Introduction to the Department of Physics and Astronomy

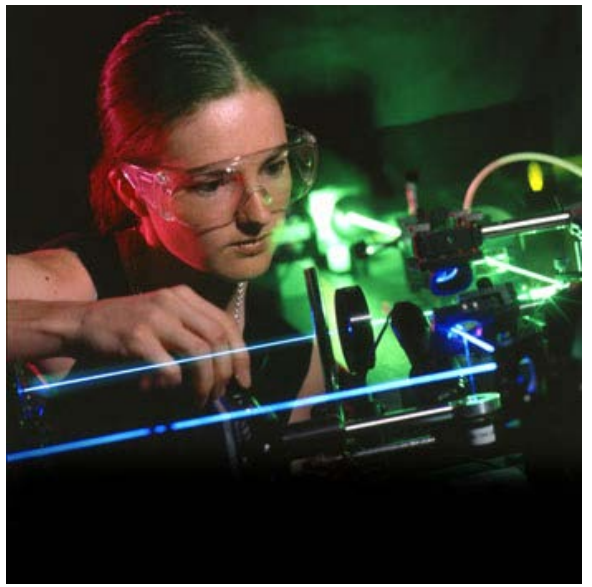
Judith Dawes,
Director of MQ Photonics Research Centre
Professor of Physics

Department of Physics and Astronomy

- Nationally leading Physical sciences Department, 5/5 in national research ranking
- 30 academics ~75 postgraduate students

Research strengths

- Lasers and photonics
  - Raman, diamond and solid state lasers; Biophotonics; Nanophotonics; Waveguides and integrated quantum optics
- Quantum science and technology
  - Quantum sensors; Quantum algorithms and quantum computing; Topological and hybrid quantum systems; Nanodiamond physics
- Astronomy, astrophysics and astronomical instrumentation
  - Theoretical astrophysics in magnetised systems; planetary nebulae and dynamics of binary systems; galactic evolution and galaxy clusters;
  - Integrated robust optical components for processing weak light



Facilities and existing industry links

Major facilities and Research Centres

Photonics

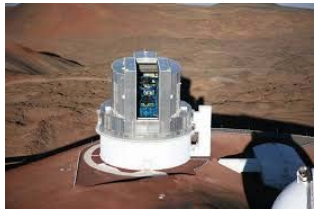
- Centre of Excellence in Nanoscale BioPhotonics (CNBP)
- World-class ultrashort laser 3D writing and 3D printing services
- About 50 optics laboratories

Quantum Science

- Centre of Excellence in Engineered Quantum Systems (EQuS)
- Laboratories in quantum nanophotonics and diamond nanoscience

Astronomy

- Access to major international telescopes: Keck, Magellan, Hubble
- Time on national supercomputing facilities
- An on-site observatory for research and teaching

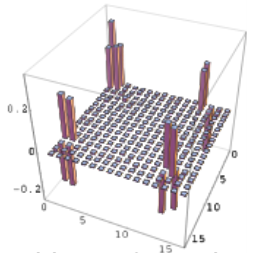


Industry links

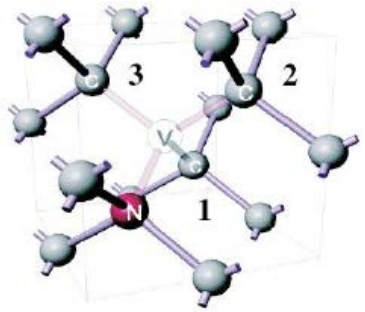
- Multiple teams in national IP accelerator programs
- Bulk laser development
  - Linkage projects and contracts on ~ 4 technologies: ultrashort UV lasers, surgical yellow lasers, high power diamond lasers for defence
  - Partners in UK and US
- Optical integrated components: *Modular Photonics*
  - Sydney water for sensing; International telescopes
- Quantum sensors and quantum algorithms
  - Lockheed Martin and US AORD/AFOSR
- Biophotonics and plasmonics
  - Diagnostics and theranostics development with pharma: AgaMatrix

Quantum Science and Technology

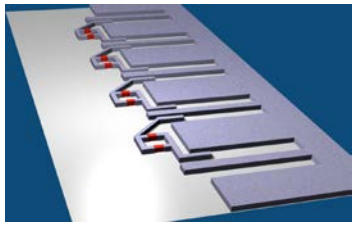
MACQUARIE University



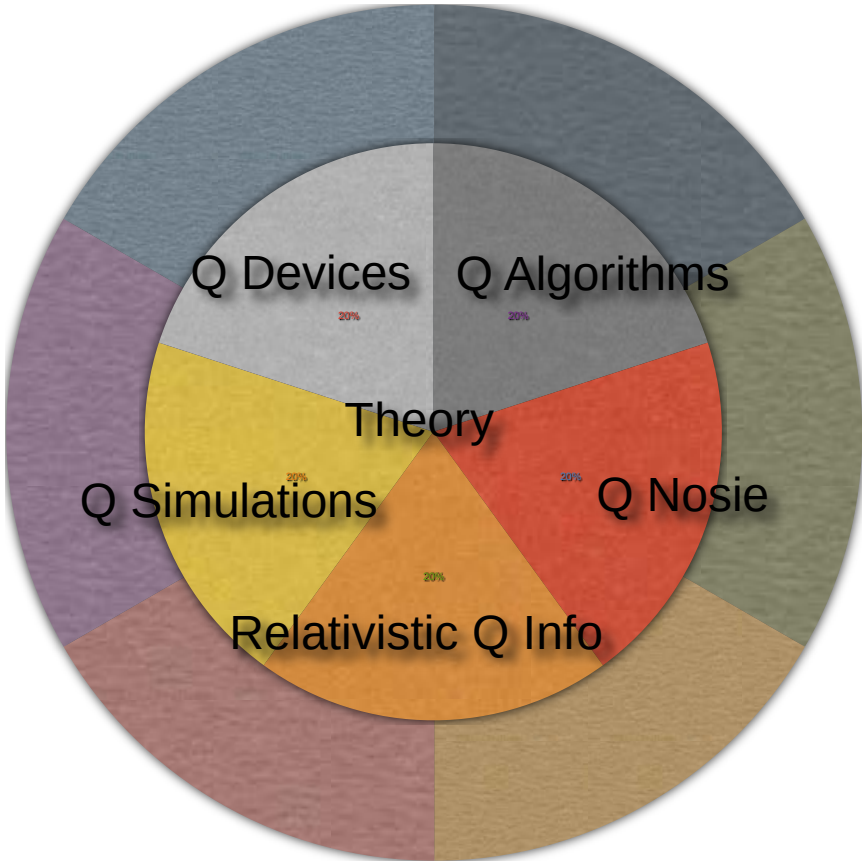
Evidence for a photonic quantum gate



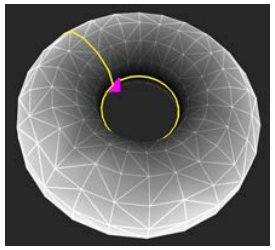
Quantum bits in Nitrogen Vacancy centre in Diamond



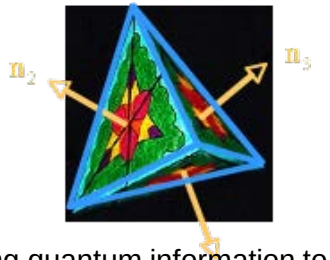
Superconducting Quantum devices



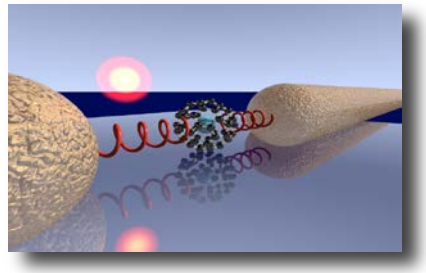
QScitech



Quantum error correcting codes encoded on a torus

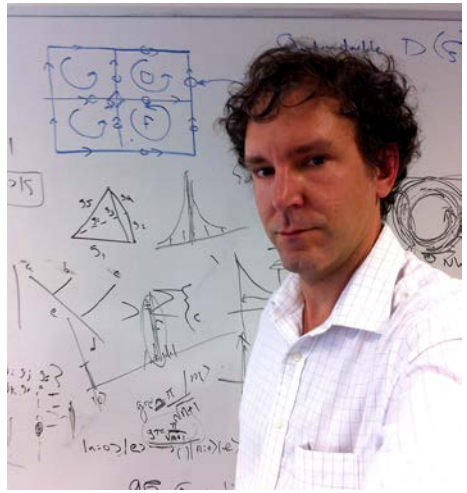


Using quantum information to communicate a spatial reference frame



Quantum nanomechanics

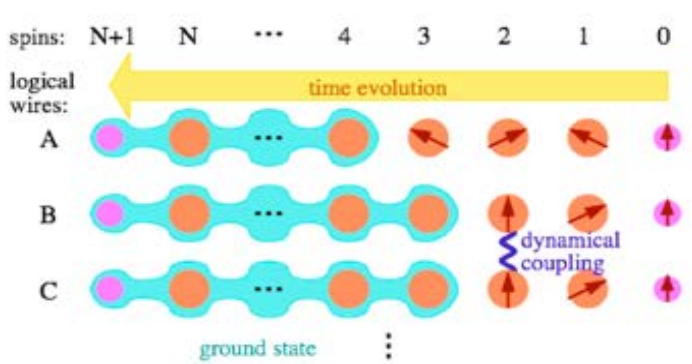
Quantum Many-Body Science

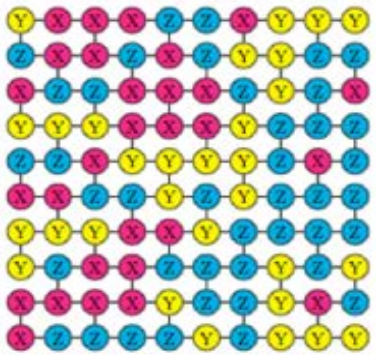


Prof Gavin Brennen

Many body quantum information

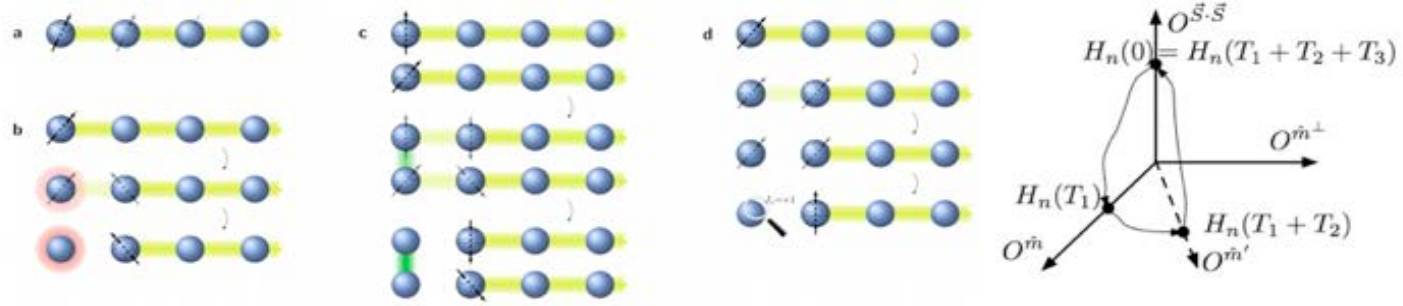
- Quantum computational phases of matter



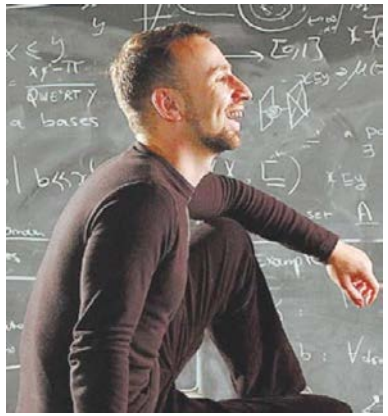


1D 2D

- Symmetry protected holonomic gates



Quantum Information and Gravity

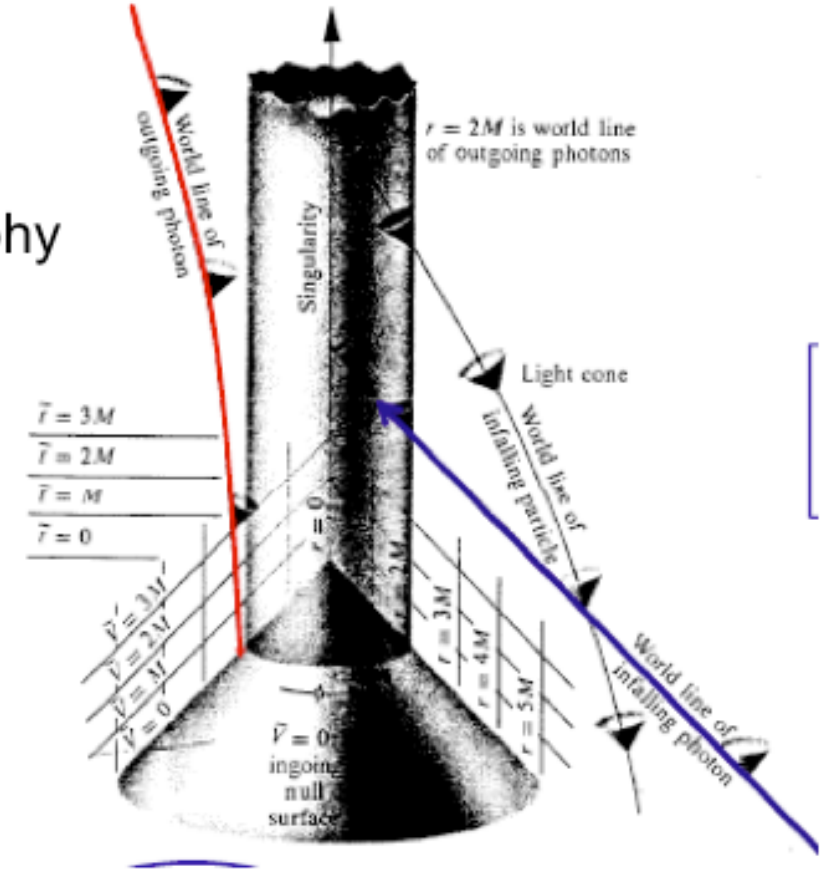


AProf Daniel Terno

Black Holes & Quantum Gravity

Research areas:

- Relativistic quantum information
- Black hole physics and holography
- Canonical quantum gravity
- Foundations of quantum theory
- Correlations and [quantum] thermodynamics



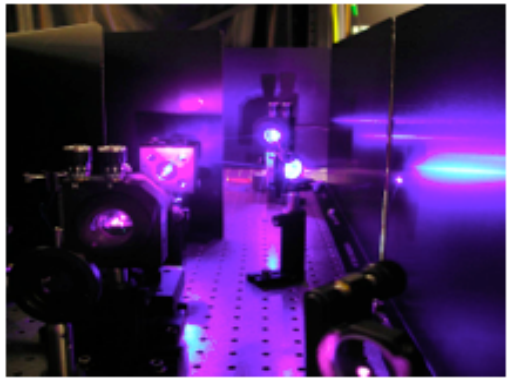
Robust Quantum Information and Sensing

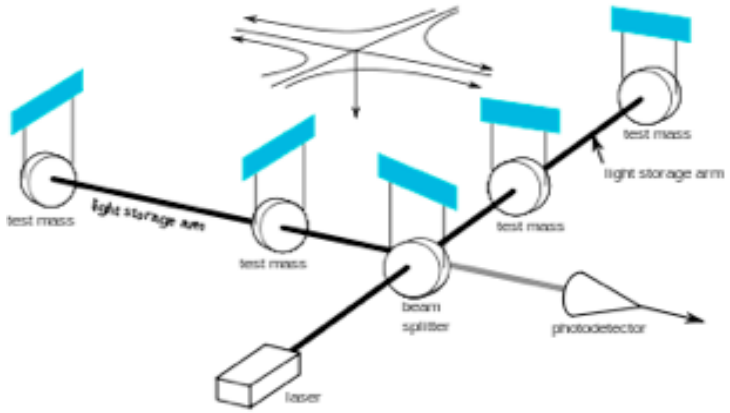
A/Prof Dominic Berry

Precision measurement

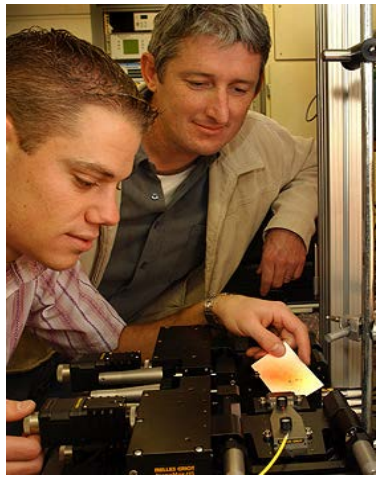
- Very precise measurements needed, e.g. for gravitational wave detection $\sim 10^{-18}$ m.
- We can use special quantum states to dramatically improve accuracy.

1. What states should you use?
2. How do you produce the states?
3. How do you perform the most accurate possible measurements?



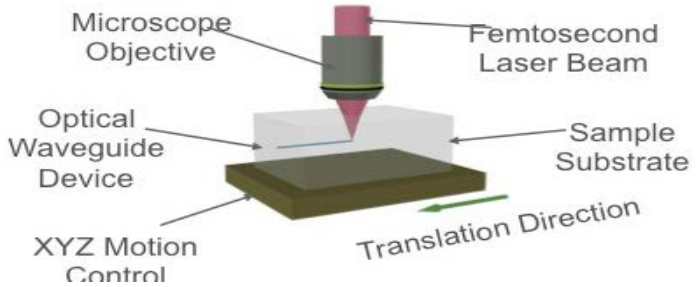


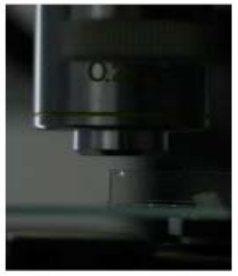
Integrated quantum photonics – experiment and theory



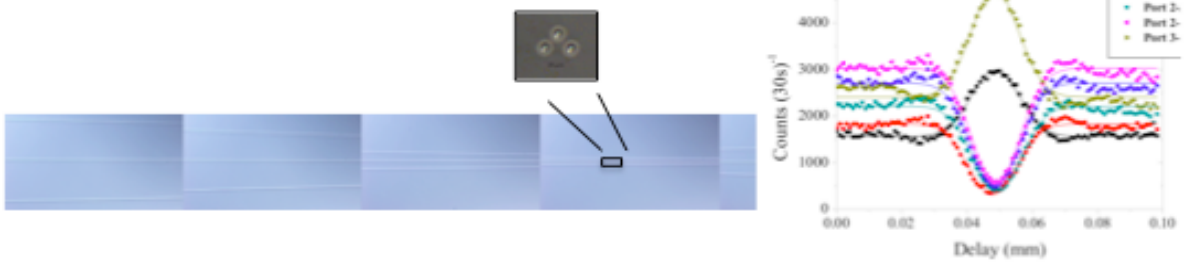
Prof Michael Withford

Prof. Michael Steel





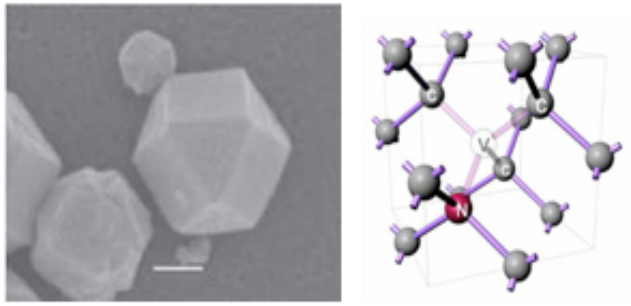
Visibility fringes from quantum interference experiment in a 3D 3-port coupler
see T. Meany et al, Optics Express (2012)



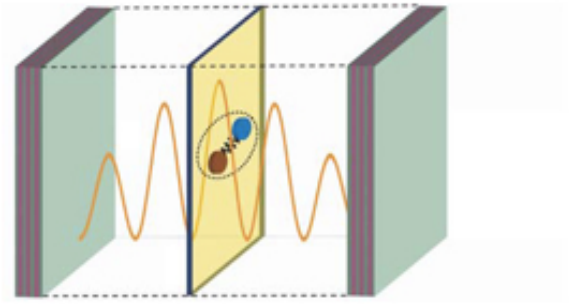
Quantum Materials and Applications

A/Prof Thomas Volz

- Our group studies light-matter interaction in the solid state using quantum optical techniques and methods.
- Potential applications in quantum photonics, quantum information processing, quantum sensing and quantum simulations.
- Main material systems:



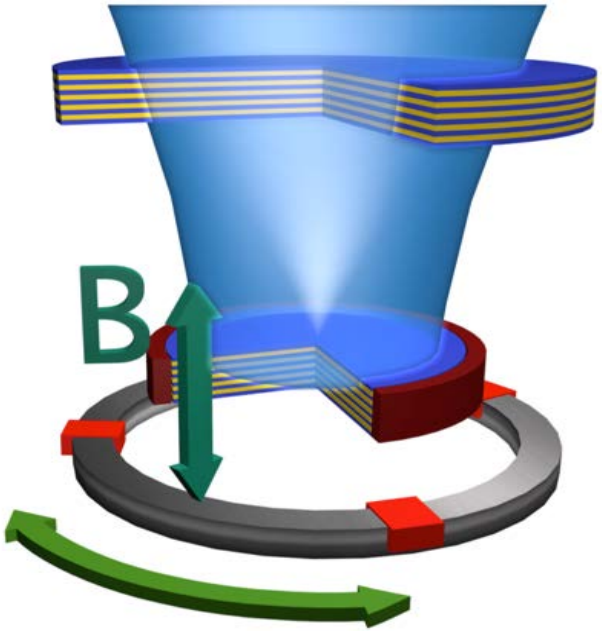
Defect centers in diamond



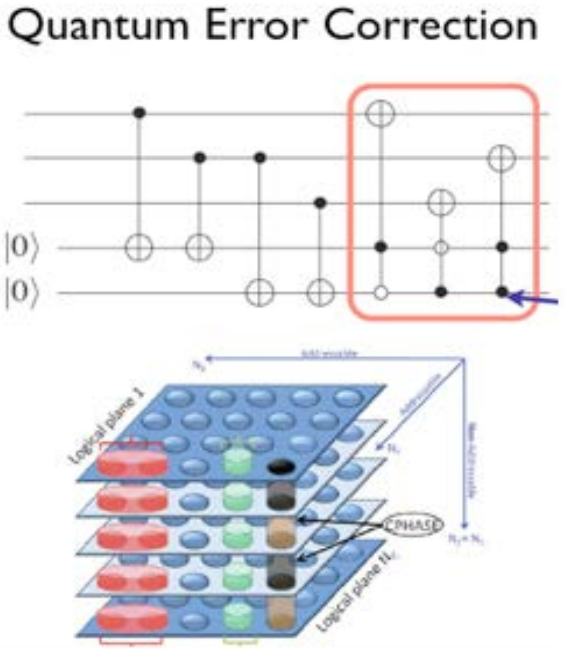
Semiconductor quantum-well polaritons

Theory of Quantum Hybrid Systems

Prof Jason Twamley



Design for quantum interface between microwave and optical systems for quantum communication, sensing and computing



Quantum Error Correction scheme which is fault tolerant but requires NO measurement!! and has high threshold

MQ PHOTONICS RESEARCH CENTRE

MACQUARIE University

MQ Photonics Research Centre

A national partner of choice for industry-focussed research in Photonics

How can we make light work for you?

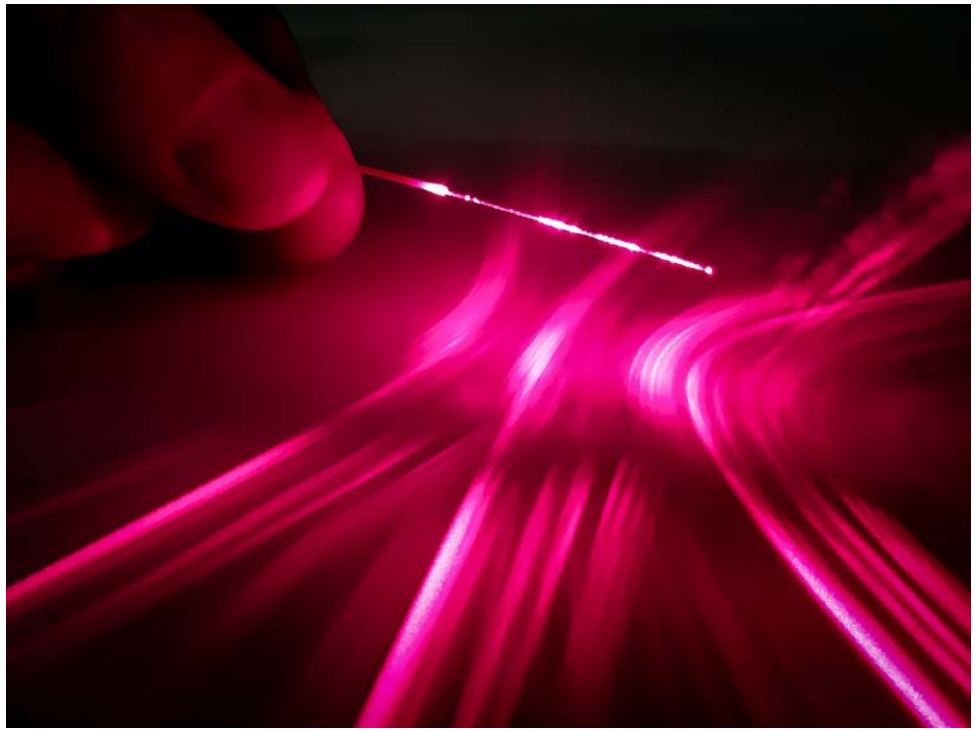


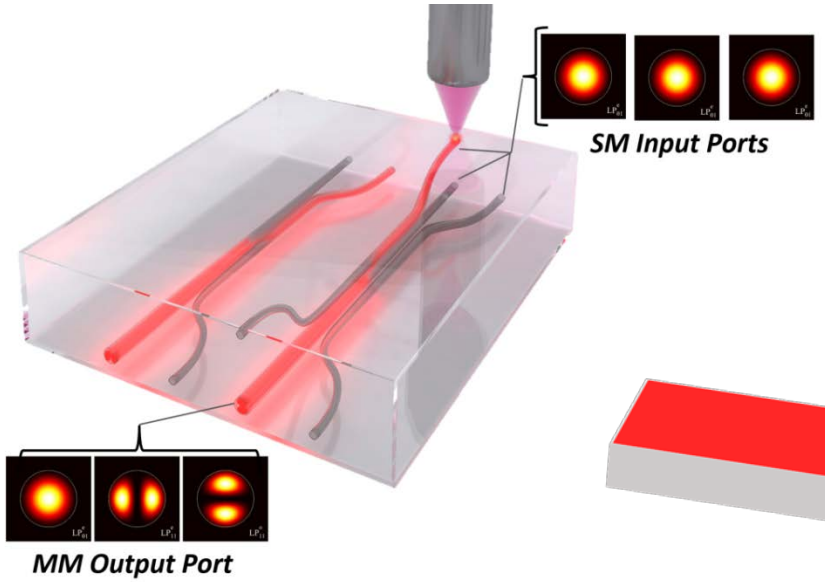
Image Dr Martin Ams, OptoFab

Judith Dawes, Director

Delivering Impact from our research

MACQUARIE University

MQ Photonics Research Centre



Modular Photonics

Innovative Products to speed up the internet

in partnership with ON POWERED BY CSIRO

Entrepreneurship training

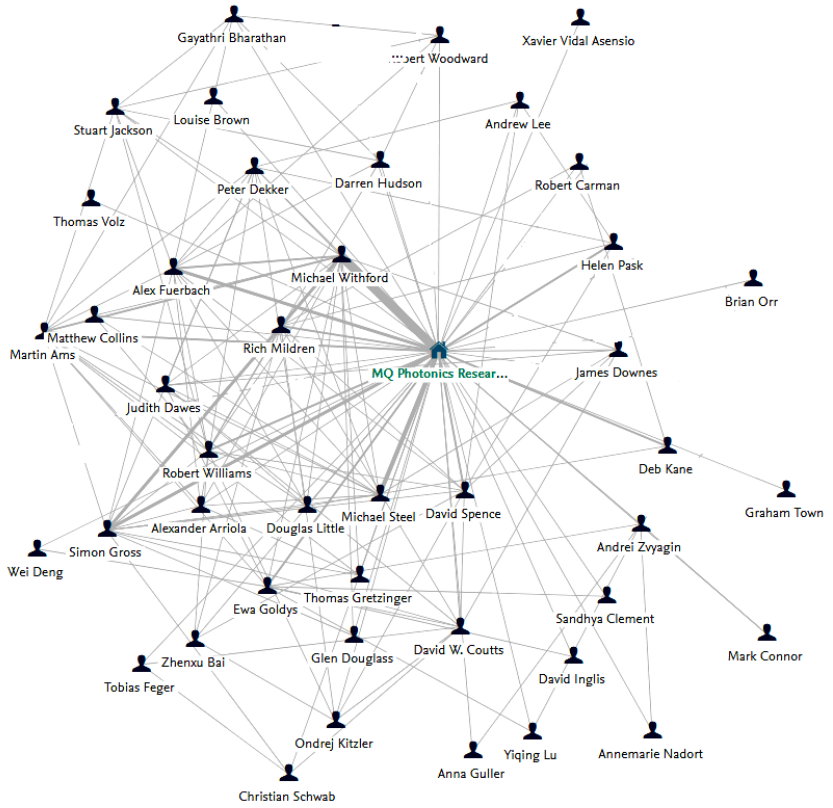
New products for our partners

M SQUARED

2017 Australian Museum Eureka Award
2018 Engineering Excellence Award
2018 Tall Poppy Award

Aim: a **two-way** interaction with Australian industry

As a **team**, work with industry, use our research expertise, increase our impact

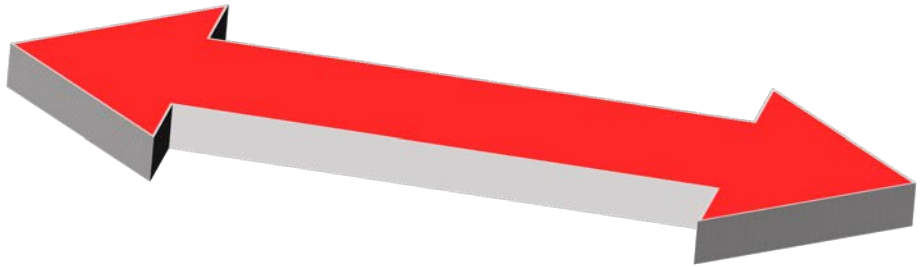


Connecting to Industry:

Understand our capabilities

Reach out through workshops

Solve industry problems



Highly collaborative team

MACQUARIE University

MQ Photonics Research Centre

AMGC ADVANCED MANUFACTURING GROWTH CENTRE LTD

MTP Connect MedTech and Pharma Growth Centre

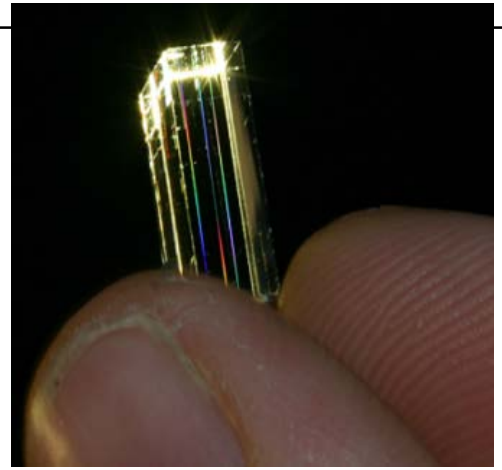
NSSN NSW Smart Sensing Network

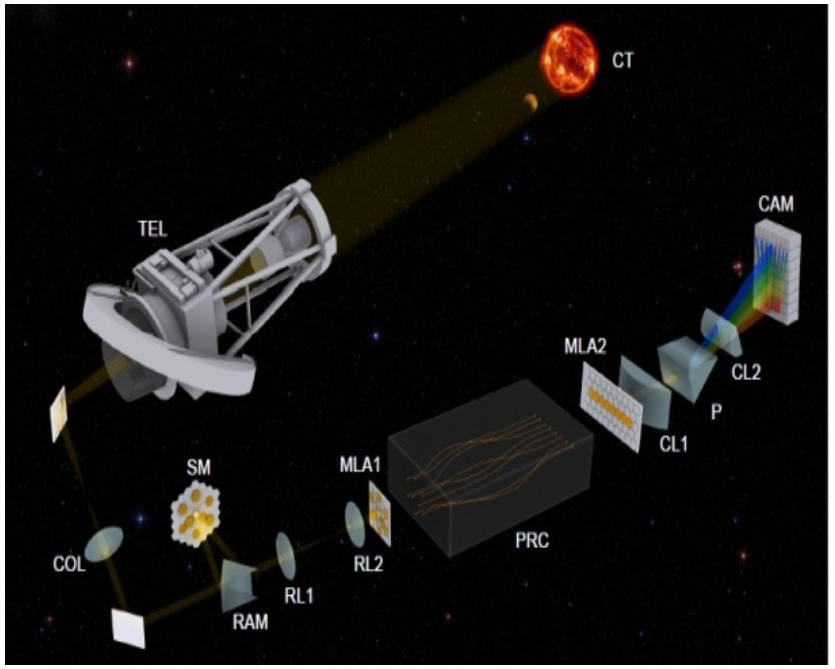
DIN DEFENCE INNOVATION NETWORK To go far, go together

MPID Macquarie Park Innovation District

MQ Photonics research themes and expertise

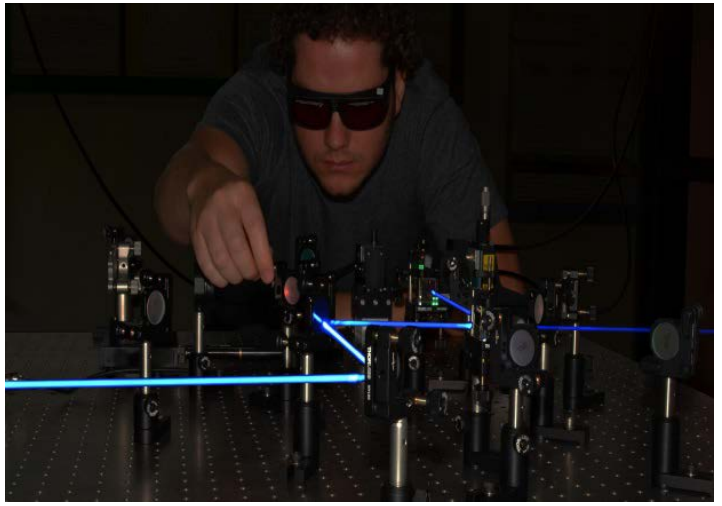
- **Integrated photonics -** waveguides in glass
- **Lasers –** IR, UV, THz, visible (pulsed, CW, ultrafast...)
- **Nanotechnology** – anti-counterfeiting, labels, photonic crystals, plasmonics, nanoparticles
- **Biophotonics** – imaging, theranostics, security
- **Astrophotonics** – high resolution, high
- throughput spectrometers, waveguide devices
- **Quantum photonics** – fundamental and applied

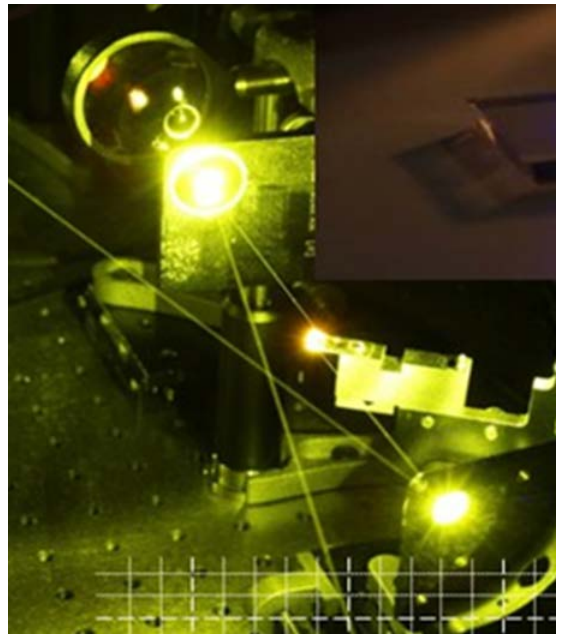




MQ Photonics research applications

- **Medical technology** – imaging, diagnostics
- **Alternative Energy** – photovoltaic sources
- **Defence** – high power lasers, countermeasures
- **Advanced manufacturing** – technology for quality control, materials processing, additive and subtractive manufacturing
- **Food and agriculture** – environmental sensing, quality control





The Yellow Laser

MACQUARIE University

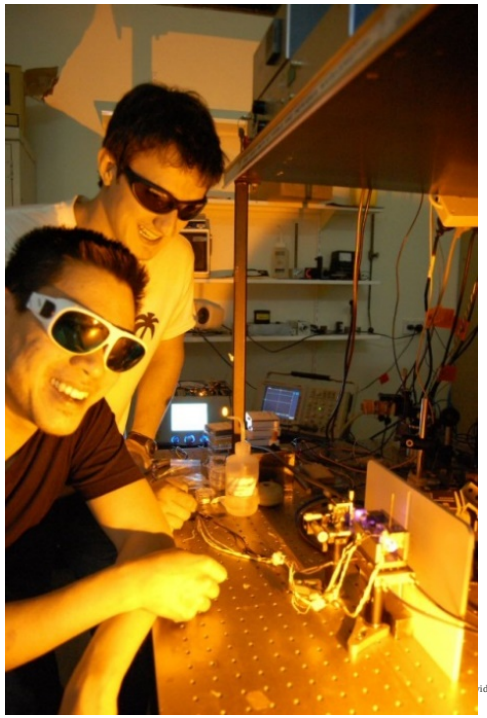
MQ Photonics has developed many novel lasers that access wavelengths in the UV, IR, THz, and visible regions.

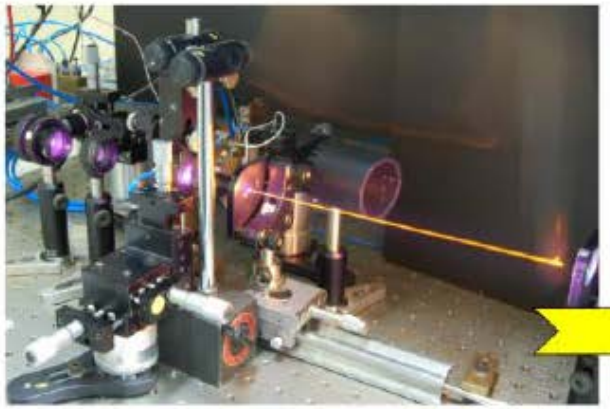
Yellow lasers are very useful for dermatology

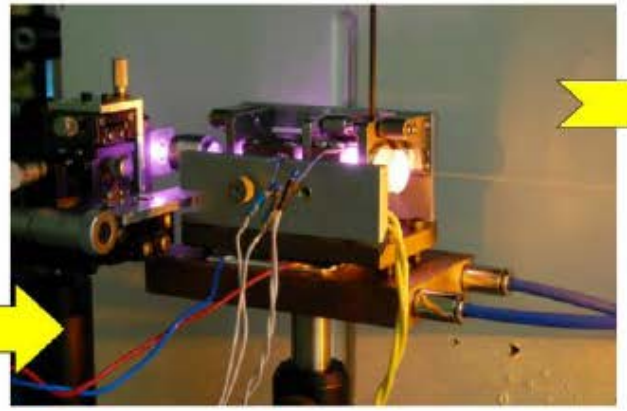
Macquarie spin off company "Lighthouse Technologies" (2004)

- Technology transfer to OptoGlobal, 100s of units sold around the world

Prof. Helen Pask
Dr Andrew Lee



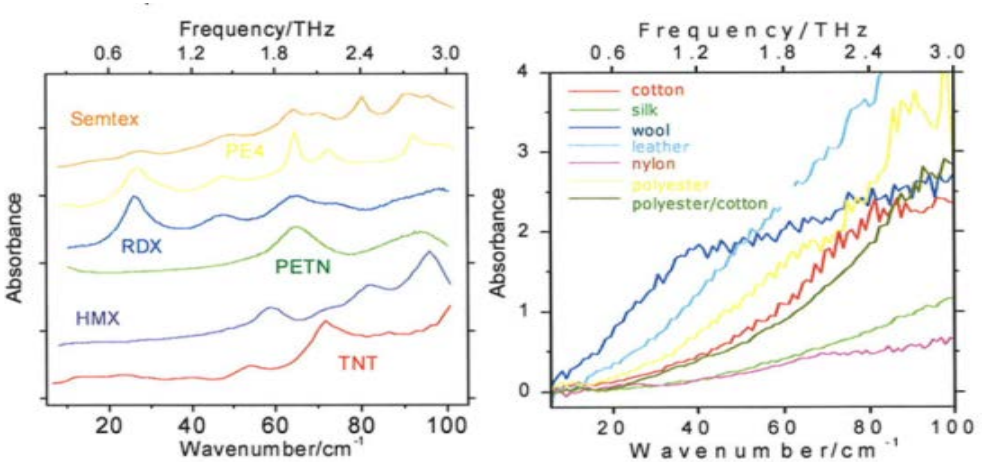




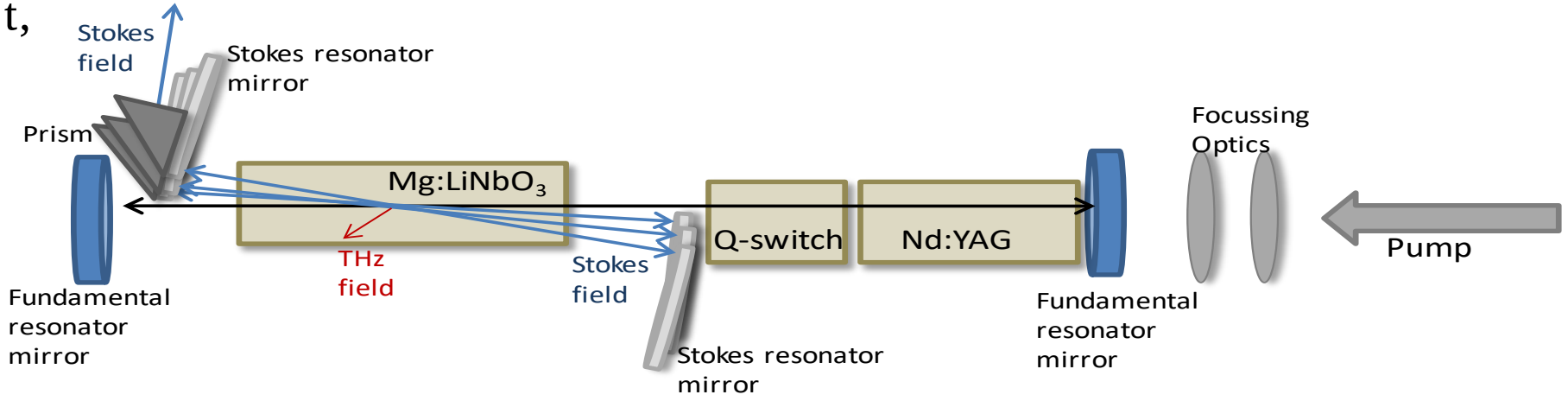
THz Sources and Applications

Compact, robust THz sources
Frequency-tunable
pulsed and CW
μW output power
Applications
THz imaging
THz spectroscopy
Security
Plant and crop management,

Imaging at 1.56 THz
Dickson *et al.* University of Massachusetts, 2006.



THz spectral properties of explosives and textiles
Teraview Press release, 2010.



Solid-state THz laser setup

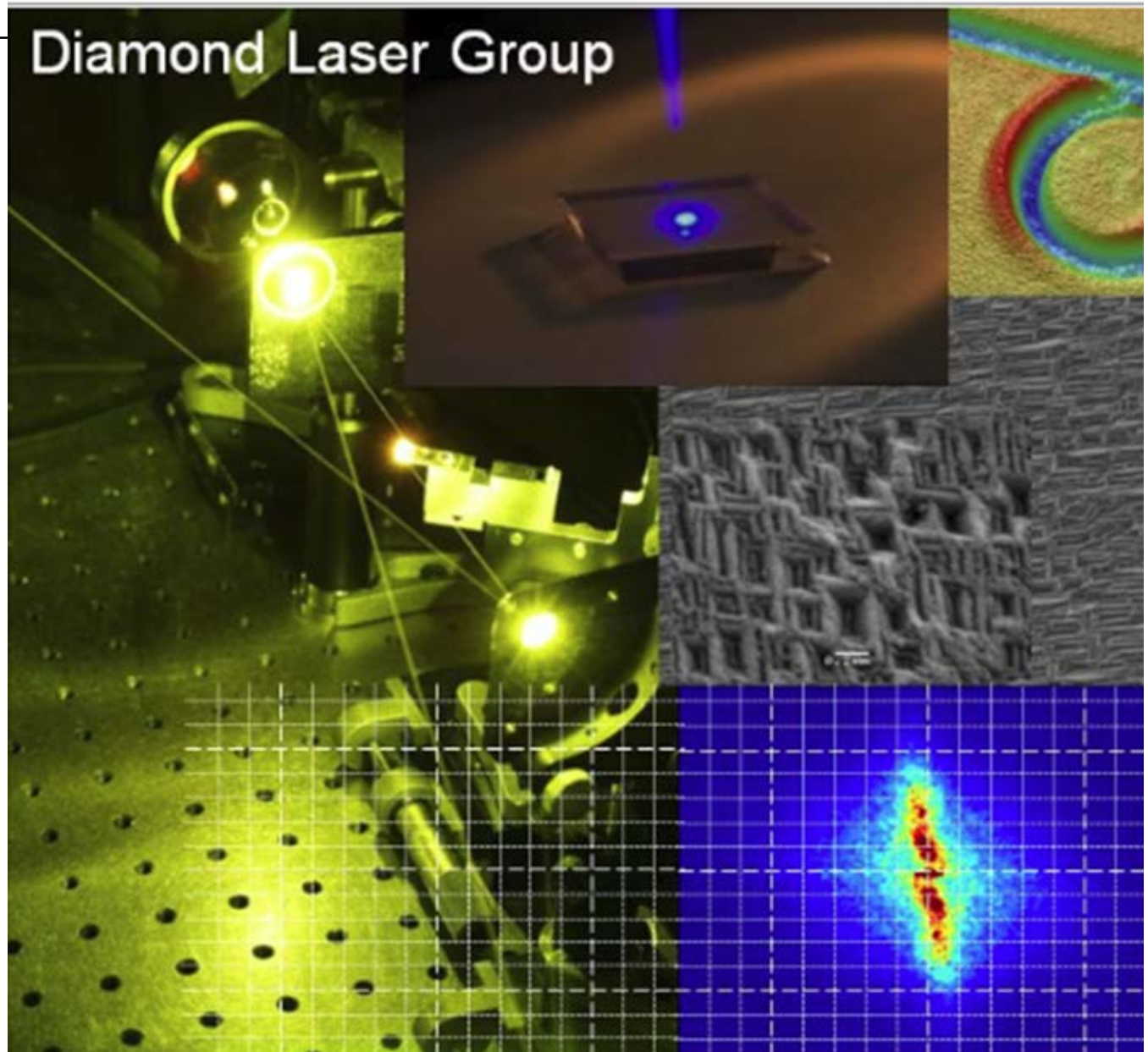
Prof. Helen Pask
Dr Andrew Lee

Diamond Raman lasers

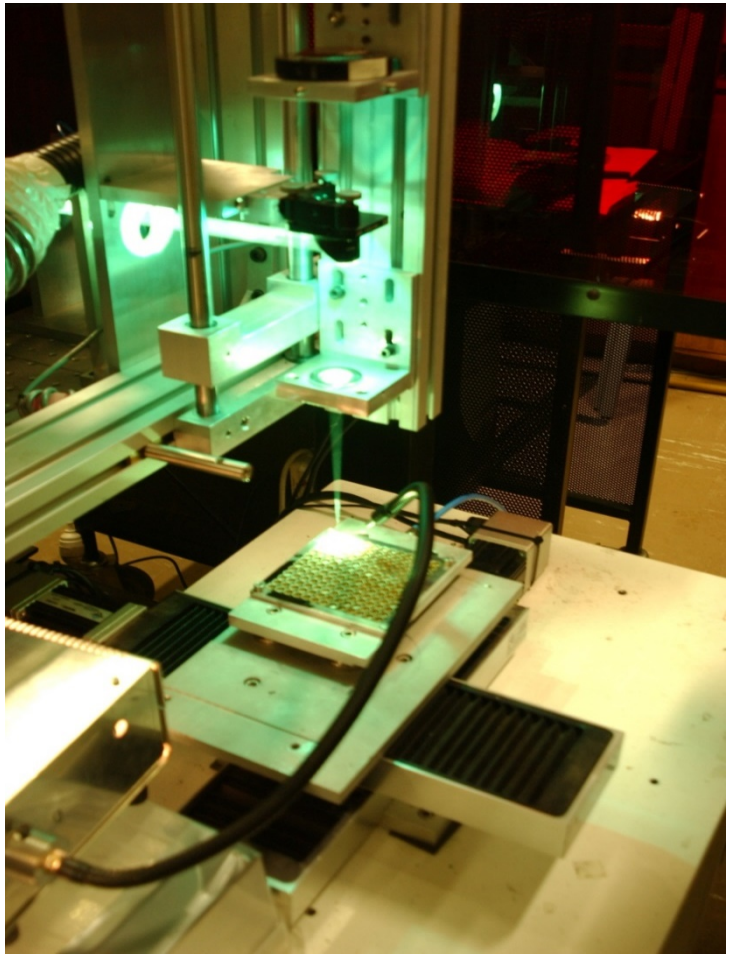
Diamond is amazing!
Large Raman shift and high gain
Excellent thermal properties
Broad transmission.

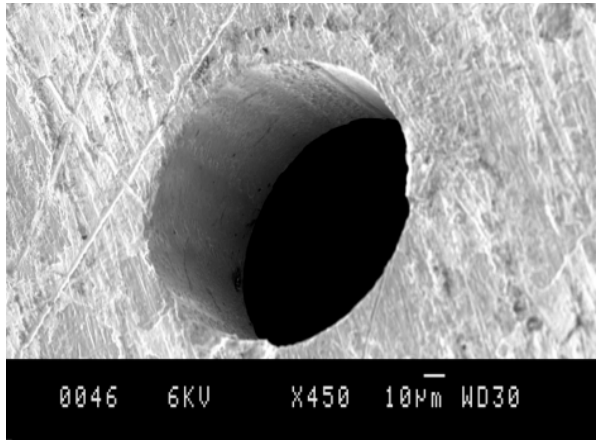
Efficient (>50%) beam conversion
UV, visible and IR,
Cw, pulsed (ns), ultrafast (ps)
Power scalable (>100's W)

Prof. Rich Mildren
Dr Robert Williams



Laser Micromachining



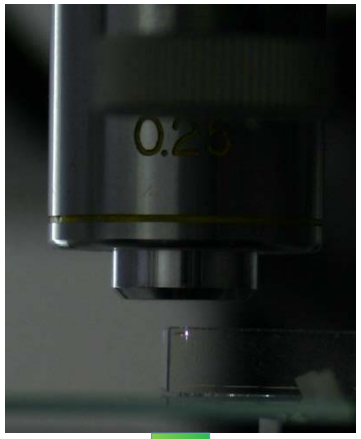


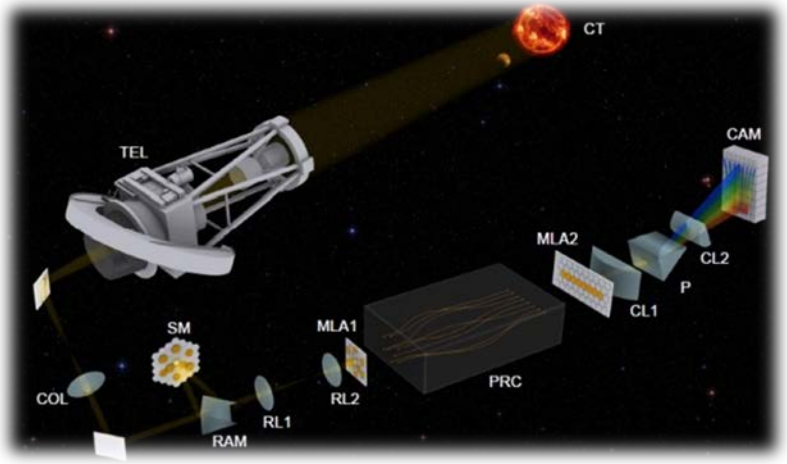
Prof. Michael Withford

3D Integrated Photonics

MACQUARIE University

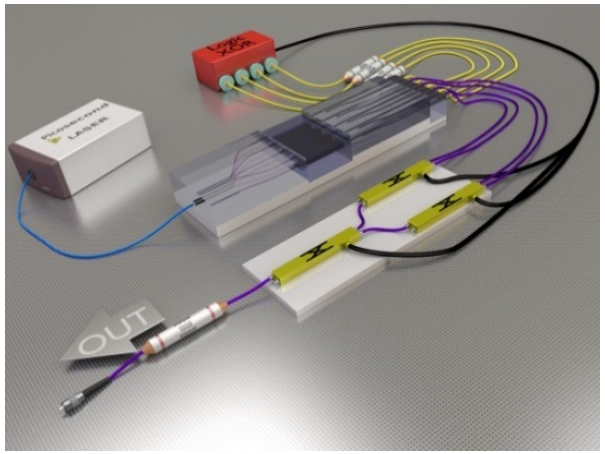
Ultrafast Laser Inscription



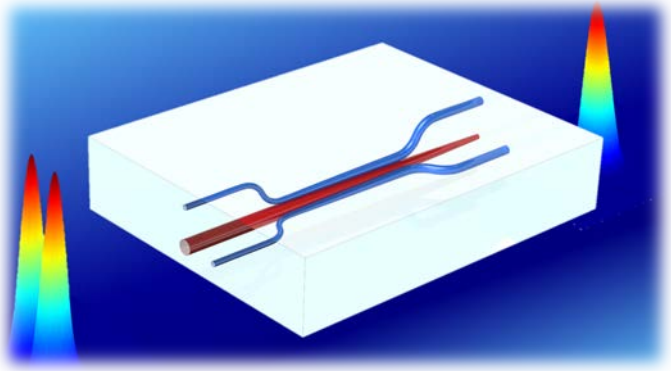


Astrophotonics

Quantum Photonics

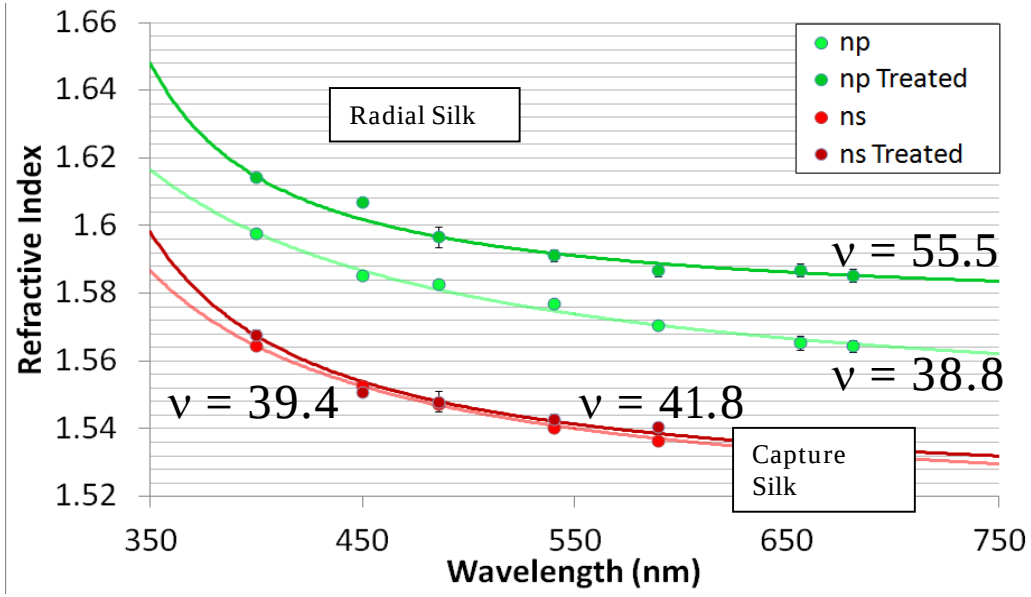


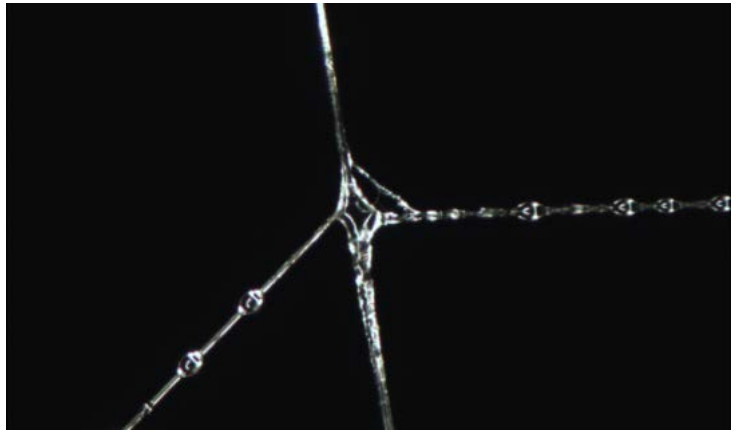
Optical Communication
Space division multiplexing



Prof. Michael Withford

Optical Properties of Spider Silk and Webs



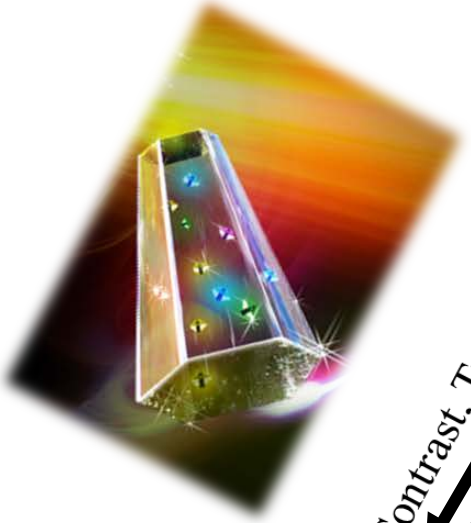


Prof Deb Kane
Dr Doug Little

Dr Douglas Little, 2014
National Measurement
Institute Prize

Biophotonics – Imaging, Diagnostics, Therapeutics

MACQUARIE University



Contrast, Tunability

Photo-stability

Biomedical Diagnostics

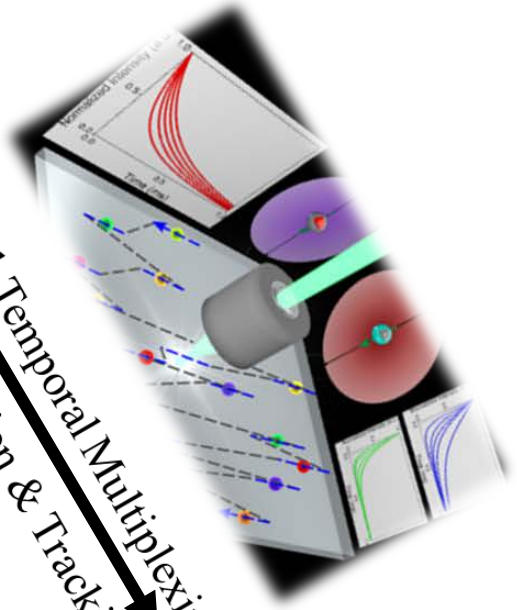
Sensitivity & Speed

Throughput & Resolution

Deep-Tissue Penetration

Spectral-Temporal Multiplexing

Rapid Detection & Tracking



New Modality

Characterisation

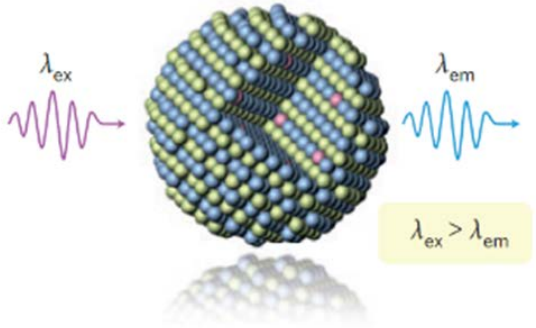
Materials

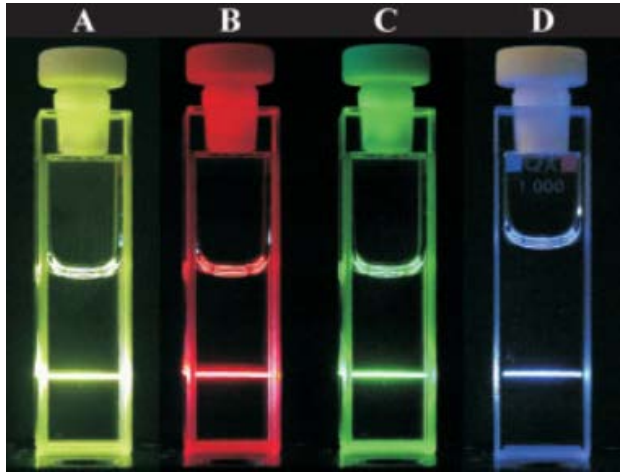
1. Long-lifetime Lanthanide Probes
2. Nanocrystals & Functionalisation
3. Responsive Biosensors/Nanomedicine

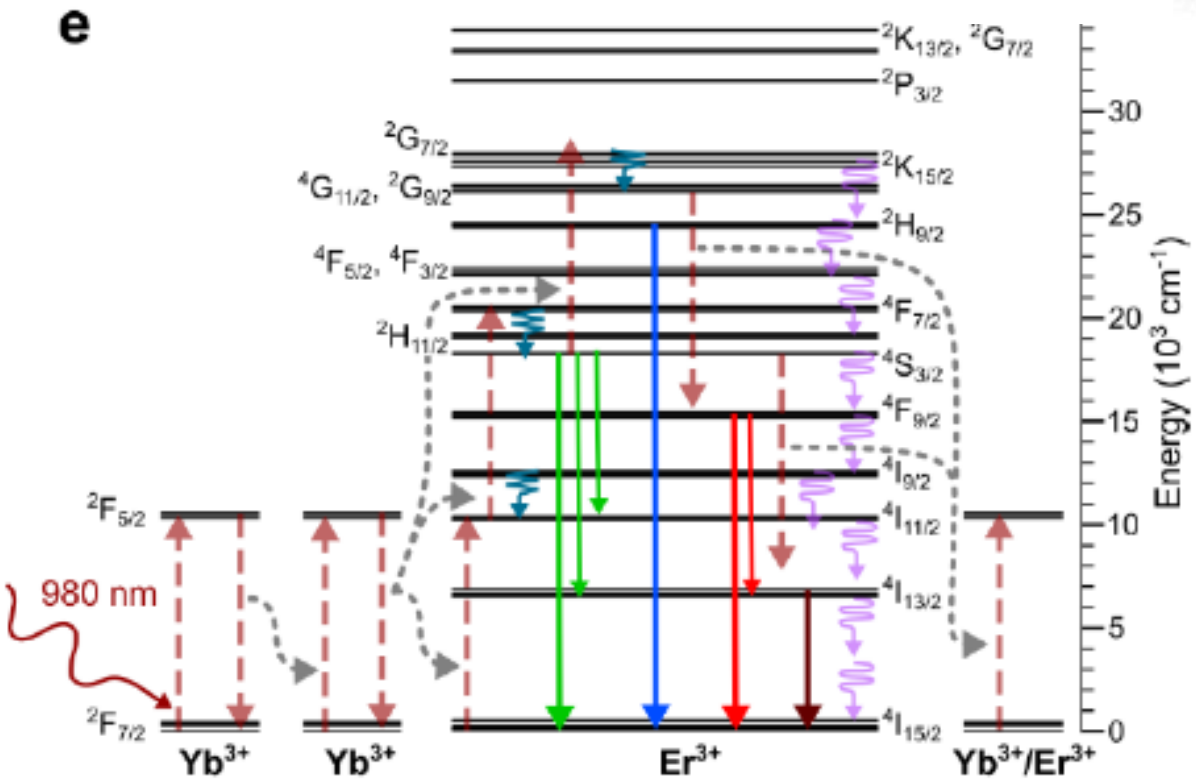
Instrumentation

1. Time-Resolved Detection
2. High-Throughput Automation
3. Microscopy/Macroscopy/Nanoscopy

Lanthanide Nanoparticles for Upconversion

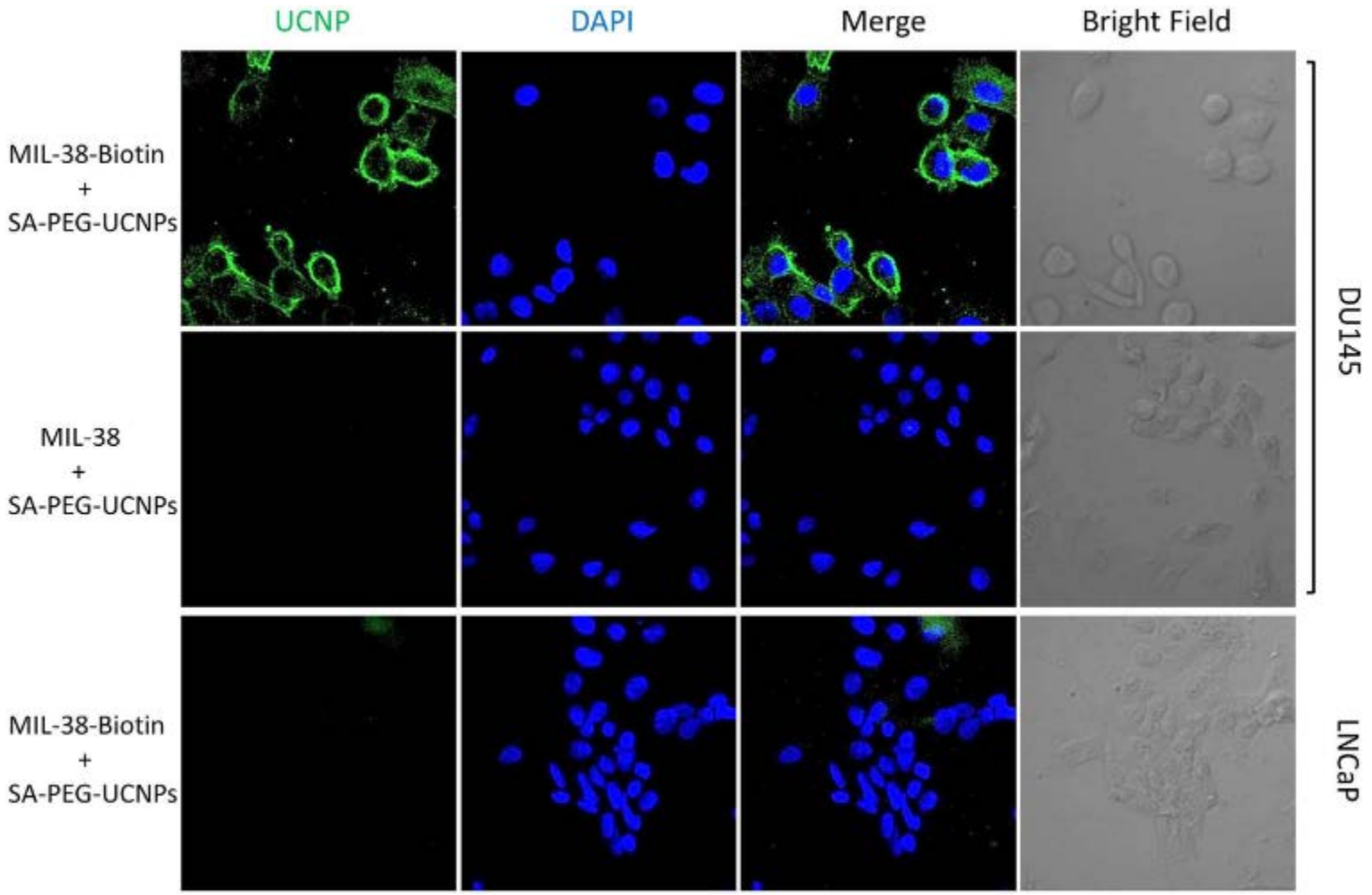






- Time-gated detection → low background;
- Inorganic → high photostability;
- Near-IR excitation → deep-tissue penetration;
- Flexible dopants → tunable emission.

Optical Detection of Labelled Cells



Improve contrast, selectivity with upconversion nanoparticles

Optical Strain Sensing using Opals

Nonthanan Sitpathom (Mahidol University)
Prof Judith Dawes

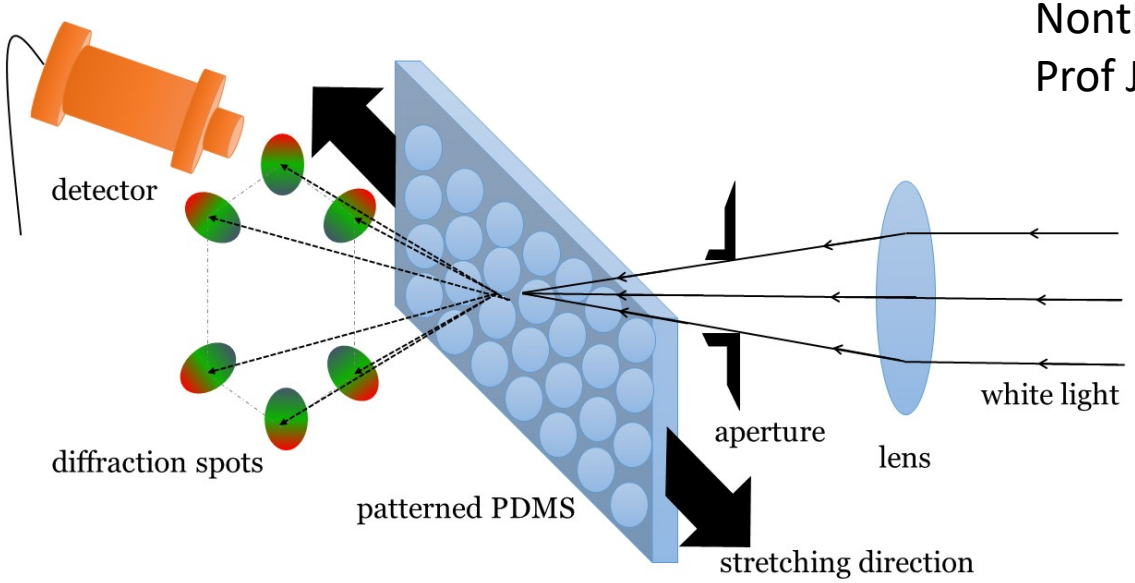
How can we measure a strain in an elastic material?
Use a colour change to aid end-users

…

- Tourniquet on a wounded arm or leg
- Elastic bandage for a surgery patient with varying gradations of pressure
- Artificial skin on a robotic arm to sense pressure changes.

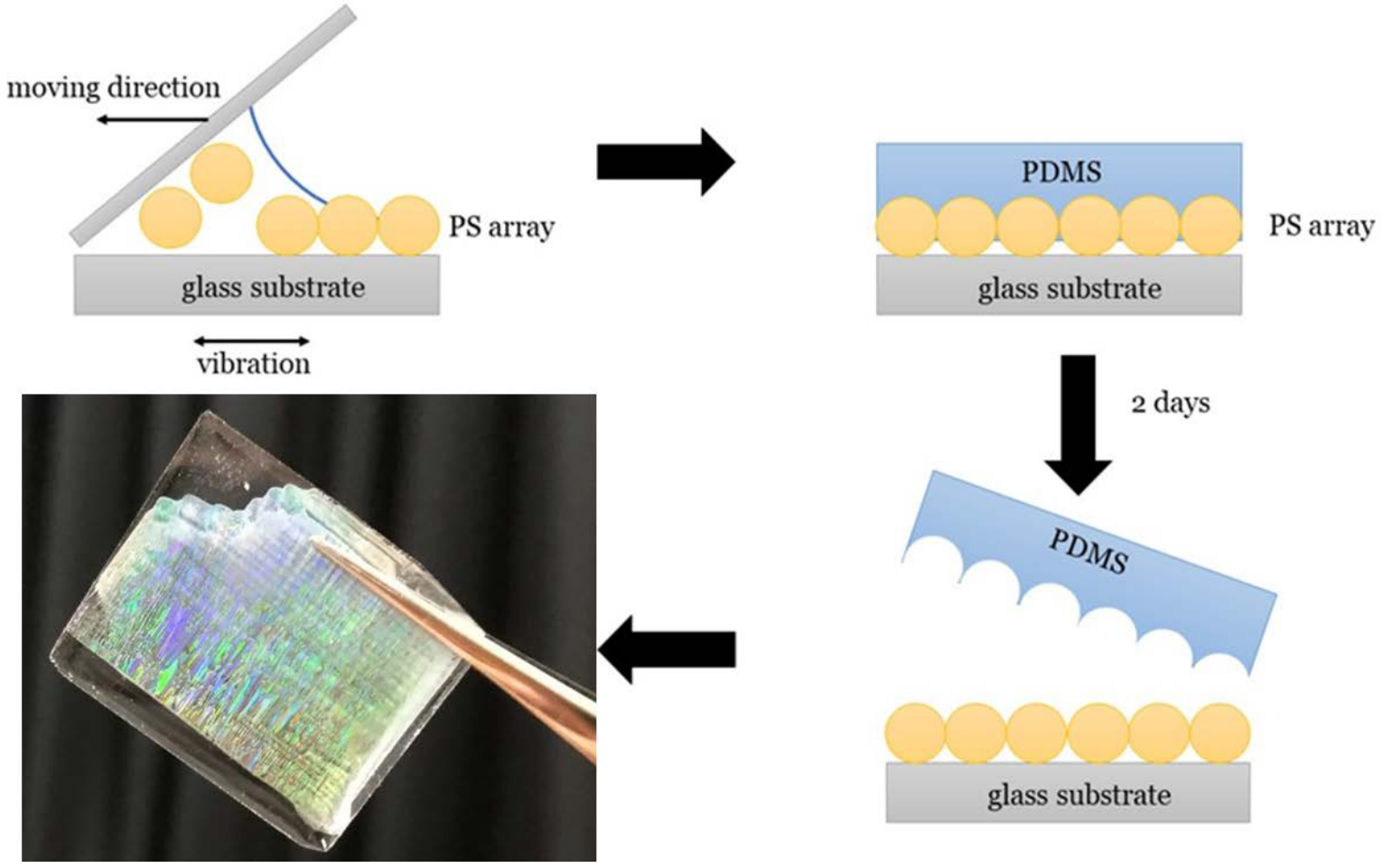
The idea: Optical Strain Sensing using Opals

Nonthanan Sitpathom (Mahidol University)
Prof Judith Dawes

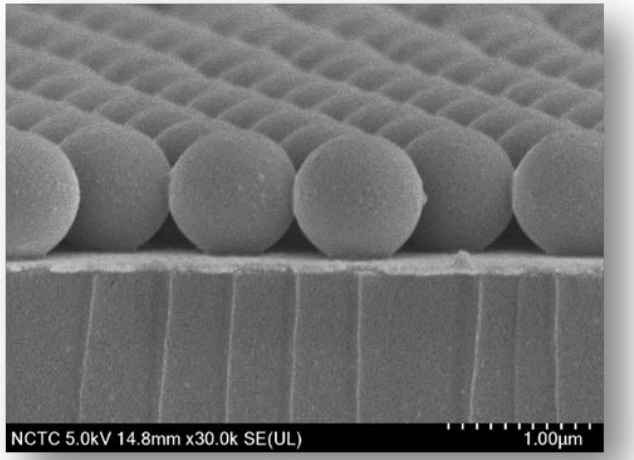


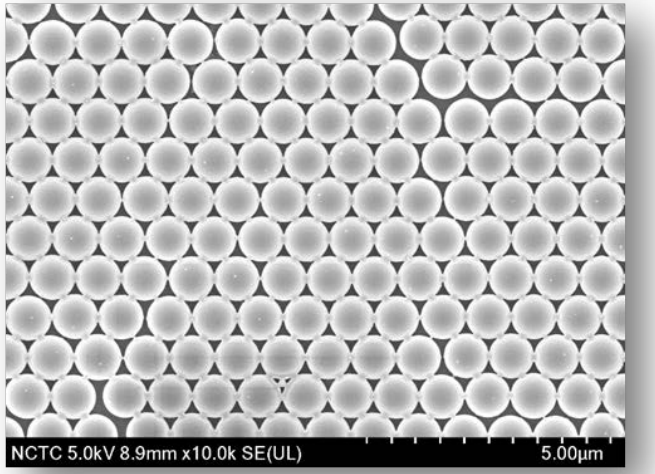
Increasing stress

Fabrication of patterned opal films



Scanning electron microscope images





Sensitivity of patterned PDMS strain sensor

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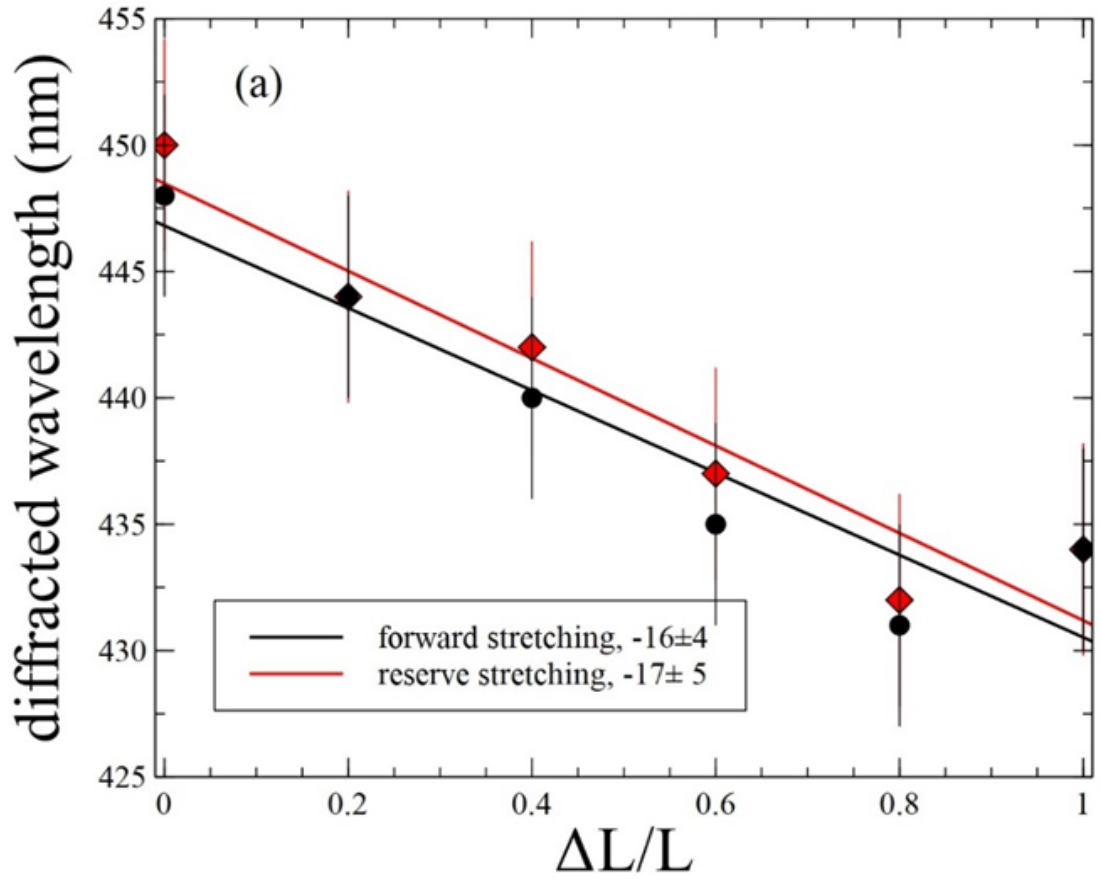
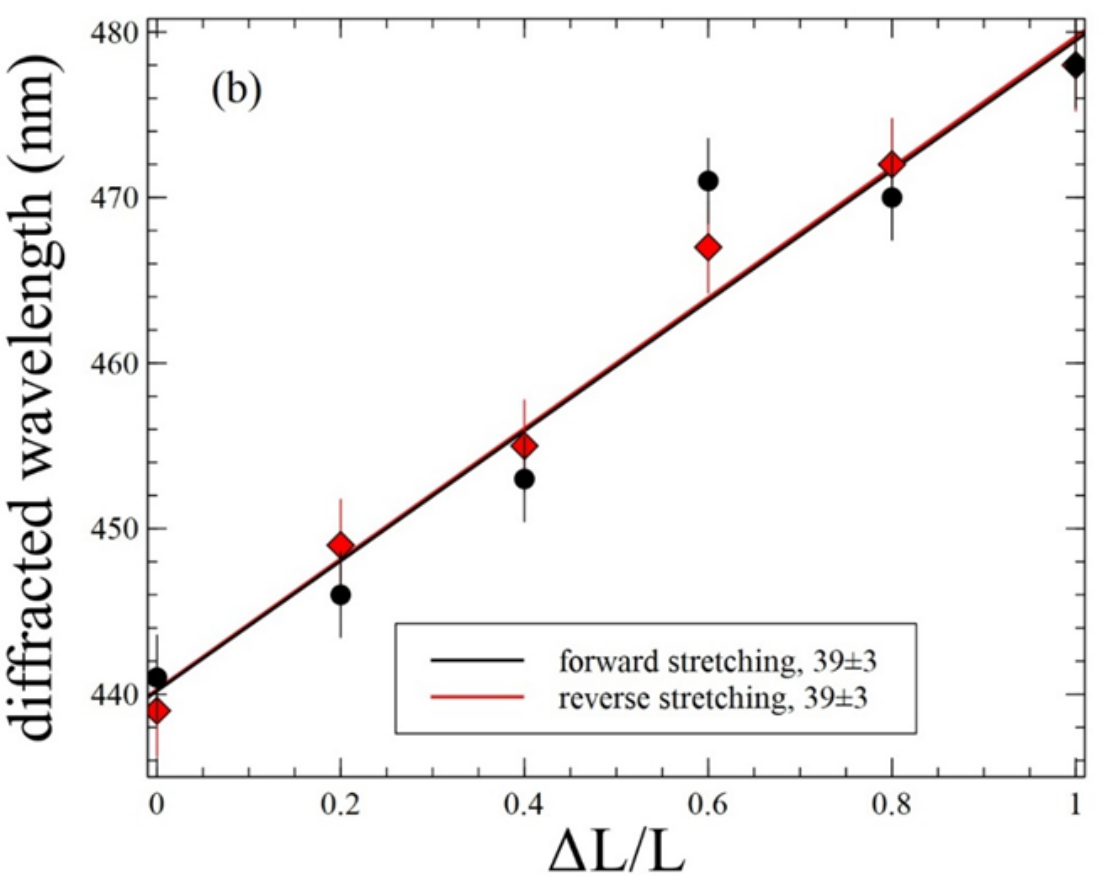
Perpendicular axis



Parallel axis



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Thank you for your attention!