Our Vision is to become a global hub of disruptive Photonics and Advanced Sensing research, creating transformational new approaches to sensing, and a new profession of transdisciplinary problem solvers.

What is Transdisciplinary Science?
A transdisciplinary approach brings discipline specialists together to work side-by-side with the common purpose of evolving new research methodologies and frameworks that span the traditional discipline boundaries and drive innovation.
Director’s Welcome

Many of the best opportunities for scientific breakthroughs over the next few decades sit between the conventional scientific disciplines. Similarly, pressing problems in health, the environment and national security require the fusion of technologies and approaches from many areas of science. IPAS has been created to bring together physicists, chemists, material scientists and biologists to pursue a transdisciplinary approach to science. We are developing novel photonic, sensing and measurement technologies that will create new tools for scientific research, stimulate the creation of new industries, and inspire a new generation to engage in science and technology. The Institute is supported by world-leading infrastructure through our laboratories and headquarters in The Braggs and an innovation culture. We work in partnership with government and industry on projects aimed at delivering real-world outcomes.

IPAS is working on a range of scientific challenges and future technologies via our six science themes:

- Biological Sensing and Medical Diagnostics
- Molecular Materials and Surfaces
- Chemical and Radiation Sensing
- Optical Materials and Structures
- Novel Light Sources
- Atmosphere, Space and High Energy Astronomy

IPAS is one of five world-leading research institutes at The University of Adelaide. The Institutes are central to the University’s strategy of supporting its recognised areas of research excellence and growing research capacity within these fields.

IPAS builds on the research capabilities within the University’s Schools and Faculties, bringing them together under a common identity. This benefits our members and stakeholders through increased research opportunities, capabilities and scale. The Australian Federal Government, South Australian State Government, DSTO, Defence SA and The University of Adelaide invested over $40M to construct the IPAS headquarters building, The Braggs, which opened in March 2013 and houses a unique suite of transdisciplinary laboratories. These facilities include glass development and processing, optical fibre fabrication, laser and device development, luminescence, environmental genomics, photonic sensor development, and synthetic, surface and biochemistry laboratories in addition to offices which co-locates IPAS researchers and students from a broad range of scientific disciplines.

IPAS is built on a strong ongoing partnership with DSTO and their support of numerous research projects and positions.

Professor Tanya Monro
IPAS Institute Director
IPAS Science Themes and Theme Leaders

The breadth of research conducted by IPAS members is categorised under six themes, each led by a pair of theme leaders.
IPAS Research Theme Goals

Molecular Materials and Surfaces
- Next generation molecular materials
- Materials that can control and respond
- Photonic technologies to improve proteomic technology
- Understanding biological processes at the sub-cellular scale
- Pushing the limits of surfaces

Chemical and Radiation Sensing
- Pushing the limits of sensing techniques and architectures
- Sensing in natural and man made environments

Biological Sensing and Medical Diagnostics
- Advanced optical sensing platforms to enable informed and rapid clinical decision making

Optical Materials and Structures
- Macroscopic materials with nanoscale properties
- New structures to control, generate and guide light
- Novel optical materials and fibres empowering new science and applications

Optical Sources
- Light for: Fundamental physics, environmental monitoring, national security, natural resources and medicine
- Light manipulating matter manipulating light
- New windows to the universe

Atmosphere, Space and High Energy Astronomy
- Understanding the atmosphere and near space environment
- Climate change: new insight by probing the entire atmosphere
RESEARCH THEME: Biological Sensing and Medical Diagnostics

Key Contacts:

**Biomarker Discovery**
A/Prof Peter Hoffmann  
E: peter.hoffmann@adelaide.edu.au

**Methathesis and Click Chemistry**
Prof Andrew Abell  
E: andrew.abell@adelaide.edu.au

**Biosensing Platform Development**
Prof Tanya Monro  
E: tanya.monro@adelaide.edu.au

**Adelaide Proteomics Centre**
A/Prof Peter Hoffmann  
E: peter.hoffmann@adelaide.edu.au

**STARR Laboratory**
Prof Tanya Monro  
E: tanya.monro@adelaide.edu.au

Development of the VESPR biosensor
RESEARCH THEME: Biological Sensing and Medical Diagnostics

IPAS research in this theme seeks to:

- Create measurement tools to enable new questions to be asked in biology and medicine
- Develop improved medical diagnostic techniques, including ‘point of decision’ technologies
- Advance next generation proteomics technologies for cancer diagnostics and treatment
- Discover and detect biomarkers using Tissue Imaging Mass Spectrometry
- Investigate proteins and peptides underpinning the development and prevention of diseases
- Design and develop drugs, including the identification and synthesis of novel small molecules to block or activate cellular targets.

Biosensing Platform Development

Harnessing breakthroughs from our other themes, we create new biosensing tools for advancing biological research, and collaborate with medical researchers to enable translation to clinical applications. This area is been supported by three of our six ARC Super Science Fellowships spanning:

- DNA detection in small volumes
- In vivo fertility probes
- Protein separation and detection.

New sensor architectures include:

- Small-volume in-fibre fluorescence assays
- Fibre-tip sensors for in vivo diagnostics
- A multi-channel sensor for virus, bacteria and biomarker detection for gastric cancer.

Biomarker Discovery

This work investigates cancers through the identification of new biomarkers, increasing our capacity to detect, identify and quantify proteins and peptides with high sensitivity and accuracy.

We use mass spectrometry and 2D gel electrophoresis combined with difference gel electrophoresis fluorescence labelling for protein identification and quantification. Driven by the need for the early diagnosis of cancer and monitoring of the disease’s progression, it also provides a better understanding of the disease at a molecular level.

Metathesis and Click Chemistry

We design, synthesise and test inhibitors to solve clinical challenges. Our investigations concentrate on proteolytic enzymes and small heat-shock chaperone proteins (sHsp) associated with amyloid fibril formation. We work to incorporate molecular ‘switches’ that, when activated, mimic a key protein or peptide. Our aim is the improved treatment and diagnosis of Alzheimer’s, traumatic brain injury, cataracts and cancer.

Protein Structure, Function and Interactions

Our focus is chemical, spectroscopic and biophysical investigations of the structures, functions and interactions of peptides and proteins. Nuclear magnetic resonance spectroscopy, circular dichroism, fluorescence spectroscopy, electron microscopy, ultracentrifugation techniques and site directed mutagenesis are used to investigate structure-function relationships of specific amino acids within peptides and proteins.
Case study

A new sensing architecture demonstrated in the paper “Highly efficient excitation and detection of whispering gallery modes in a dye-doped microsphere using a microstructured optical fibre” by Alexandre Francois (et al) reports Whispering Gallery Modes (WGM) that can be excited and detected in dye doped microspheres via a Microstructured Optical Fibre (MOF).

By placing a tiny sphere to the end of a very thin fibre, the team has demonstrated a new architecture for sensors that also provides a substantial increase in excitation and collection efficiency 200 times greater than conventional schemes. It also allows measurements to be made at the end of a fibre, this enables information to be gathered from within the body e.g. from within an artery rather than having to bring the sample out of the patient to be analysed in a laboratory setting.

The curiously named ‘Whispering Gallery Mode’ refers to a special kind of resonance that occurs when light is trapped within a resonator by total internal reflection. To achieve this, the sphere is precisely positioned on the end of a very thin (130 μm glass fibre, where it centres itself on one of the three MOF holes. The end result is a compact and robust architecture for applications such as localised in vivo/vitro biosensing.

IPAS are now actively collaborating with researchers with questions that can only be answered by in vivo measurement of biomolecules, as this new technique opens up the possibility of increasing our understanding of the origins of disease, and the response to treatment within human bodies.

One day, clinicians may have a kit of customised spheres on hand to detect relevant biomarkers and make clinical decisions on which spheres are best suited to their patient, such as being able to measure the response of a tumour to a new cancer treatment in real time, in vivo and in situ.
Pre-clinical research has led to the discovery and patenting of a panel of biomarkers that show significant promise for the early detection of gastric cancer in humans. Early detection would significantly improve survival rates for gastric cancer patients.

Current techniques for determining when to implant during IVF cycles disrupt the endometrium. A lab based demonstration of a non-disruptive real time \textit{in situ} fertility sensor proves the concept is viable.

Viruses, bacteria and proteins can be detected quickly using our surface plasmon resonance platform. This has been applied to cancer biomarker detection by combining it with a new panel of cancer biomarkers. This approach shows strong potential for earlier cancer diagnosis.

A sensor has been demonstrated that can detect single strands of DNA using a molecular beacon technique that can operate on sub-cellular scale liquid volumes. This may enable faster processing of evidence at crime scenes.
RESEARCH THEME: Molecular Materials and Surfaces

Key Contacts:

**Biological and Chemical Surface Functionalisation**
Prof Andrew Abell  E: andrew.abell@adelaide.edu.au

**Novel Materials Synthesis**
A/Prof Chris Sumby  E: christopher.sumby@adelaide.edu.au

**Functional Organic Materials**
Dr Christian Doonan  E: christian.doonan@adelaide.edu.au

**Charge Transfer and Bioelectronics**
Dr Jingxian Yu  E: jingxian.yu@adelaide.edu.au

**IPAS LARGE SCALE FACILITIES**

**Bragg Crystallography Facility**
A/Prof Chris Sumby  E: christopher.sumby@adelaide.edu.au

**Peptide Synthesis and Purification Facility**
Prof Andrew Abell  E: andrew.abell@adelaide.edu.au

**Australian National Fabrication Facility (ANFF) Optofab**
Mr Luis Lima-Marques  E: luis.lima-marques@adelaide.edu.au
RESEARCH THEME: Molecular Materials and Surfaces

IPAS research in Molecular Materials and Surfaces spans the following areas:

- Chemical surface coatings
- Surface functionalisation strategies
- Molecular-based sensors
- Bioelectronics
- New materials for gas storage or separation for renewable energy applications
- Platforms for catalysis.

Our researchers include ARC Future and Super Science Fellows, with expertise ranging from fundamental chemistry to analyte-specific sensor development (an IPAS strength).

Key infrastructure is available in the School of Chemistry and Physics, including:

- Synthetic laboratories (wet and dry)
- NMR spectroscopy and X-ray diffraction structure determination
- Peptide synthesis and purification
- Materials characterisation capabilities.

Biological and Chemical Surface Functionalisation

Biological and Chemical Surface Functionalisation work at IPAS combines organic synthesis, supramolecular chemistry and surface science to functionalise the surface of a glass optical fibre and other surfaces, enabling the detection of specific chemicals and biomolecules.

Novel Materials Synthesis

Our Novel Materials Synthesis group design and synthesise nanostructured materials. Some of these compounds display novel interactions and behaviour that we exploit to develop sensors as well as for use in separation science and as platforms for catalysis.

Charge Transfer and Bioelectronics

Our Charge Transfer and Bioelectronics work focuses on the design and synthesis of peptides with specific secondary structures whose electronic properties we then theoretically and electrochemically evaluate on surfaces.

Functional Organic Materials

IPAS researchers working on groundbreaking research in the area of Functional Organic Materials are developing the chemistry of ‘networked polymers’. These materials are synthesised from high symmetry building blocks linked via strong, irreversible covalent bonds. This emerging field has tremendous potential for new and more efficient catalysis platforms, sensing, storage and separation solutions.

Centre for Advanced Nanomaterials (CAN)

The University has established a stand-alone centre to foster, connect and harness research activities centred on the synthesis, processing and study of nanomaterials.

Key research themes in the CAN include:

- Chemical and Electrical Energy Storage
- Energy Waste Management
- Heterogeneous Catalysis
- Nanoporous materials for Gas Separations.
Case study

The paper “Fluorescence-based Aluminium Ion Sensing using a Surface Functionalized Microstructured Optical Fiber” delivers on Professor Tanya Monro’s vision of new platforms for sensing that push the boundaries of what can be done with versatile microstructured optical fibres when researchers take a collaborative, transdisciplinary approach.

Funded by the DSTO and ARC for Professor Monro’s Federation Fellowship program, this work combines commercially available chemicals with microstructured fibres in a way that retains the useful characteristics of each, paving the way for a new platform in ion sensing.

Working in the space between the disciplines of physics and chemistry, Drs Stephen Warren-Smith and Sabrina Heng joined forces under Professor Monro’s guidance to adapt an existing commercially available synthetic compound, the lumogallion fluorophore, into ‘Compound 3’ with support from Professor Andrew Abell. Designed to stick to the glass surface of a microstructured fibre while retaining fluorescence in the presence of aluminium ions, the team have made good progress with ‘Compound 3’ because it only takes a few steps to create, is made from low cost ingredients and provides a reasonably high yield.

There were some impacts on sensitivity with ‘Compound 3’ that are being addressed by tweaking the chemistry of the fluorophore and/or that of the polyelectrolyte intermediate layer to which the fluorophore attaches. Our research will also address other ways to approach the microstructured fibre coating in order to quantify the extent of its coverage.

It is the first time IPAS has produced a variant of a known fluorophore that has been adapted to enable surface functionalisation. This approach opens the door to a whole new platform for sensing that will allow us to build tools for further research, and partner with a diverse range of industries to develop products with applications in the fields of medicine, environment, agriculture and defence. The commercial opportunities for sensors based on this platform are enhanced by our new discoveries and the potential for cost effective scale.

Novel fluorophores developed in this theme are used in a range of chemical sensors
There is a global need for new antibiotics as bacteria develop resistance to current drugs. As part of a global collaboration a new class of antibiotic has been demonstrated and a patent on this discovery has been filed.

A new material with a massive potential surface area has been developed. Crystals of this material display controlled, reversible expansion and contraction that may provide opportunities in gas storage, catalysis and sensing applications.

A fluorophore for sensing aluminium was chemically modified to enable it to operate on the surface of an optical fibre. Aluminium ions can now be sensed in very small volumes and in real-time. This system could be used to monitor corrosion in aluminium structures.


RESEARCH THEME: Chemical and Radiation Sensing

Key Contacts:

Chemical Sensing

Prof Tanya Monro
E: tanya.monro@adelaide.edu.au

Radiation Sensing

Adj Prof Nigel Spooner
E: nigel.spooner@adelaide.edu.au

Environmental Dosimetry and Optical Dating

Adj Prof Nigel Spooner
E: nigel.spooner@adelaide.edu.au

Sample preparation for optical dating studies
RESEARCH THEME: Chemical and Radiation Sensing

IPAS chemical and radiation sensing research uses in-house and specialty optical fibre and unique surface coatings to develop novel optical fibre-based chemical sensing architectures.

We explore the limits of detection, including:

- Ultra-small volume samples
- Low concentrations
- Difficult to access areas.

Working with end-users and industry, we develop these sensors for monitoring water quality, corrosion, wine maturation, embryos, soil nutrients, fuel degradation and explosives. We are also researching new fibre forms of radiation dosimeters for the medicine and defence industries.

This theme is being supported by three of our six ARC Super Science Fellowships spanning:

- Photoswitchable sensor surfaces
- Explosives detection
- Small-volume gas sensing.

Chemical Sensing

Our chemical sensing research includes:

- Dip-sensors for hard to access regions including hazardous environments and in vivo
- Distributed sensors to enable information across a platform or structure
- Liquid and gas sensing techniques approaches: fluorescence, Raman and other spectroscopic techniques
- Analytes successfully sensed include hydrogen peroxide (H₂O₂), aluminium ions (Al³⁺), free SO₂, and others.

In partnership with other IPAS researchers, we have developed new functional structure surfaces to enable advanced sensor functionality. We solve problems in collaboration with irrigation companies, defence organisations, embryologists and oenologists.

Radiation Sensing

IPAS’ Radiation Sensing work focuses on the development of new radiation dosimetry tools for both fundamental research and applications in health, defence and industry. Examples include the development of:

- Fibre-based distributed dosimeters

Environmental Luminescence

The IPAS Environmental Luminescence Facility hosts the most comprehensive suite of luminescence research equipment in the world. The suite includes the world’s most sensitive TL spectrometer, a photon-counting imaging system (PCIS) developed in collaboration with ANU, state-of-the-art TL/OSL Rise readers, and specialised apparatus for the measurement of luminescence kinetics and signal stability.

We develop new forensic luminescence techniques for detection of prior exposure to ionising radiation, and provide a wide range of luminescence dating services to industry, defence and academia.

Luminescence techniques are highly versatile as they are able to accurately measure ages of up to 500,000 years past and down to doses as low as a fraction of one day’s background radiation. Our research is advancing these techniques and further extending the applicability of luminescence analysis.

Optical Dating and Environmental Dosimetry

Our researchers specialise in the physics of luminescence, particularly of minerals and artificial materials. Their aim is to advance luminescence techniques for:

- Forensic dosimetry
- Dose reconstruction following radiological incidents
- Applying TL and Optical Dating to a diverse range of questions in archaeology, geomorphology and palaeohydrology
- Dating ancient artefacts, megafaunal extinctions and human migrations across Australia.
Case study

PhD student Christopher Kalnins has been working with Professor Tanya Monro and theme leaders Associate Professor Heike Ebendorff-Heidepriem and Adjunct Professor Nigel Spooner on a transdisciplinary project that combines two IPAS research themes to demonstrate and measure a novel dosimetry architecture, Optically Stimulated Luminescence (OSL).

Christopher published his findings as lead author in the paper entitled “Radiation dosimetry using optically stimulated luminescence in fluoride phosphate optical fibers” published in Optical Materials Express by the Optical Society of America.

This paper marks the first feasible demonstration of intrinsic fibre architecture for OSL. It focuses on advancing the architecture for the purposes of distributed and environmental sensing in situations where an increase in the radiation field is possible.

One of the major challenges in this work was the ‘signal to noise ratio’ – a fairly weak signal in the presence of a lot of background noise. Christopher used a bundle of six fibres and went to great pains to eliminate as much background noise – in this case, light – as possible.

The project lab looks like a traditional darkroom, with blackened windows and a red ‘safe’ light. Closer inspection shows that all equipment with a screen or light was modified to disable it. Christopher built a lidded black box to contain most of the equipment, and eventually learned to operate his equipment by feel in total darkness, as even the ‘safe light’ interfered with his initial results.

Further work to improve the signal noise ratio has already begun. Many potential environments would benefit from this method of sensing, including environments where ionising radiation leakage from equipment or facilities could potentially occur. At some time in the not too distant future, we may see radiation sensing fibres woven into clothing or formed into tiny probes that measure the exact radiation dose to a tumor inside a patient during cancer therapy.

This project is a great demonstration of how IPAS can boost the career of young researchers through access to world leaders in six discipline-spanning research themes.
There is a critical need to detect Improvised Explosive Devices in combat zones. This project is the first demonstration of explosives sensing using raman spectroscopy in optical fibre.

A PhD project has developed new glasses and optical fibres that can be used to measure radiation. Potential for this technology ranges from new dosimeters to national security and monitoring radiotherapy.

Luminescence techniques can retrieve the radiation exposure history from common substances like salt and sand. This information can provide clues into both recent and ancient events. The team’s work has provided insights into both climate change and the megafauna extinction in Australia, and tools for mapping radiological event effects.
RESEARCH THEME: Optical Materials and Structures

Key Contacts:

**Soft Glasses and Fibres**
A/Prof Heike Ebendorff-Heidepriem  
E: heike.ebendorff@adelaide.edu.au

**Silica Glasses and Fibres**
A/Prof David Lancaster  
E: david.lancaster@adelaide.edu.au

**Optical Structure Modelling**
Dr Shahraam Afshar V.  
E: shahraam.afshar@adelaide.edu.au

**ANFF Optofab Node Materials Facility**
Mr Luis Lima-Marques  
E: luis.lima-marques@adelaide.edu.au

Theme Leaders A/Prof Heike Ebendorff-Heidepriem and Prof Tanya Monro
RESEARCH THEME: Optical Materials and Structures

Capabilities
IPAS has complete vertical integration of expertise and facilities, from modelling to device fabrication.

Modelling
- Prediction of the optical properties of waveguides and fibres
- New theoretical frameworks to explore waveguides and fibres with extreme properties and nanoscale features.

Fabrication of glasses and fibres
- Controlled atmosphere glass batching, melting and annealing
- Soft and hard glass preform extrusion
- Ultrasonic mill
- Soft glass and silica fibre drawing towers.

Characterisation
- High-resolution electron and atomic force/scanning near-field optical microscopes (AFM/SNOM)
- Transmission spectrometers and ellipsometers spanning from the ultraviolet to the far-infrared spectral region (200 nm-30 μm).

Research
Our research ranges from fundamental science to application-driven design and development, including:

- Development of glasses with enhanced infrared transmission and optical nonlinearity
- Nanophotonic glasses created by embedding nanocrystals in glass
- Advanced technologies for processing and shaping glass
- Design and fabrication of micro and nanostructured soft glass optical fibres
- Speciality rare-earth doped and passive silica fibres, including single-mode germano-silica and double/triple clad fibres
- Development of novel silica and polymer fibres, including the capacity for rare-earth and nanoparticulate doping
- Advanced light propagation theory within optical fibres and planar waveguides.

Key areas of strength include:
- Tellurite and fluoride glasses (both passive and active)
- Advanced preform technologies (extrusion and drilling based)
- Development of glasses and fibres capable of transmitting light in the mid-infrared that underpin new sensing platforms and lasers
- Custom silica fibres for fibre lasers, including air-clad rare-earth doped fibres
- Suspended and exposed core silica fibres for sensing.
Case Study

IPAS had previously only fabricated exposed core fibres from soft, non-silica glasses. The paper “Silica exposed-core microstructured optical fibers” by Roman Kostecki (et al) reports the first exposed core silica microstructured optical fibre developed by IPAS, a world leader in the field. The recently commissioned silica fibre drawing facility located in Thebarton was used to draw the fibre described in the paper.

There were two significant differences from the soft glass fabrication process, each presenting challenges to the goal of drawing a silica fibre with one of its cores exposed along the entire length: the preparation of the preform rod (approximately 10 cm x 1 cm diameter), and setting the values for a large set of parameters to give the best chance of preserving the hole shapes in the preform as it was heated and drawn down to a fibre as thin as a human hair.

In the case of the preform rod, a sonic mill was utilised to drill three holes along the length of the rod and cut away to the edges of one of those holes from the outer wall (pictured). The resulting preform was cleaned via acid etching before undergoing a series of characterisation measurements.

Parameter values including temperature, pressure, draw speed and others required a mathematical model of the fibre geometry to be used for calculating optimal values for a large parameter space. This model was based on modifications to the work done by IPAS Director Professor Tanya Monro in collaboration with the mathematics department at Southampton (Alastair Fitt and Chris Voyce) long before IPAS came into existence.

Applying the language of mathematics to the physics of the situation resulted in a highly accurate and rewarding modelling prediction - the preform was loaded into the silica drawing tower, initial parameters input, and the softened glass drew into the fibre – a success!

A subsequent series of characterisation measurements and experiments showed the new fibre performs very well (2 times order magnitude better transmission properties than soft glass with much less background noise) and is very stable mechanically, thermally and chemically.

This new configuration adds a significant piece to the already extensive platforms for sensing at IPAS, with significantly improved performance and stability that will allow researchers to create new tools for sensing that could lead to real-time applications in the areas of health, environment, agriculture and national security.
RESEARCH THEME: Optical Materials and Structures

1  SURFACE TENSION MEASUREMENT

Kieron Boyd (pictured)
Tanya Monro, Jesper Munch

A laser based technique has been developed to measure glass surface tension. This enables us to draw more advanced optical fibres.

2  TECHNIQUES FOR MODELING COMPLEX GLASS FLOW

Alastair Dowler (pictured), Heike Ebendorff-Heidepriem, Tanya Monro

Our team was the first to develop approaches to extrude glass into complex shapes. To go further we need to better understand this process. Our new work is starting to explain how glass flows. This will allow us to create more complex structures with higher first time success rates.

3  NEW LASER IN A CHIP OF GLASS

Kenton Knight, David Lancaster (pictured), Tanya Monro

Our special glass can transmit mid infra-red light. In collaboration with Macquarie University we have inscribed patterns in the glass. This creates a tuneable chip laser providing novel sources of light.


RESEARCH THEME: Novel Light Sources

Key Contacts:

**Fibre and Planar Waveguide Lasers**
A/Prof David Lancaster  
E: david.lancaster@adelaide.edu.au

**Precision Measurement**
Prof Andre Luiten  
E: andre.luiten@adelaide.edu.au

**Nonlinear Optics**
Dr Shahraam Afshar V.  
E: shahraam.afshar@adelaide.edu.au

**Solid State Lasers**
Dr David Ottaway  
E: david.ottaway@adelaide.edu.au

**Coherent Laser Radar**
A/Prof Peter Velich  
E: peter.velich@adelaide.edu.au

**Silica and soft glass fabrication facilities**
Mr Luis Lima-Marques  
E: luis.lima-marques@adelaide.edu.au

Theme Leaders A/Prof David Lancaster and Prof Andre Luiten

Fibre laser development
RESEARCH THEME: Novel Light Sources

IPAS novel light sources research combines fundamental and applied physics to generate and deliver tailored light for medicine, national security, environmental monitoring and fundamental physics applications.

Our world leading research includes:
- Planar waveguide and fibre lasers
- Solid-state lasers
- Fibre based super-continuum sources
- Fibre-based nonlinear devices.

Real world applications for these sources include:
- Atmospheric and coherent laser radars
- Gravitational wave detectors
- Spectroscopic sensors
- Laser surgery
- Laser-based electronic warfare systems.

Fibre and Planar Waveguide Lasers

Our Fibre and Planar Waveguide Lasers research is focused on developing and optimising new concepts in fibre and planar waveguide lasers. This work drives the development of unique rare-earth doped glasses and fibres at IPAS.

The lasers we are developing operate in the short to mid-infrared range, opening up new applications in molecular spectroscopy, remote sensing, medicine, and meeting custom defence needs in countermeasures and sensor validation. Highlights this year include a ‘world first’ microstructured silica holmium doped fibre laser, and achieving the record for the highest quantum-efficiency planar glass laser.

Nonlinear Optics

Laser light in optical fibres can be so intense that it modifies its own frequency and polarisation. This research aims to gain new insights into nonlinear optical processes within a variety of optical fibre materials and geometries.

Our expertise in modelling nonlinear processes in nanoscale waveguides could provide future solutions for high-speed optical switches, laser sources and sensing architectures.

The ongoing development of fundamental theory has led to new models that predict a novel ‘self-flipping of polarization states’ that are being researched under two new collaborations. We hold high hopes for some very interesting new light sources in the near future.

Solid State Lasers

Solid State Laser research at IPAS focuses on the development of low noise and high-power systems for specific applications including ultra high precision measurement, spectroscopy, and remote sensing.

The team have over 60 years of experience, have worked on international projects such as LIGC, developed Laser Radars (LIDAR), and have interests in differential absorption LIDAR applications for water vapour, methane and wind field sensing. This has led to great results in cryogenic and compact eye-safe laser systems.

Silica and Soft Glass Laser Development Facilities

The silica and soft glass facilities provide in-house manufactured glass and fibres that underpin many of our novel laser technologies, and can be accessed via the ANFF Optofab node based at IPAS.
RESEARCH THEME: Novel Light Sources

Case study

The recent work “Fifty percent internal slope efficiency femtosecond direct-written Tm$^{3+}$:ZBLAN waveguide laser” published by IPAS senior researcher David Lancaster et al. brings the team a step closer to being able to ‘print’ highly specialised lasers required for further research into a wide range of photonics and advanced sensing technologies.

A precisely focused laser beam is used to create ‘bubbles’ of plasma that alter the refractive index of the host glass, ZBLAN (Zirconium, Barium, Lanthanum, Aluminium, Sodium). When arranged in patterns, the bubbles create waveguides similar to existing IPAS microstructure fabrications.

How they differ is in how they are ‘printed’ into the host glass: 3D patterns are designed with software and applied to the host glass so that it can guide light (waveguide) in such a way that it behaves as a ‘new’ laser. While this technique has been around for a while, David’s surprise finding was how efficient and cost-effective the new laser is to produce (around 12 seconds to ‘print’ a small batch of lasers).

With the right kind of industry partner, this work could lead to faster production times and dramatic cost reductions for a large-scale commercial laser fabrication operation.

The 50% internal slope efficiency described in the paper has since been increased to 67% by tweaking the type and placement of mirrors, resulting in reduced heat loss. Significant increases in power have been reported, and by tweaking cavity geometry, the chip lasers are now ‘tuneable’ to desired light wavelength outputs. Near perfect band quality has been achieved, giving a uniform gaussian intensity profile to the output beam that approaches the theoretical limit of beam brightness.

In future, this technique could be used to develop low cost tools for sensing including tissue imaging, coherent LIDAR and spectroscopy. We will develop and showcase prototypes that have already attracted industry interest in order to work towards the creation of an advanced photonics manufacturing company.
We have developed a prototype chip laser. The high quality mid infra-red laser is widely tunable and has high peak power allowing it to meet the needs of many applications from laser range-finding to spectroscopy.

Our team has designed a cryogenic solid-state laser capable of very high power with excellent beam quality, greatly surpassing conventional technology. This is essential for a number of scientific and technological applications.

A non-linear effect called ‘polarisation flipping’ was predicted by theoretical physicists in our team. This is being explored experimentally through an international collaboration with researchers in Australia and Italy.
RESEARCH THEME: Atmosphere, Space and High Energy Astronomy

Key Contacts:

**Light Detection and Ranging (LIDAR)**
A/Prof Peter Veitch
E: peter.veitch@adelaide.edu.au

**Gravitational Wave Detection (LIGO)**
Dr David Ottaway
E: david.ottaway@adelaide.edu.au

**High Energy Astrophysics**
Dr Gavin Rowell
E: gavin.rowell@adelaide.edu.au

**Buckland Park Field Station and Observatory**
Prof Iain Reid
E: iain.reid@adelaide.edu.au

Atmospheric sensing fieldwork on the Greenland icecap
RESEARCH THEME: Atmosphere, Space and High Energy Astronomy

IPAS research in remote sensing includes the development of advanced optical systems for:

- Interferometric gravitational wave detection
- Coherent laser radar systems used to determine the structure of wind fields for monitoring pollution transport, optimum wind farm sighting and their real-time optimisation
- LIDAR systems for measuring traces gases and remote sensing of the atmosphere
- High-energy astrophysics with gamma and cosmic rays.

The team has a wealth of experience in developing the technologies that underpin remote sensing. Our members contribute to international projects such as the Laser Interferometer Gravitational Wave Observatory (LIGO), the High Energy Stereoscopic System (HES) and the Pierre Auger Observatory.

Gravitational Wave Detection with LIGO

Einstein predicted gravitational waves, and our researchers are part of the LIGO team that is building a $300M instrument to detect them. We have developed a range of laser systems and optical sensors for advanced gravitational wave detection.

Light Detection and Ranging (LIDAR)

We are developing coherent laser radar (CLR) systems for a range of eye-safe LIDAR applications including:

- Monitoring dust and pollution emanating from mining and industrial sites
- Mapping wind speeds for wind farm site assessment
- Turbine protection and turbulence detection for aerospace applications.

We are also developing differential absorption LIDAR (DIAL) to remotely sense chemicals in the atmosphere including:

- Water vapour sensing
- SOx
- CH₄

High-Energy Astrophysics

High-energy cosmic messengers such as gamma and cosmic rays enable us to study the processes in extreme objects like supernova explosions, pulsars and black holes. Detecting gamma and cosmic rays requires advanced techniques to filter the atmospheric background and apply atmospheric transmission. Our researchers are currently working on projects including the design of gamma ray telescopes and ultra high-energy cosmic ray detectors.

Buckland Park Station and Observatory

Buckland Park boasts an array of equipment dedicated to studying the atmosphere, including radars (MF and VHF), a radio acoustic sounding system and a 3-field photometer. A LIDAR for measuring temperature, density and wind velocity at altitudes between 10-105 km was recently added. Combined with the radar and passive optical systems, this facility delivers a unique atmospheric measurement capability extending from the troposphere up to the lower thermosphere.
Our researchers are part of three significant global teams involved in ‘big science’ collaborations. Thermal compensation equipment built in Adelaide was shipped to the Advanced LIGO site in USA. The giant HESS-II telescope achieved significant operational milestones in 2012.

By processing data gathered from ‘big science’ collaborations we have found clues on the origin of cosmic rays (Pierre Auger), have discovered new sources of high energy gamma rays (HESS telescopes) and have mapped dense gas clouds (Mopra telescope) to reveal their nature.

Extremely precise measurements are required in order to observe gravitational waves predicted by relativity theory. We are actively contributing to global efforts to detect these distortions of the space-time continuum.

We have installed a high atmosphere Laser Radar (LIDAR) system at the Buckland Park field site near Adelaide. This site is critical for atmospheric measurements in the southern hemisphere.
The Braggs

The Australian Federal Government, South Australian State Government, DSTO, Defence SA and The University of Adelaide have invested over $40M in the construction of The Braggs the new headquarters for IPAS. The Braggs was completed and handed over to The University in March 2013. The building contains a unique suite of transdisciplinary laboratories including: glass development and processing, optical fibre fabrication, laser and device development, luminescence dating, environmental genomics, photonic sensor development, and synthetic, surface and biochemistry. It also includes office space to co-locate IPAS researchers and students from a broad range of scientific disciplines. It also incorporates a 420-seat lecture theatre and other teaching and research facilities.

The Braggs is an accelerator facility, designed to speed up the pace of research by bringing together all the people working in these disparate disciplines and providing them with facilities required to progress further than would be possible in a traditional physics or chemistry lab (for example we now have the ability to bring clinical samples into the laboratories to test them using new measurement tools developed within our labs). All of The Braggs Labs, from the Luminescence Laboratories in the basement, to the Atmospheric Sensing Laboratories on the top floor with access to the sky, are fully equipped to ensure that the researchers are able to undertake outstanding science.
IPAS Research Facilities

A number of world-class research facilities underpin the vital research conducted at IPAS, including:

- Soft Glass and Fibre Fabrication
- Silica Glass and Fibre Fabrication
- Surface Science and Surface Chemistry
- Optofab – Facilities in Adelaide
- The Adelaide Proteomics Centre
- The STARR Lab (Reproductive BioPhotonics)
- Atmospheric Physics – Buckland Park
- Advanced LIGO and the Gingin Facility
- Bragg X-ray Crystallography Facility
- Environmental Luminescence.

These facilities service the needs of IPAS researchers and offer contract services to researchers and companies across the world. The optical fibre fabrication facilities at IPAS form part of the Australian National Fabrication Facility (ANFF), which links eight facility nodes to provide researchers and industry with access to state-of-the-art fabrication facilities.
IPAS Committees

IPAS Board

Joe Flynn  Mike Brooks  Tanya Monro  Andrew Holmes  Jurgen Michaelis  Warren Harach  Neil Bryans  Peter Gray  Cathy Foley

IPAS Scientific Management Committee

Tanya Monro  Peter Hoffmann  Andrew Abell  Chris Sumby  Nigel Spooner  Heike Ebendorff-Heidepriem  Andre Luiten  David Lancaster  Gavin Rowell  David Ottaway

IPAS Senior Advisory Group

Roger Clay  Alan Cooper  TuckWeng Kok  Shaun McColl  Jesper Munch  Iain Reid  Bob Vincent

32  2013 / Institute for Photonics and Advanced Sensing
IPAS Executive Committee

Tanya Monro  Peter Hoffmann  Andrew Abell  Carol Maelzer  Jennifer Watling  Nick Kelley  Jim Deed  Piers Lincoln  Sara Leggatt  David Adelson  Doug Pottrell

IPAS Professional Team

Piers Lincoln  Dale Godfrey  Luis Lima-Marcues  Sara Leggatt  Olivia Towers (P/T)  Jason Dancer (P/T)  Tim Spencer (P/T)

IPAS Student Committee

Eleanor King  Roman Kostecki  Tess Reynolds  Tim Engler  Nur Bahruddin
Established under the National Collaborative Research Infrastructure Strategy, the Australian National Fabrication Facility (ANFF) links eight university-based nodes to provide researchers and industry with access to state-of-the-art fabrication facilities.

The capability provided by ANFF enables users to process hard materials (metals, composites and ceramics) and soft materials (polymers and polymer-biological moieties) and transform these into structures that have applications in sensors, medical devices, nanophotonics and nanoelectronics.

The nodes

The nodes are located across Australia and draw on existing infrastructure and expertise. Each offers a specific area of expertise including advanced materials, nanoelectronics and photonics and bio-nano applications. Our commitment to providing a world-class user facility is underpinned by the sharing of best practice in service provision across the nodes.

The ANFF difference

Opening the doors to world-class infrastructure is only the first step. Without dedicated staff to support access, breakthrough research remains just an idea.

Each ANFF node has experts on hand who are experienced in meeting user requirements and maintaining leading-edge instrumentation to assist researchers. Over 60 technical staff positions are funded through the program. Researchers can either work at the node under expert guidance, or to contract for the fabrication of specialised products at a reasonable cost.

Optofab node of ANFF

Optofab consists of four facility centres and expertise based at Macquarie University, Bandwidth Foundry International, University of Sydney and the University of Adelaide, with the headquarters located at Macquarie University.

Optofab – Facilities in Adelaide

Optofab – Facilities in Adelaide specialises in optical fibre, glass and functional optical materials production. The range of key services offered include:

- Soft glass fibre fabrication and drawing
- Silica fibre fabrication and drawing
- Microstructured silica preforms and fibres
- Soft glass and polymer preform extrusion
- Soft glass production
- Surface functionalisation of glasses and fibres
- Scanning Near Field and Atomic Force Microscopy (SNOM/AFM)
- Ultrasonic milling

Contact:
A/Prof Heike Ebendorff-Heidepriem  T: +61 (0)8 8313 1136  E: heike.ebendorff@adelaide.edu.au
Mr Luis Lima-Marques  Tel: +61 (0)413 339 808  E: luis.lima-marques@adelaide.edu.au
Tanya Monro

Tanya Monro
IPAS Director

Tanya obtained her PhD in physics in 1998 from The University of Sydney, for which she was awarded the Bragg Gold Medal. In 2000, she received a Royal Society University Research Fellowship at the Optoelectronics Research Centre at The University of Southampton, UK. She returned to Australia in 2005 as the inaugural DSTO Chair of Photonics at The University of Adelaide.

Tanya won the 2012 Pawsey Medal, was named South Australia’s Australian of the Year (2011), South Australian Scientist of the Year and Telstra Business Woman of the Year (Community & Government Category) (2010) and was awarded the Prime Minister’s Malcolm McIntosh Prize ‘Physical Scientist of the Year’ (2008) and Cosmos Magazine’s ‘Bright Spark’ Award (2006).

A Fellow of both the Australian Academy of Science and the Australian Academy of Technological Sciences and Engineering, Tanya has published over 500 papers and has raised over $86M for Research.

Peter Hoffmann

Peter Hoffmann
IPAS Deputy Director

A/Prof Hoffmann is a Senior Researcher, a founding member of IPAS and is also Director of the Adelaide Proteomics Centre (APC) at The University of Adelaide. Since his PhD award in 1999 Peter has established and led proteomics groups in Australia (Melbourne) and Germany (Leipzig). His research is focused on biomarker discovery in cancer, detection of protein phosphorylation and tissue imaging mass spectrometry.

In 2005, Peter returned from Germany to Australia to establish the APC at The University of Adelaide. The APC provides the research community with services and access to the latest in proteomics technologies, serving SA, interstate and overseas universities and industry.

In addition to establishing the APC, Peter’s proteomics research group has attracted funding of over $4M via NHMRC, ARC and Ovarian Cancer Research Foundation grants. His work is on the forefront of proteomics technology and he is regularly invited to present at national and international proteomics conferences.