our response

Adding an extra dimension to help our devices process information more efficiently

To increase the amount of information processed on-chip, we can treat changes in internal properties of a particle of light, such as frequency, as a type of movement akin to that along the surface of the chip. This is termed a 'synthetic' dimension – to be used as a testbed to gain insight into complex physical models, while providing intriguing device functionalities.

In a project led by Research Fellow at our Integrated Photonics and Applications Centre (InPAC), we investigated how to create an on-chip synthetic dimension by employing the frequency of photons as if it were another dimension that exists in addition to space.

The results and current progress

Fitting more complexity into our microchips by looking beyond our three dimensions

By experimenting with variables that are outside the 2D physical space – like the frequency of light waves in small ring devices – the team was able to establish an extra coordinate that emulated particles hopping along a lattice using a robust integrated chip-based platform.

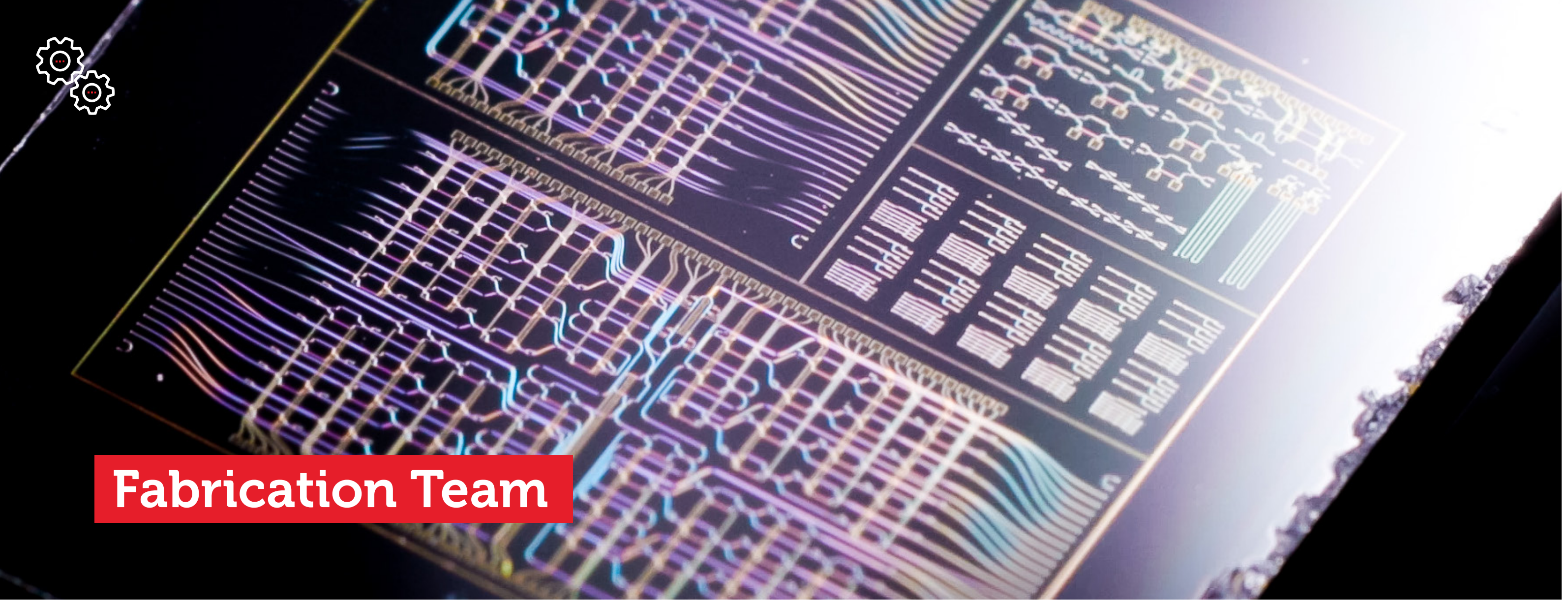
Modelling beyond 3D with these synthetic dimensions can be used to investigate light's behaviour in different contexts. These dimensions also increase 'parallelism' of photonic information, making processing more efficient.

The team strives to create more elaborate and complex lattice model arrangements achieve even smaller, robust, and powerful fingernail-sized chips to make our smart devices even smarter.

By tapping into these higher dimensions, we may see potential benefits in our smart phones and laptops, including:

- faster processing times, meaning more rapid uploading times when sending a video to a friend
- more resilient smart devices, where our phones will be more power-efficient with longer-lasting batteries that are less likely to drop out in decreased reception

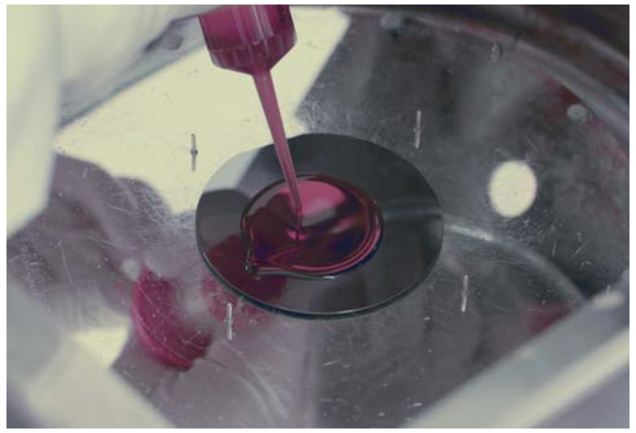
Read more about our Simulation and Design team here: https://bit.ly/47Dmwpj



Fabrication Team

Our fabrication team works very closely with the simulation and design team to ensure that everything we fabricate performs as it was designed to. We specifically focus on three processes:

- Fabricating integrated photonic chips
- Testing and validating chip performance
- Packing the chip for the users' needs, to plug into existing infrastructure (whether that be electronic or optic systems).



Team achievements

- Jamie Low submitted her thesis and began work full time with InPAC
- Sonya Palmer's research developing an integrated photonic alternative to bulk optics external cavity lasers was published as a Feature article in APL Photonics
- PhD students presented their work at various conferences, including:
  - Aditya Dubey and Jackson Jacob Chakkoria attended the Conference on Lasers and Electro-Optics/Pacific Rim (CLEO-PR) in Japan and the Australian and New Zealand Conference on Optics and Photonics (ANZCOP) in Adelaide, Australia
  - Marko Perestjuk presented at two Marie Skłodowska-Curie Actions events including the Falling Walls Lab competition in Paris and EuroScience Open Forum in Leiden, Netherlands about his research in trapping the mid-infrared light for sensors that can detect diseases in our breath, or the quality of air in our environment.
- Guanghui received an Academic Promotion to Senior Research Fellow at RMIT.
- Silicon nitride has been finessed as a material that can be used in the visible wavelengths.
- The Fabrication Team published 14 papers in 2022.

Connecting internet superhighways to keep up with data demands

A team of researchers from Monash, RMIT, University of Adelaide and the Beijing University of Posts and Telecommunications have created a fingernail-sized chip to route our internet's data more efficiently to its destination.

The challenge

With more data transferred than ever, we need infrastructure to keep up

As we send more data around the world via our internet's optical fibre superhighways, we need more complex infrastructure to keep up.

A key breakthrough in 2020 including researchers Monash, RMIT and Swinburne universities demonstrated the world's fastest internet on a single optical fibre at 42.1 Terabits per second – enough to download 1,000 HD movies in a second by adding data highways with hundreds of extra lanes.

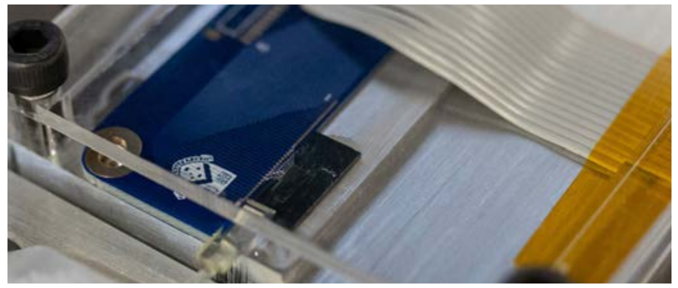
However, a key challenge was to access these hundreds of new lanes and move the data from one highway to another. Currently, switching data between each highway is done with equipment about the size of a pack of cigarettes, which takes up valuable space in exchanges and roadside cabinets. Miniaturising these systems could help to speed up our data transfer.

The response

Designing a chip capable of calibrating itself to act as a data highway interchange

Researchers at Monash, RMIT, the Beijing University of Posts and Telecommunications and the University of Adelaide have miniaturised the data-switching equipment and shrunk it to a fingernail sized photonic integrated chip. The chip can operate reliably, even when subject to vibrations and temperature changes. It also allows the data to take the most direct, efficient route to its destination.

The chip separates light colours and can steer them to different input/output fibres. In optical communications, each light colour can carry a different message, so by separating colours, the chip can route these messages to their correct destinations. But this only works if the chip can be kept 'in tune'. The separation is done by optical interference, which is critically dependent on precise time delays within the chip.



The result

A programmable and self-calibrating chip to more efficiently route data to its destination

In 2022 the team created a chip the size of a fingernail that is both programmable and self-calibrating. This finding was published in Nature Photonics. The chip begins almost as a blank slate, then once it's installed, the user can decide what they want to do with it.

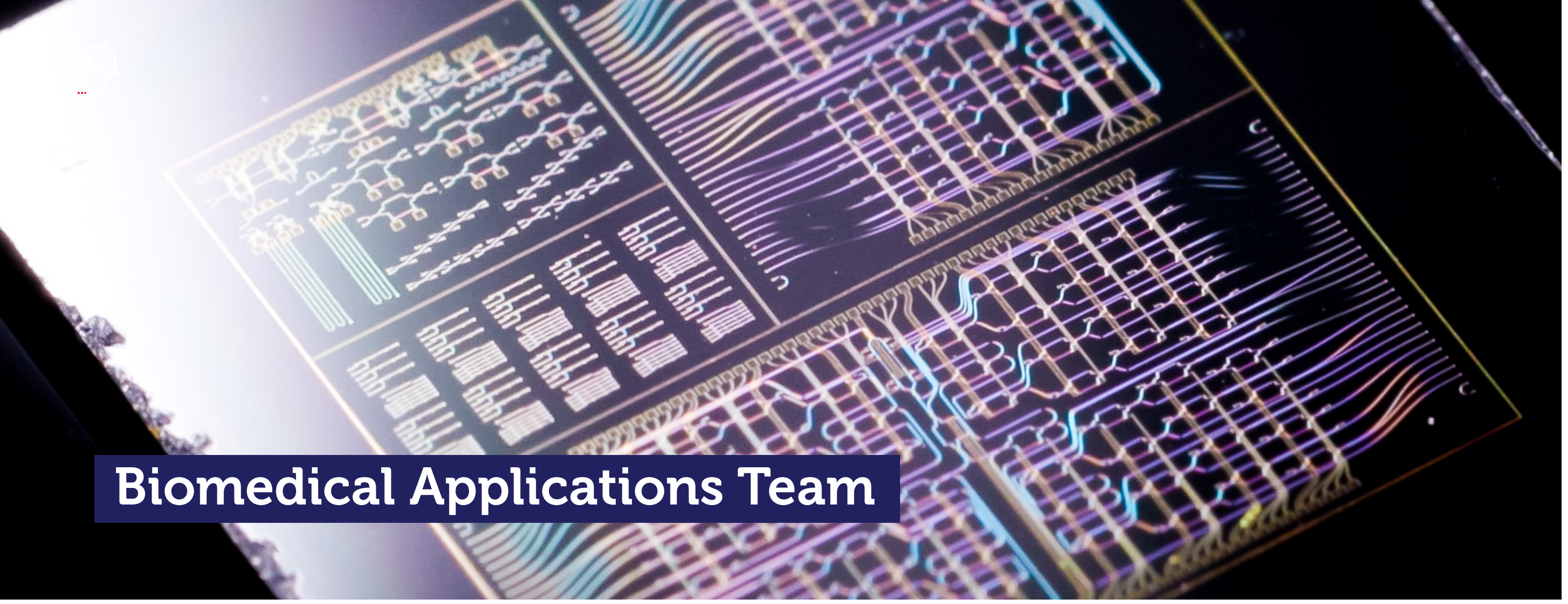
These advances complement Monash, RMIT and Swinburne's previous demonstration of information along a fibre from a single laser (42.1 Terabits per second), where it is now possible to switch the data to different destinations reliably.

This chip can adjust itself to adapt to any the network's requirements, providing a plug-and-play solution the size of a credit card that be installed anywhere in the world.

Also, the new chip can support the researchers' advances in pattern matching – one of the fundamental operations in computers and signal processing. With a more compact packaged chip the size of a credit card, it could benefit many different applications, including:

- creating safer driverless cars capable of interpreting their surroundings almost instantaneously
- rapidly reconfiguring optical networks that carry our internet, to get data where it's needed in the same quality as it was sent
- enabling AI to rapidly diagnose medical conditions, by speeding up pattern identification
- making natural language processing even faster for smart home devices

Read more about the team's research in the *Nature Communications* paper: www.nature.com/articles/s41566-022-01020-z



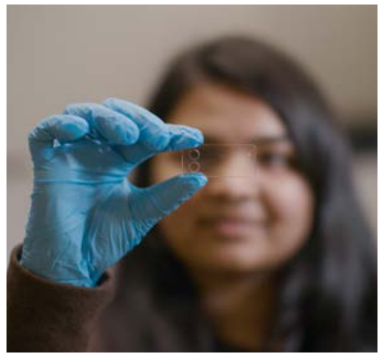
Biomedical Applications Team

Our team is dedicated to advancing biomedical research through the application of micro and nanotechnologies, such as photonics and microfluidics, with the aim of addressing both current and future biomedical challenges. We accomplish this by designing and integrating comprehensive lab-on-a-chip devices, which hold the potential to assess the internal state of the human body by analysing biofluids, cells, or tissues.

To maximise the impact of our research, we closely collaborate with clinicians, biomedical groups, and industry partners to develop user-friendly, instantaneous, and portable diagnostic and biomedical tests that can be readily deployed at the point of care.

Research achievements

- Awarded seed funding for 2023 to develop a cardiac organoid in collaboration with St Vincent's Hospital valued at $70,000 (will form basis of larger grant)
- Established collaborative infrastructure with Dr Blanca del Rosal for spectroscopic microscopy – tailored for plasmonic nanohole array biosensors
- Simplification of silicon photonic chips for biosensing - can be easily fabricated by single etching and realised as whole wafers for a steady flow of chips in 2023.
- 33 collaborators, including:
  - 14 active collaborations (30% international)
  - 18 different projects
- Two RMIT news stories about the Biomedical Applications Team members were published
  - Cesar's work on early detection tech and the battle to change the story on ovarian cancer
  - Siew's work on detecting the 'invisible' signs of heart attacks
- Successful Industry collaboration with Toyota Central Research & Development Laboratories, INC to investigate photonic integrated optical comb and its applications in biosensors.
- HatiSens, a startup launched out of InPAC in 2021 turned one and graduated successfully from the Medtech Actuator program, receiving promotion across MedTech Actuator and RMIT News



Eavesdropping on the conversation between cancer cells to identify how they spread for more effective treatment

A team of biomedical experts and technologists at the Integrated Photonics and Applications Centre and Ecole Centrale de Lyon are trying to find the clues behind why cancer cells spread to aid more personalised medicine.

The challenge

Finding the origin of spreading cancer cells to aid the best treatment

Metastatic cancers – like lung, ovarian and breast cancer – break away from where they first form and create new tumours in other parts of the body. For example, people with lung cancer may have the tumour spreading into their bones.

Understanding where a cancer originates from is a key challenge for clinicians. One clue is in the 'markers' of cancer cells that detach from the tumour and circulate in the blood of cancer patients. These cells are particularly rare and can be one in a million, making them extremely difficult to find, let alone isolate.

Without the ability to efficiently identify where the cancer began and where it will spread, clinicians cannot prescribe the best treatment. For example, if the cancer began in the lungs and has already spread to the bones, treatment focused on the lung tumour alone would not be enough.

Our response

Finding then isolating circulating cancer cells to see how they behave

The interdisciplinary team of biomedical experts and technologists at the Integrated Photonics and Applications Centre are working backwards to find out more about the way cancer cells spread. They use already isolated samples of cancer cells to learn about their behaviour, and the signals they send to other cells once they've spread.

A key part to understanding circulating cancer cells is watching what they secrete. Messages in the secretions are sent to other cells, telling them to replicate and spread. Encoded in these messages are ways to protect themselves against drugs that will kill them. If we can identify them, then we will have more information to pinpoint these hidden codes to stop cancer spreading in the first place.

Our results

Observing cancer cells in a controlled environment to learn more about them

The team is using a technology called microfluidics – a tool with tiny channels that can filter out specific molecules like DNA or even specific cancer cells (see right). This mini-plumbing tool can isolate these cells and their secretion messages which can later be used as markers to look out for in patients.

This approach, paired with a light-powered photonics platform, miniaturises the sensor needed to detect and capture these cancer secretions. The result is a tiny sensor about 20 times smaller than a five-cent piece (see image right). The combination of these two technologies is extremely accurate at finding the circulating cancer tumour cells in very small samples.

These two approaches give the team a high level of control. They can capture and observe cancer cells to induce the secretion (or conversation). They can even introduce drugs to see how the cells respond. By having such a controlled environment, the team can test:

- how the cancer cells respond
- the pattern of behaviour of different cells – whether it be how a breast cancer cell behaves compared to a lung cancer cell
- which treatments respond best to different cancers.

This technology has many potential applications for any single cell and multi cell study – particularly for aiding chemotherapy treatments, discovering new drugs, or isolating immuno-compromised cells to manipulate them then re-introduce them back into the body.

Read the review article in *Biosensors and Bioelectronics* to find out more about our research: https://bit.ly/3R95ZDV

This project, including PhD student Syed Harris Hussain, was made possible by ECLAUSion, a cotutelle PhD program between Ecole Centrale Lyon and RMIT University.

Defence and Precision Sensing Team

Our team aims to engage with industry and defence agencies to provide integrated photonic solutions for more precise, accurate and compact sensors. We specifically focus on:

- deeply engaging with industry and defence partners in precision sensing, to understand their opportunities and problems
- investigating how our InPAC photonic platforms can be used for opportunities or overcoming pain points
- developing energy efficient, compact, lightweight and robust solutions
- ultimately creating impact by collaborating with industry and defence agencies

Team achievements

- Establishment of laboratories to build InPAC's capacity at University of Adelaide
- Simulation and design of visible wavelengths on the silicon nitride platform
- Fabricating lithium niobate on insulator chips for fibre optic gyroscopes with Advanced Navigation
- Investigating above-water laser communications for application in defence – the White Paper was submitted and presented in February 2022
- Andy Boes won a DECRA Fellowship funding to make optical frequency combs (the world's most precise ruler) more accessible at more light wavelengths, like in the visible realm (transferred to Adelaide university, but still within InPAC).
- The Defence and Precision Sensing Team published four papers.

More efficiently routing internet data in peak traffic and natural disasters

As our internet use continues to grow every year, our team of researchers from Monash University and RMIT University have created a coin-sized chip to direct our internet's data more efficiently to its desired destination.

The challenge

Re-routing our internet when detours strike

The internet relies on optical fibres – each carrying data on multiple colours of light – to transport data between cities and data centres. During peak data traffic demands, faults, or natural disasters, our data needs to be re-routed to take an alternative path to its destination. Optical switches are responsible for this, by separating the colours and re-routing them.

Presently these optical switches rely on bulky components – the size of a deck of playing cards – like lenses, gratings and holograms. To keep up with higher data traffic, these optical switches need to operate at much higher densities, whilst still being able to fit into the existing infrastructure.

Fingernail-sized, light-filled microchips called photonic integrated circuits offer a technological solution to re-route many different colours of light, all on a sheet the thickness of a thousandth of a millimetre.

However, photonic integrated circuits need to be accurate to a small fraction of the wavelength of light – more accurate than a hundred thousandth of a millimetre – and temperature stabilised otherwise the colours will be incorrectly routed to the wrong destinations, meaning data won't reach its intended destination. Fabricating chips with such small manufacturing tolerances is very challenging and keeping the chips at these stable temperatures is costly.

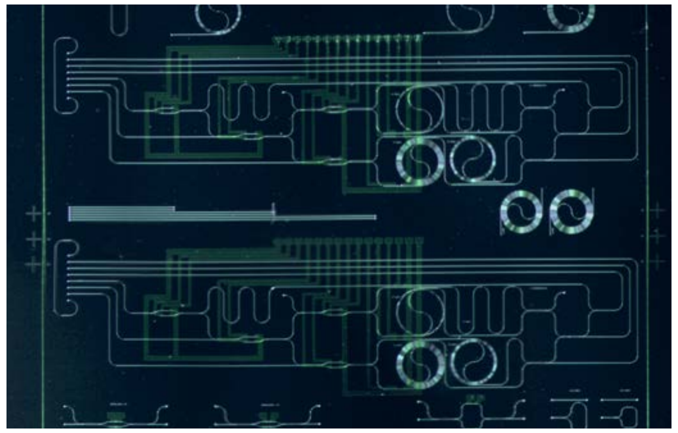


Image credit: Timothy Feleppa, Monash University

The response

Developing an on-chip reference structure to direct data to where it's needed

To help our data get to where it's intended – while keeping the photonic integrated circuits operational even with manufacturing tolerances and changing temperatures – researchers at Monash University invented a technique to allow the chips to "self-calibrate" after production.

The chips used for this demonstration were manufactured at our Integrated Photonics and Applications Centre and incorporated back into communications systems at Monash University for testing.

The results

A more accurate and robust redirect system for a more efficient internet

The teams' solution was to have the reference structure on-chip, whilst using a specialised calibration technique. This means that manufacturing tolerances of chips and temperature fluctuations can be accommodated, ensuring that the different colours of light end up at the desired destinations.

By using this technique – in combination with the photonic integrated circuit approach – the team was able to miniaturise the optical switch down from the thickness of a deck of cards, to a thousandth of a millimetre. This means that these switches can also fit into existing infrastructure.

Now, when the chip needs to rapidly re-route data in times of a fault or natural disaster, the alternative route it chooses is much faster.

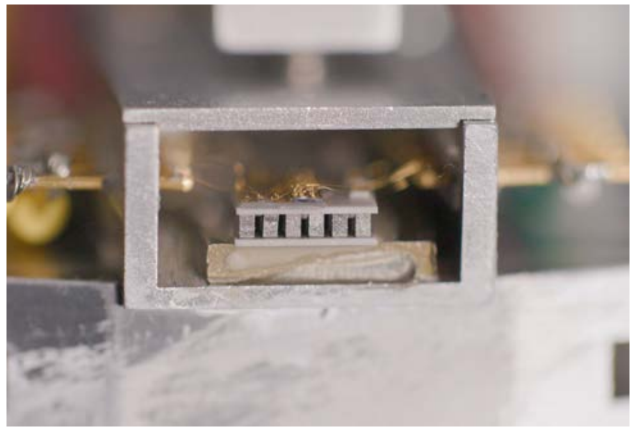
Read more about the team's research published in *Optica* here: https://bit.ly/3P6S0x7

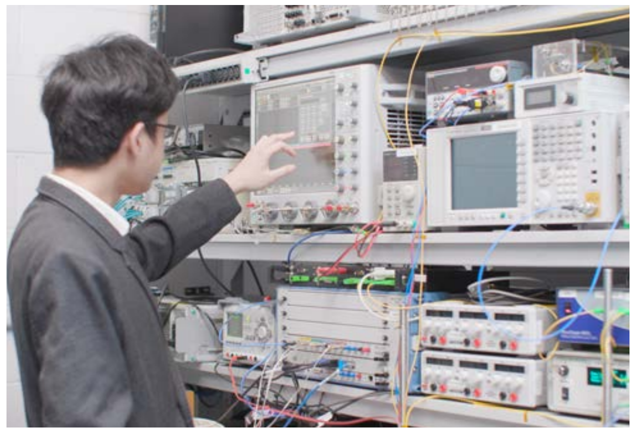
Data Communications Team

Our team explores how cutting-edge integrated photonics can achieve ultra-high speed data communications by exploiting new wavelength ranges, new advanced modulation formats and ultra-dense spatial and spectral multiplexing.

Team achievements

- Successful funding application for ARC Centre of Excellence for Optical Microcombs for Breakthrough Science (COMBS)
- Successful Future Fellowship to investigate the capacity of microcombs to create a device that can 'plug in' to our existing internet infrastructure
- Establishment of test-bed for generating comb emissions from low-loss nitride chips at Monash University, Periodically Poled Lithium Niobate (PPLN) stages re-launched
- Park (Chawaphon) Prayoonyong submitted his thesis investigating how optical frequency combs can support data communication systems, to reduce costs and the load on current internet infrastructure.
- The Data Communications team published four papers, one book chapter and one conference paper.





Retrofitting internet superhighways with more data 'lanes'

As global internet data demand grows by around 25% each year, our team at the Integrated Photonics and Applications Centre is developing technologies to get the biggest bang-for-buck out of existing optical fibres to help our infrastructure

The challenge

Keeping up with global demand for faster internet

Over the past two decades, the internet has moved from being a specialised tool to something integral to society. But global connectivity has meant that current optical fibre technologies – once thought to have almost 'infinite bandwidth' – are beginning to hit limits.

To keep up with this growth, we either need to lay new fibres in the ground – which is very costly and intrusive – or use our existing and robust fibres in a new way.

Our response

Broadening the rainbow of light our data travels along

Our Data Communications Team Leader Dr Bill Corcoran is leading a project – funded by his four-year ARC Future Fellowship – to get the most out of existing optical fibres by retrofitting new technologies.

One part of the strategy tackles the limitation of optical amplifiers, which are devices that 'boost' our data along every 50-100 kilometres in our optical fibres, within our current internet infrastructure.

Our internet data travels along optical fibres via light in the infrared part of the light spectrum. However, once the data reaches these amplifiers, only about 7% of that light spectrum can be boosted. This means all our data must be squeezed into the tiny bit of the infrared that the amplifiers work at, causing a major data bottleneck.

The results and current progress

Making our existing internet fibres the best they can be

To get around this light spectrum bottleneck, Bill and his team are using a novel device to change the colour of light that the internet is traveling down – effectively opening up new data 'lanes' – then to change again to match the colours that amplifiers can boost. The team are investigating Periodically Poled Lithium Niobate (PPLN) as a key material to enable this colour changing.

The team at the Integrated Photonics and Applications Centre – Aditya Dubey and Jackson Chakkoria – have been investigating ways to fabricate this material so it can be adopted in our existing optical fibre infrastructure.

The hope is to make our existing data communications infrastructure the best it can be.

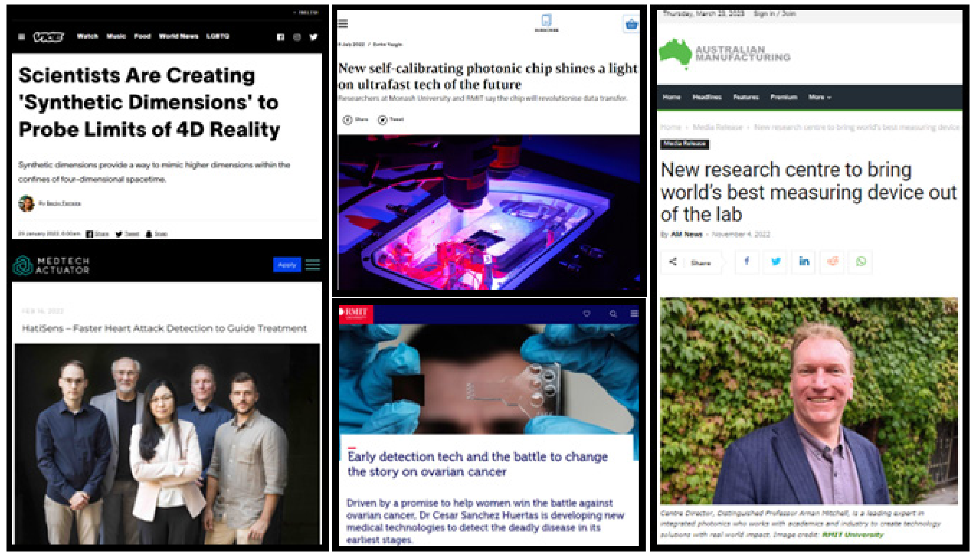
Read more about the Data Communications Team here: https://bit.ly/3yXiqlH

Media and Communication

The InPAC Science Communicator, Rachael Vorwerk, managed the Centre's media and communications strategy in 2022.

The main objectives were to build the Centre's profile, continue to grow InPAC's presence and promote the bid for the Centre of Excellence in Optical Microcombs for Breakthrough Science (COMBS).

- For his work showing how integrated photonic chips can be used to explore new dimensions of physics, Armandas Balcytis' research in Science Advances was published in VICE Media.
- RMIT article about earlier detection technology to change the story on ovarian cancer about our Biomedical Applications Team Leader Cesar S. Huertas.
- Our PhD student and HatiSens Co-Founder Siew Joo Beh was featured on the MedTech Actuator website about how she is fusing her research background with entrepreneurship, and later in an RMIT News story about detecting the 'invisible' signs of heart attacks.
- On International Day of Light, we coordinated a media effort about how photonics is transforming technology as we know it in an RMIT article.
- A paper published in Nature Photonics in collaboration with Monash University, University of Adelaide and RMIT University led to media in Cosmos Magazine, Phys Org, ITWire and Australian Manufacturing.
- An RMIT news article about the newly funded ARC Centre of Excellence for Optical Microcombs for Breakthrough Science (COMBS) led to media in Cosmos Magazine, Australian Manufacturing and Innovation Australia.
- The Centre continued to grow its LinkedIn page from 405 to 810 and grew its Twitter following from 330 to 451 followers.



Staff and Student Achievements

InPAC is proud to announce that in 2022 the students and staff of the Centre had several successful milestones:

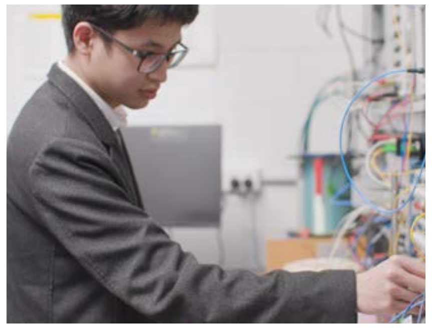
PhD Completions

- **Chawaphon (Park) Prayoonyong**

  Title: Coherent comb sources on a photonic chip

  As internet traffic is growing at 25% a year, we need to increase the bandwidth of our internet - whilst ensuring it is accessible to all.

  Building on the fingernail-sized chip responsible for the world's fastest internet in 2020, Park's research explored how to make the chip more efficient - with 10 times less noise - so that it could still maintain its high data transfer rates, even when power was scarce.



Prizes and Awards

- **Haijin Huang – Best Paper Award at the 15th Pacific Rim Conference on Lasers and Electro-Optics (CLEO Pacific Rim)**

  Haijin was awarded the Best Paper Award at The Conference on Lasers and Electro-Optics (CLEO Pacific Rim) in Japan for his paper titled Efficient Lithium Niobate on Insulator Phase Modulator Using Light Recirculation. The paper investigated how to create a modulator that can save 9 times the amount of power as traditionally done in integrated photonics chips.

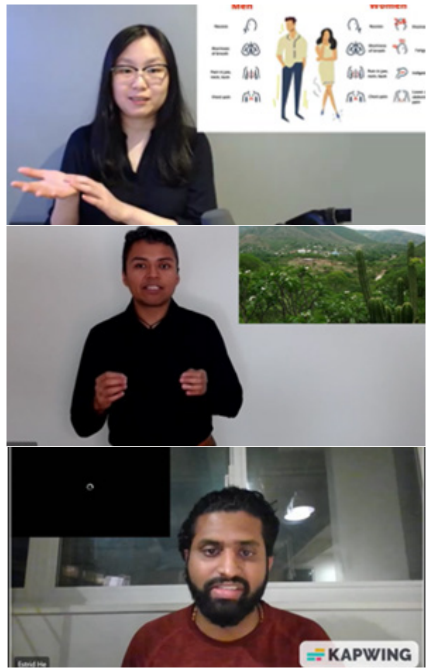
- **Mengxi (Sim) Tan, Arnan Mitchell and Thach Nguyen – Journal of Lightwave Technology Best Paper Award**

  Recognised as the most influential, highest-cited original paper published in *Journal of Lightwave Technology* in 2019, our team members – alongside Swinburne University – published a paper called Advanced adaptive photonic Radio Frequency filters with 80 taps based on an integrated optical micro-comb source. The paper found how to make radio frequencies more sophisticated for radio frequency devices that have reduced cost, footprint and complexity compared to other solutions.

Prizes and Awards

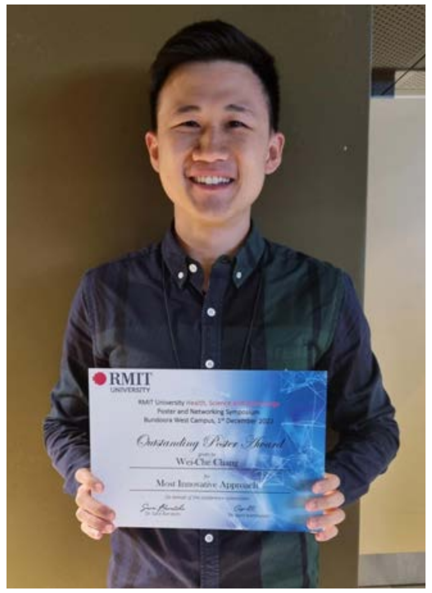
- **Rachael Vorwerk – RMIT Research Services Award**
  For helping researchers better communicate the value and potential impact of their research for improved grant outcomes, Rachael was awarded an RMIT Research Services Award. The Award recognises and celebrates professional staff and teams from across the University who have supported the research community at RMIT throughout 2022.

- **Siew Joo Beh and Jorge Lozano Lopez – 3 Minute Thesis Prizes**
  Two PhD students from the Biomedical Applications Team – Siew Joo Beh and Jorge Lozano Lopez – received second place and an Honourable Mention in the RMIT Three Minute Thesis Competition. Jackson Jacob Chakkoria also took part about how his research is helping to strengthen the backbone of our internet infrastructure.



- **Sumeet Walia – Eureka Prize for Emerging Leader in Science**
  For his work as an entrepreneurial leader that is helping to improve lives and promote equity, Sumeet Walia won the Eureka Prize for Emerging Leader in Science. Sumeet investigates artificial vision technologies, smart window coatings and UV exposure skin sensors, and is a passionate advocate for diversity and inclusion in STEM.

- **Wade (Wei-Che) Chang - RMIT Health, Science and Technology Poster and Networking Symposium**
  For his poster titled *Microfluidic solutions for real-time and multiplexed single-cell analyses to study immune cell dynamics*, Wade's project was voted the most innovative concept from 50 posters at the 2022 RMIT University Health, Science and Technology Poster and Networking Symposium.



Journal Publications and Conference Proceedings

1. Zhou, H., Xu, K., Ha, N., Cheng, Y., Ou, R., Ma, Q., Hu, Y., Trinh, V., Ren, G., Li, Z. & Ou, J. Z. Reversible Room Temperature H2 Gas Sensing Based on Self-Assembled Cobalt Oxysulfide. *Sensors* **22**, (2022).
2. Xu, X., Ren, G., Feleppa, T., Liu, X., Boes, A., Mitchell, A. & Lowery, A. J. Self-calibrating programmable photonic integrated circuits. *Nature Photonics* **16**, 595-602, (2022).
3. Xu, X., Ren, G., Dubey, A., Feleppa, T., Liu, X., Boes, A., Mitchell, A. & Lowery, A. J. Phase retrieval of programmable photonic integrated circuits based on an on-chip fractional-delay reference path. *Optica* **9**, 1401-1407, (2022).
4. Tan, J., Xiao, H., Ma, M., Zhou, X., Yuan, M., Dubey, A., Boes, A., Nguyen, T. G., Ren, G., Su, Y., Mitchell, A. & Tian, Y. Arbitrary access to optical carriers in silicon photonic mode/wavelength hybrid division multiplexing circuits. *Opt Lett* **47**, 3531-3534, (2022).
5. Palmer, S., Boes, A., Ren, G., Nguyen, T. G., Tempone-Wiltshire, S. J., Longhurst, N., Farrell, P. M., Steiner, A., Marciniak, C. D., Monz, T., Mitchell, A. & Scholten, R. E. High bandwidth frequency modulation of an external cavity diode laser using an intracavity lithium niobate electro-optic modulator as output coupler. *APL Photonics* **7**, 086106, (2022).
6. Ou, J. Z., Hu, Y., Zhang, B. Y., Haque, F. & Ren, G. Plasmonic Metal Oxides and Their Biological Applications. *Materials Horizons*, (2022).
7. Liu, X., Ren, G., Xu, X., Dubey, A., Feleppa, T., Boes, A., Mitchell, A. & Lowery, A. 'Dial Up' Photonic Integrated Circuit Filter. *Journal of Lightwave Technology*, 1-9, (2022).
8. Li, T., Zhu, L., Lu, L., You, R., Bian, X., Ren, G. & Yu, L. Highly Sensitive Optical Fiber Plasmonic Sensors by Integrating Hydrogen Doped Molybdenum Oxide. *IEEE Sensors Journal* **22**, 7734-7742, (2022).
9. Jiang, Y., Han, X., Huang, H., Zhang, P., Dubey, A., Xiao, H., Yuan, M., Frigg, A., Nguyen, T. G., Boes, A., Li, Y., Ren, G., Su, Y., Mitchell, A. & Tian, Y. Monolithic Photonic Integrated Circuit Based on Silicon Nitride and Lithium Niobate on Insulator Hybrid Platform. *Advanced Photonics Research*, (2022).

10. Huang, H., Han, X., Balčytis, A., Dubey, A., Boes, A., Nguyen, T. G., Ren, G., Tan, M., Tian, Y. & Mitchell, A. Non-resonant recirculating light phase modulator. *APL Photonics* **7**, 106102, (2022).

11. Han, X., Jiang, Y., Frigg, A., Xiao, H., Zhang, P., Nguyen, T. G., Boes, A., Yang, J., Ren, G., Su, Y., Mitchell, A. & Tian, Y. Mode and Polarization-Division Multiplexing Based on Silicon Nitride Loaded Lithium Niobate on Insulator Platform. *Laser & Photonics Reviews* **16**, 2100529, (2022).

12. Han, X., Chen, L., Jiang, Y., Frigg, A., Xiao, H., Nguyen, T. G., Boes, A., Yang, J., Ren, G., Su, Y., Mitchell, A. & Tian, Y. Integrated Subwavelength Gratings on a Lithium Niobate on Insulator Platform for Mode and Polarization Manipulation. *Laser & Photonics Reviews*, (2022).

13. Ha, N., Xu, K., Cheng, Y., Ou, R., Ma, Q., Hu, Y., Trinh, V., Ren, G., Yu, H., Zhang, L., Liu, X., Zhang, J., Li, Z. & Ou, J. Z. Self-Assembly of Ultrathin Nickel Oxysulfide for Reversible Gas Sensing at Room Temperature. *Chemosensors* **10**, 372, (2022).

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20. Prayoonyong, C. & Corcoran, B. Optimising microring resonator based optical frequency comb distillation for optical communications systems. *Opt. Express* **30**, 17836-17847, (2022).

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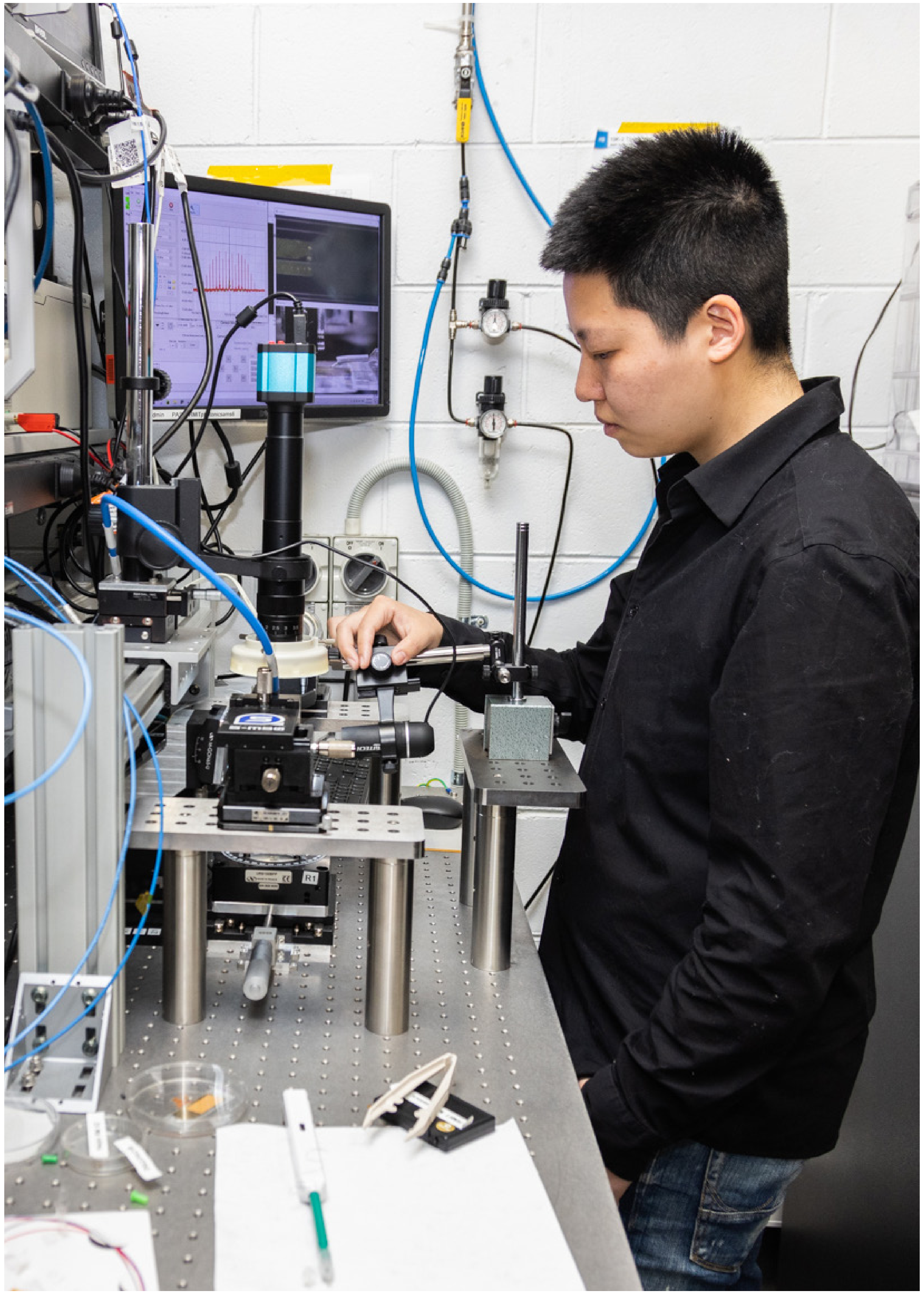

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