SUPA

IAC Meeting 2018

Photonics Theme

Jennifer E. Hastie

Institute of Photonics, Department of Physics,
University of Strathclyde

Photonics

Photonics is a key theme in SUPA, with ~90 core photonics academics working in Scottish physics departments:

- Dundee > 5
- Glasgow > 10
- Heriot Watt > 30
- St Andrews > 17
- Strathclyde > 30

Scottish photonics industry

Fraunhofer Centre for Applied Photonics (CAP)
– SUPA Associate Member
2nd phase funding - £5M - announced Feb 2018

Fraunhofer UK/CAP:2nd phase funding

8 February 2018
The UK headquarters for Europe's largest contract research organisation, based at the University of Strathclyde, has received an investment of more than £5million.
The second phase of work of the Fraunhofer Centre for Applied Photonics (FhCAP) will be supported through funding from the Scottish Government and Scottish Enterprise.

Paul Wheelhouse, MSP: *"Photonics is a key enabling technology and Scotland punches above its weight with a thriving, globally-competitive sector, with the Fraunhofer Centre for Applied Photonics at its heart. "Their range of expertise and services is unique in the UK, and Glasgow was chosen by the internationally respected Fraunhofer Institute as their European location to build on the considerable Scottish strengths in advanced photonics…"*

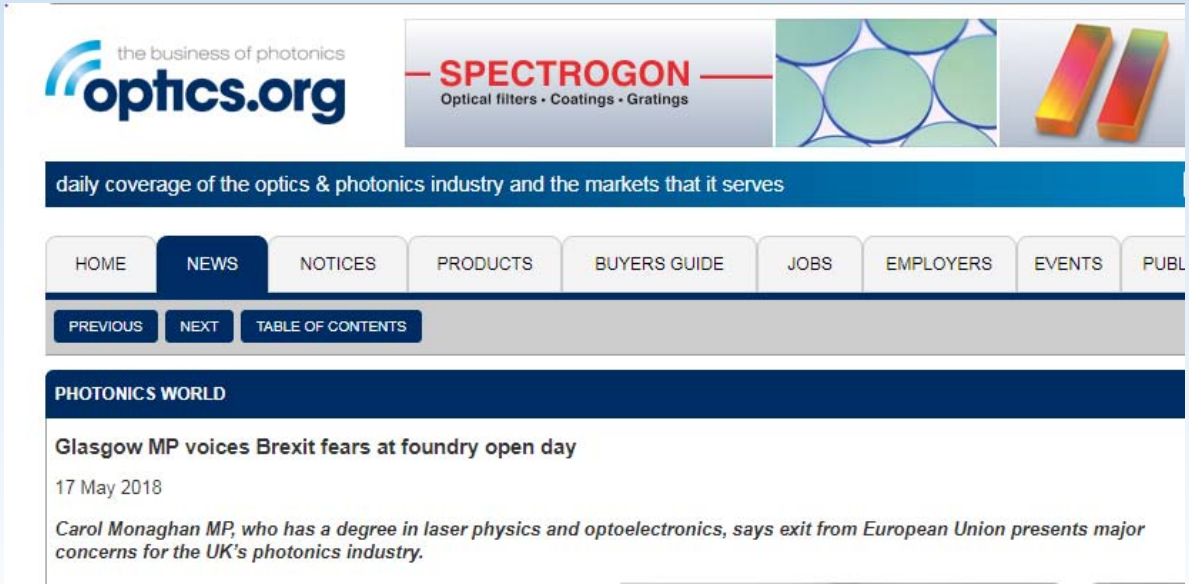
Slide courtesy of Martin Dawson

Fraunhofer UK

CST Global Expansion

CST Global Technology Day, 10th May 2018

- Opening of extended compound semiconductor production facility in Blantyre
- Keynote speaker: Carol Monaghan MP
- Launch of 'T@CST photonics collective':
  - Industrialists, academics, engineering, funders, and government.
  - *"Identify the steps necessary to commercialise new photonics technologies being developed."*



http://optics.org/news/9/5/17

The landscape

Opportunities for UK photonics

HM Government → Industrial Strategy

Building a Britain fit for the future

- 4 Grand Challenges:
  - AI and Data Economy
  - Clean Growth
  - Future of Mobility
  - Ageing Society
- *"We will invest in pioneer funding for **quantum technologies, up to £20m**, recognising the impact this could have across a number of challenge areas. A new set of products from medical devices to sensors and safer communication systems may be possible using the emerging physical science known as quantum technology."*

UK Government Brexit document, 6th September 2017

17. The UK's strength in science and innovation is spread across the four nations. Scotland has a significant interest in this area, being home to three universities in the world's top 100[23] and several international research centres. These centres include the Fraunhofer Centre for Applied Photonics at the University of Strathclyde – a world-leading centre in applied laser research and development,[24] and the world's first international Max-Planck Partnership. The latter brings together leading physics research groups across Scotland and Germany to further research in quantum technologies used in hi-tech sectors such as oil exploration and computing.[25] Welsh leadership in the compound semiconductor

→ Photonics Roadmap

- **IOP Report May 2018: "The Health of Photonics"**

  How light-based technologies are solving industry challenges, and how they can be harnessed to impact future economic growth.

- Contributions from SUPA Photonics academics and Scottish Photonics Industry
- UK photonics industry contributes £13 bn to the economy
- Identifies short, medium, and long term priorities for: system-level integration, LEDs, optical comms systems, new optical materials, sensors, lasers and imaging, and photonics for manufacturing
- Photonics for the 4 grand challenges identified in the Government Industrial Strategy

Major projects/initiatives

Multi-institution collaborations and networks

Training networks

EPSRC Centres for Doctoral Training

Applied Photonics
Heriot Watt University (lead), Universities of **Dundee**, **Glasgow**, **St Andrews**, and **Strathclyde**
23 industrial partners, including Fraunhofer CAP
→ **Industry-Inspired Photonics Imaging, Sensing and Analysis** (invited to full proposal, Jul 2018)

Integrative Sensing and Measurement
University of Glasgow (lead) and the **University of Edinburgh**
Industrial, research and international partners

Optical Medical Imaging
University of Edinburgh (lead) and the **University of Strathclyde**

Diamond Science & Technology
University of Warwick (lead), **University of Strathclyde** and 6 other UK universities
30 industry partners including **Fraunhofer CAP**
→ **Diamond Science & Technology II** (invited)

Advancing and Applying Quantum Technologies (invited)
University of Strathclyde (lead), Universities of **Glasgow** and **Heriot Watt**

Emerging Technologies and Data Analysis for Advanced Imaging and Sensing (EMERGE) (invited)
University of Glasgow

Horizon 2020 Marie Skłodowska-Curie Innovative Training Network

Collective effects and optomechanics in ultra-cold matter (ColOpt)
University of Strathclyde (co-ordinator), **University of Glasgow** and 7 other academic partners
€3.9M, Jan 2017

SUPA SU2P and IMPP

SU2P

Partners: Universities of **Strathclyde, St Andrews, Heriot Watt, Glasgow** and **Edinburgh**

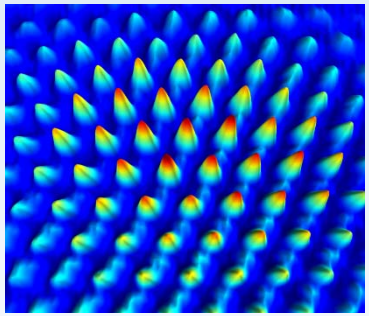
Partner: **Stanford University**

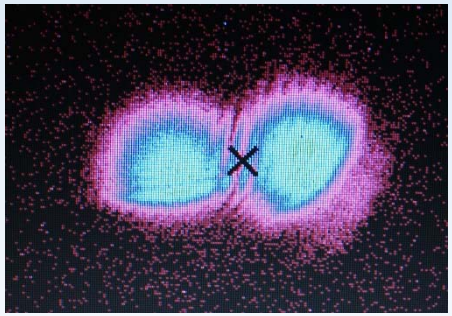
International Max Planck Partnership

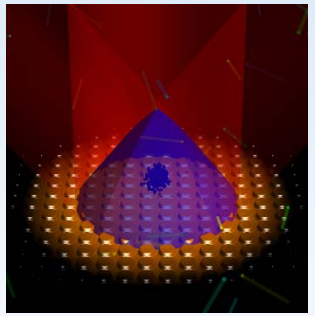
Measurement and Observation at the Quantum Limit

Partners: Universities of **Glasgow**, **Strathclyde**, **St Andrews**, **Heriot Watt** and **Edinburgh**

Partner MPIs: Gravitational Physics (Hannover), Science of Light (Erlangen), Quantum Optics (Garching), Chemical Physics of Solids (Dresden), and Solid State Research (Stuttgart)







EPSRC Quantum Tech. Hubs

UK NATIONAL QUANTUM TECHNOLOGIES PROGRAMME

- £270M investment to fund a national network of Quantum Technology Hubs
- Launched December 2014
- 17 universities
- 132 companies at time of launch

UK National Quantum Technology Hub Sensors and Metrology

QUANTIC

NQIT Networked Quantum Information Technologies

QUANTUM COMMUNICATIONS HUB

Universities: Birmingham (lead), **Glasgow**, Nottingham, Southampton, **Strathclyde**, Sussex

Aims: develop a range of quantum sensor and measurement technologies that are ripe for commercialisation by UK business.

Applications include: defence, geophysics, medical diagnostics, construction, naval navigation, health monitoring, GPS, network timing, and gravity imaging.

EPSRC investment: £35M

EPSRC Quantum Tech. Hubs

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UK National Quantum Technology Hub Sensors and Metrology

QUANTIC

NQIT Networked Quantum Information Technologies

QUANTUM COMMUNICATIONS HUB

Universities: **Glasgow** (lead), Bristol, **Edinburgh**, **Heriot-Watt**, Oxford, **Strathclyde**

Aims: develop new ultra-high sensitivity cameras with capabilities far beyond current state-of the art.

Applications include: visualising gas leaks, seeing through smoke, around corners and under skin, single-photon cameras, single-pixel cameras, gravity field imaging, extreme time-resolution imaging.

EPSRC investment: £23M

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UK National Quantum Technology Hub Sensors and Metrology

QUANTIC

NQIT Networked Quantum Information Technologies

QUANTUM COMMUNICATIONS HUB

Universities: Oxford (lead), Leeds, **Strathclyde**, Sussex, Bath, Southampton, Cambridge, **Edinburgh**, Warwick

Aims: develop networked quantum information technologies to surpass current supercomputers. Flagship project is the Q20:20 quantum engine.

Applications include: drug development, analysing 'Big Data', ultra-fast generation of quantum random numbers, secure communication, distributed sensing.

EPSRC investment: £38M

EPSRC Quantum Tech. Hubs

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UK National Quantum Technology Hub Sensors and Metrology

QUANTIC

NQIT Networked Quantum Information Technologies

QUANTUM COMMUNICATIONS HUB

Universities: York (lead), Bristol, Cambridge, **Heriot-Watt**, Leeds, Royal Holloway, Sheffield, **Strathclyde**

Aims: development of quantum key distribution; working towards market-ready technologies; smaller, lower-cost devices to be integrated into existing systems and infrastructure; chip-scale integration.

Applications include: encryption of communications, passwords, ID; financial transactions; mobile banking.

EPSRC investment: £24M

EPSRC Quantum Tech. Hubs

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UK National Quantum Technology Hub Sensors and Metrology

QUANTIC

NQIT Networked Quantum Information Technologies

QUANTUM COMMUNICATIONS HUB

Phase II?

UK quantum chiefs urge MPs to back funding commitment for industry phase

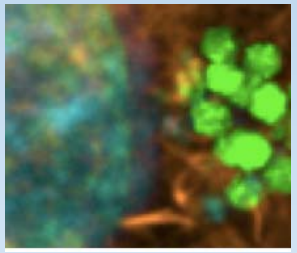
Optics.org, 5th June 2018

Sir Peter Knight: “Photonics contributes more to the GDP of the UK than pharmaceuticals.”

http://optics.org/news/9/6/6

EPSRC large projects

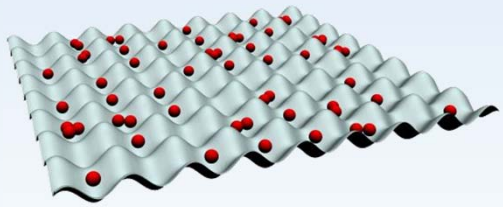
PROTEUS



Interdisciplinary Research Collaboration (IRC)

- Consortium Universities: **Edinburgh**, **Heriot-Watt** and Bath
- Aim: develop a revolutionary technology that will provide quick, in situ, in vivo diagnoses and management of lung diseases in the clinical environment.
- 2013 – 2019; **EPSRC investment: £11.3M**

DesOEQ



Programme Grant (Physical Sciences)

Designing out-of-equilibrium many-body quantum systems

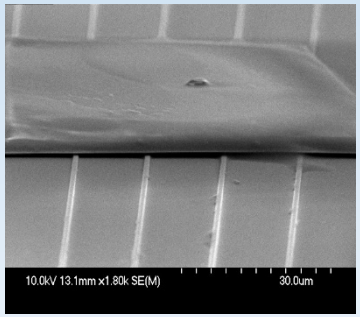
- Universities: **Strathclyde**, Cambridge, Oxford
- Aim: explore, understand, and design out-of-equilibrium quantum dynamics that are relevant for future communication and quantum technologies, using quantum simulators.
- 2017 – 2022; **EPSRC investment: £5.8M**

EPSRC large projects - new

Programme Grant (Physical Sciences)

Resonant and shaped photonics for understanding the physical and biomedical world

- Universities: **St Andrews** and York
- Aim: explore new and innovative ways to use light to measure the natural world; in particular exploiting resonant structures and shaped light.
- 2017 – 2022; **EPSRC investment: £5M**



Programme Grant (Manufacturing)

'Hetero-print': A holistic approach to transfer-printing for heterogeneous integration in manufacturing

- Consortium Universities: **Glasgow**, **Strathclyde**, Cambridge, Manchester, and Sheffield
- Aim: introduce significant new capabilities for the manufacture of electronic, photonic, and other systems via micro- and nano-transfer printing.
- 2018 – 2023; **EPSRC investment: £5.5M**

Photonics Grants

>£23M in project grants awarded since last IAC

(this does not include numerous grants and PhD projects with individual values <£100k)

Photonics grants

Heriot Watt University - £7.9M

- Seeing inside buildings, Phase II
  EPSRC £215k, Jun 2017 – Daniele Faccio
- The silicon vacancy in silicon carbide: a promising qubit in a technological material
  EPSRC £101k, Jun 2017 – Cristian Bonato
- Imaging through obscurants using single-photon and few-photon detection in the short wave infrared (phase two)
  Centre for Defense Enterprise £333k, Jul 2017 – Gerald Buller
- Platform Grant: Multi-modal manufacturing of medical devices
  EPSRC £1.3M, Jul 2017 – Duncan Hand
- DRAFTS: Drone-assisted Fourier-transform spectroscopy for fugitive emission sensing
  STFC £300k, Aug 2017 – Derryck Reid
- Putting chaos to work: multi-photon entanglement in complex scattering media
  EPSRC £1.2M, Sep 2017 – Mehul Malik
- Red Alert: autonomous aerial surveying
  Dstl £110k, Oct 2017 – Derryck Reid
- Two-dimensional photonics fabrication facility
  EPSRC £582k, Oct 2017 – Brian Gerardot

Photonics grants

Heriot Watt University - £7.9M

- Low noise, high-throughput, time-resolved single-photon sensor for quantum applications
  EPSRC £167k, Oct 2017 – Robert Thomson
- SHARK: laser surface engineering for new and enhanced functional performance with digitally enabled knowledge base
  European Commission £384k, Oct 2017 – Duncan Hand
- 2DQP
  European Commission £1.26M, Jan 2018 – Brian Gerardot
- ULTRAfast laser WELDing of highly dissimilar materials – development of a truly industrial process
  IUK £275k, Jan 2018 – Duncan Hand
- Novel non-linear optical-fibre sources for time-resolved molecular dynamics: towards the next generation of ultrafast spectroscopy
  EPSRC £589k, Apr 2018 – Dave Townsend
- Nano-scale imaging with Hong-Ou-Mandel interferometry
  EPSRC £276k, Apr 2018 – Jonathan Leach
- PISTACHIO: Photonic imaging strategies for technical art history and conservation
  EPSRC £824k, May 2018 – Derryck Reid

Photonics grants

University of Strathclyde - £6.8M

- Control and applications of structured light and chiral molecules
  Leverhulme Trust £287k, Jun 2017 – Alison Yao
- Tartan SW: a new method for spectrally-resolved standing wave cell microscopy and mesoscopy
  BBSRC £151k, Aug 2017 – Gail McConnell
- gMOT: Scalable manufacture and evaluation of miniature cold atom traps
  EPSRC £264k, Sep 2017 – Erling Riis
- QT Hub partnership project with Kelvin Nanotechnology
  EPSRC £252k, Sep 2017 – Erling Riis
- Feasibility of magneto-cardiography in livestock (QuBeat)
  EPSRC £161k, Oct 2017 – Erling Riis
- Nonlinear optics and dynamics of relativistically transparent plasmas
  EPSRC £1.14M, Nov 2017 – Paul McKenna
- Parametric wave coupling and non-linear mixing in plasma
  EPSRC £762k, Nov 2017 – Kevin Ronald
- Brain photonics
  US Office of Naval Research Global £262k, Nov 2017 – Antonio Hurtado

Photonics grants

University of Strathclyde - £6.8M

- Engineering many-body quantum states and dissipative dynamics in quantum simulators
  The Air Force Office of Scientific Research £540k, Dec 2017 – Andrew Daley
- Low-cost, open-access imaging for identifying and quantifiying water quality (GCRF)
  Royal Society £100k, Dec 2017 – Brian Patton
- Multiscale neural imaging – from synapse to whole-organism
  Royal Society £100k, Dec 2017 – Brian Patton
- Tuneable photoswitches for chromatic aberration-free multicolour super-resolution imaging
  Academy of Medical Sciences £100k, Mar 2018 – Sebastian Van De Linde
- Field demonstration of atomic vapour cell magnetometry
  EPSRC £190k, Jan 2018 – Erling Riis
- Compact multispectral imager for nanosatellites
  UK Space Agency £0.9M, May 2018 – Daniel Oi
- 'Hetero-print': A holistic approach to transfer-printing for heterogeneous integration in manufacturing
  EPSRC £1.5M, Jun 2018 – Martin Dawson (PI – Pete Skabara, Dept. Chemistry, Univ. Glasgow, £5.5M total award)
- Quantum research CubeSat (QUARC) II – QT Hub Partnership Project
  EPSRC £125k, Jun 2018 – Daniel Oi

Photonics grants

University of St Andrews - £8.4M

- Strong light-matter coupling in nanoscale semiconductors for fast & tunable light-emitting devices
  VolkswagenStiftung £210k, June 2017 – Malte Gather
- Making the most of interference: new metrology application of laser speckle
  Leverhulme Trust £178k, Jun 2017 – Kishan Dholakia
- Resonant and shaped photonics for understanding the physical and biomedical world
  EPSRC £2.8M, Jul 2017 – Kishan Dholakia (Platform Grant, total award: £5M)
- ULTRAGLASS: ULTRAfast GLASS based lasers
  IUK £161K, Jul 2017 – Tom Brown
- Super receivers for visible light communications
  EPSRC £378k, Aug 2017 – Graham Turnbull
- Royal Society Doroth Hodgkin Fellowship
  Royal Society £500k, Aug 2017 – Marcel Schubert
- CBET-EPSRC: Hybrid organic-CMOS devices for optogenetic simulation and lens-free fluorescence imaging of the brain
  EPSRC £383k, Sep 2017 – Malte Gather
- MCLAREN: Miniaturised cold atom gravimeter for space applications
  IUK/EPSRC £204k, Oct 2017 – Kishan Dholakia

Photonics grants

University of St Andrews - £8.4M

- M Squared – St Andrews Biophotonics Nexus – **Prosperity Partnerships**
  EPSRC £1.4M, Nov 2017 – Kishan Dholakia
- Meeting the sensitivity grand challenges in pulsed electron magnetic resonance
  EPSRC £739k, Nov 2017 – Graham Smith
- H2020 MiLEDI
  European Commission £288k, Nov 2017 – Ifor Samuel
- Beating lasers: long term monitoring of cardiac cells with intracellular lasers
  Royal Society £147k, Mar 2018 – Marcel Schubert
- EPSRC-JSPS Core-to-Core Grant Application – Thermally activated delayed fluorescence
  EPSRC £1M, Aug 2018 – Ifor Samuel

University of Glasgow - £0.6M

- Relativistic electron vortices
  EPSRC £204k, Dec 2017 – Steve Barnett
- Nano-scale imaging with Hong-Ou-Mandel interferometry
  EPSRC £423k, Apr 2018 – Daniele Faccio

Research Output

With selected highlights

Research output

SUPA Photonics impact since the last IAC

> 100* papers in top-ranking multidisciplinary and field specific journals, including:

High impact interdisciplinary journals

- Nature: 1
- Nature Communications: 11
- Scientific Reports: 10

High impact physics journals

- Physical Review Letters: 10
- Physical Review A: 10
- Applied Physics Letters: 11
- Nano Letters: 2

High impact field-specific journals

- Nature Photonics: 3
- Nature Physics: 1
- ACS Photonics: 6
- Optica: 6
- Laser & Photonics Reviews: 1
- Journal of Biophotonics: 4
- Biomedical Optics Express: 4
- Optics Express: 23
- Optics Letters: 2

*__Minimum__ numbers based on a literature search.

Research highlights

University of Glasgow (Physics)

Strong activities in ***fundamental optics*** (e.g. Padgett, Barnett, Courtial, Franke-Arnold, Faccio) and ***optical instrumentation*** (e.g. Harvey & Taylor)

SCIENTIFIC REPORTS

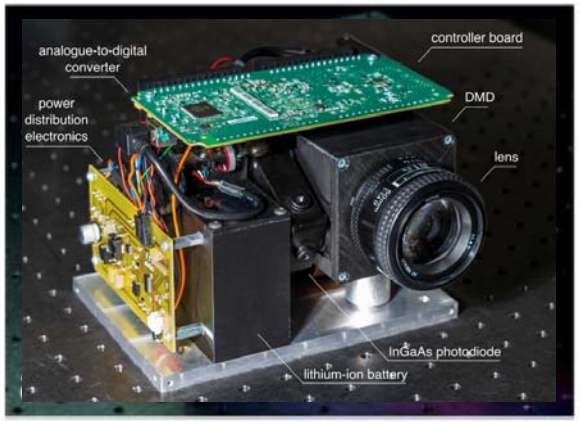
OPEN

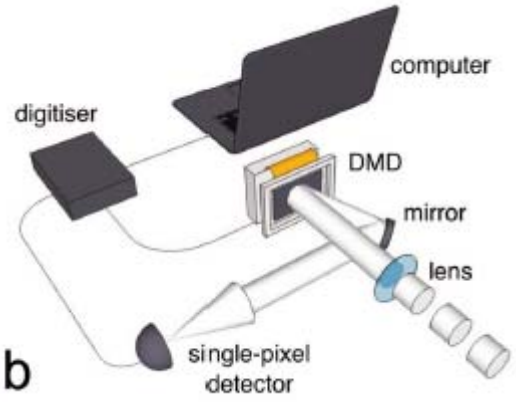
Deep learning for real-time single-pixel video

Catherine F. Higham[1], Roderick Murray-Smith[1], Miles J. Padgett[2] & Matthew P. Edgar[2]

Received: 12 September 2017
Accepted: 17 January 2018
Published online: 05 February 2018

Single-pixel cameras capture images without the requirement for a multi-pixel sensor, enabling the use of state-of-the-art detector technologies and providing a potentially low-cost solution for sensing beyond the visible spectrum. One limitation of single-pixel cameras is the inherent trade-off between image resolution and frame rate, with current compressive (compressed) sensing techniques being unable to support real-time video. In this work we demonstrate the application of deep learning with convolutional auto-encoder networks to recover real-time 128 × 128 pixel video at 30 frames-per-second from a single-pixel camera sampling at a compression ratio of 2%. In addition, by training the network on a large database of images we are able to optimise the first layer of the convolutional network, equivalent to optimising the basis used for scanning the image intensities. This work develops and implements a novel approach to solving the inverse problem for single-pixel cameras efficiently and represents a significant step towards real-time operation of computational imagers. By learning from examples in a particular context, our approach opens up the possibility of high resolution for task-specific adaptation, with importance for applications in gas sensing, 3D imaging and metrology.





Higham et al. *Sci. Rep.* **8**, 2369 (2018)

Research highlights

Heriot Watt University

Strong activities ***quantum and ultrafast science and nonlinear optics*** (e.g. Reid, Andersson, Gerardot, Kar, Buller, Ferrera, Cataluna, Travers) ***laser manufacturing*** (e.g. Hand & Esser)

Yue et al. *Sci. Rep.* **7**, 11440 (2017)

SCIENTIFIC REPORTS

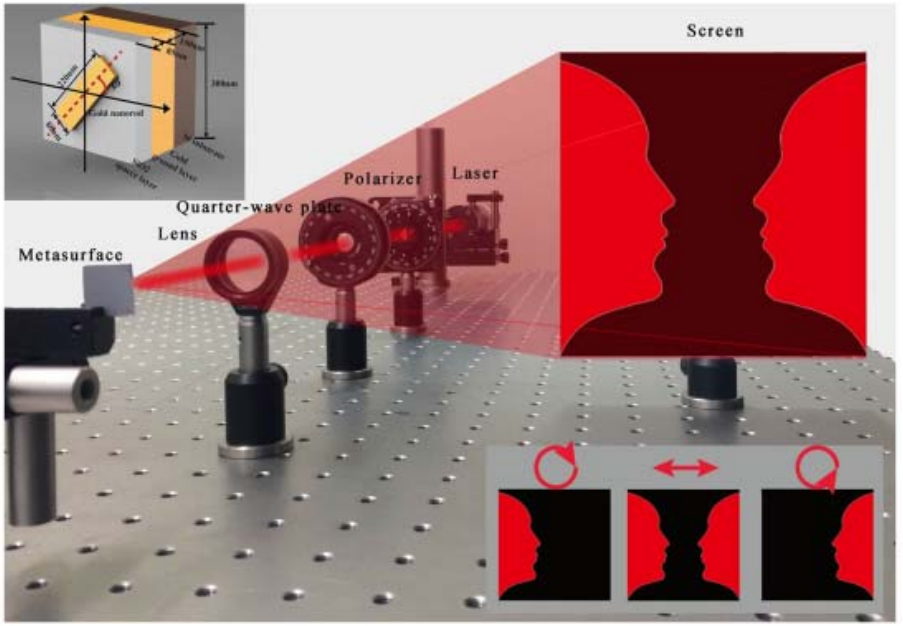
OPEN

Geometric Phase Generated Optical Illusion

Fuyong Yue[1], Xiaofei Zang[1,2], Dandan Wen[1], Zile Li[3], Chunmei Zhang[1], Huigang Liu[1,4], Brian D. Gerardot[1], Wei Wang[1], Guoxing Zheng[3] & Xianzhong Chen[1]

Received: 9 May 2017
Accepted: 1 September 2017
Published online: 12 September 2017

An optical illusion, such as "Rubin's vase", is caused by the information gathered by the eye, which is processed in the brain to give a perception that does not tally with a physical measurement of the stimulus source. Metasurfaces are metamaterials of reduced dimensionality which have opened up new avenues for flat optics. The recent advancement in spin-controlled metasurface holograms has attracted considerate attention, providing a new method to realize optical illusions. We propose and experimentally demonstrate a metasurface device to generate an optical illusion. The metasurface



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Clerici et al. *Nat. Comm.* **8**, 15829 (2017)

nature COMMUNICATIONS

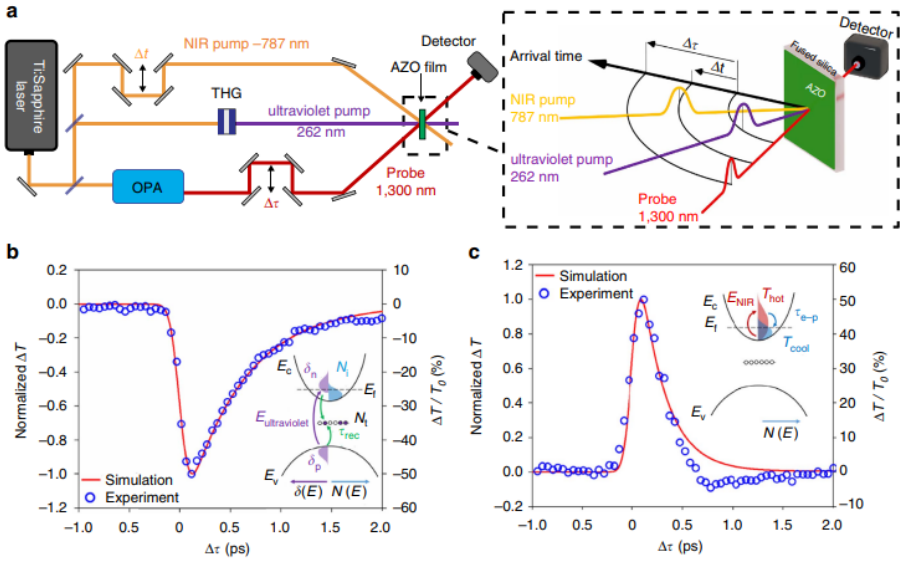
ARTICLE

Received 24 Mar 2017 | Accepted 4 May 2017 | Published 9 Jun 2017

DOI: 10.1038/ncomms15829 OPEN

Controlling hybrid nonlinearities in transparent conducting oxides via two-colour excitation

M. Clerici[1], N. Kinsey[2,†], C. DeVault[3], J. Kim[2], E. G. Carnemolla[4], L. Caspani[4,5], A. Shaltout[2,†], D. Faccio[4], V. Shalaev[2], A. Boltasseva[2] & M. Ferrera[4]



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http://www.bbc.co.uk/news/uk-scotland-41517202

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NEWS

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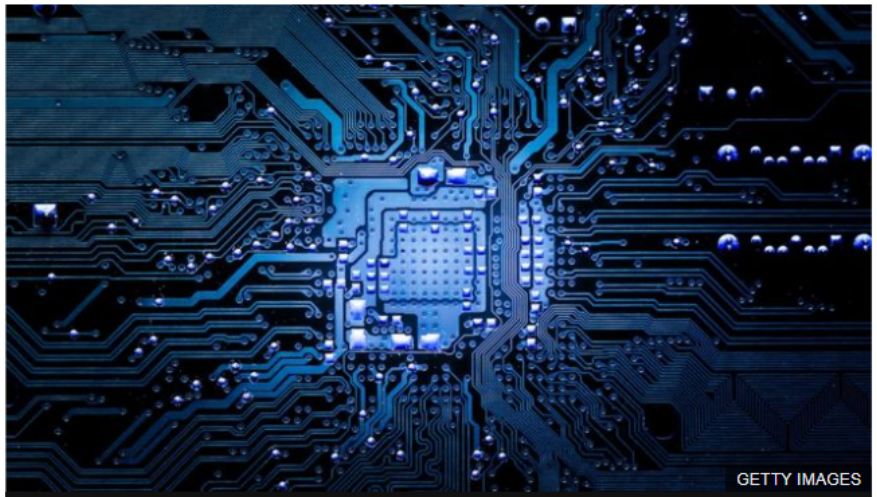
Beating the electronic speed limit with light

By Ken Macdonald
BBC Scotland Science Correspondent

6 October 2017 Share



A speed limit is looming for computer chips

The heart of any smartphone, tablet or computer is an electronic chip. And

Research highlights

University of St Andrews

Strong activities in ***biophotonics, semiconductor optoelectronics, quantum optics, nano-photonics*** (e.g. Dholakia, Samuel, Turnbull, Brown, Di Falco, Gather & Koenig)

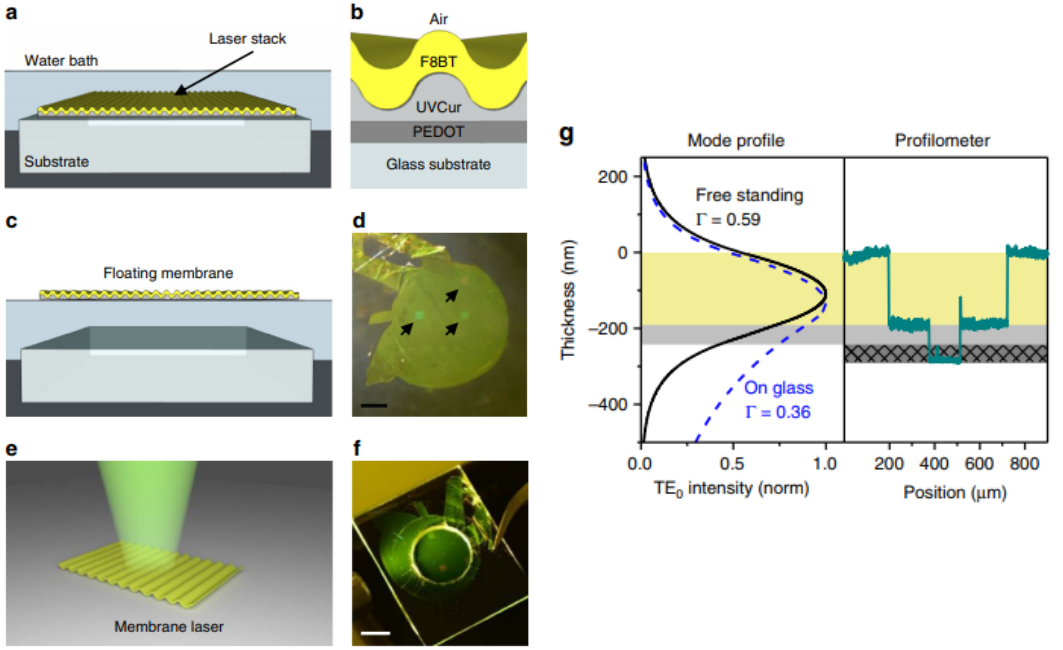
nature COMMUNICATIONS

ARTICLE

DOI: 10.1038/s41467-018-03874-w OPEN

Flexible and ultra-lightweight polymer membrane lasers

Markus Karl [1], James M.E. Glackin [1], Marcel Schubert [1], Nils M. Kronenberg [1], Graham A. Turnbull [1], Ifor D.W. Samuel [1] & Malte C. Gather [1]



Karl et al. *Nat. Comm.* **9**, 1525 (2018)

Research highlights

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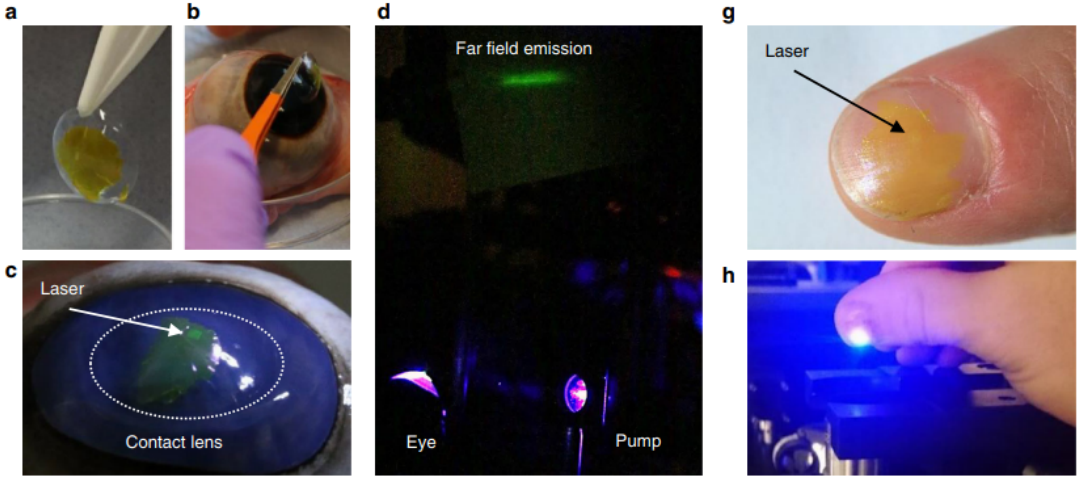

Karl et al. *Nat. Comm.* **9**, 1525 (2018)

Research highlights

University of Strathclyde

Strong activities in ***quantum optics,*** (e.g. Riis, Kuhr, Daley, Haller, Arnold, Griffin), ***nonlinear photonics*** (e.g. Oppo, Ackemann, Yao), ***quantum theory of light*** (e.g. Jeffers), ***optoelectronic devices*** (e.g. Dawson, Strain), ***advanced lasers*** (e.g. Kemp), and ***neurophotonics*** (Mathieson).

Zhai et al. *Optica* **5**, 80 (2018)

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Talbot-enhanced, maximum-visibility imaging of condensate interference

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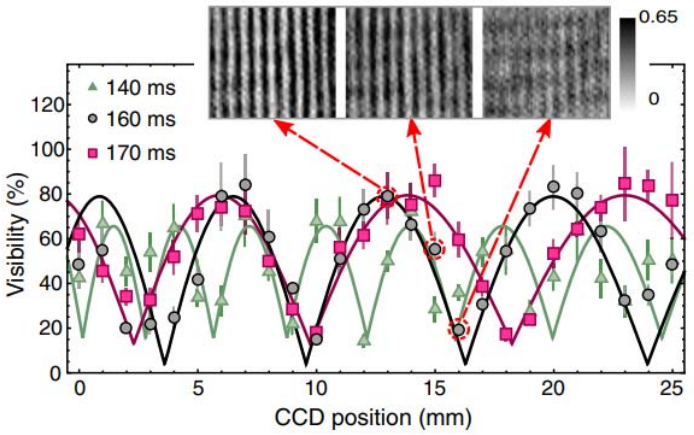

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NANO LETTERS

Letter

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Integration of Semiconductor Nanowire Lasers with Polymeric Waveguide Devices on a Mechanically Flexible Substrate

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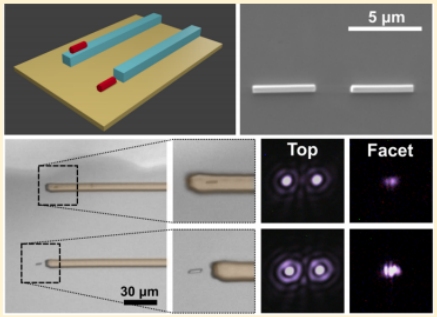
Supporting Information

ABSTRACT: Nanowire lasers are integrated with planar waveguide devices using a high positional accuracy microtransfer printing technique. Direct nanowire to waveguide coupling is demonstrated, with coupling losses as low as −17 dB, dominated by mode mismatch between the structures. Coupling is achieved using both end-fire coupling into a waveguide facet, and from nanowire lasers printed directly onto the top surface of the waveguide. In-waveguide peak powers up to 11.8 μW are demonstrated. Basic photonic integrated circuit functions such as power splitting and wavelength multiplexing are presented. Finally, devices are fabricated on a mechanically flexible substrate to demonstrate robust coupling between the on-chip laser source and waveguides under significant deformation of the system.



KEYWORDS: *Nanowire lasers, nanowire coupling, photonic integration, nanophotonics*

Jevtics et al. *Nano Lett.* **17**, 5990 (2017)

Awards and recognition

SUPA researchers working in the area of photonics

Awards and recognition

- **Miles Padgett (Glasgow)** received the **2017 Max Born Award** from the **Optical Society of America** in recognition of "contributions to optics and especially to optical momentum, including the optical spanner, the use of orbital angular momentum in communication systems, and an angular form of the Einstein-Podolsky-Rosen paradox."
- **Kishan Dholakia (St Andrews)** was awarded the **2017 Thomas Young Medal by the Institute of Physics** for "*his work in the fields of optical micromanipulation and optical beam shaping including new insights into the understanding of complex light fields and their propagation*"
- **Derryck Reid (Heriot Watt)** was elected to **Fellow of the Optical Society of America**.
- **Brian Gerardot (Heriot Watt)** was awarded a 10-year **Royal Academy of Engineering Chair in Emerging Technologies** for integrated two-dimensional classical and quantum photonics