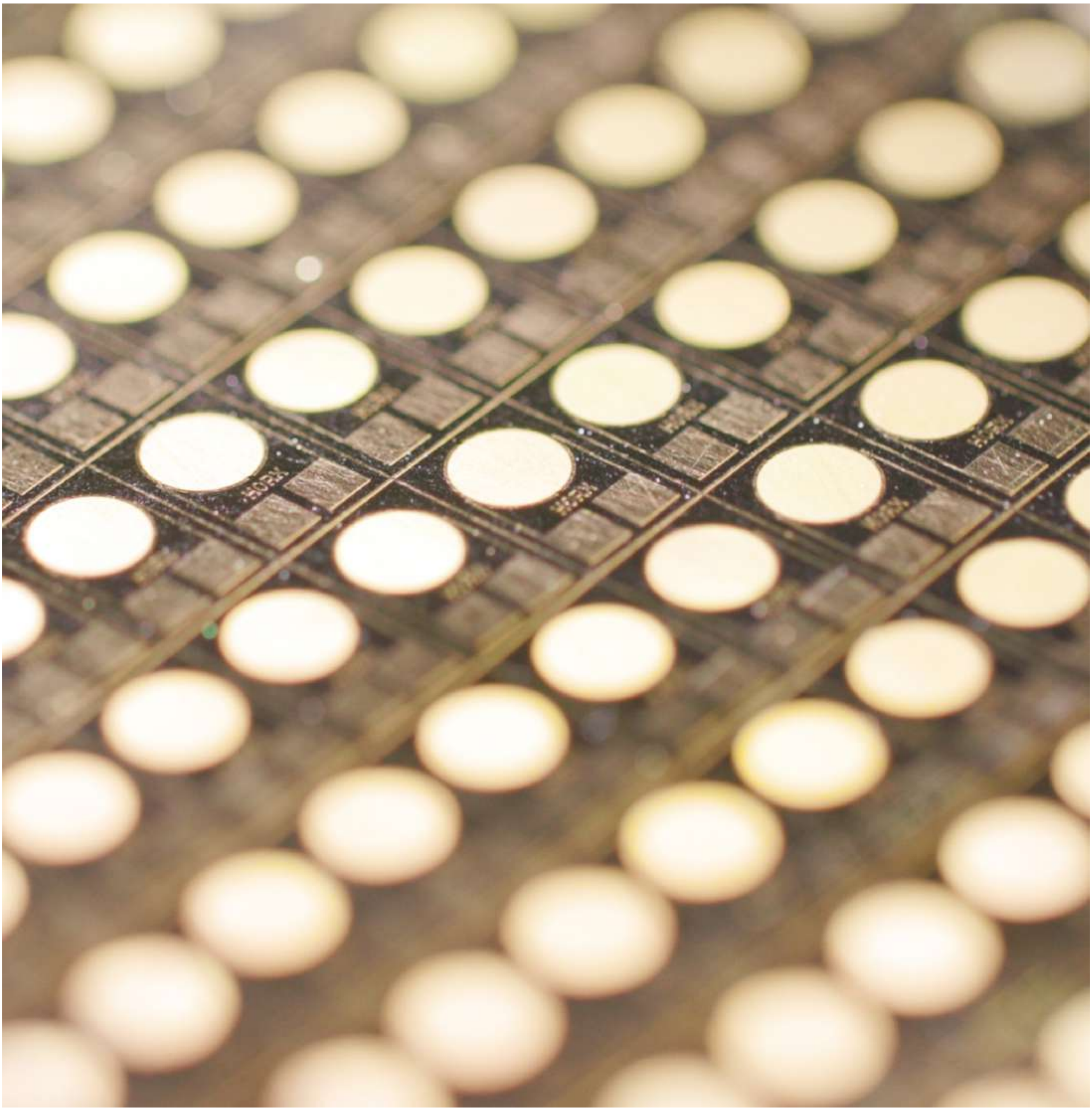


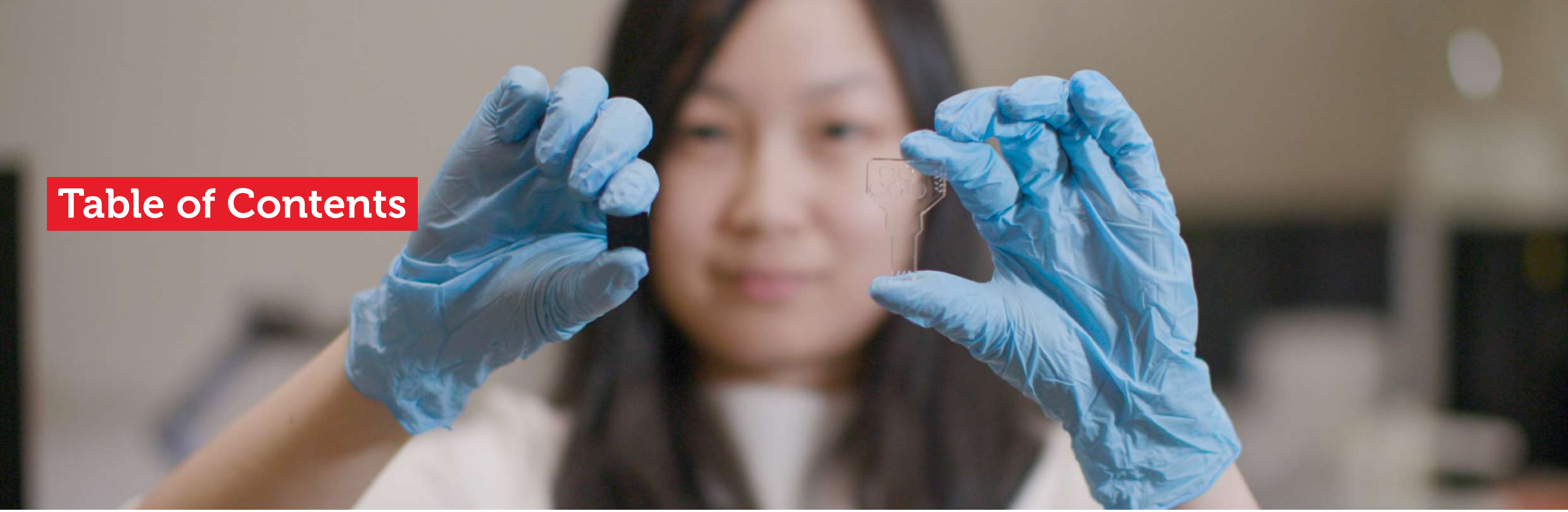
Integrated Photonics and Applications Centre

Annual Report

2020

RMIT UNIVERSITY

InPAC
Integrated Photonics and Applications Centre



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Centre Mission and Objectives

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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 become 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 microchips using the same technology currently used to mass manufacture integrated electronics. Photonic Integrated Circuits (PICs) 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 at the Integrated Photonics and Applications Centre (InPAC) is to be recognised as world leaders in 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 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.

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.

Objectives

Research: 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

It's been an exciting year for photonics as an industry, and also for our Centre to have grown so much already in its first year with 26 team members.

But firstly, you might be wondering *what exactly is photonics?* A big focus for this year has been raising awareness about the field of photonics. So it's fitting to briefly explain what photonics is. For us, it's the science of generating, manipulating and using light to make new technological advances.

Just like electronics (which uses electrons to process information), in photonics we use photons that can carry more information and can be used to fill gaps that are not yet addressed with current technologies. While electronic technologies are excellent for processing digital information, they lack the precision and sensitivity to detect the 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.

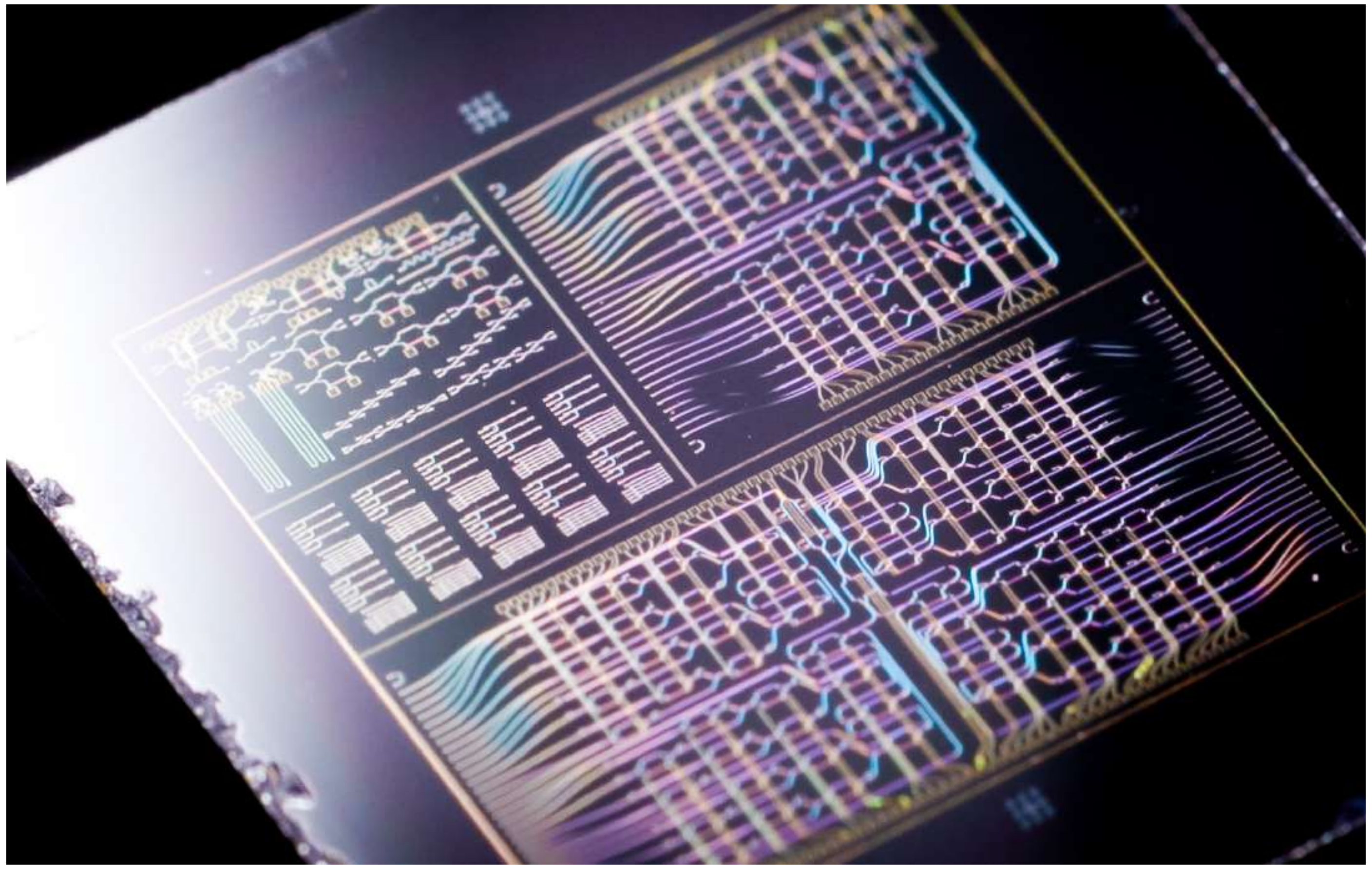
From keeping satellites on course to powering the world's fastest internet, photonics is already a big part of society today.

Our Centre focuses particularly on *integrated photonics* – where an entire photonic and electronic circuit can be printed on the surface of a microchip. We require deep insight into fundamental physics, theory and materials science to manipulate photons in structures with sub-micron dimensions, but also the advanced technology and design approaches that can enable these integrated photonic chips to be manufactured at scale. Bridging this gap between breakthrough science and industrial application is where our Centre provides most value – here we can connect researchers with fresh ideas to industry and end-users with important problems in Australia and around the world.

The current state of play

You may not realise how significant photonics is to Australia. The broad range of applications powered by photonics has made it a booming industry, contributing $4.3 billion per year to the Australian economy. This is equivalent to the $4.3 billion farmgate production of the dairy industry in Australia. We knew photonics was important to Australia, but even we were surprised by this finding. This staggering number was found in a report we helped produce with the Australian and New Zealand Optical Society (ANZOS) that surveyed hundreds of Australian and New Zealand companies about their manufactured goods that use photonics. The report also found that the industry employs more than 9,500 people in high-tech, high-productivity jobs. Photonics is poised to expand the country's manufacturing sector and help drive economic growth.

It is in this context that we have launched the Integrated Photonics and Applications Centre. There is major end-user need for photonics in our own economy and great potential to grow this by harnessing the emerging capabilities of integrated photonics. We just need to find these industries and work with them to learn how *integrated photonics* can transform the products into world-leading solutions, while reassuring them that taking the first few steps can be quick, inexpensive and have a clear pathway to scale.



At a global scale, photonic chip-enabled industries are predicted to grow exponentially over the coming years. Currently, this is dominated by photonic chips for data centres, but other applications such as sensors are growing rapidly. We see strong interest from Australian industry as well. As you will see in this report, we are currently engaging with industries including Defendtex, MOGLabs, Advanced Navigation, Baraja, Nirtek, BluGlass and many more that are highly interested in photonic chip sensors and we believe this is just the beginning.

This strong interest from Australian industry is crucial to achieve the InPAC vision. We need this 'pull' from sectors outside academia to drive and motivate our research and to take our ideas and indeed our research trainees forward to achieve real-world impact. As we build our momentum, I believe that soon we can create a complete world-leading manufacturing base for photonic chips, right here in Australia. Creating and developing a sustainable photonic chip research and industrial ecosystem is a major purpose of InPAC.

The InPAC vision also relies on multi-disciplinarity and diversity. As you will see in this report there is vast multi-disciplinarity across the Centre and I am particularly proud of the diversity in background, career stage and gender of our doctoral candidates. However, as we move forward, we need to work to ensure the same balance is maintained in our early career researchers and our team leaders. We are making some progress here, but we need to do more and this will be a major focus for 2021.

Overall, given the circumstances of our launch year, I think 2020 has been absolutely stellar and I look forward to what's to come in 2021 and beyond!

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

Centre Members

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

Staff

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: Communication and Information Systems

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

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.

Simulation and Design Team

Team Leader: Simulation and Design

Dr. Thach Nguyen

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

Staff

Aditya Vashi

Aditya is automating a laboratory setup to help photonics researchers to check the behaviour of their optical chips with higher accuracy and precision, all in less time.

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

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.

Precision Sensing and Defence Team

Team Leader: Precision Sensing and Defence

Dr. Andy Boes

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

PhD Student

Andreas Frigg

Andreas is exploring how to form high quality and efficient silicon nitride waveguides that are used to make sensors more accurate and robust to keep satellites and remote vehicles on track.

PhD Student

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

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 (Ecole Centrale de Lyon)

Panteha Pedram

Panteha is working on developing new 2D materials, identify their nonlinear optical properties, and the integration of these 2D materials onto chip-based devices for applications such as data communications.

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.

Technology and Fabrication Team

Team Leader: Technology and Fabrication

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

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.

Staff

Tanveer Mahmud

Tanveer is developing advanced technologies to create three-dimensional polymer structures on integrated photonic platforms for telecommunication and biochemical sensing 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: Biomedical Applications

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. Francisco Lopez

Francisco investigates how to use microfluidics and micromechanics to ensure all components can be integrated seamlessly to allow for more precise biomedical fluid handling, personalised care devices and sensitive sensors.

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.

PhD Student

Markus Knoerzer

Markus is investigating optical biosensors and is introducing new ways to interpret their signals to make them more sensitive, precise and robust so patients can operate these sensors themselves, just like a blood glucose meter.

PhD Student

Siew Joo Beh

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

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 biomarkers from cancer cells that are circulating in the blood.

Centre Members

Changes of memberships

The Centre is newly established. Hence there are no changes in the membership.

Recruitment of new members

Within RMIT

The Centre is inherently collaborative and seeks to engage people who can benefit from photonic chips.

We will also hold an annual workshop, where we invite researchers who are close to the Centre to discuss synergies and develop proposals of how these synergies can become more formal collaborations or new teams (either applications or platforms) within the Centre.

We will specifically look to address any gaps or imbalances that we have identified in the Centre, not only in terms of emerging science, technology and applications, but also in terms of diversity and particularly in terms of gender and career stage.

Staff

We advertise staff positions regularly on online recruitment sites. These positions are generally aligned to specific research projects that are funded externally (eg. industry, ARC etc.).

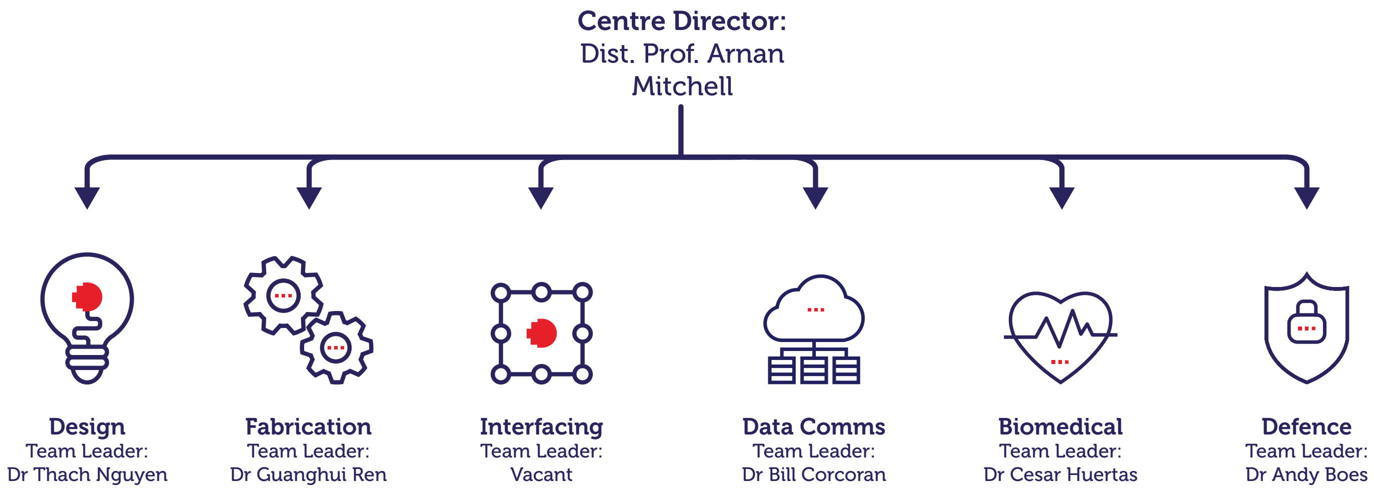
Higher Degree by Research (HDR) students

We advertise Centre PhD positions throughout the year on the InPAC webpage. We also advertise regularly via online recruitment sites with open PhD positions that are funded externally through our industry partners and competitive grant funding. We are also primed to guide HDR students to apply for competitive scholarships and programs that can support their studies within our Centre.

Structure and Governance

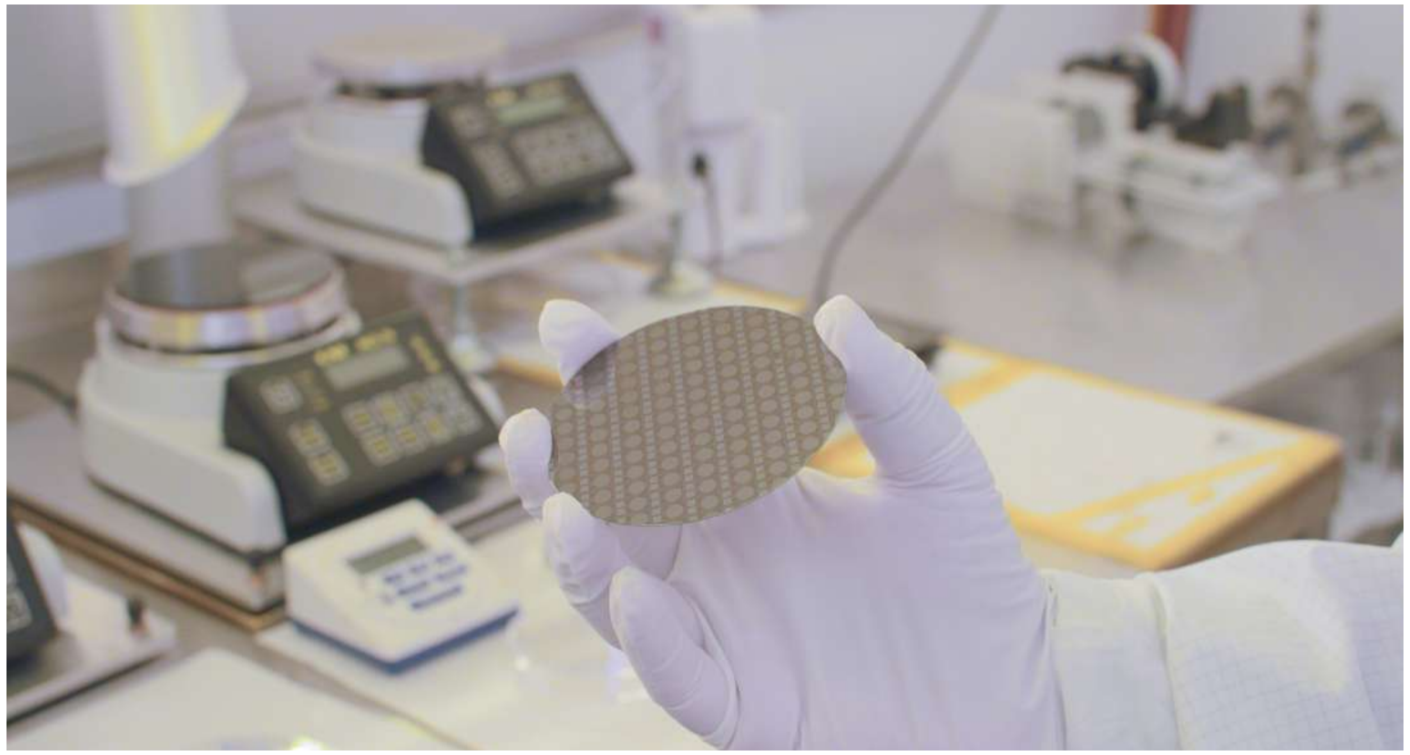
Organisation structure of InPAC:

The Integrated Photonics and Applications Centre 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.

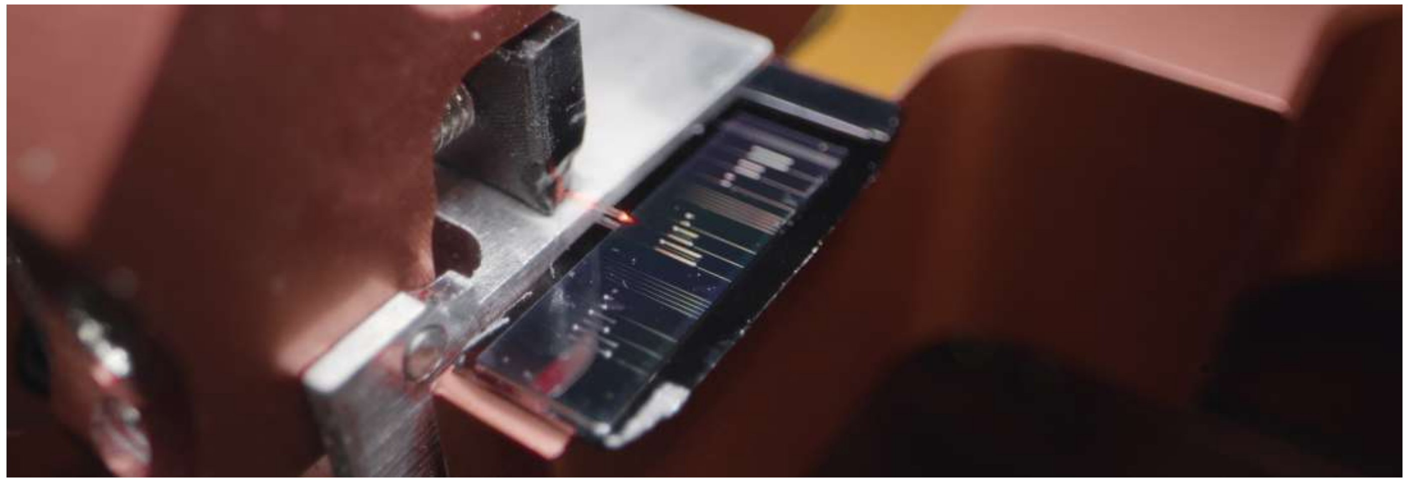


The Centre is newly established, so there are no changes to structure and Governance of the Centre.

Currently the Interfacing team position is vacant and we aim to fill this position in the next year by an early or mid-career researcher.



Report on 2020 Achievements and Activities



In our planning to launch InPAC in 2020, we had imagined ramping up our global engagement with a campaign of conference talks and lab visits. Then the COVID-19 pandemic erupted and the borders shut and we knew we had to pivot. We realised that since suddenly everyone around the world was shut off from all the people they usually work with, this could be a great time to put energy into reaching out and making new connections.

With everyone online, establishing close contacts was just as hard for everyone and so we found that people all over the world were open to connecting with us. This strategy has worked well through the pandemic in 2020. We have established many new connections all over the globe, while strengthening and rekindling connections in Australia with partners interstate and around Melbourne. Some of these initiatives are already baring fruit and we now feel well set up for 2021 and beyond.

2020 Plans

InPAC is a newly established Centre at RMIT, hence there was no formalised plan for 2020.

Key Achievements

The Centre had many key achievements in 2020, as highlighted below.

Media/Communications:

- The world's fastest internet on a single optical chip journal article attracted more than 1,100 online articles worldwide
- The $2.8 million CRC-P grant news story resulted in news across several trade magazines.
- The Centre also established its own webpage and LinkedIn page and grew its Twitter following from 18 followers to 225 followers in less than a year.

Research Excellence

- The Centre members published a total of 26 journal publications, all of which were in Q1 journals.
- Highly significant, breakthrough demonstrations were reported in some of the leading journals in the research fields of the Centre, such as Nature Communications, Advanced Materials, Laser and Photonics Reviews and Nanophotonics.
- Centre members were recognised for the research excellence by being awarded a Fulbright Fellowship (Sonya Palmer) and Victorian Fellowship (Dr Andy Boes).

Research Funding

- InPAC was successful in attracting two major research grants in 2020:
  - (i) The Cooperative Research Centres Projects (round 9) with Advanced Navigation, the Australian National University and Airsight ($2.8M)
  - (ii) Australian Research Council Linkage Project with Advanced Navigation and Melbourne University ($1.03M).

Centre Impact

The Centre has made the following impact in 2020:

- Increased media presence with stories in The Independent, BBC News, ABC News, The Australian, The Conversation, Manufacturers' Monthly, Space Connect and Electronics Online.
  - These media stories then led to Main Sequence Ventures enquiring about commercialising technology, industry partners wanting to collaborate via a joint grant application, and several HDR students enquiring about joining the team.
- Two talks by Arnan Mitchell including co-chairing the Nanotechnology Forum as part of the Conference on Lasers and Electro-Optics Pacific Rim and an RMIT Distinguished Professor Talk which received very good feedback.
- The awarded funding will enable InPAC to focus a significant part of their work on translating photonic integrated circuits chips to real-world contexts.
- InPAC is also engaging with Baraja, MOGLabs and BluGlass to explore integrated photonic solutions for their products.
  - These examples highlight the direct benefit of InPAC's research to the Australian industry, defence agencies and wider optics community.

Performance Against Targets

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

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.

The Centre has a highly collaborative environment, where team members with many different backgrounds work with each other. This is achieved by the structure of the Centre, which embodies the flow from concept to rapid prototyping. This structure requires the input of all InPAC members to achieve high impact outcomes.

All researchers within the Centre actively support, coach and mentor each other and their junior colleagues to achieve success in their research and career goals. The Centre is also actively enriching the research environment by hosting international visitors (Xudong Zhou, Juan Manuel Gomez Cruz, Brianna Bradley and Linh Ho in 2020) as well as facilitating visits or researchers to international research groups. Unfortunately, the latter was not feasible due to COVID-19 in 2020.

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.

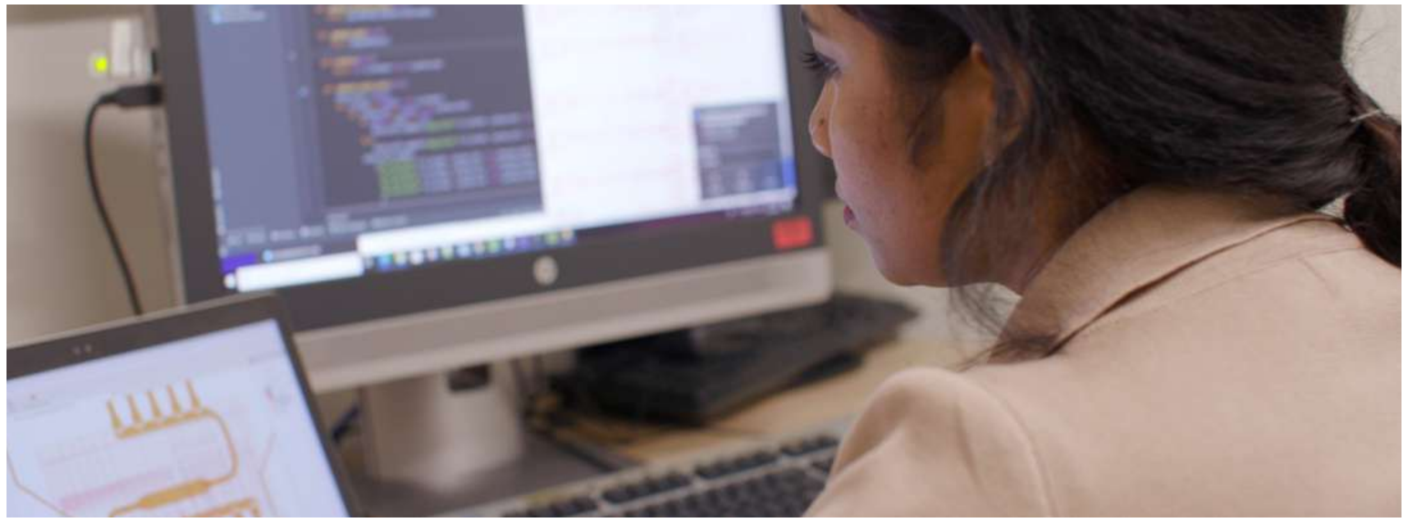
Targets:

- Panel of examiner forms submitted at third milestone and approved by the School of Graduate Research prior to all candidate submissions;
  - In 2020, we did not use the proposed formalising for the graduation of Markus Knoerzer, however we are happy to implement this as a process for the HDR students that will have their third milestone in 2021.
- On time completion of milestones and submission of thesis.
  - In 2020 the milestones of all HDR students were on time. Markus' PhD submission was slightly delayed by a few months after the 3.5 year mark, which was partially caused by the global pandemic and loss of access to key facilities.

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

Targets:

- New international partners/collaborators;
  - We are in the process of establishing a co-tutelle agreement with Lanzhou University, which should be completed in 2021. We are in the process of starting a new collaboration with Prof. Gunther Roelkens from Ghent University and will send a student for a visit to them in 2021.
- Increase in publications with international co-authors;
  - More than 80% of InPAC's publications have international co-authors.



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

Target:

- At least three journal publications from each HDR candidate targeting Q1 outlets;
  - The PhD student that graduated in 2020 (Markus Knoerzer) was an author/co-author on five Q1 journals during the PhD studies.
- In 2020, the Centre published 28 journal articles
  - 75% of publications in Q1 journals.

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.

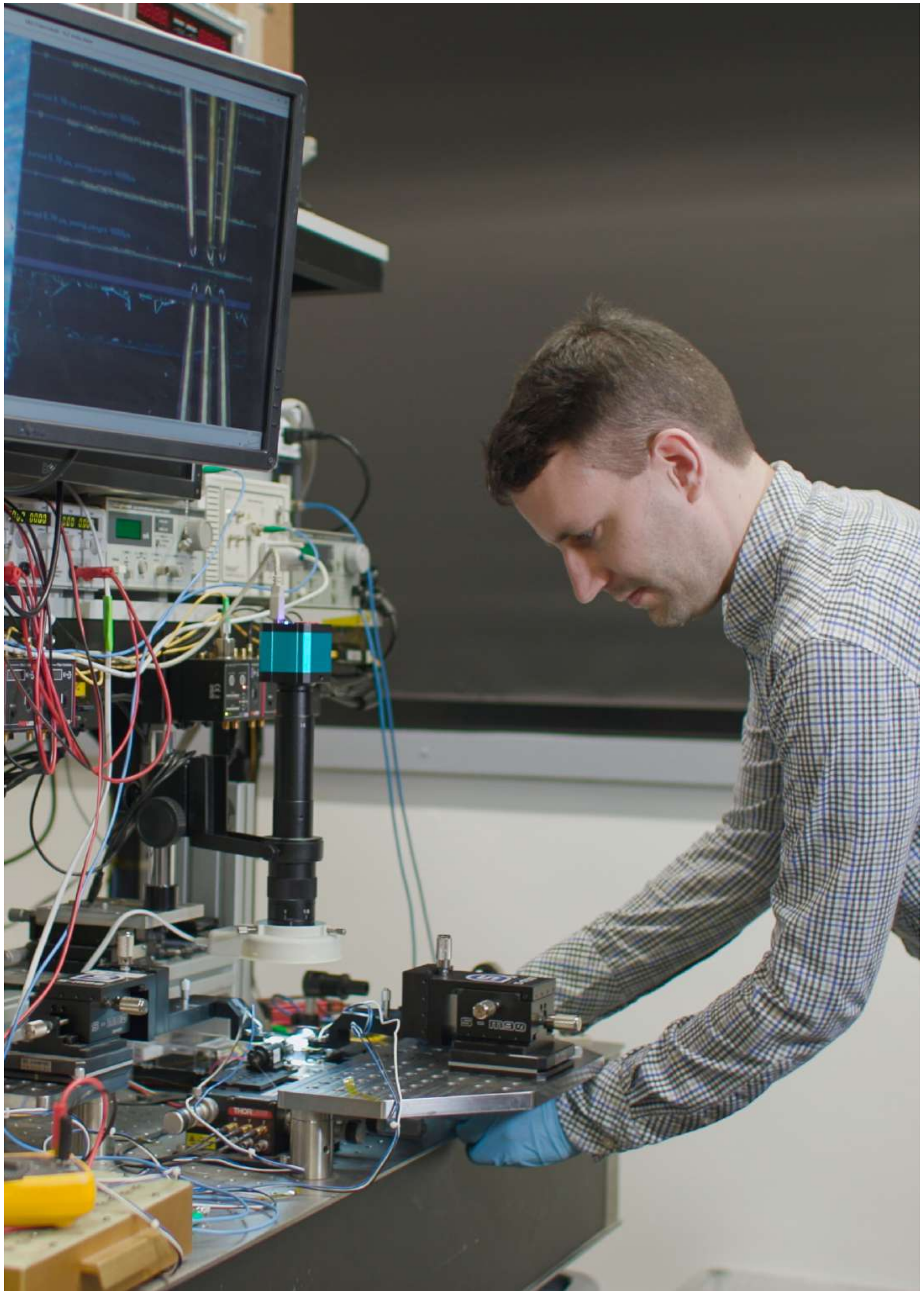
Target:

- New partnerships;
  - In 2020, we established new partnerships with Defendtex, MOGLabs, Advanced Navigation, Baraja, Nirtek, Bionics Institute and BluGlass.
- Build global engagement;
  - Develop new research impact case studies (provided in the Key Research Areas section below).
  - Increase the Centre's Twitter and LinkedIn following.

In the following we summarise the performance indicated in the table below.

We'll be looking for an increase of 15% of all our performance measures for 2021.

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

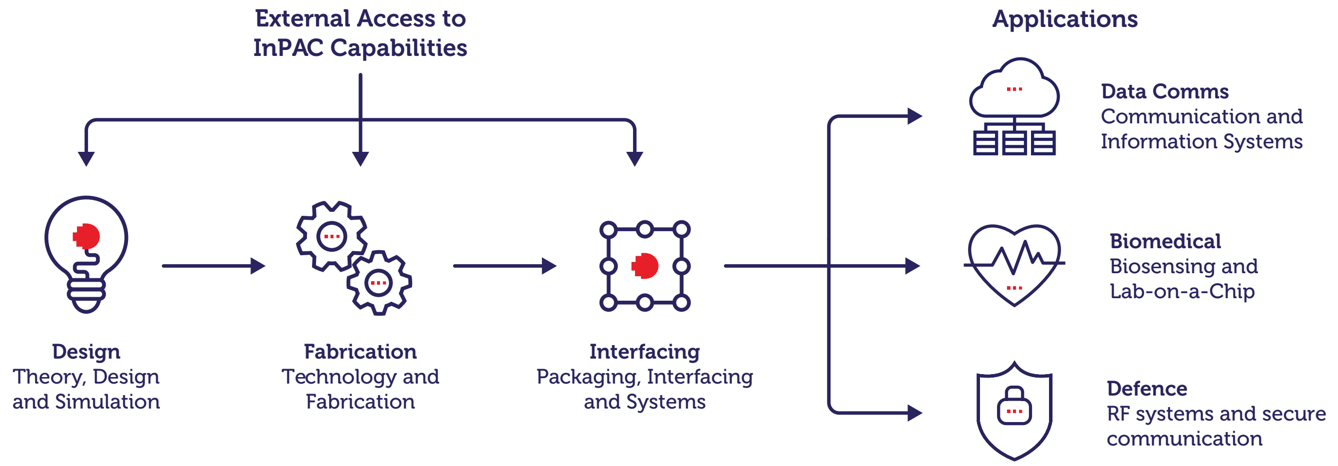


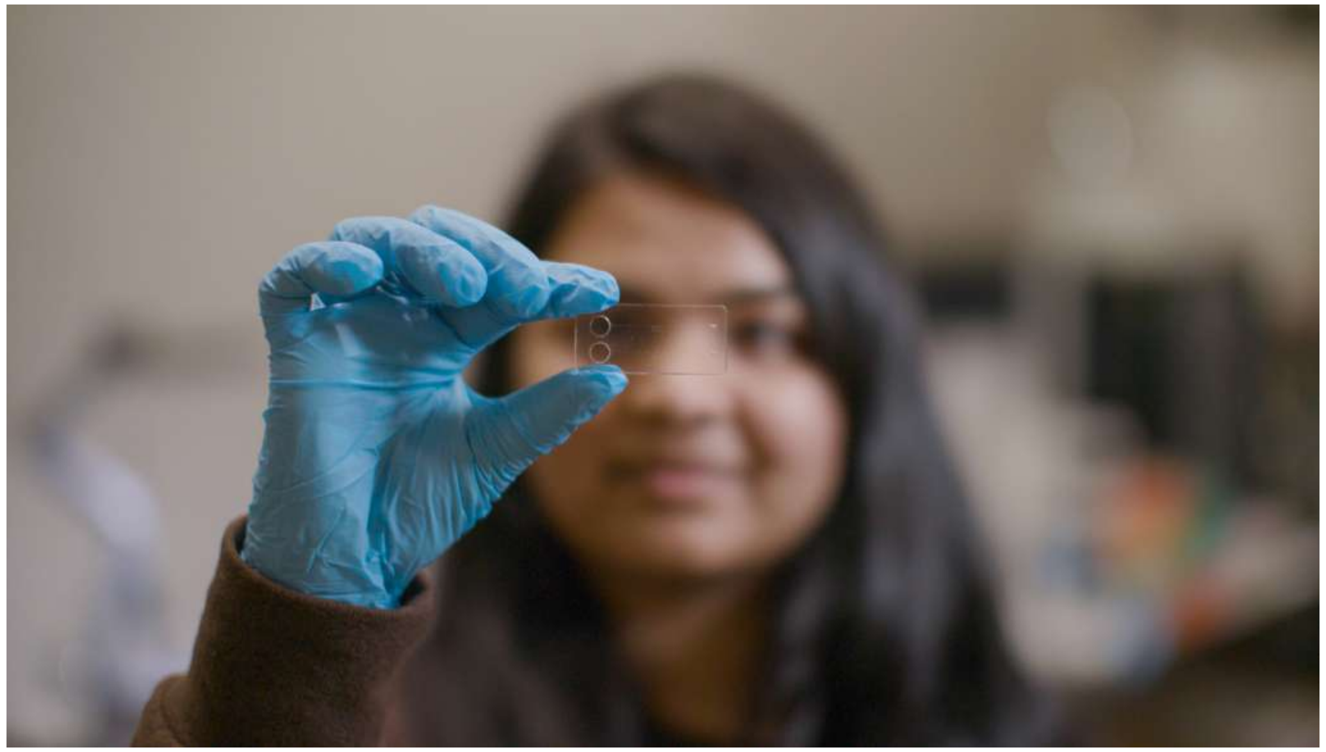
Key Research Areas

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.

Simulation and Design Team

As the design team, we understand that a complete integrated photonics design framework is crucial for success. We use the industry standard IPKISS design framework, which covers the complete circuit design flow process. Our partner Luceda Photonics created this software for the design, simulation and layout of photonic integrated circuits.

Designing for industry compliance and mass manufacture

To ensure that designs are industry-compliant and scalable to mass manufacture, we are continuing to develop many significant plug-ins for the IPKISS framework. These include direct interfaces and process design kits for a range of electron-beam lithography tools, automated characterisation tools, and a comprehensive electromagnetic simulation suite called REME.

Our goal is to create products for our users as scalable as possible, to ensure our designs fit into their existing systems. We also ensure that the chips we create will behave as intended, by designing and simulating our chips in the computer first before making them in the lab.

Moving towards thin-film lithium niobate

We have created Australian Silicon Photonics, with Ghent University using our service. Now we are applying what we've learnt from the silicon platform and translating it to the emerging thin-film lithium niobate platform.

We will work closely with the fabrication team to design and validate a library of standard building blocks so that the circuit designers can efficiently create sophisticated circuits. Similarly, we will also harness the opportunities of the thin-film lithium niobate platform to explore new phenomena with the aim of creating new integrated photonic components.

Research achievements

- We continue to collaborate closely with Luceda Photonics to ensure that the Centre has continued access to the IPKISS design framework so we can effectively design devices and circuits for the new photonic integrated circuit platforms by our staff and students.
- Our team was involved in 10 journal publications in 2020.
- We published in an invited journal article in IEEE Journal of Selected Topics on Quantum Electronics, providing an overview of our pioneering work in the novel phenomenon of lateral leakage and bound states in the continuum in silicon photonic waveguides and the emerging thin-film lithium niobate waveguide platform [17].
- We worked closely with the fabrication and biosensing teams to improve the sensitivity and stability of silicon photonic sensor chips, ensuring that a stream of silicon photonic chips can be reliably produced by the fabrication team for sensing experiments.
- Our simulation and design tools were expanded and adapted to support our increasing research activities in thin-film lithium niobate.

Allowing an Artificial Intelligence brain to attach meaning to what it's seeing – all in real time

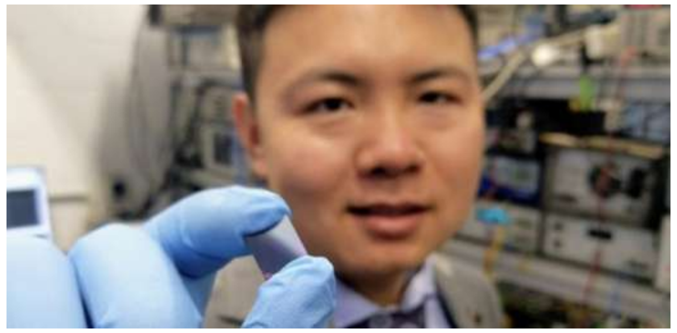
Alongside an international team including Swinburne and Monash universities, we demonstrated the world's fastest and most powerful 'brain-like' processor on a chip smaller than a five-cent piece.

The Challenge

Making AI processing more rapid to prevent collisions in driverless vehicles

Our brains – the most sophisticated computers on earth – capture and process huge amounts of information from our eyes that help us to make rapid decisions, like slamming the brakes on to avoid a car crash.

Currently, the closest thing to emulating these processing speeds are racks of traditional digital computers which are currently too large and power-hungry to fit into every driverless car.



Our Response

Using the brain's visual cortex as inspiration for an artificial brain

We teamed up with an international team of researchers including Swinburne and Monash universities to investigate how we can use light to achieve brain-like functionality – all with vastly reduced power requirements on a chip smaller than a five-cent piece.

Our team wanted to create an artificial neural network that could extract key features of raw data – like the shape of a tree or person – and teach it to attach meaning to what it's seeing, just like the brain's visual cortex.

The Results

Creating the world's fastest processor at 10,000 times faster than anything to date

Published in the prestigious journal Nature, our team demonstrated the world's fastest brain-like processor for AI, capable of processing mammoth amounts of data at 10 trillion operations per second – 10,000 times faster than any other optical neural processor to date.

The chip was made from previously designed and validated components that can be integrated together in a chip the size of a fingernail.

With this technology, driverless cars could now have a real-time collision avoidance system on board that is compact, low-cost and energy efficient. It could also monitor weather patterns and process biomedical images at rapid speeds.

"Collaborating with InPAC was crucial in creating the world's fastest optical AI accelerator to allow us to initiate the ideas and validate the success of our experiments."

– Dr Xingyuan (Mike) Xu, Lead Author

Read more about the partnership at www.rmit.edu.au/news/all-news/2021/jan/fastest-optical-processor

SEPTEMBER 2019
First team meeting with Swinburne and Monash Universities talking about the possibility of the project. Design experiments to use micro-comb for neuromorphic applications

OCTOBER 2019
Carry out experiments and write draft on the results

APRIL 2020
Submitted Nature paper

OCTOBER 2020
Submitted CRC-P application

ONGOING
Investigating alternatives to replace the off-chip weighting and signal feeding functionalities

Fabrication Team

Our fabrication team works very closely with the simulation and design team to ensure that everything we fabricate performs in the way it was intended.

Top five research achievements

- We established the silicon photonic platform (Silicon-Nitride) loaded thin-film lithium niobate on insulator (Silicon Nitride/Lithium Niobate on Insulator) platform that can be used to create integrated photonic circuits for InPAC users and end-users.
- Our team fabricated integrated silicon photonic chips for Baraja, the start-up company specialising in autonomous driving sensing. We also fabricated Gallium Nitride (GaN) integrated photonic chips for Bluglass who are focused on integrated LEDs and lasers.
- In collaboration with Lanzhou University in China, our team fabricated integrated silicon photonic chips for telecommunications applications based on optical mode mux/ demux.
- In collaboration with Associate Professor. Jianzhen Ou's group, our team fabricated hybrid integrated two-dimensional functional materials on the integrated silicon photonic chips for biochemical sensors and optical switches.
- The fabrication team co-published nine journal articles.

Creating many fabrication platforms ready for many applications

The focus of our team is to fabricate integrated optics platforms for many different applications. The platforms include silicon photonic platform (Silicon and Silicon-Nitride), and hybrid integrated silicon photonic platform (Silicon + 2D materials, Silicon + Silicon-Nitride, and Silicon-Nitride + Lithium Niobate).

Our team also develop process design kits for different platforms, which make up a library of building blocks for end-users to create sophisticated photonic integrated circuits compatible with mass manufacturing standards.

Creating building blocks compatible with lithium niobate ready for mass manufacturing

The next step for our team is to build on our knowledge of the silicon platform and make a new platform with lithium niobate.

Just as we did with the silicon platform, we are now making the lithium niobate platform more reliable with a new library of reliable components for any circuit designer. We want to use a library of building blocks so any circuit designer (a PhD student, academic, or someone from industry) can easily put together a prototype chip that we know will work the first time and will be compatible with mass manufacture.

Ensuring a steady stream of photonics students in a $4.3 billion industry

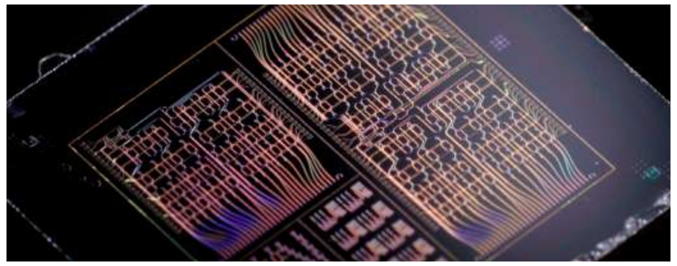
We're training the next-gen photonics design students to keep up with the rate industry is requesting them.

The Challenge

Needing more high-quality photonics graduates to keep up with a booming industry

From smart TV's and the internet to the LEDs that light our homes, many industries are powered by photonics that make it a booming industry. In Australia alone, the photonics industry contributes $4.3 billion to the economy and employs more than 9,500 people in high-tech, high-productivity jobs.

With an industry growing so rapidly, we currently do not have enough photonic chip design, simulation and fabrication graduates to keep up with the rate at which industry is requesting them.



Our Response

Creating a library of verified integrated photonic components for rapid chip turnaround time

We collaborated with Professor Wim Bogaerts at Ghent University to help specialist silicon photonics design students learn skills in translating a photonic circuit idea into a working chip.

To reduce the chip turnaround time for students – which often took up to six months – we adapted the software we use at InPAC and made it compatible with the software used at Ghent University (powered by Luceda Photonics).

We created a library of components compatible with our manufacturing process at InPAC. Then, with each verified 'lego block', the students could design with these components to build their own circuits.

The Results

Making high quality photonic chips in two weeks instead of six months

With our library of verified components compatible with our InPAC fabrication process, we can now offer a rapid turnaround time of six weeks for printing silicon photonic chips.

This rapid turnaround time means that students are now learning skills in iterative design and fabrication and end up with a thoroughly tested high-quality end-product. This means they are more likely to publish their work, making them more competitive for the job market.

Industry and academics can also take advantage of this library of certified components to design and fabricate their own chips, knowing that it will be fully compatible with mass manufacturing processes.

"At MOGLabs, we are very impressed with the graduates we have hired from InPAC and look forward to more in the future – we are in constant need of new photonics graduates with real-world skills."

– Robert Scholten, Co-Founder MOGLabs

Read more about how to work with us: https://www.rmit.edu.au/research/centres-collaborations/integrated-photonics-and-applications-centre/key-research-areas

Timeline of how to work with us

WEEKS 1 AND 2
– Get in contact with us for the quick prototype fabrication service for us to learn about your needs.
– Discuss your requirements and we will supply different solutions.

WEEK 3
Organise contract and Non-Disclosure Agreement

WEEK 4
Prepare the design based on InPAC's rules and process design kit

WEEK 5
Validate the designed layout

WEEKS 6–10
Fabricate the chip

WEEKS 11
We will measure the performance of the chip (optional)

WEEK 12
– Show you the first iteration of the prototype
– Rework based on feedback, or send the fabricated chips to customers

Biomedical Applications Team

Our team is made up of biomedical researchers, biotechnologists, chemists and engineers that work to advance diagnostics by offering advanced tests for early illness prediction.

Research achievements

- Our team was successful in the Marie Curie co-fund ECLAUSion project, a very competitive funding scheme used to recruit a highly qualified PhD student co-tutored with Ecole Centrale de Lyon (France).
- We have consolidated our international collaborations with the Bionanophotonics and Systems Laboratory (EPFL, Switzerland) and Escobedo's Lab (Queens University) for the development of optofluidic nanoplasmonic biosensors using our sophisticated and complex microfluidic framework.
- The team has participated in numerous grant schemes in 2020, establishing strong and long-term collaborative projects, including the RMIT Translational Immunology Research Program and the Walter Eliza Hall Institute.
- In collaboration with the NanoBiosensors and Bioanalytical Applications Group (Catalan Institute of Nanoscience and Nanotechnology, Barcelona), we have created a direct and fast surface universal functionalisation approach that allows us to generate multiomics plasmonic biosensor arrays using Poly-Adenine oligonucleotides as anchors for both DNA and antibody bioreceptors [23].
- The team has celebrated its first PhD completion by Markus Knoerzer, who created a highly robust and efficient integrated silicon photonic biosensor using signal processing methods based on cutting-edge telecommunication technology.

Combining photonics and microfluidics to create on-the-spot diagnostic tests

Many procedures, from cancer diagnosis to even a COVID-test, require very manual laboratory procedures under supervision of specialists. To overcome these wait times and need for specialist knowledge, we are miniaturising equipment that normally takes up entire laboratory benches, onto a chip the size of a fingernail.

This is thanks to the combination of two research fields – ultrasensitive biosensors powered by light and complex microfluidics – that allow us to create ultrasensitive on-the-spot-diagnostic tests that have the potential to rapidly detect viral infections, allergies or diseases.

Detecting single cells and tiny molecules with ultrasensitive biosensors powered by light

We are looking to create robust and ultrasensitive photonic biosensors, capable of detecting the presence of single cells and molecules. In addition, we are creating multiplexed platforms that can perform different processes automatically in the same microchip. We intend to create this by experimenting with new microfluidic fabrication and signal processing approaches.

Detecting heart attacks before they happen with a tiny sensor

Heart attacks are the leading cause of death worldwide, with cardiovascular disease leading to more than 17.8 million deaths each year.

The Challenge

Detecting when fatty deposits in our arteries are unstable

The leading cause of deadly heart attacks is the build-up of fatty deposits called 'plaques' in the walls of arteries. If an unstable plaque ruptures, it can completely block smaller blood vessels downstream stopping the heart muscle from getting the oxygen it needs. An angiogram is currently the best way to measure plaque build-up by determining its presence and degree of narrowing – but this test lacks the ability to accurately distinguish between a stable and an unstable plaque.

Currently, when a plaque is found, treatment will only be administered if the artery is blocked by more than 70 per cent – yet evidence suggests unstable plaques can cause heart attacks well below this threshold. More accurate detection of unstable plaques is therefore critical to saving lives.

Our Response

Collaborating to create a device to detect vulnerable plaques in the heart

Professor Karlheinz Peter and Matthew Hoskins from the Baker Institute, along with Professor Paul Stoddart from Swinburne University founded Nirtek to create a device that can find unstable plaques. The device uses laser imaging to immediately insert a stent to stabilise it. Nirtek engaged with us to establish a low-cost optic fibre based beam forming system that is compact and can be ramped up to large-scale manufacture.

Image: NIRAF Guidewire System by Nirtek

The Results

A device that shines light on unstable plaques for heart attack prevention

After several iterations, the team created a photonic device that allows the detection of small unstable regions within the coronary arteries of the heart. The device can be inserted through a catheter to illuminate plaques within the arteries with laser light. When infra-red light is shone on unstable plaques, they auto-fluoresce, alerting the cardiologist to the need for treatment such as a stent or targeted medication to stabilise the plaque.

This is the first technology capable of detecting unstable plaques before they rupture and cause blockage, ultimately detecting heart attacks before they happen.

"The InPAC team were valuable partners in the design and prototyping process, and we look forward to further engagement with this highly skilled team."

– Matthew Hoskin, CEO, Nirtek

Read more about the partnership at https://baker.edu.au/news/media-releases/laser-tech-startup

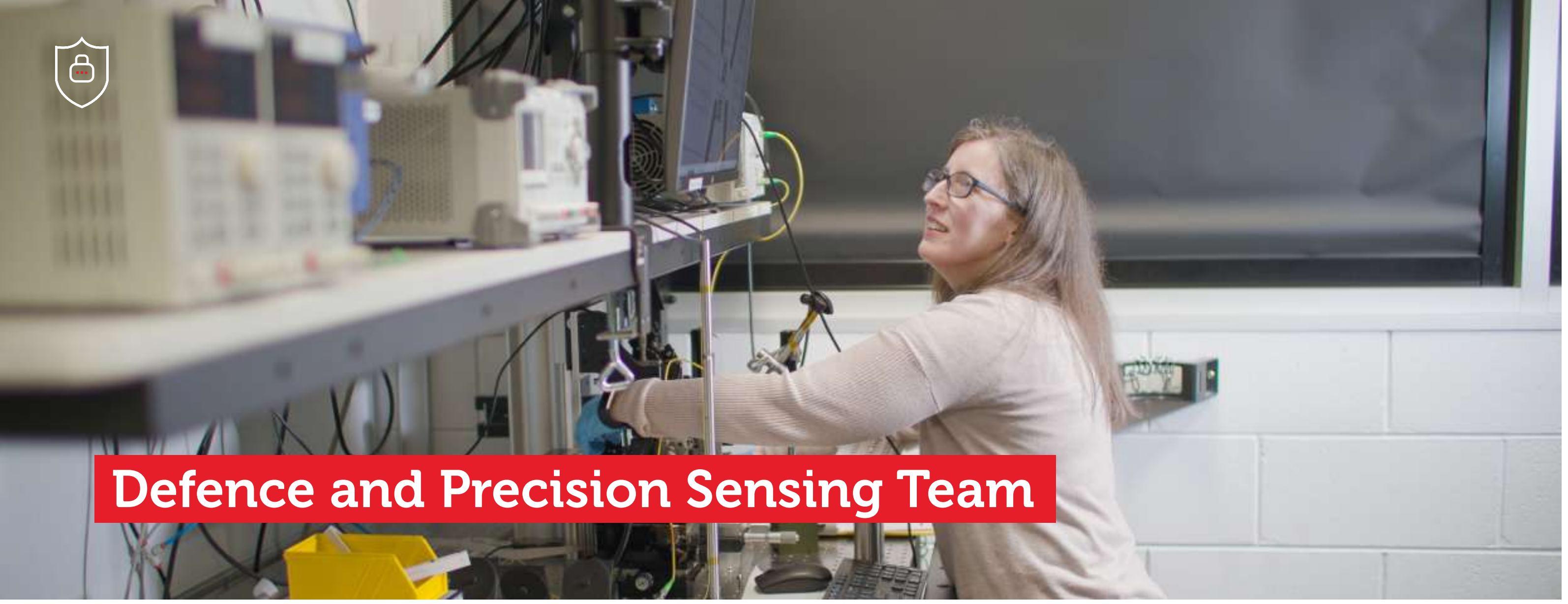
APRIL 2020
First team meeting with Nirtek via the medical device partnering program

AUGUST 2020
Began literature review, simulation, and design of NIRAF beam formation & detection technology

OCTOBER 2020
Started fabrication of first prototypes

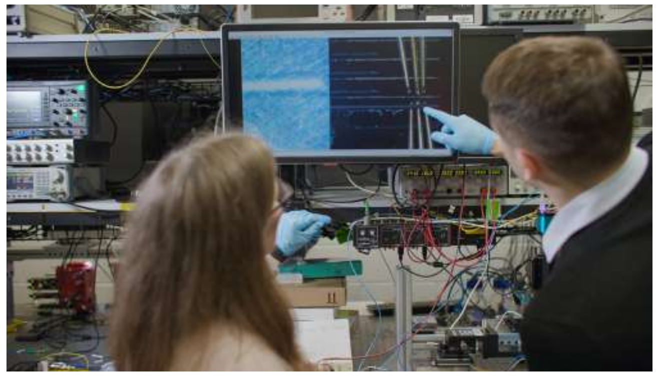
DECEMBER 2020
Prototyped the first InPAC-developed component for testing

ONGOING
Nirtek continue research and development of the product including the integration of the InPAC-developed component into the overall system



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.



Creating smaller, more accurate sensors for growing industries

At InPAC we are investigating new photonic platforms like lithium niobate on insulator and silicon nitride and employing them for defence-related products. A special focus is set on energy efficient, compact, lightweight and robust (mechanical and electro-magnetic) solutions. The new photonic platforms will help to make sensors small enough to fit on drones for railway monitoring, satellites travelling at 11,000 kilometres per hour, and driverless vehicles for rapid decision-making.

Embedding sensors onto drones to monitor railway infrastructure health

In 2021, a focus area for our team is to fabricate the first chip prototypes for the Cooperative Research Centre Project to test more compact optical gyroscopes with our industry partner Advanced Navigation. This will also include increasing the maturity of the integrated photonic platform and focusing on technological challenges such as low loss optical interfaces.

As part of this work, we will also hire two additional high-calibre research fellows and PhD students on the industry projects, which will help to grow our team in 2021.

Top five research achievements

- Our team was awarded a Cooperative Research Centre Project (CRC-P) with navigation system manufacturer Advanced Navigation.
- We were awarded a Linkage Project grant from the Australian Research Council to shrink the coffee cup-sized coils in gyroscopes down to the size of a fingernail – meaning the whole system can be integrated and then mass manufactured in the millions, all at the cost of only a few hundred dollars.
- Our team was involved in 11 publications of the Centre's publications in 2020.
- Our team members were awarded a Fulbright Fellowship (Sonya Palmer) and a Victorian Fellowship (Andy Boes) in 2020.
- With our collaborators at the University of California, Santa Barbara, we were able to create optical frequency combs that demonstrate ultra-high efficient generation. The demonstrated pump powers are well below the power that integrated laser light sources can provide, hence this demonstration paves the way for energy efficient and compact optical frequency comb sources suitable to address the need for microwave photonic and communication applications [26].

Creating autonomous drones to monitor the health of railway infrastructure

While accurate positioning is a critical function in industries such as transport, infrastructure and space, current technical solutions are still too expensive, large or energy hungry.

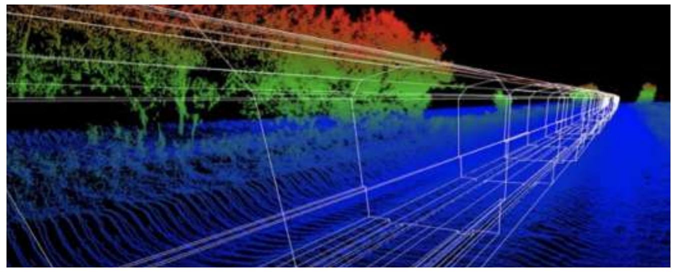
The Challenge

Reducing the cost of expensive, large and energy-hungry gyroscopes

High-performance gyroscopes are devices that measure rotation and orientation of whatever they are mounted upon. They can be used to improve the navigation and safety of autonomous cars, correct the course of satellites travelling at 11,000 km/h and enhance the precision of drones used for remote infrastructure inspection.

The global market for high performance gyroscopes in the fields of autonomous infrastructure inspection and autonomous vehicle navigation is expected to reach $US13.7 billion by 2024.

The price of one high-performance gyroscope has remained greater than USD $20K for more than a decade, meaning these technological solutions are still out of reach for use in many transport, infrastructure and space applications.



Our Response

Partnering with a navigation system manufacturer to reduce the cost of high-performance gyroscopes by 85%

A new Cooperative Research Centre Project (CRC-P) was announced in July 2020, aimed to cut the cost of high-performance gyroscopes by 85%.

The project is led by navigation system manufacturer Advanced Navigation, our Centre Director Arnan Mitchell and Defence Team Leader Andreas Boes from RMIT University, The Australian National University (ANU) and commercial partner Corridor Insights.

The Results and Current Progress

Creating tiny, powerful gyroscopes mounted on drones for railway infrastructure monitoring

The team has identified the integrated photonic circuit components needed to implement ANU's optical measurement technique – capable of detecting the tiniest changes between two light waves – to ensure the device provides an accurate reading.

While traditional high-performance gyroscopes normally take up a whole laboratory bench, our team miniaturised the components by integrating them onto a fingernail-sized chip powered by light. This chip will be light enough to mount on drones to monitor railway infrastructure and is approaching the suitable size, weight, power and cost for safely navigating driverless cars.

"Working with the researchers at InPAC has been very easy and collaborative from the beginning – we are now working with the team to create low cost chips that can be used on satellites, drones and even self-driving cars."

– Chris Shaw, CEO of Advanced Navigation

Read more about the partnership at www.rmit.edu.au/news/all-news/2020/jul/world-leading-gyroscopes

Timeline of how the project worked

AUGUST 2017
First team meeting with Advanced Navigation

OCTOBER 2018
Began first packaging of optical component

APRIL 2019
Innovation Connections project

JANUARY 2020
Guanghui began creating new chip design

MARCH 2020
Submitted CRC-P application

JULY 2020
CRC-P funding announced

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 modulations formats and ultra-dense spatial and spectral multiplexing.

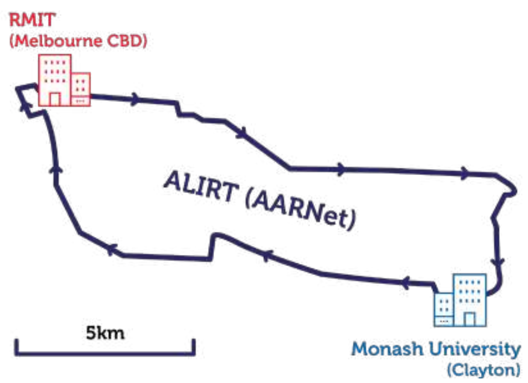
Increasing the bandwidth for faster internet for everyone

To achieve the ultimate internet data capacity over our optical fibre links, future communication systems will need to use the fully available bandwidth. A way to do this is with a device called a microcomb that creates a rainbow of infrared light allowing data to be transmitted on many frequencies of light at the same time, vastly increasing bandwidth.

Top five research achievements

- We produced a new world-record data capacity from an integrated chip, hitting over 39 terabits-per-second in a single 'real-world' installed optical fibre, a rate three times the record peak for the whole NBN combined.
- Our record result was picked up by global media, in outlets with an average readership of more than two billion people. Locally, our research was featured in The Australian, ABC TV News 24 and Triple M radio's popular Hot Breakfast.
- Our technologies have been provisionally patented, and gained interest from venture capital and NBN Co. We've also started new national and international collaborations on the back of this work.
- Our team has produced 10 papers in Q1 journals and key international conferences over 2020 and 2021.
- Our team has grown from one PhD student and team leader Bill Corcoran in 2020 to three PhD students and a postdoctoral researcher in 2021.

To test these internet speeds, our team sends information around "real-world" fibre links, like those of Australia's National Broadband Network. InPAC hosts the Australian Lightwave Infrastructure Research Testbed (ALIRT)* – a unique 'dark fibre' facility provided by Australia's Academic Research Network (AARNet) – to allow collaborative research between institutes in Melbourne.



Breaking our world's fastest internet record and translating the results to industry

We are combining three key approaches to extend upon our record result from 2020 to pack even more data into our existing optical fibre infrastructure: new microcomb technologies, InPAC's state-of-the-art lithium niobate platform, and wavelength conversion technologies. This combination will bring us closer to translating our record results to industry, to grow capacity and extend the useable lifetime of systems like Australia's NBN.

*ALIRT is part of the INPAC laboratories linking RMIT and Monash University. The testbed was established under ARC Linkage Infrastructure and Equipment Funds LE170100160 as a collaboration between RMIT, Monash, Swinburne and AARNET. This project was supported by ARC Discovery Project 'Rainbows on Demand: coherent comb sources on a photonic chip' DP190102773.

Creating the world's fastest internet on a single optical chip

COVID-19 placed immense pressure on the world's data communications infrastructure as more people worked from home than ever before, demonstrating the need for faster internet speeds.

The Challenge

The world's insatiable demand for bandwidth

New internet-reliant technologies like self-driving cars, remote controlled mining and medical equipment, will require even faster and increased bandwidth in the future. To keep up with this demand, we need continued growth in data carrying capacity in the backbone fibre optic technology that carries all this data.

Our Response

Collaborating to develop a chip capable of achieving high data transfer speeds

With our knowledge in photonic chip technologies and high-capacity optical communications, InPAC researchers at RMIT and Monash universities partnered with Swinburne for their expertise in microcomb technology with the aim to increase the data carrying capacity of our internet.

InPAC also offered an important and unique piece of the puzzle – the Australian Lightwave Infrastructure Research Testbed (ALIRT) – the real-world optical fibre network to test internet speeds on.

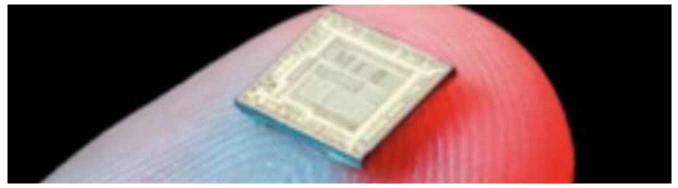
The Results

Achieving the world's fastest internet on a single optical chip at 39 Terabits per second

Together with Swinburne university, we achieved the world's fastest internet data speeds – enough to download 1,000 high-definition movies in a second – from a single optical chip. These speeds are around three times the record data rate for the entire NBN and about 100 times the speed of any single device currently used in Australian fibre networks.

Our breakthrough chip was powered by a device known as an optical microcomb – a fingernail-sized optical chip that replaces 80 separate infrared lasers. The team plugged a system based on the microcomb chip into ALIRT's existing optical fibres and sent the maximum amount of data down each channel to simulate peak internet usage.

This home-grown technology has the potential to fast-track the next 25 years of Australia's – and the world's – telecommunications capacity.



Using ALIRT, we can quickly validate that our new data technologies are compatible with real-world systems, bringing us closer to translating our work out of academia and into industry.

"The use of microcombs to achieve this record-breaking internet speed on a single optical chip is astounding – it is a very exciting step forward to keep up with our world's need for even faster internet speeds."

– Andrea Blanco-Redondo, Head of Silicon Photonics Department at Bell Labs, USA

Read more about the partnership at www.rmit.edu.au/news/all-news/2020/may/fastest-internet-speed

Timeline of how the project worked

- **OCTOBER 2018** First team meeting with Monash, Swinburne and RMIT
- **NOVEMBER 2018** Began first communication test with a soliton crystal microcomb
- **DECEMBER 2018** World's first field trial of a microcomb communications systems in ALIRT
- **MAY 2019** Invented virtual sub-banding technique to increase capacity
- **JULY 2019** Final test of ALIRT, reached speeds of 39 Terabits per second
- **AUGUST 2019** Submitted journal article
- **MAY 2020** Nature Communications paper published
- **ONGOING** Spin off with industry and further academic collaborations

Media and Communication

In March 2020, InPAC hired a science communicator, Rachael Vorwerk, to raise awareness about the Centre's research output.

Objectives

In consultation with the InPAC team, including the Team leaders and PhD students, Rachael drafted a communications plan with the following objectives, and subsequent outputs:

Building the InPAC narrative

- Develop the InPAC website housed on the RMIT website | **The InPAC website is now live on the RMIT website**
- Create case studies highlighting InPAC's current research | **See Key Research Areas section of this Annual Report**
- Profile the InPAC team members and their achievements on the InPAC website and social media | **Two PhD profiles can be found on the InPAC website under PhD positions, many LinkedIn posts and tweets were sent out celebrating various InPAC team successes.**

Social Media

- Build InPAC's twitter following | **InPAC's following has increased from 18 followers to 225 followers**
- Create an InPAC LinkedIn account | **InPAC now has 107 followers on LinkedIn**
- Build Arnan's profile on LinkedIn | **Arnan Mitchell currently has 2,191 connections**
- Build Arnan's profile on Twitter | **Arnan Mitchell currently has 752 followers**

Media

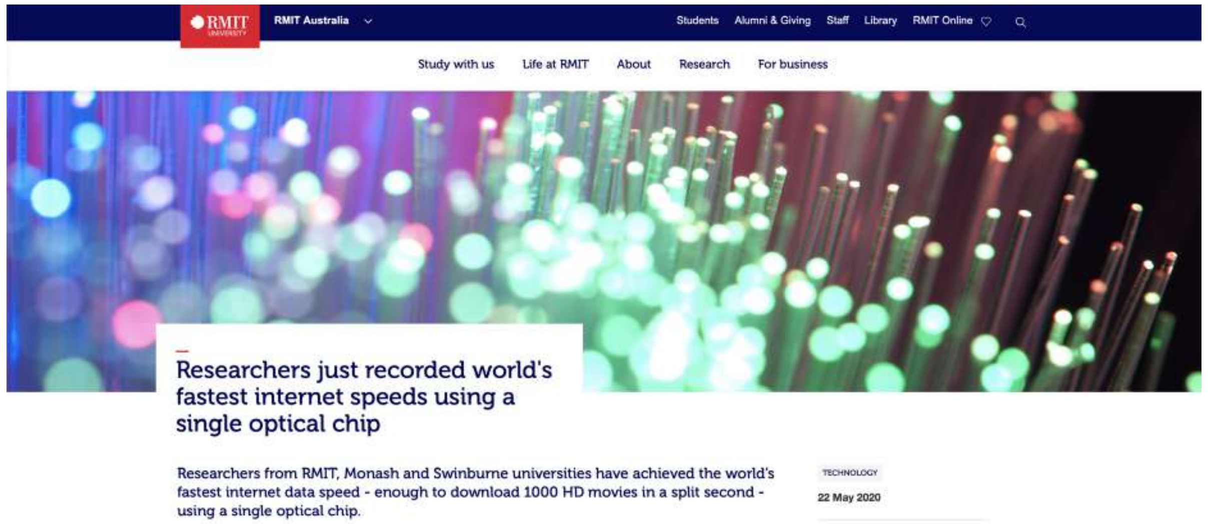
- Prioritise stories for media releases | **Two media releases were sent out in 2020**
- Increase Arnan's media presence | **Arnan was quoted in four RMIT news stories in 2020 and was recognised as an RMIT 2020 Media Star in Science, Engineering and Health.**

Outcomes

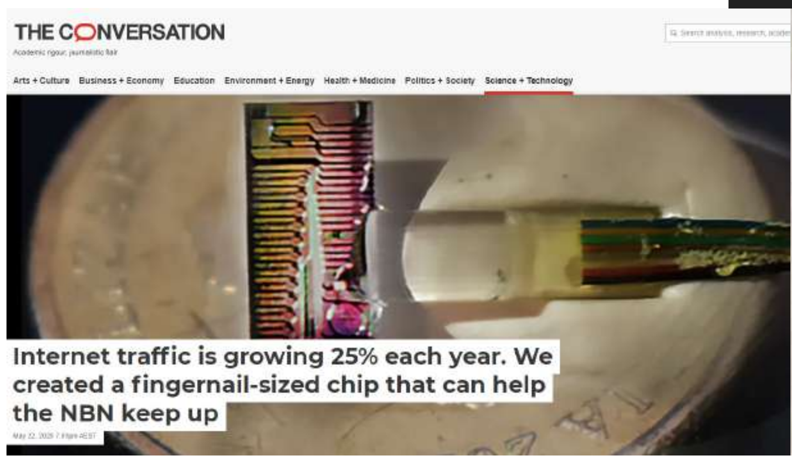
Three RMIT News Stories

Australian researchers record world's fastest internet speed from a single optical chip | 22 May 2020

A collaboration with Monash University, RMIT and Swinburne universities.



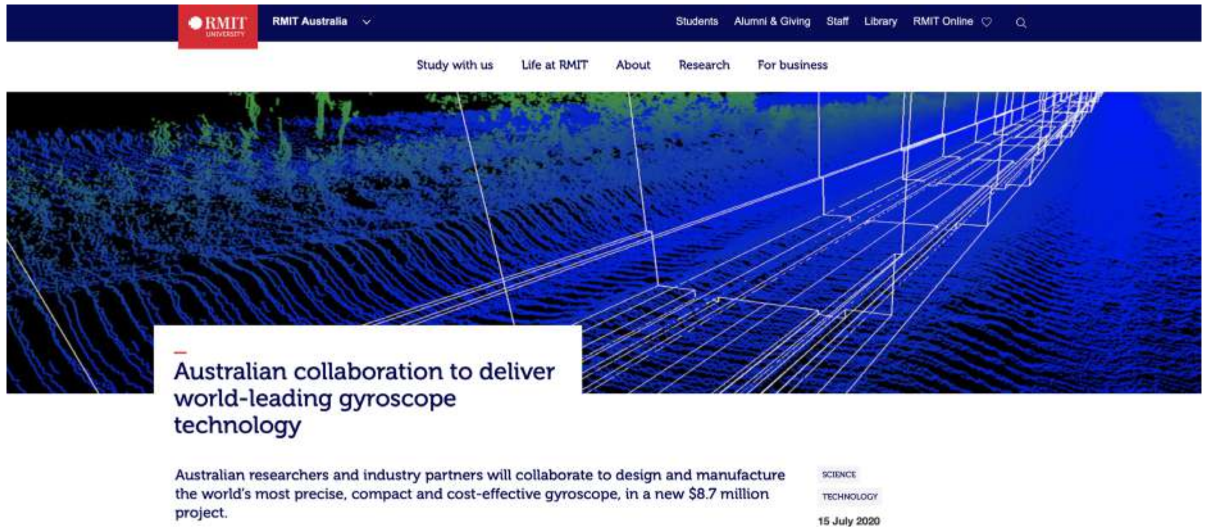
The Nature Communications journal article reached The Independent, BBC News, ABC News, The Australian and The Conversation and many more. It was also the most downloaded in the 2020 Top 50 Physics Articles for Nature Communications, was part of the Australian Science Media Centre's Top 10 Science Stories of 2020 and became RMIT's biggest story in recent years, with more than 1,100 online articles worldwide.



Three RMIT News Stories

Australian collaboration to deliver world-leading gyroscope technology | 15 July 2020

A collaboration with navigation system manufacturer Advanced Navigation, RMIT University, Australian National University (ANU) and commercial partner Corridor Insights.



The $2.8 million CRC-P grant enabled an $8.7 million total project investment (cash and in-kind) and resulted in news across trade magazines including Manufacturers' Monthly, Space Connect and Electronics Online.

Leading tech firm, Main Sequence Ventures, subsequently enquired about commercialising the technology, while a joint grant application was arranged with researchers specialising in atomic clocks.

SmartSat CRC and defence industry partners sought opportunities to collaborate on ultrahigh speed satellite communications and long-range secure communications, while several HDR students enquired about joining the team.

Three RMIT News Stories

Let there be light: how photonics is transforming tech as we know it | 30 July 2020

A study commissioned by The Australian and New Zealand Optical Society found that the photonics-based industry contributes more than A$4.3 billion to the Australian economy.

This article was an important positioning piece for Arnan Mitchell, to help position him as a leader in the field of photonics, and as an explainer piece about the significance of photonics on Australian manufacturing.

Other Highlights

- Arnan's Distinguished Professor Lecture about how the internet works through photonics, received very good feedback that it was very accessible to a wide audience.
- An RMIT article and video were published about National Science Week, which featured InPAC's world's fastest internet story as the number one point of the article.
- The team experimented with an Instagram story about how the internet works – the story gained a reach of 2,430 people.
- Arnan Mitchell and Andy Boes were both co-authors in an *Advanced Material* paper about the world's first photodetector than can see all shades of light, alongside Vaishnavi Krishnamurthi and Sumeet Walia – a great first step to interface our chips with Sumeet's materials.
- Arnan Mitchell was recognised as an RMIT Media Star and a Top Performer in Science, Engineering and Health in 2020.

Staff and Student Achievements

InPAC is proud to announce that in 2020/21 the students and staff of the Centre had several successful milestones:

PhD Completions

- **Dr. Markus Knoerzer**

  Title: Advanced interrogation methods for integrated photonic biosensors

  Markus' PhD studies aimed to investigate how advanced technologies from the field of optical data communication and microwave photonics can be used to improve the robustness and deployability of integrated photonic biosensors.

Awards and Prizes

- **Fulbright Fellowship – Sonya Palmer**

  This Fellowship will support Sonya in a 10-month research mission at the University of California, Santa Barbara to investigate narrow linewidth integrated photonic lasers for quantum optical applications.

- **Victoria Fellowship – Dr. Andy Boes**

  This Fellowship will enable Dr. Andy Boes to visit several international collaborators in Europe and US, to get a deeper understanding of the commercialisation of photonic integrated circuits.

- **Geoff Opat Early Career Researcher Prize – Dr. Andy Boes**

  This prize from the Australian and New Zealand Optical Society is for work performed during the five years after award of PhD and is the most prestigious award for young researchers in optics in Australia and New Zealand.

- **RMIT Award for Research Excellence – ECR – Technology – Dr. Andy Boes**

  This prize recognises an individual researcher at RMIT who has achieved the highest level of excellence in their research activity for the preceding five years. The purpose of this Award is to recognise and encourage outstanding researchers with proven reputations undertaking research that is of major importance in its field and who have made a significant contribution in advancing knowledge and research outcomes.

Successful Grants

- **CRC-P (round 9) - Digital Interferometry Optical Gyroscope for autonomous navigation**

  Advanced Navigation will collaborate with research partners ANU and RMIT and commercial partner, Corridor Insights to develop the world's leading high-performance gyroscope. Accurate positioning is a critical function in industries such as Space, Transport and Infrastructure, current solutions have poor price/performance, the novel approach using low-cost fibre and integrated optical waveguides will deliver a solution that is an 85% cost reduction over current systems and will enable new customer applications that has previously not been possible.

- **ARC Linkage Project (LP200100029) - Photonic chip inertial movement sensors**

  This project aims to create a new class of optical inertial movement sensors using integrated photonic chip technology. By replacing optical fibre coils with compact waveguides, integrating light sources on-chip and by harnessing smart sensing approaches, we intend to reduce the required power from watts to milliwatts and reduce the dimensions from meters to centimetres. The expected project outcomes are sensors with military grade precision but with the size, cost and manufacturability of consumer electronics. This technology will fill a strategic gap in the movement sensor market enabling applications ranging from robotic infrastructure monitoring, manufacture and surgery to guiding satellites and other space craft.

2021: Next Steps

In 2021 we want to be more strategic with the student and staff awards and prizes. To achieve this, Rachael will put together a list of some of the major awards and prizes that Centre members can apply for and InPAC will create an applications strategy for such award/prize applications.

Activity Plan for 2021

In 2021 we know that the world will have changed. We will be experimenting with how to best maintain our collaborations and grow new connections in an online world. We will also focus on consolidating and preparing for a return to COVID-normal.

We are particularly looking to build on our collaborations in photonic chip gyroscopes and explore opportunities in structural sensing for aerospace and civil infrastructure. We will also formalise our governance structure and devise ways to achieve broader gender diversity across the Centre.

In the following we provide a detailed plan of activities and targets for the next three years that aims to address the expectations formulated by the STEM College for RMIT Centres:

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.

From 2021 on we will hold an annual workshop to foster the collaboration and enhance the visibility of the Centres' capabilities internally as well as to external partners. We further plan to collaborate with other complementary research centres that will use the technologies that the Centre creates to deliver impact (e.g. CADES).

We will also send some of the Centre members to visit the labs of our international collaborators, which will enable them to build their own networks and strengthen existing links.

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.

Targets:

- Panel of examiner forms submitted at third milestone and approved by SGR prior to all candidate submissions;
    - We will implement this methodology from 2021 onwards.

- On time completion of milestones and submission of thesis.
    - We will continue to have the milestone for the HDR students on time and aim to achieve thesis submission in time (3.5 years).

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

Targets:

- New international partners/collaborators;
    - We continue to reach out to potential new collaborators, particularly for the application areas of data, defence and biomedical. This will include the establishment of a collaboration with Prof. Gunther Roelkens, which will enable us to gain the capability of integrating photodetectors on the photonic circuit chips
- Increase in publications with international co-authors;
    - The InPAC team has a strong international footing, with many overseas collaborators. We will maintain these relationships and establish new collaborations as indicated above. We aim to continue a high rate of publications (~80%) with international collaborators.
- International research income growth of at least 10% per annum.
    - We will strengthen our collaboration with US-based industries and defence institutes to increase our international funding. To achieve this we will also seek out advice from RMIT researchers that already have collaborations with US-based companies and defence institutes and whose capabilities are complementary (e.g. the research group of Prof. Pier Marzocca).

Increase research income.

Targets:

- Minimum 15% growth in total research income annually.
    - On average we aim to achieve this funding growth by a number of measures:
        - Each staff member (postdocs and team leaders) are asked to apply for competitive research grants, such as the ARC discovery projects and appropriate fellowships.
        - Each applications team should apply for one or more large scale industry grants in the next three years, particularly aiming for ARC Linkage Projects and CRC-P applications. When the Centre is running at capacity, there should be three CRC-Ps in various stages of their lifecycle each year.
        - The Centre will actively pursue small direct funded projects from industry in defence by promoting the Centre's capabilities at national workshops and conferences. The aim is to grow these initial engagements into larger scale projects as more capabilities, needs and opportunities arise.

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

Targets:

- At least three journal publications from each HDR candidate targeting Q1 outlets;
  - At InPAC we structure the PhD studies in four to five research questions. The first research question is an introduction to the topic, and two to four are investigations that should lead to Q1 publications. This is an ambitious goal that aims to guide the student and keep them on track. If this structure is successful, then each HDR candidate will end up with three journal publications in their candidature. We will continue to apply this strategy to achieve that, but we also acknowledge that the last year required readjustments of the PhD studies due to the limited access to research facilities due the global pandemic.
- Centre outputs grow by a minimum of 15% per annum;
  - With the growth of the Centre members (through the hiring of additional postdocs and HDR students) and publication aims of each PhD student, we anticipate that this will lead to an increase of the research publication output of around 15% in the next three years.
- 75% of publications in Q1 journals.
  - We will continue to aim publishing in high impact journals and anticipate that more than 90% of our publications will be in Q1 journals.

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.

Targets:

- 20% increase in industry funding annually;
  - The outlined research funding growth of 15% (see above) is aimed to be achieved by focusing on funding opportunities with industry and defence agencies. Hence, we believe that this strategy will also automatically fulfil the requirement to increase the industry funding by 10% annually.
  - New partnerships;
    - The Centre will actively pursue small direct funded project from industry in defence by promote the Centre's capabilities at national workshops and conferences. The aim is to grow these initial engagements into larger scale projects to better understand capabilities, needs and opportunities.
- Create new research impact case studies to demonstrate the real-world applications of each of the Application Teams
  - The Centre will continue to create new research impact case studies as part of the InPAC's Centre's annual report (similar as we have done for this report). We will also create a downloadable version of this report on the Centre's webpage, so that industry partners and external collaborators can see the capabilities of Centre.

Journal Publications

1. Jiang, Y., Zhang, Z., Yang, J., Han, X., Xiao, H., Ma, W., Ren, G., Mitchell, A., Tian, Y., "*A Flexible and Reconfigurable Optical Add-Drop Multiplexer for Mode Division Multiplexing Systems*", IEEE Photonics Technology Letters, 32 (24), art. no. 9239389, pp. 1515-1518, (2020). DOI: 10.1109/LPT.2020.3033714
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8. Xu, X., Tan, M., Wu, J., Boes, A., Nguyen, T.G., Chu, S.T., Little, B.E., Morandotti, R., Mitchell, A., Moss, D.J., "*Broadband Photonic RF Channelizer with 92 Channels Based on a Soliton Crystal Microcomb*", Journal of Lightwave Technology, 38 (18), art. no. 9099964, pp. 5116-5121, (2020). DOI: 10.1109/JLT.2020.2997699
9. Sinobad, M., DellaTorre, A., Armand, R., Luther-Davies, B., Ma, P., Madden, S., Mitchell, A., Moss, D.J., Hartmann, J.-M., Fedeli, J.-M., Monat, C., Grillet, C., "*Mid-infrared supercontinuum generation in silicon-germanium all-normal dispersion waveguides*", Optics Letters, 45 (18), pp. 5008-5011, (2020). DOI: 10.1364/OL.402159
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18. Jia, H., Chen, H., Wang, T., Xiao, H., Ren, G., Mitchell, A., Yang, J., Tian, Y., "*Multi-Channel Parallel Silicon Mode-Order Converter for Multimode On-Chip Optical Switching*", IEEE Journal of Selected Topics in Quantum Electronics, 26 (2), art. no. 8936920, (2020). DOI: 10.1109/JSTQE.2019.2958997
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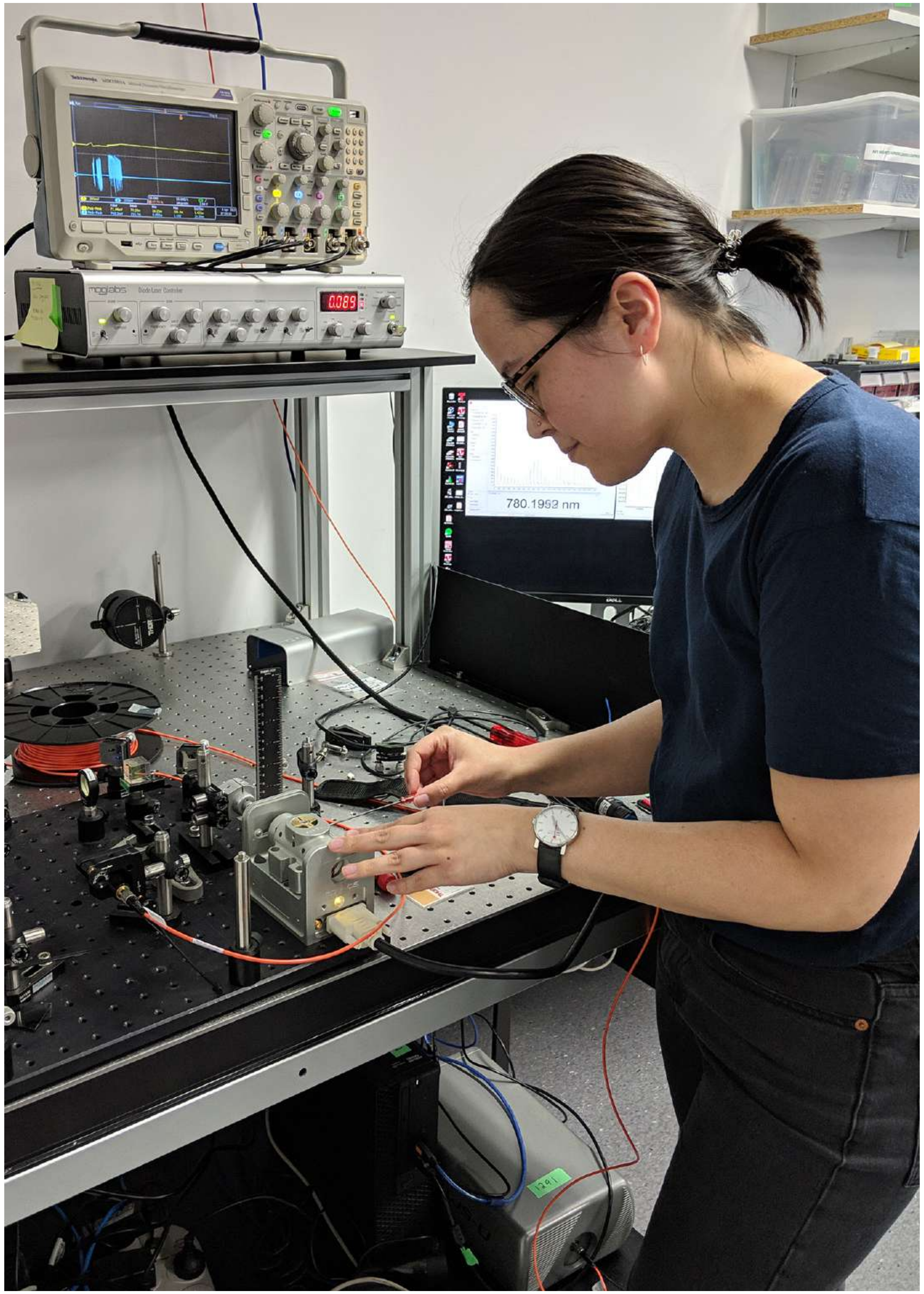
28. Ha, N., Xu, K., Ren, G., Mitchell, A. and Ou, J.Z. (2020), "Machine Learning-Enabled Smart Sensor Systems". Adv. Intell. Syst., 2: 2000063. https://doi.org/10.1002/aisy.202000063



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