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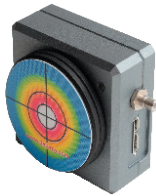
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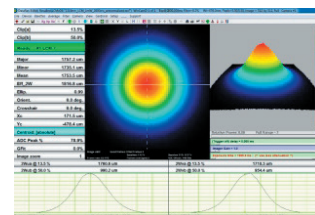
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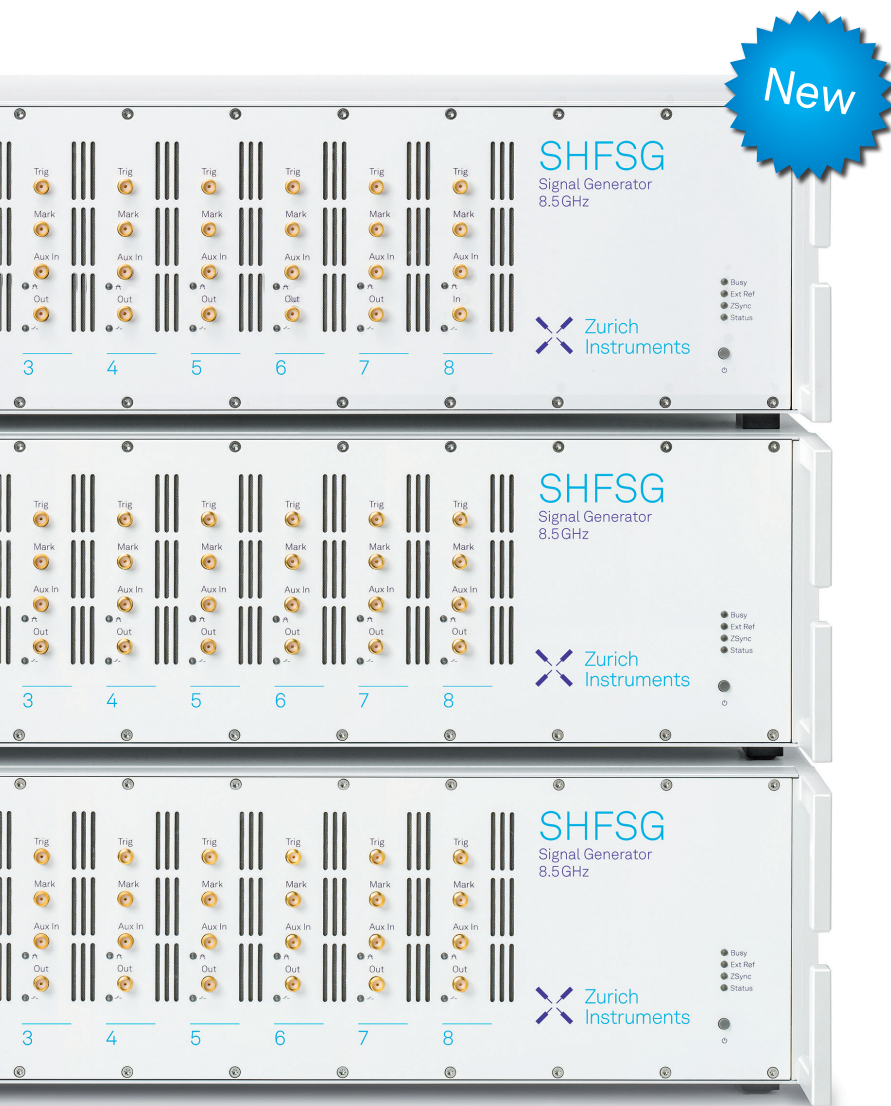
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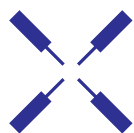
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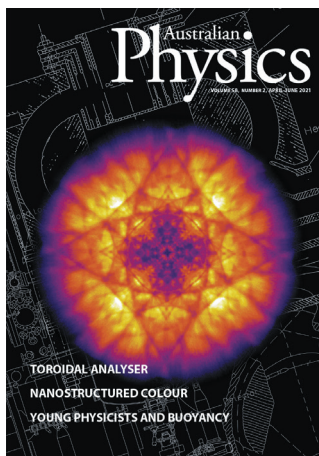
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Full-hemisphere photoelectron diffraction pattern of C 1s core level electrons excited from the (100) face of hydrogen terminated diamond (incident energy $h\nu = 675$ eV).

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A Publication of the Australian Institute of Physics

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Enquiries should be sent to the Editors.

Published four times a year.

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Print Post approved PP 224960 / 00008

ISSN 1837-5375

PRODUCTION & PRINTING

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1/3B Newlands Road, Reservoir VIC 3073
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Editorial

Making things

It's halfway through 2021, and the impacts of pandemic-driven decisions are clearly on the minds of many Australian scientists. Alongside this, physicists in education, research, industry and commerce are meeting new challenges and opportunities. Some of those opportunities revolve around making things.



In the wake of 2020, local development and manufacturing has, thankfully, been propelled back on the agenda. In this issue, we have an extended piece on angular resolved photoelectron spectroscopy, featuring a unique toroidal analyser, designed and built in Australia. This instrument is a good pre-pandemic precursor of what could be achieved in a post-pandemic



environment of translating research into something tangible. Making and building things (and relationships) takes time, so we arguably need to keep sight of the longer-term opportunities arising from here on. Of course, that's easier said than done when we are in the middle of dealing with immediate fiscal and structural challenges in our sectors.

In this issue of Australian Physics, we also showcase the work of Ann Roberts, AIP Alan Walsh Medal winner, on controlling colour through control of the nanoscale. The applications range from fine art conservation to banknote security features and biomedical sensing, and the article underscores Australian prowess in designing and fabricating such nanophotonics.

Further on in the magazine, the Young Physicists explore buoyancy and why ships float, a timely link to the awkward lack of buoyancy of the Ever Given container ship recently wedged in the Suez Canal. It is a good reminder how even simple events can disrupt global supply chains and why making things locally is also important for building resilience.

As this issue goes to press, Melbourne finds itself again in lockdown and the immediate future is uncertain. We hope that you and the people close to you will find the energy and strength to carry you through the forthcoming period.

Best wishes,

David Hoxley and Peter Kappen.

From the executive

Disruptive Innovation?

On 3 June, the Minister for Education & Youth, Alan Tudge, gave a speech to outline his priorities for Australia's universities. He described the government's research commercialisation agenda as his top priority. He also mandated that enhancements of student experiences "must start with a return to the previous face-to-face learning". At the end of his speech, he described freedom of speech and freedom of academic inquiry as the "essential values which underpin the very essence of a university".

So far, so good. These statements resonate with many scientists, teachers and researchers across the country. And they are positions that, broadly speaking, the AIP has supported. Perhaps the AIP's advocacy has helped shape the public debate around these topics and perhaps has had a small role in influencing the government's strategies?

But Alan Tudge wants major change. His "aim is not just to make incremental progress". He wants "to fundamentally shift the dial". Statements such as "The current university system is incentivised to deliver and reward research excellence more than research commercialisation", from the government's consultation paper, may give an idea of what change may look like.

Research commercialisation is not the only area where the government wants major change. The other one was in relation to university funding, through the introduction of the Job-Ready Graduates legislation. That legislation saw a large reduction of funds for universities for some disciplines, including a 16 percent reduction in funding for universities for science degrees including physics. The key outcome of that legislative change was a greater separation of funding for teaching and research activities – perhaps indicating the end of the traditional mixed employment model of teaching/research academics.

Are these major changes to the academic model of universities warranted? It is good to have goals, and to articulate strategies to achieve them. However, all big changes carry risks. Is the model of teaching and research at Australia's universities so broken beyond repair, so that it is worth the risks that come with a major change? And has a strong case been made that the proposed changes will lead to an overall better outcome for Australia's society? I am not convinced.

The value of university research activity should be far broader than the scale of the economic return of



commercialisation activities. Fostering stronger industry-university partnerships is a welcome goal as long as core academic values are respected, including research independence, academic freedom, commitment to excellence and the close integration of teaching and research, and as long as funding dedicated to this goal is not a substitute for funding fundamental research. We should recognise that the potential which the government seeks to tap into with the commercialisation scheme is found in this reservoir of fundamental excellence.

What can the AIP do to inform this discussion? What can the AIP do to further support enhanced university research commercialisation? An obvious first step is to create an active dialogue between those of our members who work in academia, and those who work in industry. I believe that such dialogue will likely give a fairly broad consensus on a common goals, new and old. Such dialogue is also likely to inform the best way to tweak our current system to achieve the goal of greater connections between universities and industry while preserving the current qualities of the university system.

Gerd Schröder-Turk

[1] Alan Tudge, "Our priorities for strengthening Australia's universities", Universities Australia Higher Education Conference, 3 June 2021

[2] See www.aip.org.au/advocacy for the AIP's public statements on Research Commercialisation, online learning, and the Job Ready Graduate legislation

AIP Alan Walsh Medal 2020 winner article – Nanoscale structural colour

Professor Ann Roberts

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Editors' note – The Alan Walsh Medal, an initiative of the NSW Branch of the AIP, celebrates significant contributions by a practicing physicist to industry in Australia. In 2020, the AIP awarded the Medal to Professor Ann Roberts in recognition of her outstanding contribution to the fields of plasmonics, nanophotonics, and optics more broadly. Her deep understanding of fundamental optics has enabled new advances in art conservation and attribution, particularly in collaboration with the Grimwade Centre for Cultural Materials Conservation, and to the development of new generation banknote security features in collaboration with the Reserve Bank of Australia.

Advances in top-down approaches to nanofabrication over the past decades accompanied by the development of new theoretical tools and the availability of increased computational power have led to an explosion of interest in the role that nanoscience can play in our lives. It is well-known that many insects such as butterflies and beetles owe their striking colouration to their microscopic structure, rather than the inherent optical properties, of the relevant materials. The colours resulting from diffraction of light from gratings and CDs are also well-known. Advances in nanotechnology now permit us to create nanoscale features producing light-matter interactions that lead to wavelength-dependent reflection and transmission of visible light. This results in a characteristic surface colouration. Furthermore, unlike the use of dyes and pigments utilised in the conventional colouration of consumer and other products, structural colours do not fade with time and exposure to light and

can be created with a minimal set of materials potentially simplifying aspects of the manufacturing process and recycling at the end of life of the product.

Producing surface colouration

For the past decade members of my group have been investigating approaches to producing surface colouration in metallic surfaces composed of metals such as aluminium and glass. One such strategy involves a design that can be obtained using a 'top down' embossing process followed by deposition of metals. A key aspect of this approach is that through the selective introduction of asymmetries a polarisation sensitivity can also be introduced into surface permitting a means to tune the colour for aesthetic reasons and tagging applications. As an example, the classic 'plasmonic pixel' that we have been investigating involves a nanoparticle 'floating' above its complementary metal screen (Figure 1a)

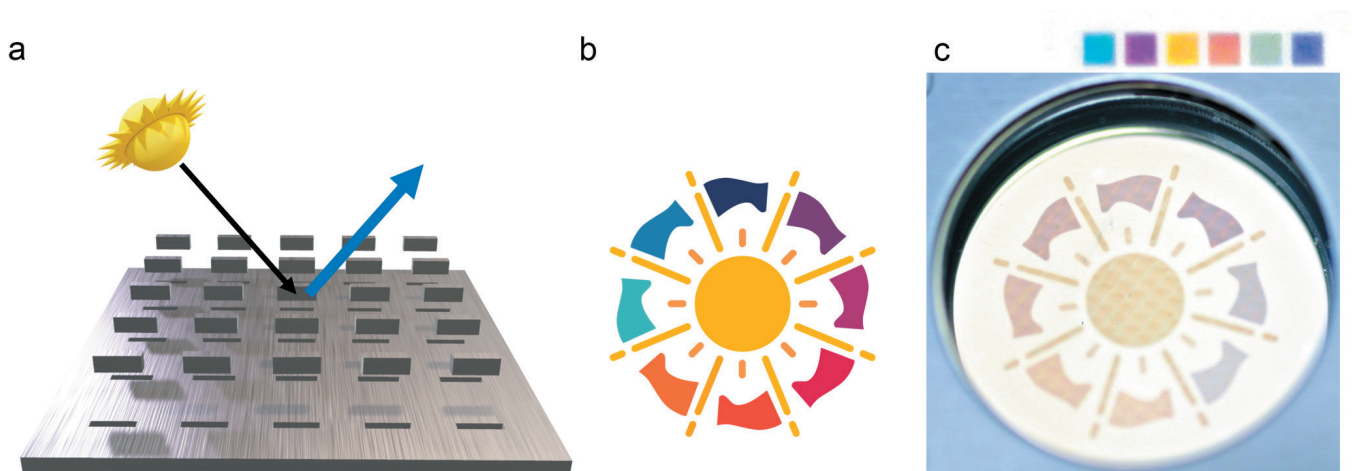


Figure 1: Plasmonic pixel schematic (a) and a rendering of the logo for the International Year of Light (b) using this approach (c). The inset shows swatches of cyan, magenta, yellow, red, green and blue. [Image (c) courtesy Dr Timothy James, inset reproduced with permission from [1]].

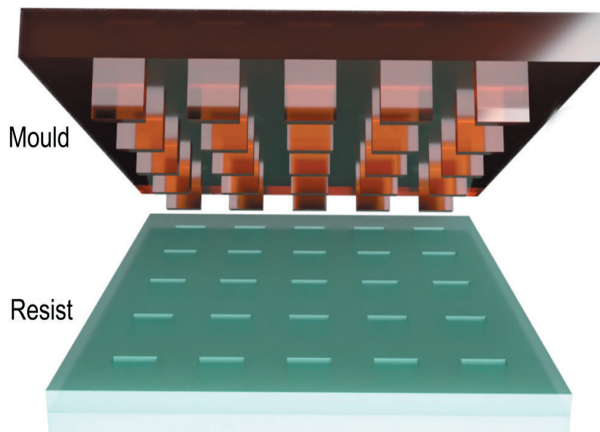


Figure 2: Nanoimprint lithography. A mould with nanoscale protrusions of order 100 nm in length is embossed into a thermal or UV-curable polymer.

although the entire device is supported by a transparent substrate and is embedded in clear polymer [1]. Optical resonances of the unit cell lead to characteristic minima in the reflectance spectrum producing a colour that depends primarily on the size and shape of the particle, the vertical ‘gap’ size and the optical constants of the materials used.

Figure 1c shows an example of structural colouration produced by this device. The original image (Figure 1b) is the logo for the International Year of Light. The colouration seen when light polarised parallel to the long axis of the rods is reflected from the device is apparent with good colour reproduction. The inset shows (from left to right) reproductions of cyan, magenta, yellow, red, green and blue [1]. Rotating the polarisation by 90° (not shown) reveals muted colouration and little variation in hue across the device highlighting one of the potential differences between structural and non-structural colour. Polarisation independent colouration can be achieved through the choice of a symmetric unit cell. Note that the appearance persists as the device is rotated in contrast to conventional diffraction-based colouration. One of the attractive attributes of this design is the fact that it is amenable to large scale printing. The nanostructure can be defined using nanoimprint lithography (Figure 2). This requires a silicon mould fabricated using electron beam lithography and reactive ion etching. The mould, which can be repeatedly reused, is ‘stamped’ into a thermal or UV-curable resist on a substrate. Following this patterning process, the deposition of a thin metal layer creates the structure of interest. Typical feature sizes in the resulting device are of the order of ten nanometres and members of my group have demonstrated fabrication of centimetre scale samples maintaining this resolution.

Another intriguing outcome of this research is the observation that the transverse features on the mould determine not only the resulting two-dimensional pattern, but also the embossing depth. Since the gap between the particles and the film in the final metallised device has a very significant impact on the resulting colour, and this parameter is partly determined by the imprint depth, the colour can also be tuned by tailoring the spacing between the features on the mould [2]. Given that multilevel features can be achieved using a simple binary mould with no requirement for complex grayscale lithography, this represents another promising avenue, not only for simple mass-production of coloured surfaces, but also other applications requiring low-cost nanofabrication.

Another attractive feature of this design is that it can be incorporated via monolithic integration into a photodetector (Figure 3). The colour palette shows photographs taken in reflection from a structure fabricated in silicon. By adjusting both the size and spacing of the nanoscale features, the colour transmitted into, and absorbed by, the silicon can be controlled. The resulting detectors are of the order of 100 nm in thickness paving the way for ultracompact, hyperspectral imaging devices. Figure 3 shows a device with six distinct sections containing rod-like structures with different dimensions that produce different colours in reflection (and their complementary colours in transmission). The resulting detector has a sensitivity to six different regions of the visible spectrum [3]. Similar approaches can create devices that provide information about the polarisation state of incident light creating an avenue for the production of compact, nanophotonics-enabled, multimodal sensors.

The world of colour by nanostructure

Further to the approaches presented here, numerous architectures for nanostructural colour have been shown to be compatible with mass fabrication. This includes the ‘top down’ processes described above as well as exciting

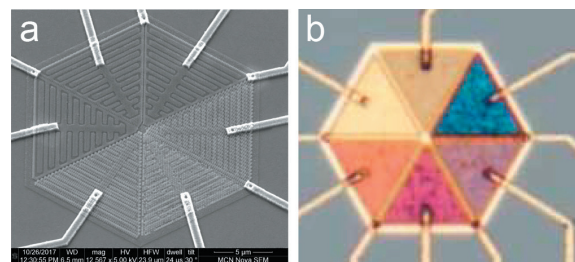


Figure 3: SEM (a) and optical microscope (b) images of a plasmonic pixel device (size 20 mm) in silicon [Reproduced with permission from [3]].

developments using templates to selectively arrange chemically synthesised nanoparticles [4]. The interested reader is referred to several excellent review articles on this topic including reference [5].

Patterning on the nanoscale is now taking structural colour from the natural world into new technologies with applications as diverse as product tagging and security, architecture, consumer goods, imaging and optical sensing. The ability to control the spectral content of light with ultracompact filters is pivotal to the role of optics-integrated devices for Industry 4.0 and a central theme of the new ARC Centre of Excellence for Transformative Meta-Optical Systems (TMOS). The future of nanoscale structural colour is bright!

Acknowledgements

I would like to thank all those who have contributed to this work including current and former group members Timothy James, Jingchao Song, Eugene Panchenko, Jasper Cadusch and Faris Shahidan, collaborators Professor Paul Mulvaney and Heyou Zhang and partner investigators at the RBA. Facilities at the Victorian Node of the Australian Nanofabrication Facility (Melbourne Centre for Nanofabrication) and the University of Melbourne are acknowledged along with funding from the Australian Research Council through the Linkage Projects Scheme.

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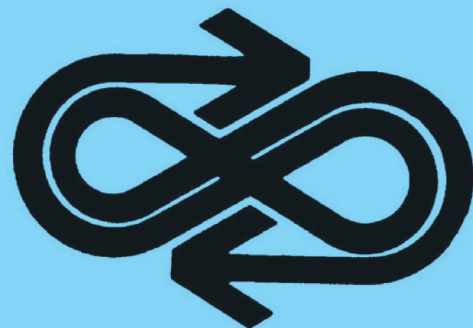
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Ann Roberts obtained B.Sc. (with First Class Honours and University Medal) and Ph.D. degrees in physics from the University of Sydney. After a position as a postdoctoral associate in the School of Electrical



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The Toroidal Analyser – a unique Australian angle-resolved photoelectron spectrometer

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Photoelectron Spectroscopy techniques characterise the electronic, physical and chemical structure of the surface of a material. These techniques rely on exciting electrons from a surface using UV light or x-rays and measuring the distribution of these photoelectrons with regards to energy and/or emission angle using a ‘photoelectron analyser’. In 2018, a project led by La Trobe University saw installation of a toroidal analyser capable of capturing the full photoemission hemisphere at the Australian Synchrotron. As the latest generation in a unique family of toroidal instruments developed in Australia for performing these measurements, it promises world-class possibilities for advanced characterisation of the physical and electronic structure of surfaces in Australia.

Photoelectron spectroscopy

Photoelectron Spectroscopy (PES) is a family of electron spectroscopy techniques which probe the occupied electronic states of a material’s surface using the photoelectric effect. When using photoelectron spectroscopy, a sample of interest is illuminated by a monochromatic source of high energy photons with energy $\hbar\omega$, typically from the UV or X-ray regime, exciting electrons in the material from their initial bound states (E_i) and into final states (E_f) above the vacuum level (E_{Vac}). These liberated photoelectrons are then collected by a photoelectron analyser which determines the electron intensity distribution with respect to kinetic energy (E_K). As demonstrated in Figure 1, the kinetic energy can then be converted to a quantity which is more meaningful to researchers in materials science and condensed matter physics – the *photoelectron binding energy* (E_B) of the initial state, which is a unique fingerprint for a particular chemical environment or electronic state. This is achieved using the equation

$$E_B = \hbar\omega - E_K - \varphi \quad (1)$$

where φ is the work function of the system, a parameter which can be found through calibration against a standard metal sample.

As electrons can only travel a short distance through a material before inelastically scattering – a distance typically referred to as the inelastic mean free path – the sampling depth of these photoelectron spectroscopy techniques is typically on the order of a few nanometers into a sample surface. Combined with the ability to measure photoelectron kinetic energies –

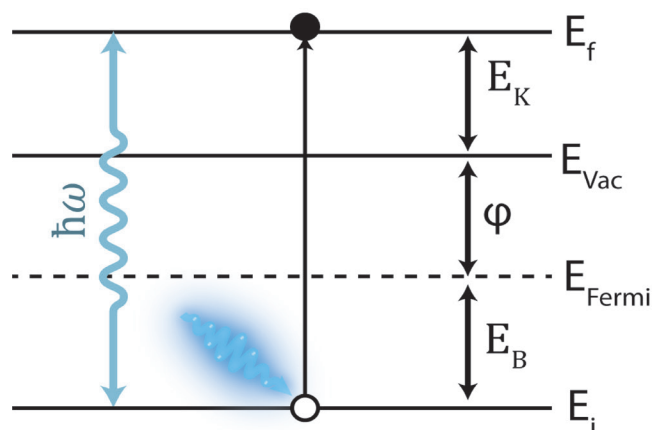


Figure 1: Energy level diagram of the photoexcitation process. A photon with energy $\hbar\omega$ excites an electron from an initial state E_i to a final state E_f , resulting in the electron having kinetic energy E_K . E_{Fermi} is the Fermi energy of the sample, which is treated as the zero point of the energy scale.

and thus binding energies – accurately, photoelectron spectroscopy techniques are a very useful tool for surface analysis. The most commonly available techniques in this family are:

- UV Photoelectron Spectroscopy (UPS) –ultraviolet light is used to excite electrons in the valence band ($E_B < 20$ eV) of a material. This gives nuanced information about the chemistry of a material, as well as allowing determination of parameters such as the work function φ
- X-ray Photoelectron Spectroscopy (XPS) – which uses X-rays to excite atomic core levels ($E_B < 20$ eV), giving information about chemical bonding at the surface of a material.

What is ARPES?

Of interest to researchers in the fields of condensed matter physics and materials science is the “electronic band structure” of a material. Put simply, the band structure shows the range of allowed energy levels that an electron may occupy and the momentum values which an electron may have within that material. Characterising the band structure allows a deep understanding of a variety of material properties, including optical absorption and electrical transport, as well as understanding advanced quantum phenomena such as quantum well formation, superconductivity and spin transport in materials. Of critical importance to understanding these properties is knowledge of the energy and momentum distribution of states at key symmetry points in the material Brillouin Zone (BZ), which is the fundamental unit cell of a material in “momentum space” (also referred to as “ k -space” or “reciprocal space”). For readers who are unfamiliar with this concept, it will be a key part of any introductory solid state physics textbook, such as “Introduction to Solid State Physics” by C. Kittel [1].

We can use Angle-resolved photoelectron spectroscopy (ARPES) to directly observe the occupied band structure of a material. This is achieved by performing a photoelectron spectroscopy experiment in which the photoelectron intensity distribution is monitored with respect to not only the photoelectron kinetic energy, but also the direction that the photoelectron is emitted. Because the direction of an electron's motion is dictated by its momentum, the measured electron emission direction with respect to the surface after photoexcitation is, due to conservation of momentum, related to the momentum (or wavevector) it had inside the crystal.

Figure 2(a) shows a typical experimental geometry for ARPES, with all angles labelled using the conventional nomenclature of the field. The polar angle θ is the emission angle of the photoelectron with respect to the surface normal, while the azimuthal ϕ angle is determined relative to a crystal direction of choice. Equations (2) – (4) are the equations used within the commonly assumed “free electron final state” model of photoemission for converting emission angle to the Cartesian components of momentum. This model relies on one material-dependent parameter, the inner potential V_0 , which can be experimentally determined or estimated theoretically. For practical reasons it is common to use the component of momentum in the direction parallel to the surface, k_{\parallel} (5), in place of k_x

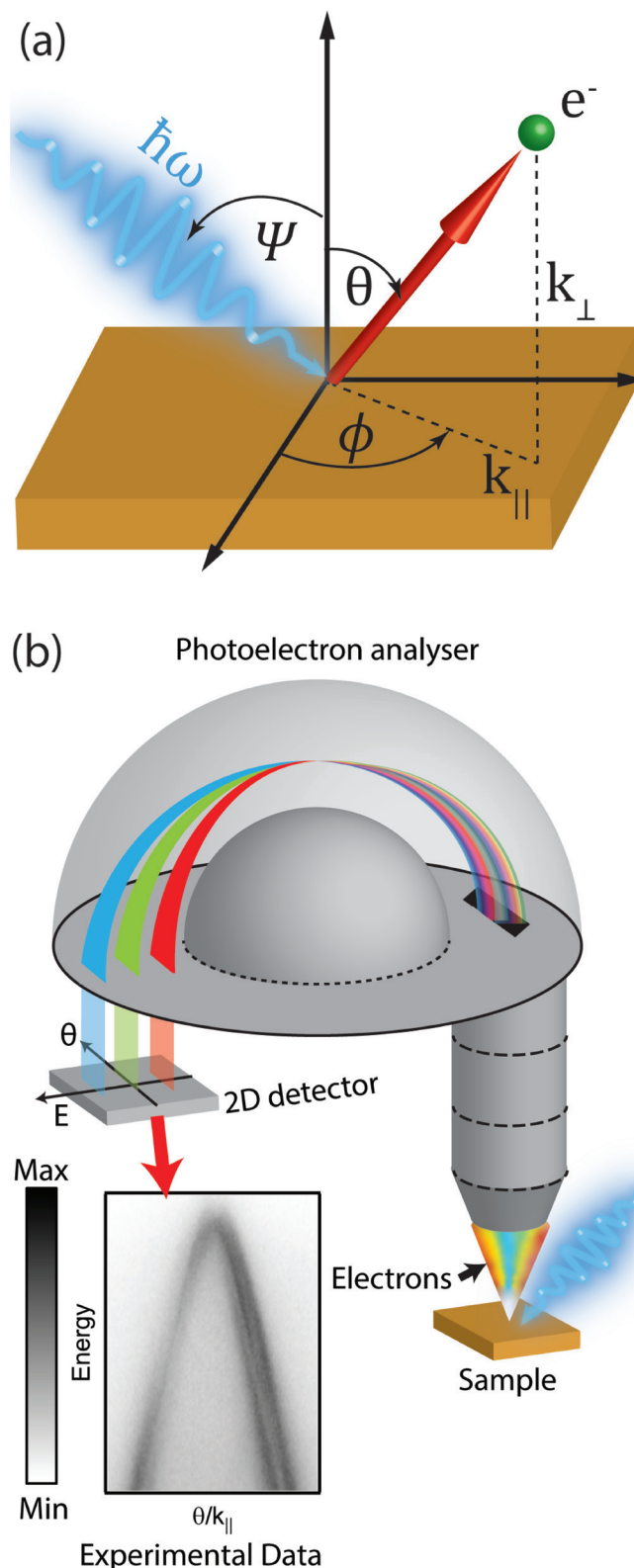


Figure 2: Schematic representation of an ARPES experiment. a) shows the photoexcitation of an electron (e^-) with the relevant angles and electron momentum components labelled using conventional nomenclature, while b) shows the subsequent path of an electron through a hemispherical analyser to a 2D detector, producing an energy distribution curve.

and k_y , as there is no absolute origin for the in-plane components of momentum. Similarly, k_z is usually referred to as k_{\perp} - the component of momentum in the direction perpendicular to the surface.

$$k_x = \frac{\sqrt{2mE_K}}{\hbar} \sin \theta \cos \phi \quad (2)$$

$$k_y = \frac{\sqrt{2mE_K}}{\hbar} \sin \theta \sin \phi \quad (3)$$

$$k_z = k_{\perp} = \frac{\sqrt{2m(E_K \cos^2 \theta + V_0)}}{\hbar} \quad (4)$$

$$k_{\parallel} = \sqrt{k_x^2 + k_y^2} = \frac{\sqrt{2mE_K}}{\hbar} \sin \theta \quad (5)$$

Depending on the limitations of an ARPES instrument which is being used for a particular experiment, and the information which a researcher wishes to extract from a band structure, there are a variety of approaches used in conducting ARPES. For a detailed overview of the theoretical background and practical application of ARPES, the reader is directed to the works of Yang *et al.* [2], Lv *et al.* [3] and Damascelli [4]. In brief, the salient points when designing an experiment are:

- Lab-based UV/X-ray sources and synchrotron radiation can be used as the photon source. The energy tuneable nature of a synchrotron source offers advantages to measurements where probing the band structure with respect to k_z is desirable, as the photon energy dictates the maximum possible momentum value which can be probed.
- A researcher may measure the energy distribution of states along a particular direction of k -space for a crystal, in which case they will typically set the angle ϕ to correspond to a particular crystal direction and set θ to an angle appropriate for the magnitude of the in-plane momentum they wish to probe, and then measure the energy distribution of states in that particular geometry. Depending on how much of the k -parallel characteristics of the states the researcher wishes to know and the angular acceptance of the analyser (see below), this may require performing measurements at multiple θ settings. This measurement is referred to as an “Energy Distribution Curve” (EDC).
- Alternatively, a researcher may be more interested in seeing the k -space picture of a state at a particular fixed

initial state energy – this is referred to as a “constant energy surface” (CES). Typically this is recorded by setting the analyser to monitor the appropriate binding energy while scanning the angles θ and ϕ as appropriate to record the particular sector(s) of k -space which are of interest.

Most commercially available ARPES instruments employ a hemispherical sector analyser – such as that sketched in Figure 2(b) – as the photoelectron spectrometer, equipped with a 2D detector which is capable of resolving photoelectron intensity in terms of both energy and emission angle θ . These systems have the advantage that the same analyser may be rapidly re-configured by the user for many different photoelectron spectroscopy measurements, including ARPES, UPS and XPS. Most commercial designs typically have an acceptance angle of 12°, 30° or 60°. This parameter determines how much of the photoemission hemisphere emitted by the sample is recorded by the analyser and, correspondingly, limits the amount of the band structure which can be measured at one time. In order to capture more of the photoemission hemisphere – and thus characterise portions of the band structure which lie at larger momentum values – it becomes necessary to alter the sample geometry with respect to the analyser and photon source, and record multiple datasets with overlapping angular regions. Acquiring data in this manner is time consuming, and creates measurement artefacts due to mechanical backlash in motion control systems. Once the data has been acquired it requires extensive post-processing to “stitch” it together to achieve a high-quality result. In addition, altering the angle of the sample with respect to the photon source changes the photoemission transition matrix elements [5], complicating data analysis.

These issues may be overcome by analysers which operate differently to hemispherical analysers and which are designed specifically with ARPES measurements in mind. A “full hemisphere” analyser measures the entire photoemission hemisphere without adjusting the experimental geometry. Typically, these instruments do not feature the high energy resolution performance of the hemispherical analyser however, their advantages – that large band structures may be acquired without changing photoelectron transition matrix elements, and that data stitching is not required to assemble a full dataset – mean that full hemisphere systems fulfil a critical role and are significantly better than hemispherical analyser systems for certain types of measurements.

The development of ARPES instrumentation in Australia

Since the early days of the ARPES technique, a variety of spectrometer geometries have been developed; good reviews in the field can be found in [6, 7]. A common theme through the years has been novel ways of maximising the angular acceptance from the sample to reduce data acquisition times, and it is here that Australian physicists have played an important role.

It may be less known that Australia has a rich history of research and development in electron spectroscopy instrumentation. In the late 1960s, the Department of Physics at La Trobe University was established under the leadership of Professor Elwyn Davies. At this time, PES was in its infancy worldwide, and the ARPES technique yet to be developed. Recently hired academics to the department brought diverse expertise in surface science, electrical engineering, ionising discharge sources, charged particle counting and more. In 1969 Profs. Robert Leckey, John Jenkin and John Liesegang formed the “Research Centre for Electron Spectroscopy”, with a strong focus on electron spectrometer research and development. Aided by capable mechanical and electronics workshops with skilled technical staff, a variety of photoelectron spectrometers, which accepted electrons over a wide range of angles (angle-integrated), were built in house and used for early photoemission studies.

It was realised that, to make the best comparison between theory and experiment, the band structure should be observed directly which required an angle resolving spectrometer. Instruments able to do this were developed in the early 1970s. Most of these spectrometers accepted electrons from a single-angle combined with a goniometer sample stage; sections of the band structure could be observed, but the measurement time for an entire portion of the band structure was quite long. As a single monolayer of adsorbed molecules on a surface can degrade under typical ultra-high vacuum (UHV, $\sim 10^{-10}$ mbar) conditions, an experiment could only last for a few hours. At the same time, interest was building in being able to measure the entire emission hemisphere of photoelectrons from the surface. Emergent techniques such as full-hemisphere X-ray photoelectron diffraction and holography were demonstrating great promise in revealing element-specific structural information of surfaces and interfaces through photoemission. It was clear that spectrometer advancements were required to reduce measurement time to an acceptable level.

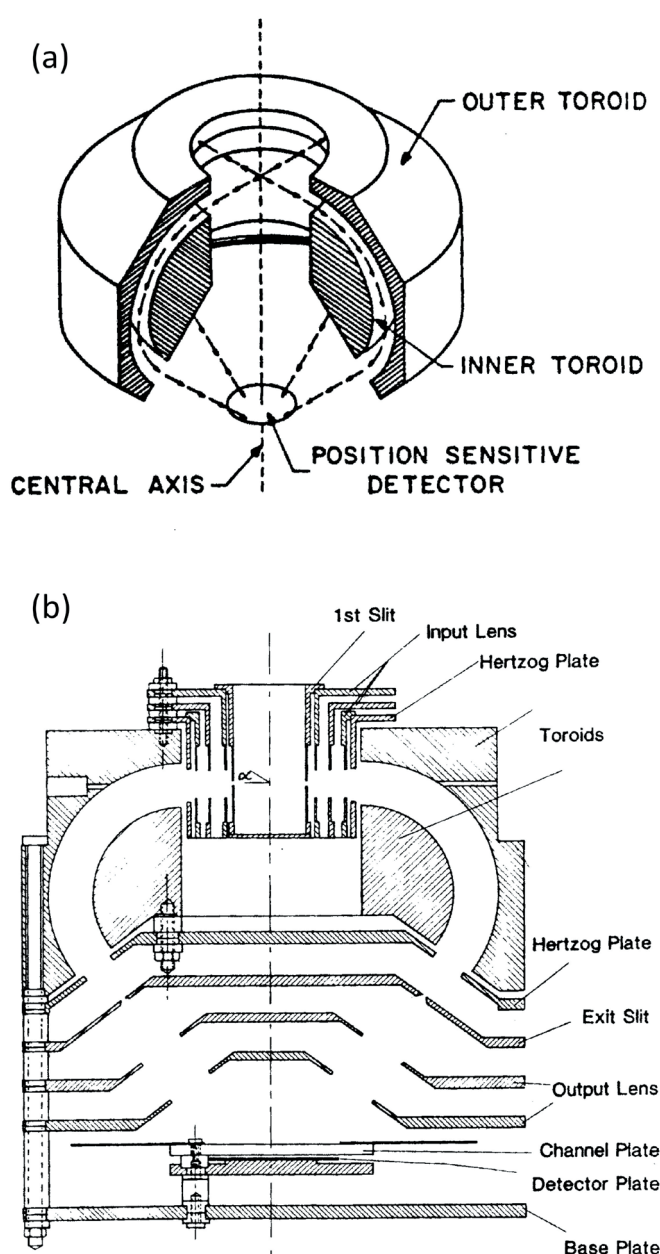


Figure 3. (a) Isometric projection of toroidal sectors, showing electron trajectories preserving emission angle from the source (b) First generation toroidal analyser built by the Research Centre for Electron Spectroscopy, La Trobe University, 1985.

In 1978 John Riley and Robert Leckey commenced design and construction of a “toroidal” electrode-based spectrometer to address this challenge. A toroidal electrode geometry offers direct imaging of a wide range of emission angles from the sample to the detector without distortion (Figure 3). Building on previous developments in toroidal electrode design and theoretical modelling, the group constructed early prototypes and conducted successful measurements in the Physics Department. In 1985, a “first generation” instrument combined a 1D delay line detector with a 270° acceptance in polar angle, allowing for both gas

phase and surface studies [8]. Soon after, in what was to be a multi-decade partnership with researchers from the Physics Department at Max Planck Institut für Festkörperforschung, Stuttgart, and later at Friedrich-Alexander-Universität, Erlangen-Nürnberg (FAU), the La Trobe group constructed Australia's first toroidal ARPES analyser for a synchrotron light source. This 1st generation instrument was delivered to the synchrotron light source BESSY I in 1985 and was used throughout the 1990s to cater to Australia's small but growing user community in ARPES.

Following the decommissioning of BESSY I in 1999, funding was approved for construction of a 2nd generation toroidal analyser for the newly built BESSY II synchrotron in Berlin. This instrument, shown in Figure 4, was also built in collaboration with researchers from FAU, and was delivered to BESSY II in 2003. Larger than its predecessor, the 2nd generation toroidal analyser offered higher angle and energy resolution, and vastly improved motion control functionality across the system. The spectrometer was employed to study the electronic and physical structure of a variety of surfaces. Highlights of the 2nd generation toroidal analyser include the early electronic and chemical structure determination of graphene on silicon carbide [9] and pioneering experiments which began the field of molecular tomography [10].

Latest Generation Toroidal Electron Spectrometer @ ANSTO

In recognition of an anticipated demand for local ARPES capability by a growing Australian synchrotron user community, construction of a third generation toroidal analyser was funded by an Australian Research Council Linkage Infrastructure, Equipment and Facilities (LIEF) grant in 2009. The instrument was designed, engineered and tested in the Department of Physics of La Trobe University, and delivered to the Australian Synchrotron in September 2017. It was then integrated at the Soft X-ray spectroscopy (SXR) beamline and has been offered in the general user program since early 2018. The analyser is now instrumental in building interest in ARPES within the Australian surface science community. It has enjoyed strong support and collaboration with the ARC Centre of Excellence in Future Low-Energy Electronics Technologies (FLEET), whose researchers have published some of the first outcomes.

As the latest instrument in a series developed over 35 years, the third generation toroidal analyser has

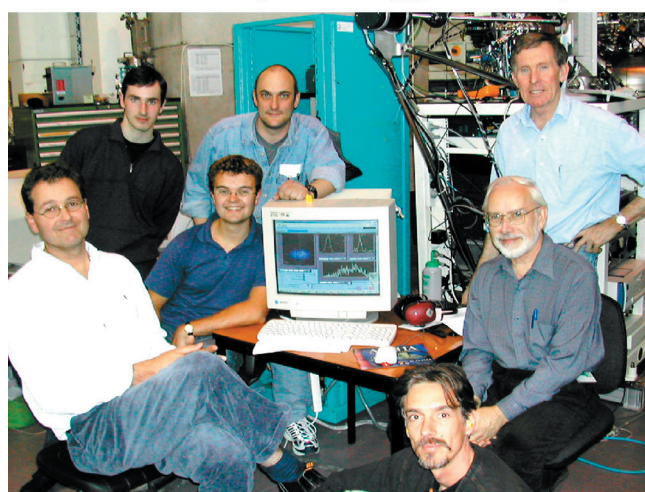
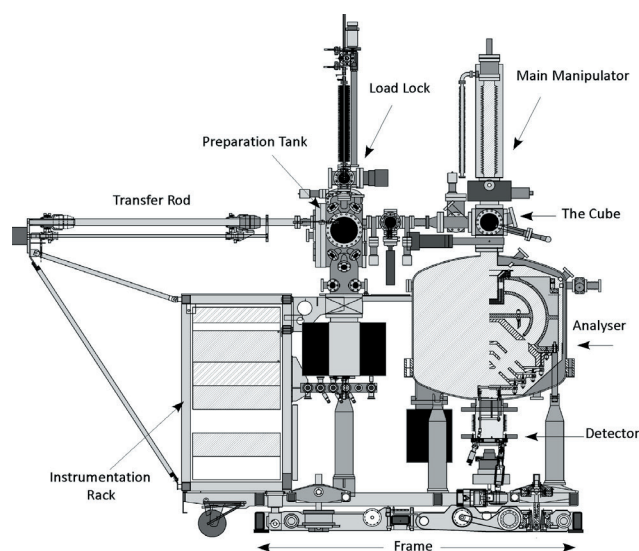


Figure 4. Upper panel: Second generation La Trobe University toroidal analyser, delivered to German synchrotron BESSY II in 2003. Lower panel: The first synchrotron ARPES spectrum from the instrument, and a happy team. From left to right: Eric Huwald, Konstant Emtsev, Anton Tadich, Thomas Seyller, Len Broekman, Robert Leckey, John Riley

numerous features which are uncommon among typical photoelectron analyser systems. Figure 5 shows a schematic overview of the system. In between synchrotron experiments, the toroidal analyser can be used for offline ARPES experiments by using a vacuum ultra violet (VUV) helium discharge lamp ($h\nu = 21.2$ eV, 40.8 eV). For synchrotron experiments, the toroidal analyser is moved onto the beamline using a servo-motor driven “omni wheel” system that allows translation and rotation on the experimental floor. Once coarsely positioned at the beamline, a mechanised support frame allows for alignment to the beamline to within 10 microns, a remarkable tolerance given the system weight of ~1.5 tonnes.

For conducting the ARPES experiment, the user's sample

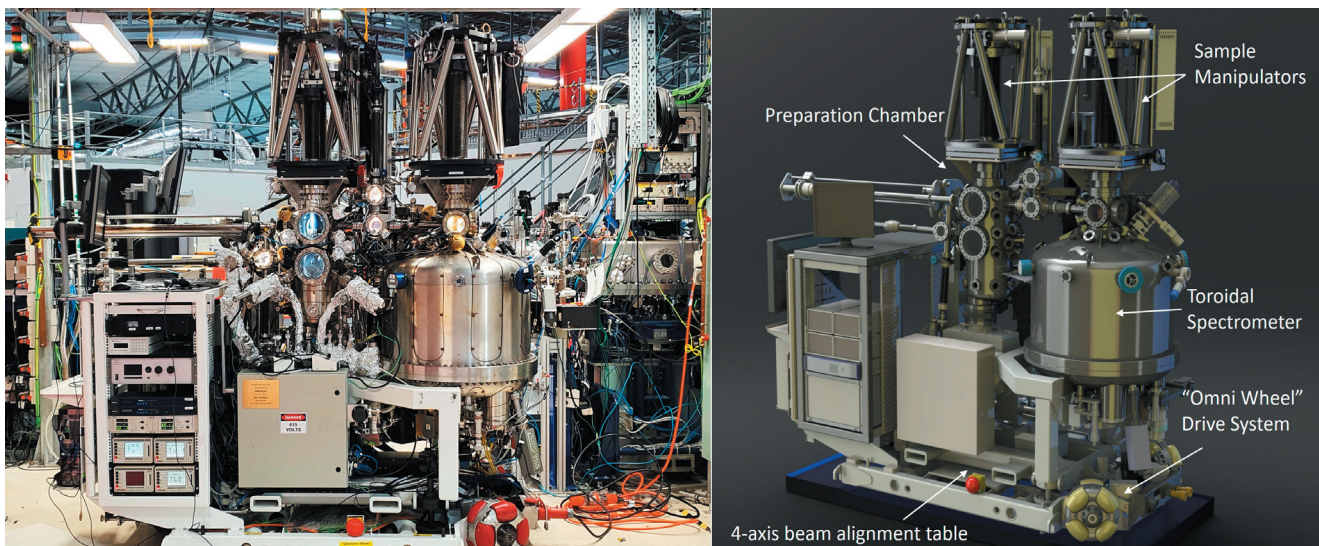


Figure 5. Photo (left) of the current toroidal analyser at the Australian Synchrotron, and a schematic diagram (right). Several key components are highlighted and are discussed in the text.

must be single crystalline and remain atomically clean during data acquisition, typically a period of a number of hours; ultra-high vacuum (UHV) is therefore necessary and is featured across the system's key chambers. A dedicated "Preparation chamber" offers a variety of options for preparing a single crystal sample under UHV, such as ion bombardment, annealing, cleaving, gas dosing and even thin film growth via molecular beam epitaxy (MBE)

Once a sample is suitably prepared, it is transferred by the user under a continuous UHV environment to the Spectrometer chamber for measurement. The main manipulator stage which holds the sample can be cooled to $\sim 80\text{K}$ with liquid nitrogen for improved energy resolution; liquid helium cooling is currently under commissioning for further improved resolution, and for enabling the study of quantum phenomena which are only observed at low temperatures, such as superconductivity. A specialised laser arrangement for automated centering of the manipulator combined with software imaging of the sample stage allows for a precise spot to be selected for analysis. This is particularly important for cleaved samples, small single crystals or for avoiding imperfections.

The heart of the toroidal analyser is the unique toroidal electron optics. As with all electron spectrometers, the electron optical system in the toroidal analyser uses electrostatic fields to guide photoelectrons from the sample through to the detector, dispersing them in energy and angle. Figure 6 shows a cross section of the spectrometer chamber, with the key elements indicated. With the exception of some minor supporting

structures, all electrodes are cylindrically symmetric to 360° about the vertical axis. The first element is the Input Lens, inside which the sample is placed in a vertical orientation and receives incident radiation as shown. From the full 2π steradian emission of electrons from the sample's surface, a narrow slit around the perimeter of the Input Lens accepts a "fan" of polar emission angle ($-90^\circ \leq \theta_p \leq 90^\circ$) into the lens at a particular sample azimuthal angle ϕ (Figure 7(a)). The Input lens then refocusses and retards the electron beam into the toroidal sector entrance. By setting a given voltage within the Input Lens, one selects the electron kinetic energy E_K^C which follows the central equipotential line in the toroidal sector.

The toroidal sector consists of the Outer and Inner Toroid electrodes. A negative (positive) voltage is applied to the Outer (Inner) Toroid, causing an inward deflection of the electrons around the sector and energetic dispersion; electrons with higher kinetic energies take a larger radius trajectory than those with lower energies, resulting in a linear spread in energy at the output (Figure 7(b)). Finally, a three-element accelerating Output Lens re-images this distribution onto the detector itself, a microchannel plate/phosphor screen module in vacuum which is imaged by a low noise CCD camera. The resultant detector output is shown in Figure 7(c). As can be seen, a small band-pass of kinetic energy from the sample is measured over a 180° polar angle arc centred on the surface normal. Typically this 180° arc is divided into 1000 channels, resulting in an angular resolution of around 0.2° . At approximately the central radius of this distribution lie those electrons whose kinetic energy was defined by the Input Lens. Parallel detection in kinetic

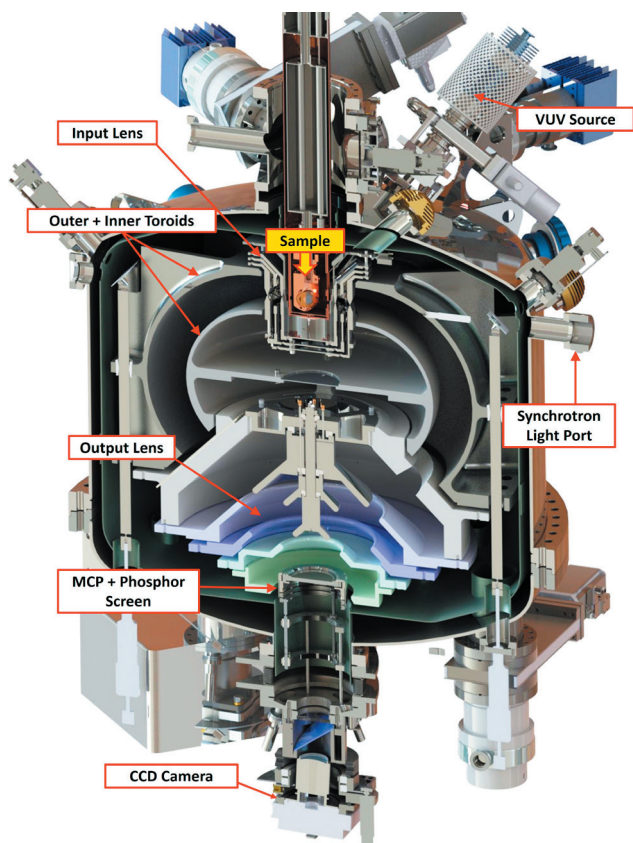


Figure 6. Cross-section through the spectrometer chamber showing the toroidal electrodes and input/output lenses (red), points of entry and path of VUV/synchrotron radiation (yellow), and detector components (blue)

energy is of great benefit; it allows for increased statistics in energy scans, for example.

What is important to emphasise is that the detection geometry of the toroidal analyser is extremely useful for straightforward measurement of the entire emission hemisphere of electrons above the sample. One simply chooses the electron kinetic (and hence binding) energy to be detected, and then steps the sample azimuth. By sweeping through 180° , the entire emission hemisphere is mapped, with the kinetic energy window yielding a continuous 3D dataset centred at the nominal energy.

Example measurements

In the last decade there has been an increasing interest in understanding the electronic structure of advanced condensed matter systems that feature emergent phenomena, often referred to as “quantum materials”, and in atomic scale engineering of surfaces in order to form bespoke electronic systems which display interesting quantum properties. Examples of the material systems of interest include high temperature superconductors, 2D materials (e.g graphene), topological insulators, Dirac semi-metals, surface transfer doping for 2D carrier gases,

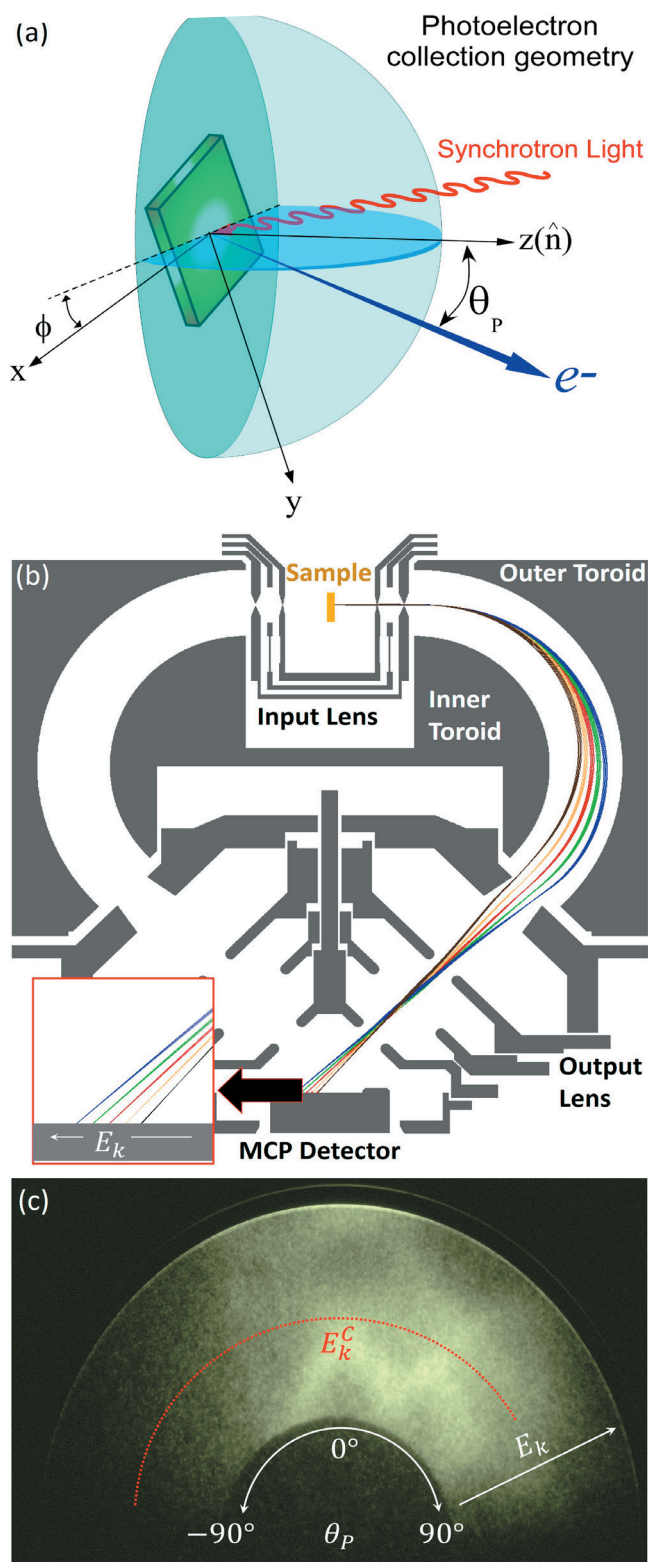


Figure 7 (a) Angular acceptance: for fixed azimuthal ϕ relative to crystalline axes, all polar emission angles θ_p are measured (blue fan) (b) Electron optics simulation (SIMION™) for five equi-spaced energies, illustrating the linear energy dispersion (c) MCP detector image, displaying the band-pass of kinetic energy and 180° of polar angle. The red dashed line indicates the nominal radius of the central energy E_k^c .

and much more. Studying the atomic-scale formation and physical structure of such systems, and how these interact with the electronic properties of such systems, is a unique challenge which often requires applying a combination of different experimental techniques. The full hemisphere photoelectron spectroscopy techniques to which the Toroidal analyser is well suited are a tool which is well suited to this current materials research landscape, and are very complimentary to other techniques – including, but not limited to, scanning tunnelling microscopy, electron diffraction, and Density Functional Theory calculations - for understanding material structure and properties.

Fermi Surface Mapping

The Fermi Surface is the constant energy surface in momentum (k) space separating the occupied electron states from the unoccupied states at zero Kelvin. Its topology governs many microscopic and macroscopic properties, such as charge carrier transport, optical and magnetic response, heat capacity, phase transitions and structural instabilities. Probably the most well-known FS from condensed matter physics textbooks is that of copper (Figure 8(a)). Here, the FS touches the Brillouin zone boundaries, leading to “necks” joining with neighbouring FS in the repeated Brillouin zone scheme.

Whilst there exists a variety of “Fermiology” methods for measuring the FS, including the de Haas-van Alphen (dHvA) [11] and Shubnikov–de Haas (SdH) effects [12], these techniques yield only extremal areas or projections of the FS and thus do not give a complete picture of the FS. They also require an applied magnetic field and require low temperature and defect free crystals, requirements which limit the materials which can conveniently be probed with these methods. ARPES, on the other hand, can yield FS topology using a straightforward and flexible experimental setup, and is the premier method for FS mapping [4]. The essential idea is that at a particular photon energy, and measuring electrons excited from the Fermi Energy, one obtains a direct “cut” through the FS in the repeated zone scheme which manifests in the electron momentum distribution emitted by the sample. For materials with a 3D electronic structure, such as copper, one can reconstruct the 3D FS by changing the photon energy and cutting through the FS in a series of slices. Being able to measure a wide angular range provides a number of advantages, primarily that the entire FS can be captured in one measurement. The full hemisphere mapping capabilities of the toroidal analyser enable rapid mapping of the FS. Figure 8(b) and (c) show

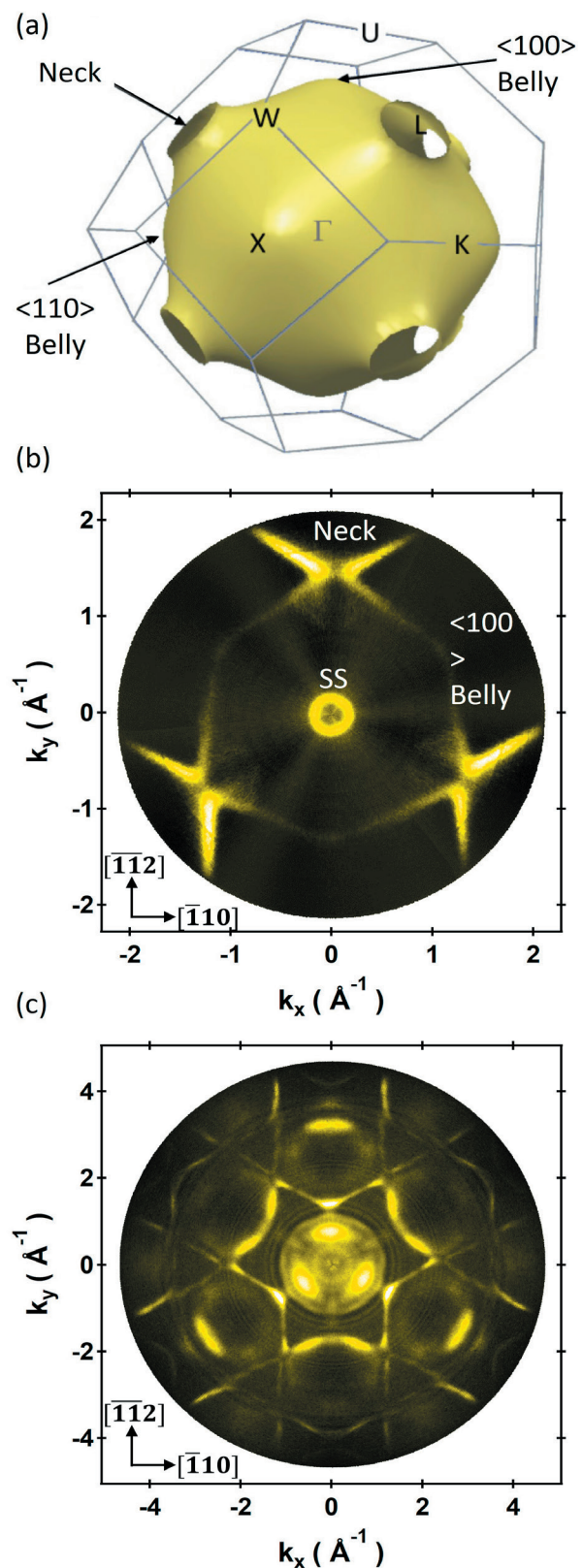


Figure 8 (a) The Fermi Surface of copper. Brillouin zone boundaries, symmetry points of the face centred cubic lattice, and key FS features, are indicated (<http://www.phys.ufl.edu/fermisurface>) (b,c) Fermi Surface of Cu(111) taken with the toroidal analyser at $h\nu = 21.2$ eV and 90 eV, respectively. Data is presented as a 2D projection of the emission hemisphere in the surface plane

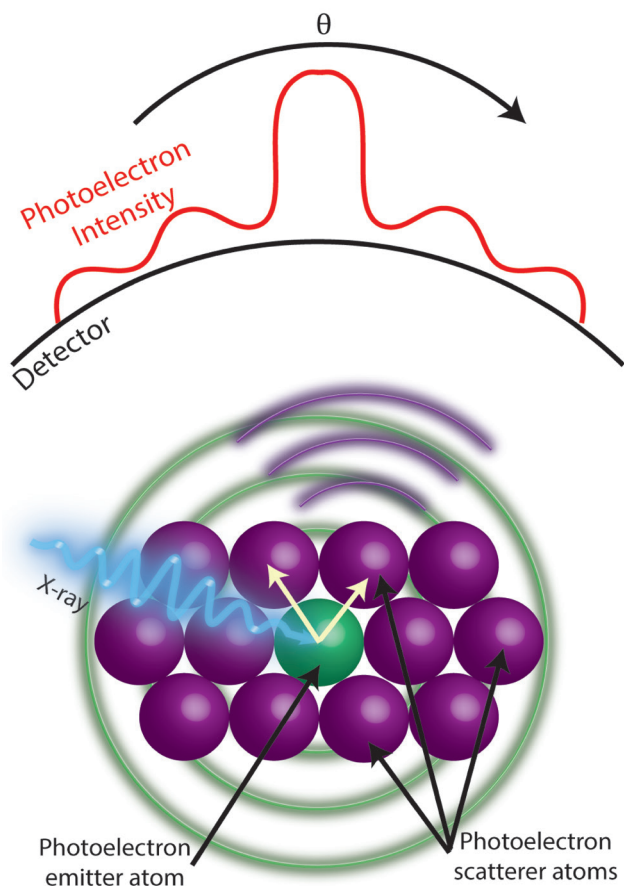


Figure 9: The atomic-scale process of x-ray photoelectron diffraction, with the primary outgoing photoelectron wave from the emitter (green) and the scattered wave from a scatterer (purple) shown. For visual clarity only one scattered wave is drawn, but in practice all scatterers would create a scattered wave.

full hemisphere photoemission maps from Cu(111) taken at the Fermi Energy using the VUV source energy of $h\nu = 21.2\text{eV}$ and synchrotron light at 90eV respectively. The data is plotted using Equations (2) and (3), yielding the in plane momentum projection of the emission hemisphere. The centre of the images corresponds to normal emission, and the perimeter to grazing emission, from the sample. In Figure 8 (b) one can clearly see the FS outline, illustrating the characteristic “neck” and “belly” features. Key dimensions of the FS with respect to the directions shown can be determined. In the centre, the Shockley surface state (SS) is observed, which is a well-known 2D electron state existing at the surface of Cu, Ag and Au(111) surfaces [13]. At the higher photon energy in Figure 8(c), one can see that the cut through the FS extends over many Brillouin zones, highlighting the contours of the FS in the repeated zone scheme.

Although this is an example of a FS from a simple and well known material, the full hemisphere technique using the toroidal analyser clearly illustrates the

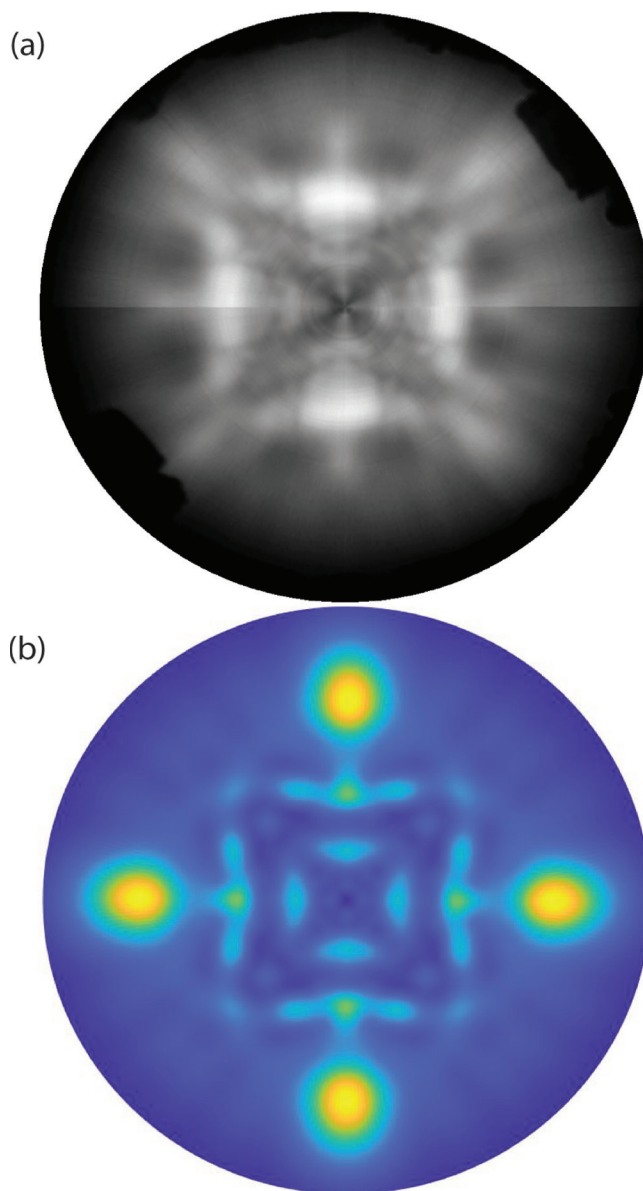


Figure 10: Experimental (a) and simulated (b) XPD patterns acquired on the hydrogen-terminated (100) diamond surface for a binding energy corresponding to the bulk carbon core level (approx. 283 eV), for a photon energy of 350 eV. The irregular dark features at the edge of the experimental pattern are a result of the mounting of the sample to the sample holder.

advantage of the instrument. For other systems with complex topology of electron/hole pockets, warping and nesting effects, the ability to resolve a wide area of FS topology in momentum space is very beneficial.

X-ray Photoelectron Diffraction (XPD)

Full-hemisphere X-ray Photoelectron Diffraction (XPD) is a unique tool for characterising surfaces, by taking the chemical information which XPS is capable of extracting and, alongside it, extracting structural information about the way in which that chemistry is positioned on

the surface. As shown in Figure 9, in XPD X-rays are used to excite core-level photoelectrons from a material. If we consider the photoelectron to be wave-like, it is capable of partially scattering from nearby atoms in the crystal. As the primary outgoing photoelectron wave and the scattered photoelectron waves propagate towards the detector, they undergo both constructive and destructive interference, in a manner which is strongly sensitive to the kinetic energy of the photoelectrons and the atomic environment surrounding the emitter, in particular to the path-lengths between neighbouring atoms and the electrostatic environment created. The result for a sample which is a highly ordered crystal is an intensity pattern which changes depending on the angle of the electron emission, and which can be analysed in order to gain an understanding of the precise arrangement of atoms in a crystal.

In practice, full hemisphere XPD involves measuring a constant energy surface corresponding to the binding energy of a particular chemical species. This might also be repeated for multiple photon energies – and therefore multiple photoelectron kinetic energies for the same chemical species – to modify the diffraction conditions. These measurements are compared to simulated diffraction patterns produced using simulation codes such as EDAC [14] from an initial guess at the structure of the system – either based on other experimental data, or from Density Functional Theory (DFT) calculations of the system of interest. The XPD simulation code then begins a process of altering the positions of various atoms in the guessed structure in order to optimise the agreement between the simulated and experimentally acquired diffraction patterns. In this manner, it is possible to determine the average arrangement of particular atoms and chemical species in a layer with sub-angstrom precision.

Figure 10(a) shows a XPD pattern from a (100) oriented hydrogen-terminated diamond surface acquired at SXR using the latest Toroidal Analyser, compared against a preliminary pattern simulated using EDAC (Figure 10(b)). What the reader should notice is the same four-fold symmetry in both images and a similarity in the structures, particularly in the middle of the patterns. Towards the edge, multiple-scattering effects influence the intensity of the features in a manner which requires more sophisticated iterative simulations to account for appropriately.

Future Outlook

Photoelectron spectroscopy techniques offer a wealth of information about the properties of a material, in particular enabling sophisticated surface-based chemical analysis and detailed insight into the electronic and optical properties of a material. In Australia there has historically been a small but strong photoelectron spectroscopy community, ever since the beginning of photoelectron spectroscopy as a field in the 1960s. In the present day there are more than 14 lab-based XPS instruments across 5 states, in addition to the XPS endstation on the SXR beamline at the Australian Synchrotron. These instruments are used for a wide variety of materials research, including in the development of biocompatible materials, advanced structural materials, and quantum materials. However, until recently, few if any of these instruments could perform ARPES or XPD measurements in a useful manner. This has meant that the local ARPES and XPD community has largely been restricted to researchers with pre-existing experience with these techniques and access to international synchrotron facilities, or researchers with collaborators who possess appropriate lab-based instrumentation for these techniques. The lack of local instruments has limited opportunities for local researchers to gain experience with these techniques and to develop research programs which are reliant on utilising these techniques. Given the shifting landscape of materials research and the increasing importance of quantum properties and atomic scale engineering, these techniques are becoming quintessential tools for the development of quantum materials, and having a local capability for learning and applying such techniques is therefore a requirement to maintaining the relevance of Australian research efforts in this sphere.

The development and installation of the latest generation toroidal analyser at the Australian Synchrotron in 2018 is therefore well timed. This instrument offers a local capability to perform synchrotron-based ARPES and XPD measurements, promoting local interest in these techniques and nucleating the formation of a local community applying them to their research. While full hemisphere photoelectron spectroscopy is not new, it is an uncommon capability with significant benefits for specific PES studies. By combining the tuneable photon energy and high energy resolution offered by the synchrotron source with the capabilities of this latest instrument, there is an opportunity to locally establish world-class capabilities in this field.

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Acknowledgements

The authors would like to acknowledge Emeritus Prof. John Riley (La Trobe University) for assisting in the preparation of this article by contributing a number of critical details of the early development of photoelectron spectrometers in Australia. We also acknowledge the hard work of Eric Huwald, without whom the 3rd generation Toroidal Analyser would not have been constructed. The ongoing support of the toroidal analyser project from the ARC Centre of Excellence in Future Low Energy Electronics (FLEET) is gratefully acknowledged.



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Dr. Anton Tadich is a Senior Scientist at the Soft X-ray Spectroscopy beamline at the Australian Synchrotron, and Partner Investigator with the ARC Centre of Excellence in Future Low Energy Electronics Technologies (FLEET). His research expertise focusses on the application of synchrotron photoemission and absorption spectroscopies to determine the electronic and chemical surface properties of emergent materials in condensed matter physics.



Dr. Alex Schenk

Dr. Alex Schenk is a lecturer and researcher in physics at La Trobe University. His research expertise focuses on atomic-scale modification of diamond surfaces and 2D materials for low-dimensional quantum electronics and quantum computing, using synchrotron-based photoelectron spectroscopies and scanning tunnelling microscopy to determine the surface chemistry and electronic structure evolving from this modification.

#PhysicsGotMeHere

This occasional column highlights people who have a qualification in physics but are in roles we might not traditionally associate with physicists. The information is drawn from the 'Hidden Physicists' section of the AIP e-bulletin.

Dr Jonathan Hall, Co-Founder & Director, Presagen

As infertility continues to increase each year, more couples look to IVF to help them have children. Using deep learning, computer vision, statistics, and physics techniques, Life Whisperer, Presagen's flagship AI technology, identifies morphological features that constitute a healthy embryo which are often invisible to the human eye. Life Whisperer is able to identify viable human embryos prior to transfer of the embryo to the patient. It works through a web browser accessed in the clinic, enabling clinicians to drag-and-drop microscope images and instantly receive a report as to the confidence of viability to support the embryologist's decision about which embryo to transfer. Life Whisperer requires neither significant clinical process change nor costly hardware.

My career story so far: I completed two PhDs (like a crazy person), one in theoretical particle physics (2011) focusing on quantum chromodynamics, and one in nanotechnology specialising in biosensing in embryos (2017). Both have received awards in their respective fields. These topics have a common thread of simulating resonances in finite volumes (although at vastly different orders of magnitude!). I chaired the international IONS-KOALA 2014 Conference on optics, atomic and laser applications, and in 2016, I was fortunate enough to be a member of one of the few teams to reach the inaugural CSIRO ON Prime pre-accelerator program for commercialisation in Sydney. There, we championed an idea for developing a new web-application for classifying human embryo viability and won the Australian eChallenge awards for both Medical Innovations and Research Commercialization.

We set up Presagen as the company that houses the core AI technology so that it can be leveraged for future medical imaging products. We developed a new decentralised training technique (patent-pending) to change the way health and medical information from around the world is connected. We believe in putting couples first, and empower prospective patients with the goal to improve IVF success rates and reduce the cost and emotional burden on couples by selecting the best embryos.



Dr Jonathan Hall

After officially launching the company in February of 2017, Life Whisperer made significant progress over a short period of time. We were recognised by the AIIA as Startup of the Year and Machine Learning/Big Data Innovation of the Year—SA, made the Top 5 of the finals at TechCrunch Startup Battlefield held in Sydney in 2017, and won 'Global Winner—One to Watch' for the APAC region at Talent Unleashed, whose judges included global innovation giants Richard Branson and Steve Wozniak. Since then I've been fortunate enough to make the honours list of 10 MIT Technology Review Innovators under 35 (Asia Pacific) in 2019, and be named among the InDaily 40 Under 40 Business Leaders in South Australia, receiving the Entrepreneurial Award for the state in 2019.

Nicole Reynolds, Operations Manager, Australian Institute of Physics

As the Operations Manager I look after the daily running of the AIP: answering member requests, managing finances and the AIP member database, assisting with advertising, liaising with publishers and printers for the mailout of Australian Physics, and working with Science In Public on the monthly bulletin. The best thing about my role with the AIP is its diversity and flexibility. I work part-time, and in amongst my daily tasks are projects, ranging from assisting in the transition to the AIP's new membership software, setting up the Public Fellows List, through to working on organizing the AIP's database. To-come, I am facilitating the transition of the aip.org.au content from Wordpress to Wild Apricot servers, so stay tuned!

My career story so far has not been your typical linear progression. I started out as a scientist, enthusiastic about science communication, and now am a marketing and communication graduate who is passionate about working with science-related businesses to achieve their goals. The general theme through my career has been a thirst for learning and new ideas.

I discovered science communication through working at Kickstart at USYD while completing my Physics BSc. Science communication is a great way for physicists to give back to the community; explaining the physics problems of our time and using physics to explain the world around us. During my BSc I was lucky enough to get a summer vacation physicist position at ANSTO. That set me along a life-long love of magnetism and neutron science.

I went on to do a MPhil of Physics at UNSW through ANSTO. During this time, I had the privilege of attending the Oxford Neutron School. The culture and excitement of traveling to further my physics career led me to pursue a PhD in Quantum Magnetism at ETH, Switzerland. I travelled to France and England to perform experiments at neutron facilities and attended schools, meetings and lectures with my European peers. I had great fun growing crystals, categorizing them and using them for neutron, muon and x-ray experiments.

Unfortunately, my health had other ideas for my career, and 9 months after an unexpected spinal surgery

Nicole Reynolds



I made the hard decision to stop my PhD and move back to Australia to focus on physical recovery. As I soon found out, focusing on your health cannot be a full-time occupation. So, I decided to improve my skill set in between my therapy sessions. I took a short course in science communication writing and completed a certificate IV in marketing and communications at TAFE.

Six months into my marketing and communications course, I applied for the Operations Manager role with AIP. It was a fantastic decision. I love thinking of ideas for assisting with the running and outlook of the AIP. With the aid of some old colleagues, I found a surprising new role that allows me to stay connected to the physics world, uses my problem-solver brain and continually improves my skill set, all of which combine into a career path that, perhaps most importantly, I thoroughly enjoy.

Young Physicists and Buoyancy

Chris Hall, Australian Synchrotron, ANSTO Melbourne, Victoria – christoh@ansto.gov.au

Why do some objects float in a liquid, and others sink? Why do some balloons go up whilst others fall down? All this and more in this edition of Young Physicists.

Whilst reading or watching the news as a young physicist, you might wonder about the physics around what is happening in our sometimes chaotic but always interesting world. Perhaps a rocket has been launched to reach the International Space Station. A remote vehicle is exploring Mars some 265 million kilometres away. Even not very nice things such as bushfires or pandemics might get you thinking about hot gases and radiation, or vapour droplets carrying tiny viruses. One interesting event that happened in the weeks whilst thinking

become known as the Archimedes Principle, and it is this that gives us the first glimpse of why things float.

We are naturally aware that if we throw lightweight objects into water, they float, and equally, that heavy things will sink. If we drop an empty bottle into a swimming pool it might float to start with because it is light. Then it starts to fill up with water and it sinks. Why is this? Archimedes worked this out whilst taking a bath. He looked at the phenomenon of buoyancy with



Kees Torn (a CC license from flickr, available at <https://flic.kr/p/2iCPa2z>) taken March 9, 2020.

about this article was the blockage of the Suez Canal by a very large ship, the *Ever Given*, a 400m long 60m wide container vessel which weighs around 200,000 tonnes. Very heavy, yet still it floats on water in the canal (when it was not stuck sideways that is). Have you ever wondered why metal ships float? This is a question for the physics of buoyancy.

Scientific reasoning behind the observation that some objects float on a liquid rather than sink into it goes back to around 2,300 years ago. The scientist who first wrote down a theory to describe it was Archimedes of Syracuse. He was considered to be a leading scientific thinker of that time, and one of the greatest mathematicians of all time. Archimedes was a brilliant man who applied his skills to many things, including how to mathematically describe buoyancy. His book was called 'On Floating Bodies', thought to have been written about 250 BCE. In it he describes the start of what is now known in physics as hydrostatics. One of the propositions in the book has

a scientist's eye. He observed that when an object is fully immersed in a liquid, it moves the liquid aside and thus takes up its space. All the time gravity is acting on the liquid and solid masses generating a downward force. We know from the works of Sir Isaac Newton that a force (F), due to gravity acting on a mass, can be calculated if we know the mass (m) and the acceleration (a), we multiply them together: $F = m \times a$.

Archimedes didn't know about gravity as such, but he did observe that objects seemed to be pulled towards a distant point below the Earth's surface. He also knew that this force was stronger for heavier objects than for lighter ones. This is the property of an object we call its weight. He could easily measure weight using scales.

So, Archimedes might have thought about the weight of the water before the object is immersed, and that it might be different from the weight of the object being immersed. He likely identified that the differences

in these weights gives rise to an effective force we call buoyancy. In his famous eponymous principle he proposed that the upwards force on the immersed object is due to the difference in weight between the part of the object below the liquid and that of the liquid it displaces. When they are equal it floats. Wow! That's quite a feat of thinking.

Let's think about what practical use that idea might have. Here's one: the mass of an object is determined by its volume (V), multiplied by the density (ρ) of the material from which it is made.

$$m = V \times \rho$$

(In physics and science we often use Greek letters for things. The letter 'rho' (ρ) typically stands for density. Another famous letter is 'pi' (π); we use that, for example, to calculate the area of a circle $A = 2\pi r^2$.)

If we immerse an object in a liquid we know from Archimedes that the volume of liquid it displaces must be equal to the volume of the object. It's not difficult to measure the volume of a liquid. You might have seen cylindrical jars used in laboratories with graduations on the side telling you how much liquid is contained. If we immerse an object in a liquid in one of those jars, and take the volume measurements before and after, this will give us the volume of the submerged object. This process works for complex shaped objects as long as there are no air bubbles trapped by its shape. So, we can measure the object's volume. Its mass is simple to determine using scales.

The story goes that Archimedes himself used this idea in a very practical way. He was thinking about a problem posed by the king Hiero II of Syracuse. The king asked: how can I determine the purity of the gold which makes up my crown? The weight of the crown was measured, but the king thought the purity of the metal was suspicious. The purity is strongly linked to the metal's density. So to get density we flip that equation around and divide the mass (or weight) by the volume. There was a problem... no one could figure out how to measure the volume of something with as complicated a shape as a crown. Archimedes might have been thinking about his displacement theory when he stepped into his bath. The volume of his legs as he stood there, were given

by the volume of water displaced, as measured by the rise of the water level on the side of the bath. He could use the same measurement with the king's crown. Legend has it in this moment of physics inspiration he ran out of his bathroom naked, shouting *Eureka!*, meaning in Greek 'I've found it'.

So let's see if we can use Archimedes' method to say something about that big ship in the Suez Canal. When the *Ever Given* was floating it must have displaced a mass of canal water equal to the mass of the ship with its cargo. In the shipping world the weight of the ship plus cargo is known as the 'displacement' for good reasons. Can you see how we can figure out what is known as the ship's 'draft'? That's the distance from the bottom of the hull to where the water level meets the ship's side. We can avoid the complexity of worrying about the shape of the hull. Let's approximate it as a box, 400 m long and 60 m wide. These two measurements multiplied by the draft will give the volume of the hull below the water, and so the volume of the water it displaced. The density of water is well known. Measurement scientists have decided that one litre of pure water weighs one kilogram, and is equal to 1000 cubic centimetres.¹ So, can you calculate the weight of 1 cubic metre of water? If you said 1000 kilograms, or a metric tonne, well done! From this we can then say the ship's displacement of 200,000 tonnes balances 200,000 cubic metres of water. Finally we ask: if the volume of water displaced is calculated by 400m times 60m times the draft. What is the draft? Grab your calculator and see if you come up with 8.33 metres. We can say the canal needs to be much more than 8.33 metres deep, even if our ship has a flat bottom.²

Over to you

If you want to further explore the idea of buoyancy, try building a 'Cartesian Diver'. This is an interesting and simple demonstration of how a gas (air) can change its volume when its pressure changes, but water does not. Making it more or less buoyant. There are lots of different ways to make this toy. Many are shown on the web. Here's a good one: <https://www.madaboutscience.com.au/shop/science-extra/post/cartesian-diver>

Photo is credited to Kees Torn. Publically available on flickr (<https://flickr.com/photos/68359921@N08/49643352087>)

¹ The water in the Suez Canal is salty. So its density will be greater than 1 g/cm³. Let's ignore that for now.

² The Suez Canal was originally dug 8 m deep. As bigger ships started to use it, the average depth was increased. Its depth is now greater than 24 m.

Physics around the world

Stacked molecules create efficient and stable pure-blue OLEDs

Researchers in Japan have developed pure-blue organic light-emitting diodes (OLEDs) with high efficiency and long lifetimes. They say that this blue light source matches the excellent performance of red and green OLEDs, overcoming one of the major hurdles hindering the development of OLED displays. The team achieved this by stacking two novel emitter molecules on top of each other and splitting the energy conversion and emission processes between them.

OLEDs utilize carbon-containing molecules that emit light in response to an electrical current. They produce vibrant colours and can form thin and even flexible devices. This makes them promising light-source technologies for future displays. While liquid crystal displays (LCD) use liquid crystals to selectively block emission from a filtered backlight covering many pixels, OLED displays use separate red, green and blue emitting pixels that can be individually turned on and off. This produces deeper blacks and reduces power consumption.

However, while red and green OLEDs with excellent performance exist, producing efficient blue OLEDs with long, stable lifespans has proved challenging.

“Stable blue emitters based on a process known as fluorescence are often used in commercial displays, but they suffer from a low maximum efficiency,” Chin-Yiu Chan, of the Center for Organic Photonics and Electronics Research at Kyushu University, tells *Physics World*. “On the other hand, so-called phosphorescent emitters can achieve an ideal quantum efficiency of 100%, but they generally exhibit shorter operational lifetimes and require an expensive metal such as iridium or platinum.”

Recently research has focused on molecules that emit light using a process known as thermally activated delayed fluorescence (TADF). In most OLED materials, around 75% of the electrical charge produces triplet energy states that do not fluoresce. But TADF molecules can use thermal energy to convert these triplet states into singlet states that do emit light.

In 2019, researchers led by Takuji Hatakeyama,



Based on hyperfluorescence, which uses a two-molecule process to emit light, these highly efficient organic light-emitting diodes emit pure-blue light and exhibit significantly improved lifetimes compared with other devices, all without using expensive metal atoms. (Courtesy: Masaki Tanaka, Kyushu University)

at Kwansai Gakuin University, reported a very efficient TADF material that produces ultrapure-blue light with a narrow emission of just 14 nm. But the molecule, named v-DABNA, is quite slow at converting triplet states into singlets. This means that it degrades quickly under operation because the high-energy triplet states affect its electro-chemical stability.

Working together, researchers from Kyushu University and Kwansai Gakuin University have now developed a new TADF molecule, as they report in *Nature Photonics*. This new molecule rapidly converts triplet states to singlets, which helps it maintain its electro-chemical stability. The researchers found that by using this molecule as an intermediate, high-speed energy converter in combination with v-DABNA, they can drastically improve the lifespan of the latter, while maintaining its narrow emissions.

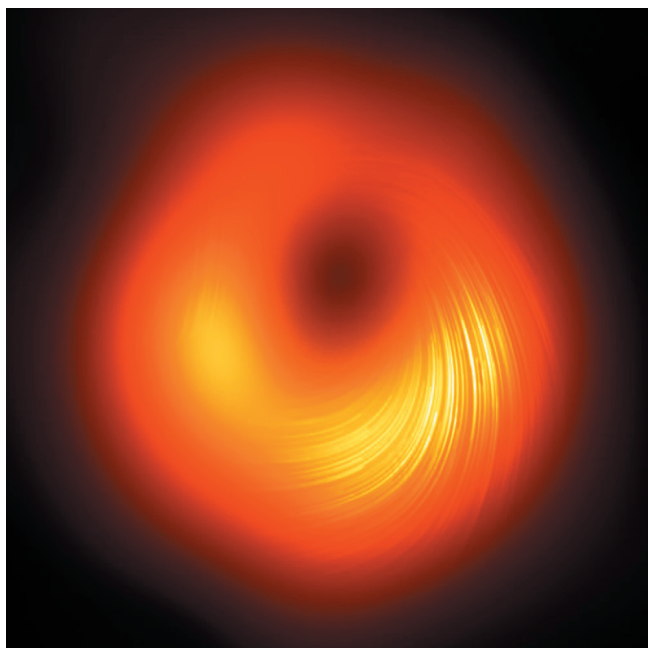
The new intermediary molecule produces a wide emission spectrum of pure blue. Much of this energy is then absorbed by v-DABNA, which in turn emits its narrow emission of ultrapure blue.

(extracted with permission from an item by Michael Allen at physicsworld.com)

New black hole image reveals magnetic fields

A new image showing magnetic fields surrounding the supermassive black hole M87* has been created by scientists working on the Event Horizon Telescope (EHT). The magnetic structure was mapped by measuring the polarization of the light emitted by matter in the hot region around the black hole. Understanding the magnetic properties of that region could provide

important insights into how powerful jets of radiation and matter are emitted by some black holes.



Magnetic swirl: a view of the M87 supermassive black hole in polarized light. The lines mark the orientation of the polarization, which is related to the magnetic field around the shadow of the black hole. (Courtesy: EHT Collaboration)

In 2019 the EHT made history by capturing the first image of the shadow of a black hole. This is a dark region surrounding a black hole that is expected to be about three times the diameter of the black hole's event horizon, which is the point beyond which even light cannot escape a black hole. The supermassive black hole is called M87* and is located at the centre of a galaxy about 55 million light-years away. From the image, the team worked out that M87* has a mass of about 6.5 billion times that of the Sun. Back in 2012, astronomers using the EHT were also able to see the base of a powerful jet that blasts out about 5000 light-years from M87*.

Now, scientists working on the EHT have analysed the polarization of light from the bright region surrounding the shadow. There, some matter is being sucked into the black hole while other matter is being blasted out in jets. How these jets are formed is a matter of debate amongst astrophysicists but understanding the magnetic fields near supermassive black holes could provide important clues.

Strongly magnetized gas

The region surrounding the shadow is hot and violent region and therefore large amounts of light are created as matter is accelerated. If strong magnetic fields are present, then the emitted light will be polarized. Using

models to analyse the observed polarization, EHT scientists have concluded that only the presence of a strongly magnetized gas can explain their observations.

(extracted with permission from an item by Hamish Johnston at physicsworld.com)

Hydroplaning of tyres is imaged using tiny fluorescent particles

Detailed images showing how water drains through tyre grooves during hydroplaning have been obtained by Serge Simoëns and colleagues at France's University of Lyon. Their technique could provide crucial guidance to engineers trying to design tyres that are better suited to driving in wet conditions.

When a tyre rolls over a wet or flooded road, a build-up of water pressure at the front of the tyre can generate a lifting force. Known as hydroplaning, the effect can cause tyres to lose all contact with the road if this lift becomes greater than the weight of the car. To minimize its influence, tyre treads must drain as much water as possible from front to the back, without significantly



Groovy tread: a Michelin tyre showing the radial and transverse grooves that form the tread. (Courtesy: Scott Robinson/CC BY 2.0)

reducing road adhesion. Since the fluid dynamics involved in hydroplaning are highly complex, tread designs must be informed by detailed information about these flows.

Particle imaging velocimetry (PIV) is a widely used technique for measuring flow velocities in 2D. It involves seeding fluid with fluorescent tracer particles that must be small enough to accurately reflect the dynamics of the fluid surrounding them. Then, a 2D slice of the fluid

is illuminated by a laser sheet, causing the particles to glow and create a direct image of the flow.

(extracted with permission from an item by Sam Jarman at physicsworld.com)

Iridium in undersea crater confirms asteroid wiped out the dinosaurs

Strong evidence that the dinosaurs were killed-off 66 million years ago by an asteroid hitting Earth has been found in Chicxulub crater under the Gulf of Mexico.



Asteroid dust: Sean Gulick of the University of Texas at Austin (right), and Joanna Morgan at Imperial College London examine cores retrieved from the crater during the 2016 research mission led by the International Ocean Discovery Program. (Courtesy: The University of Texas at Austin/Jackson School of Geosciences)

An international team has measured an abundance of the rare element iridium in the crater and similarly high concentrations of the element are known to occur in sediments laid down at the time of the Cretaceous–Paleogene boundary (K–Pg) extinction event, which saw many species on Earth vanish.

Measuring 200 km across, the Chicxulub crater is believed to have been created by an 11 km-wide asteroid crashing into Earth. The impact would have sent vast amounts of vaporized rock into the atmosphere, blocking out the Sun and creating a winter that could have lasted several decades. The result, scientists believe, was the mass extinction of 75% of species on Earth including the non-flying dinosaurs.

The crater was discovered in the 1990s, but the idea that the K–Pg extinction was caused by an asteroid impact was proposed a decade earlier by a team that included the physics Nobel laureate Luis Alvarez. They found an

unusually high amount of iridium in sedimentary rocks laid down at the K–Pg boundary. Iridium is rare in the Earth’s crust because it is a siderophile, which means that it dissolves in iron and therefore tends to sink into the Earth’s core. Iridium is much more abundant in asteroids, leading Alvarez and colleagues to conclude that the vaporization of an asteroid released large amounts of iridium into the atmosphere, which then fell to the ground as dust as the dinosaurs disappeared.

Huge tsunamis

As well as the subsequent discovery of the Chicxulub crater, the impact extinction theory is backed up by evidence that huge tsunamis occurred in the Gulf of Mexico and Caribbean regions at the time. However, the evidence linking the Chicxulub impact to the K–Pg extinction is not conclusive. The iridium could have been put into the atmosphere by another asteroid impact or impacts; and some scientists have suggested that increased volcanic activity, rather than an asteroid, could have caused the extinction.

In 2016, Sean Gulick at the University of Texas at Austin and Joanna Morgan of Imperial College London led an international team of scientists on the International Ocean Discovery Program on an expedition to the Chicxulub crater. They took about 900 m of rock core samples and found a similar spike in iridium content in sediment laid down just after the crater was formed.

(extracted with permission from an item by Hamish Johnston at physicsworld.com)

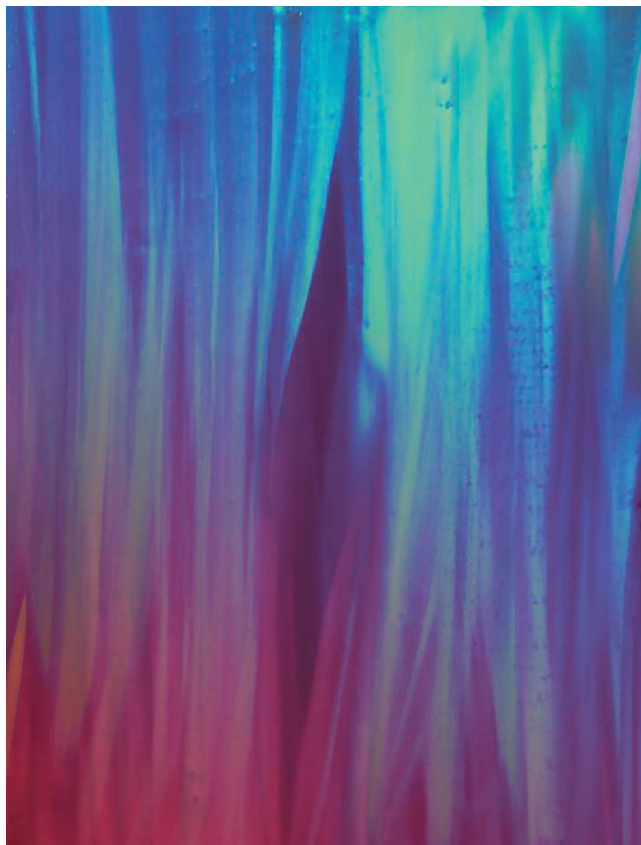
Improved hydrogel could make artificial tendons

A strong, flexible and tough hydrogel that contains more than 70% water could be used to make durable artificial tendons and other load-bearing biological tissues. The new hydrogel was made by researchers at the University of California, Los Angeles, US and is based on polyvinyl alcohol (PVA) – a material that is already approved for some biomedical applications by the US Food and Drug Administration.

Biological tendons are also more than 70% water, yet they remain strong and tough thanks to a series of connecting hierarchical structures that span length scales from nanometres to millimetres. Researchers have been trying to mimic these materials using hydrogels, which are three-dimensional polymer networks that can hold a large amount of water and are structurally similar

to biological tissue. The problem is that so far, hydrogels that contain as much water as natural tendons tend not to be as strong, tough or resistant to fatigue as their biological counterparts.

Salting out a freeze-casted structure



The artificial tendon material developed by UCLA materials scientists. Credit: Sidi Duan, Shuwang Wu, Mutian Hua, and Ximin He/UCLA

In their work, a team led by Ximin He of UCLA's Samueli School of Engineering began by freeze-casting, or solidifying, PVA to create a honeycomb-like porous polymer structure. The micron-sized walls of the pores in this material are aligned with respect to each other and serve to increase the concentration of PVA in localized areas.

The researchers then immersed the polymer in a salt solution ("salting out") to precipitate out and crystallize chains of the polymer into strong threads, or fibrils, that formed on the surface of the pore walls. This phenomenon is known as the Hofmeister effect.

Hierarchical assembly of anisotropic structures

The resulting hydrogels have a water content between 70 and 95%. Like natural tendons, they contain a hierarchical assembly of anisotropic structures spanning lengths from the molecular scale up to a few millimetres.

He and colleagues tested various salt ions in their experiments and found that sodium citrate was the best at salting out PVA. When they used a mechanical tester to measure the stress-strain characteristics of the resulting hydrogel, they found that it had an ultimate stress of 23.5 ± 2.7 megapascals, strain levels of 2900 ± 450 %, a toughness of 210 ± 13 megajoules per cubic metre, a fracture energy of 170 ± 8 kilojoules per square metre and a fatigue threshold of 10.5 ± 1.3 kilojoules per square metre. The researchers say that these mechanical properties resemble those of natural tendons. They also note that their hydrogel showed no signs of deterioration after 30 000 stretch cycles.

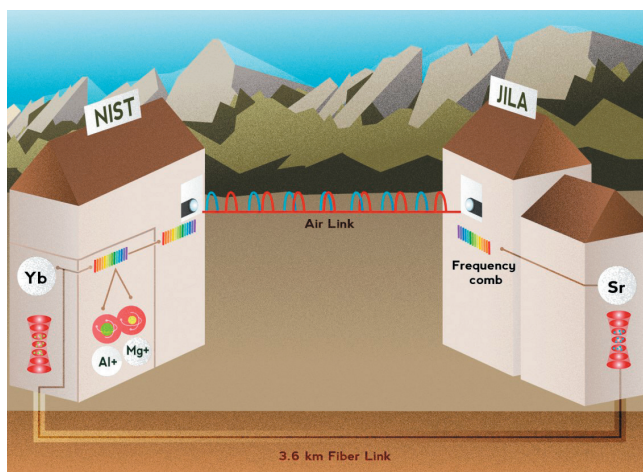
Replicating other soft tissue

Since the Hofmeister effect exists for various polymers and solvent systems, He says the technique used in this work, which is detailed in *Nature*, could apply to other materials too.

(extracted with permission from an item by Isabelle Dumé at physicsworld.com)

Three top atomic clocks are compared with record accuracy

The time kept by three of the world's best atomic clocks has been compared by connecting them using optical fibres and an over-air link. The comparisons were done by the Boulder Atomic Clock Optical Network Collaboration in the US and are ten times more accurate than previous attempts. The measurements have revealed unexpected variations in the time kept by the clocks, which could provide insights into how the devices could be improved. The research could play an important role in developing a new standard for the second, which



Time triangle: illustration of how the ytterbium (Yb), strontium (Sr) and aluminium-magnesium (Al+/Mg+) atomic clocks were connected. (Courtesy: N Hanacek/NIST)

would involve distributing and comparing atomic-clock time signals throughout the world.

Atomic clocks use the frequency of a specific atomic transition as an extremely stable time standard. While the second is currently defined by caesium-based clocks that operate at a microwave frequencies, physicists have built much more accurate clocks that are based on light. These optical clocks tick at much higher frequencies than microwave clocks and can keep time that is accurate to about one part in 10¹⁸, which is about 100 times better than the best caesium clocks.

The international metrology community aims to replace the microwave time standard with an optical clock, but first must choose from one of several clock designs being developed worldwide. To evaluate and improve these optical clocks – and ultimately create a global network of time standards – researchers must be able to compare their time signals. This can be done using an optical fibre connection or by transmitting optical signals through the air. Indeed, air transmission could play an important role in deploying optical clocks in satellites, where microwave clocks are currently used.

In this latest work, David Hume and colleagues at the US's National Institute of Standards and Technology (NIST) and the University of Colorado have compared time signals of three optical clocks, which are all located in Boulder Colorado. One clock uses ytterbium atoms, another strontium atoms and the third a combination of aluminium and magnesium ions.

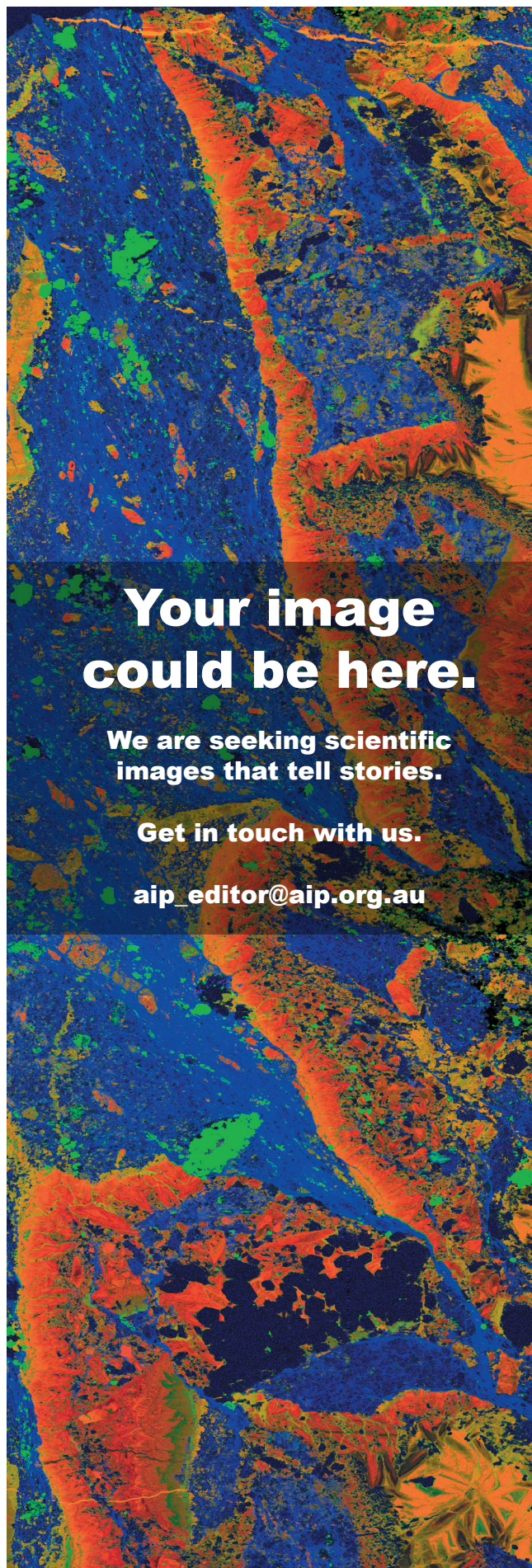
Frequency combs

A 3.6 km optical fibre link was used to compare the ratio of frequencies of the ytterbium and strontium clocks, which were located at NIST and the University of Colorado respectively. The strontium and aluminium–magnesium clocks (the latter located at NIST) were compared using a 1.5 km over-air optical link between two buildings. This involved the use of frequency combs, which allow signals at very different frequencies to be compared.

The over-air technique is also relatively immune to disturbances caused by turbulence in the air. Indeed, the team found that the fibre and free-space links offered similar levels of performance – the exception being when the free-space link was operated during a snowstorm.

The ytterbium and aluminium–magnesium clocks were in different labs at NIST and were compared using a fibre connection. The team managed to measure ratios of frequencies of the three pairs of clocks at an accuracy of one part in 10¹⁸, which is an order of magnitude improvement on the previous record of one part in 10¹⁷.

(extracted with permission from an item by Hamish Johnston at physicsworld.com)



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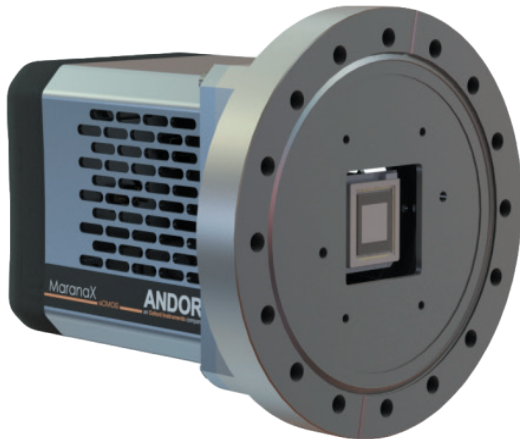
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Product News

Coherent Scientific

Fastest sCMOS for direct EUV detection



Marana-X is Andor's new ground breaking sCMOS camera for direction detection of EUV and soft X-ray. The Marana-X reads out a 4.2 megapixel high resolution array in less than 50 milliseconds while maintaining very low read noise; hundreds of times faster than similar resolution CCD detectors.

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Bruker's latest generation benchtop profilers, the ContourX range, utilises the new VisionExpress user interfaces and includes Bruker's latest image acquisition technology – Universal Scanning Interferometry (USI), an operator independent technique that builds upon traditional phase and contrast based interferometry techniques.

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or dull, independent of colour. USI provides the widest simultaneous measurement sensitivity range of any currently available technique allowing simultaneous measurement of sub-nanometer roughness on surfaces with features 10's micron in height, making it perfectly adapted for semiconductor devices, microfluidics and precision parts, while providing more dynamic range for 3D printed surfaces, machined parts and general devices.



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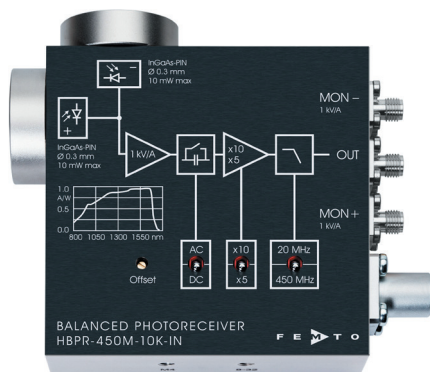


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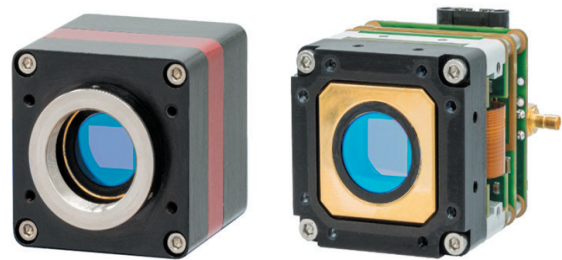
With the completely newly developed HBPR photoreceiver platform, Femto are setting a new standard for balanced photoreceivers.

The Low-noise balanced photoreceivers of the HBPR series offer differential measurement of optical signals in the wavelength range from 320 nm to 1700 nm (SI or InGaAs) with bandwidths of up to 500 MHz. The optical inputs are optionally free space or fiber-coupled. Among other things, the devices enable highly sensitive, precise detection of laser pulses even at high repetition rates and rapidly changing signal shapes.

The photoreceivers use two photodiodes selected in pairs, which are connected in anti-parallel, and a subsequent low-noise transimpedance amplifier in order to detect

the differential signal. The HBPR series is characterized by very low input noise (NEP) down to 3.7 pW/ $\sqrt{\text{Hz}}$ and high common mode rejection (CMRR) of up to 55 dB. Various models with Si or InGaAs photodiodes and bandwidths from 100 MHz to 500 MHz are available. The output coupling is switchable (AC/DC), the gain adjustable in two stages and the bandwidth can be limited to 20 MHz. Two monitor outputs with 10 MHz bandwidth enable fast, separate acquisition of the individual input signals.

The best HD SWIR Camera just got better – Raptor Owl 1280



Raptor launched the Owl 1280 in 2018 as the first HD Vis-SWIR on the market. This camera is widely considered “best in class” and has been successfully integrated in large volumes by our OEM customers across the globe. But we never sit still. We have undertaken continuous improvement of AI algorithms with the ultimate goal of optimizing image quality. The OWL 1280 is packed with new firmware features.

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Raptor offers “off the shelf” cameras that are available today for evaluation or purchase. But we realise that you may have custom requirements, please contact us today to discuss!

Gentec-EO announces high laser power meter with low back-scattered power



Gentec-EO, the leading provider of laser beam measurement instruments, has announced a new laser power meter for multi-kW lasers with the lowest back-scattered power rating in its category. With its TUBE extension to reduce back-reflections and internal cooling system, the HP60A-15KW-GD-TUBE absorbs up to 99% of the laser's power, and can withstand long-term exposure of up to 15 kW of continuous power.

The HP60A-15KW-GD-TUBE has a golden reflector cone that was specially developed for the high intensities of high-power fiber lasers. By reflecting incident light off the sides of the opening, the cone distributes the intensity over a larger area (which is covered by our proprietary high damage threshold absorber) and increases the damage threshold to 10 kW/cm² at full power. With such high damage thresholds, you can now measure your laser power without having to expand your beam.

By redirecting light inside the detector, the gold cone reduces back-scattered light. A water-cooled tube extension further reduces the back reflections, for a combined effect of letting only 1-2% of the incident radiation diffuse out of the detector opening. This very low reflection rate ensures a safer working environment with high-power lasers.

This detector comes with both a DB15 connector (for use with a Gentec-EO display such as MAESTRO, TUNER or UNO) and a USB2.0 output for direct measurement on a PC. A wireless module is also available for custom order, which allows for remote monitoring of your laser's power at up to 30 m distance from the detector.

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Cobolt TorXE pulsed laser for marking, LIBS and acoustics

HÜBNER Photonics is proud to introduce the Cobolt Tor XE, a high performance compact Q-switched laser at 1064 nm and with 0.5 mJ/pulse. Using the same sophisticated laser cavity design as the other lasers in the Cobolt Tor Series, the Cobolt Tor XE delivers a unique combination of kHz repetition rates, short pulse lengths (<3.5 ns) and exceptional pulse-to-pulse stability (jitter < 2 us) in a TEM₀₀ beam. In addition, through advanced and fully integrated control electronics the emission can be triggered from single pulses up to 1 kHz pulse trains or bursts of pulses using external or internal trigger signals.

All Cobolt lasers are manufactured using proprietary HTCure™ technology and the resulting compact hermetically sealed package provides a very high level of immunity to varying environmental conditions along with exceptional reliability. With demonstrated lifetime capability of >60 000 hours and several thousand units installed in the field, Cobolt lasers have proven to deliver unmatched reliability and performance both in laboratory and industrial environments and are offered with market leading warranty terms.



TopMap Micro.View - compact optical profiler

TopMap Micro.View is an easy to use and compact optical profiler from Polytec. Combine exceptional performance and affordability with this powerful metrology solution. An extended 100 mm Z-measurement range with CST Continuous Scanning Technology allows complex topographies to be measured at nm resolution. This convenient table-top setup features integrated electronics, with the smart focus finder simplifying

and speeding up the measurement procedure. Benefit from the optional ECT Environmental Compensation Technology, securing reliable and accurate measurement results even in noisy and challenging production environments. Micro.View is the cost-effective quality control instrument for inspecting precision engineered surfaces in the field of manufacturing and research.



The encoded and motorized turret secures a seamless transition between objectives. Micro.View+ also features the latest Focus Finder plus Focus Tracker, keeping the surface in focus at all circumstances. The fully motorized sample positioning stages allow for stitching and automation.

Key applications include:

- Material Science (Tribology, Coatings, Texturing)
- Medical (implants, artificial joints, 3D printing in Medical)
- Precision Engineering (Component manufacturing incl. 3D-Printing)
- Semicon/MEMS & Electronics (etching technology, defects, microelectronic structures)
- Optics (micro optics, optical polishing surface roughness measurements)

For more information, contact Warsash Scientific on +61 2 9319 0122 or sales@warsash.com.au.

Zurich

First signal generator for superconducting and spin qubits

Zurich Instruments launches the SHFSG, the first signal generator specially designed for superconducting and spin qubits. The SHFSG can output signals from DC up to 8.5 GHz without the need for mixer calibration, and provides a clean and low-noise signal in a bandwidth of 1 GHz.



The SHFSG takes advantage of the super-heterodyne frequency conversion technique to ensure better linearity and fewer spurious tones than with standard IQ-mixer-based methods. Also, the SHFSG can be programmed to generate complex pulse sequences. As a result, the SHFSG generates clean and stable signals without requiring users to spend time on mixer calibration or system maintenance. The integrated synthesizers help to increase the fidelity of qubit gate operations thanks to their low phase noise and low timing jitter across the entire output frequency range. The SHFSG is available in two variants, one with 4 channels and one with 8 channels.

A high level of integration with the upper levels of the quantum stack comes through the LabOne software, driver compatibility with Labber and QCoDeS, and API support for Python, C/C++, MATLAB®, LabVIEW™ and .NET.

The SHFSG integrates seamlessly with all devices in the Zurich Instruments Quantum Computing Control System, so that it is ready to run fast feedback and error correction protocols. A single SHFSG helps to reduce the complexity of small qubit setups; a few synchronized instruments make it possible to scale up to systems of 100 qubits and more.

AAPPS Bulletin

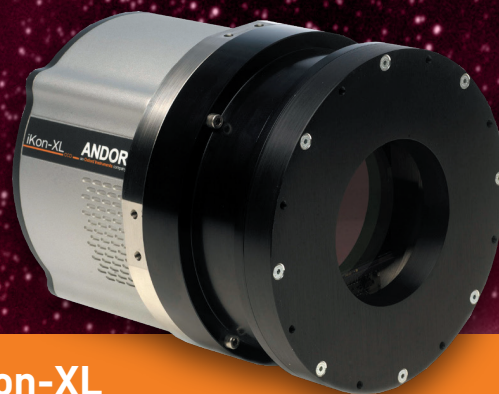
High Performance Cameras for Astronomy

ANDOR
an Oxford Instruments company



Balor

Very large area sCMOS camera
16.9 Megapixel, 49.5mm x 49.2mm
Up to 54 frames/second
Low read noise
Extended dynamic range



iKon-XL

Very large area CCD camera
16 Megapixel, 61.4mm x 61.4mm
-100°C TE cooling
No liquid nitrogen, no cryo cooler
Extended dynamic range



Marana

Back-illuminated sCMOS camera
95% quantum efficiency
4.2 Megapixel, up to 22.5mm x 22.5mm
Up to 74 frames/second
Affordable pricing



iXon Ultra

EMCCD camera
Single photon sensitivity
95% quantum efficiency
Direct data access for low latency
High frame rate

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