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Optics & Photonics Group
Faculty of Engineering
The University of Nottingham

Research Portfolio

September 2016

Optics & Photonics Group Overview

The Optics & Photonics Group is a discipline based research group focused on research in optics. It spans a wide range of physical scales and is applied to the life sciences interface, healthcare and advanced manufacturing. We pride ourselves on being able to cover the complete developmental spectrum from discovery through to application in industry and healthcare. The vision for the group is a broad church conducting world leading research in state of the art facilities designed to provide a rich, collegiate and multidisciplinary atmosphere.

The group consists of four related and interlinked applications based research clusters:

Healthcare optics

- Optical diagnostics and sensing in healthcare, from smart socks to smart surgical tools.
- Novel imaging and measurement modalities for instance combining light and ultrasound and novel sensors for example: bioluminescence or nano-temperature probes.
- Translation of sensing and imaging technology into the clinic and healthcare arena.

Nano-optics and photonics

- Development of new and novel imaging modalities that can defeat the Rayleigh limit, for example: probe microscopy, nano-sensors, nonlinear microscopy, spatially incoherent sensing and nano-ultrasonics.
- Development and integration of nano-sensors into *in vitro* and *in vivo* healthcare and engineering applications.
- Interfacing and communication between the nano- and macroscales – two way communication with the nanoscale.
- Novel fabrication of micro- and nano-structures.

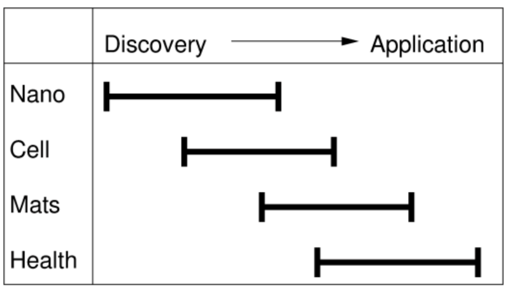
Materials and NDE/T:

- Inspection, imaging and measurement of materials and components from the nanoscale up to the metre scale.
- Development of real time, distributed and in process monitoring and measurement systems.
- Integrating senses into materials and components.

Cell optics:

- R/W microscopy and biological in-life programming of cell behaviour.
- Real-time functional imaging in living mammalian and plant tissues.
- Optogenetic cell behaviour.
- Surface-Enhanced Raman sensing and imaging nano-sensors.
- 3D printing of biological structures.
- R/W microscopy and biological in-life programming of cell behaviour.

The research clusters individually cover a range of the development spectrum but also feed through research from one to the other, together with applications and demand feeding through in the opposite direction.



Fibre optic ultrasonic transducers for inspection of aerospace components

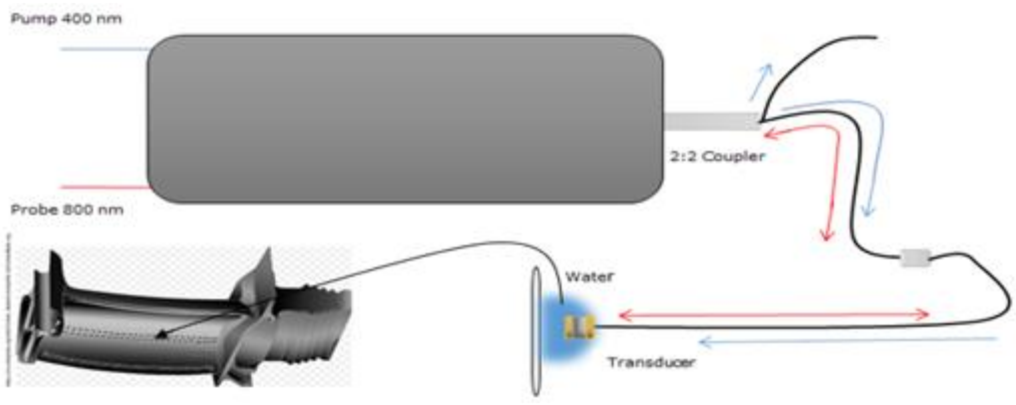
Matt Clark, Leonel Marques, Fernando Perez Cota, Richard J Smith, Mitra Soorani, Kevin Webb

For many advanced engineering components, with complex shapes and internal structures inspection for defects or wear is becoming very challenging.

Using technology developed originally for ultrasonic cell imaging it is possible to produce extremely small transducers that can be built on the tip of optical fibres. These small transducers have many potential applications in industry, such as investigating coating properties through very small (sub mm) access holes in parts.

In this project we are developing microscopic optoacoustic transducers fabricated on the tip of a single mode optical fibre. The aim is to produce a flexible transducer that can work across a broad range of frequencies (MHz to GHz) to address a number of different demanding applications.

The transducers being developed can generate and detect ultrasound. The detection is very sensitive as the transducer operates in a manner similar to a Fabry-Pérot interferometer. The generation of acoustic waves is thermoelastic so there can be no damage to the part/ coatings being inspected.



Cartoon of the concept: pump and probe laser beams are coupled into a fibre system. The transducer is at the tip of the fibre which can be inserted into sub-mm access holes to inspect the state of the part. The acoustic waves are generated by the pump pulse and the returning echoes are read out by the probe laser beam.

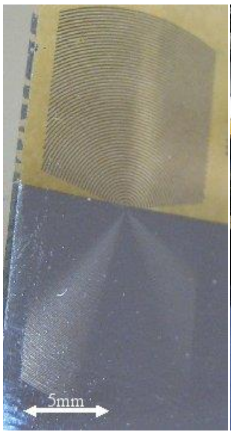
Cheap Optical Transducers (CHOTs) and portable CHOTs demonstrator

Victoria Ageeva, Teti Stratoudaki, Matt Clark

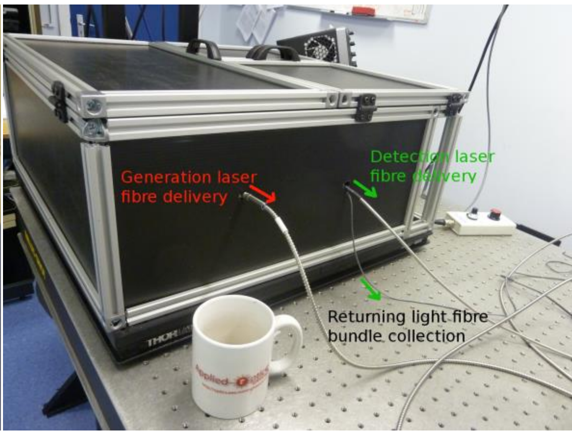
Cheap Optical Transducers (CHOTs) are a non-contact, wireless, couplant-free alternative to the traditional piezoelectric transducers that have been developed at the Optics & Photonics Group, University of Nottingham, and can be used for ultrasonic inspection. Because they are cheap and very small, they can be used in large numbers and in different ways to normal ultrasonic probes. For example, they could be mounted permanently on the component for easy repeatable measurements or considered as disposables: use once and throw away. CHOTs are structures attached to the surface of the test component that are optically excited using a simple laser set-up to either generate or detect ultrasound. The use of CHOTs enables testing of components inaccessible by other techniques and potentially enabling on-site and in-service ultrasonic testing currently unavailable to the industry.

CHOTs are nanometre-height patterns printed or attached onto the component. Using principles of laser ultrasonics they are able to remotely generate and detect ultrasound when illuminated by a laser, providing a simple non-contact and couplant-free alternative to the conventional piezoelectric transducers. They are fully customisable for the required application providing control over the directivity and the mode of the generated ultrasound (surface acoustic waves or longitudinal bulk waves), type of the wave (plane or focused wavefront), generation efficiency and bandwidth of the signal.

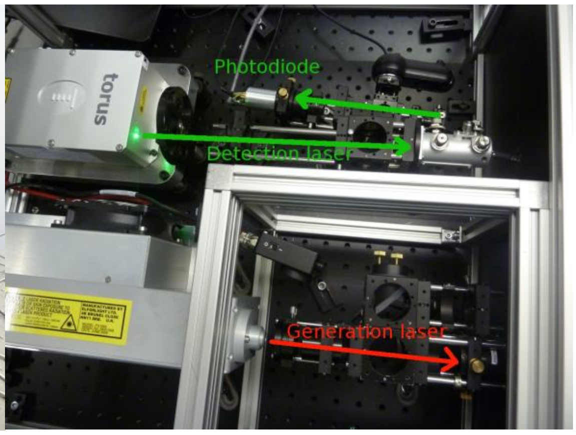
A basic CHOT measurement system for generation and detection of ultrasound consists of a pair of CHOTs on the surface of a sample, a pulsed generation and a CW detection laser to illuminate the corresponding CHOTs, minimal optics to expand and collimate the beams and to collect the returning probing beam (containing ultrasonic information), and a photo-detector. We have designed and constructed a portable CHOTs demonstrating system that houses the CHOTs pulser, the equivalent of a conventional ultrasonic transducer pulser.



CHOT for generation and detection of focused 20MHz SAW on a glass slide.



CHOTs portable demonstrator.



Inside the CHOTs portable demonstrator.

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Endoscopic system for *in situ* ultrasonic inspection of aero-engines using Cheap Optical Transducers (CHOTs)

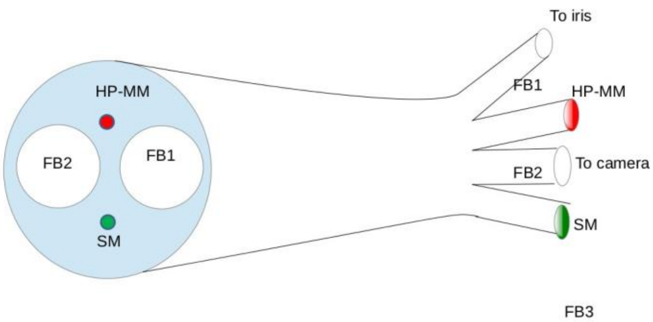
Victoria Ageeva, Teti Stratoudaki, Matt Clark

This is a research project jointly funded by the EPSRC and Rolls-Royce plc to enable on-site non-contact ultrasonic inspection of the aeroengine components by an endoscopic system based on the Cheap Optical Transducer (CHOT) technology.

Cheap Optical Transducers (CHOTs) use principles of laser ultrasonics to remotely generate and detect ultrasound, providing a simple non-contact, couplant-free alternative to the traditional piezoelectric transducers. They are practically weightless nanometre-height patterns attached or printed on the component, and activated by lasers. CHOTs for Surface Acoustic Waves (SAWs) are used in this project.

The framework of this project includes: application of the SAW CHOT technology to the non-destructive testing in an aero-engine environment combined with the development of the endoscopic light delivery system to provide access to the components via existing service ports in the engine, as well as the investigation and development of the corresponding CHOT manufacturing techniques to enable remote or in-situ application of the sensors.

CHOTs endoscopic system for in situ inspection of aero-engines.



FB1=Fibre bundle for collection of CW light from d-CHOT and imaging
FB2=Fibre bundle for imaging.
HP-MM=High power multi mode fibre for ultrasonic generation using g-CHOT.
SM=Single mode fibre for detection using d-CHOT (d-CHOT illumination).

Schematic of the future fibre arrangement at the inspection end.

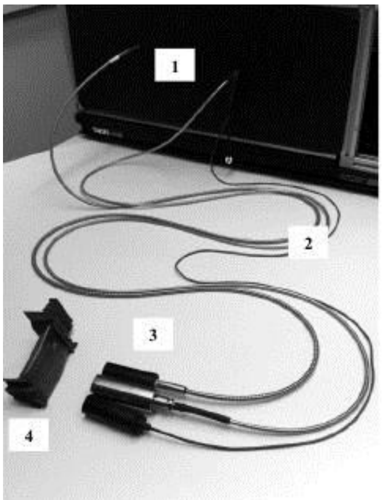
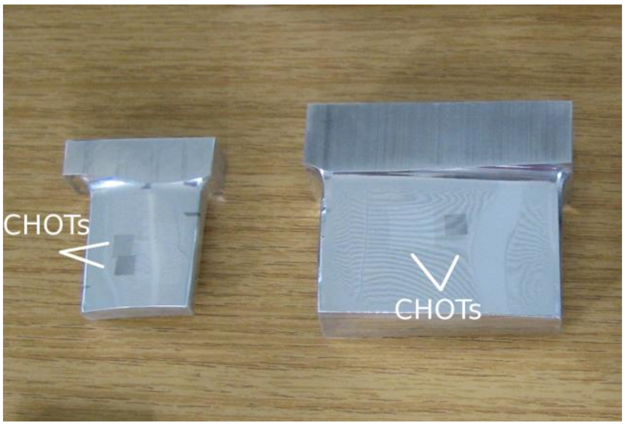


Photo of the existing endoscopic CHOTs system.

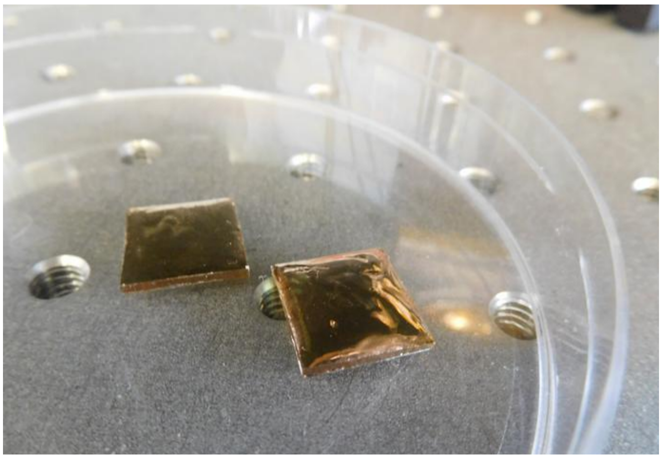


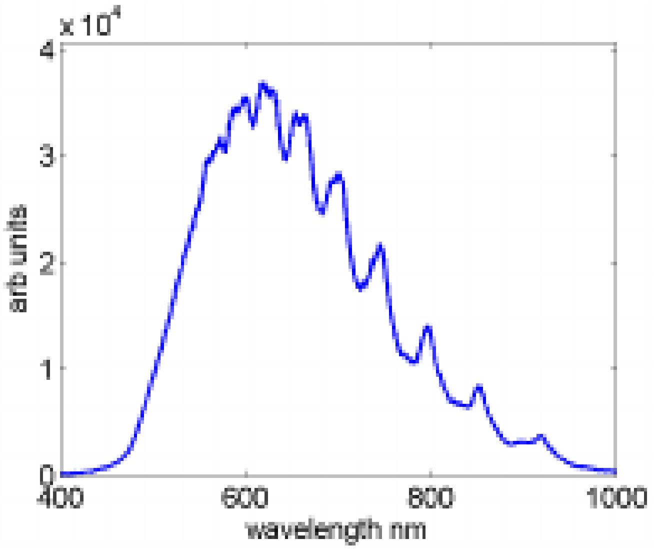
Mock turbine blade samples with CHOTs.

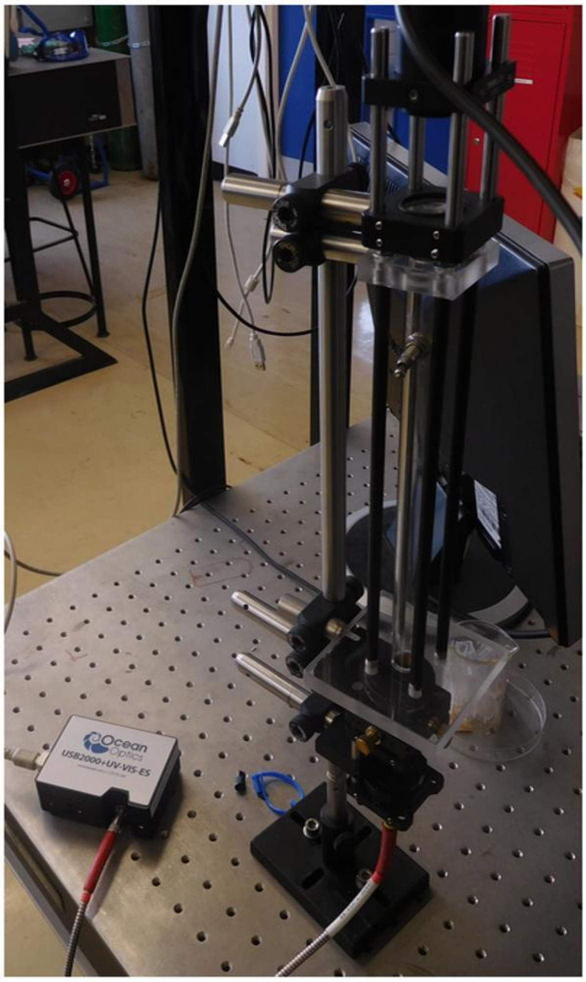
Micro-scale optical pressure sensors

Rikesh Patel, Leo Marques, Barbara Turnbull, Richard Smith

One of the projects being investigated alongside the nano-scale CHOTs (Cheap Optical Transducers) development, which is currently designed to operate in the gigahertz region, is to see if can be repurposed to react to changes in the environment, for example pressure. There is often a need to make measurements of local media without the instrumentation affecting the measurement, e.g. detecting ice flow and the pressures they exert at different points could change with the presence of off-the-shelf sensors. Either calibration is required at all times (which requires knowledge beforehand) or, in this case, a sensor can be made small enough that its effect on measurements is negligible. The aim in this project is to design a CHOT to act as a microscale static Fabry-Pérot interferometer that will react to pressures of a few kilo-pascals.







Top left: prototype 'sandwich' shaped sensor-CHOTs.
Right: initial pressure chamber design.
Bottom left: plot of FP fringe patterns off an S-CHOT.

Ultrasonic inspection of coated samples

Victoria Ageeva, Richard Smith, Rafael Fuentes Dominguez, Matt Clark

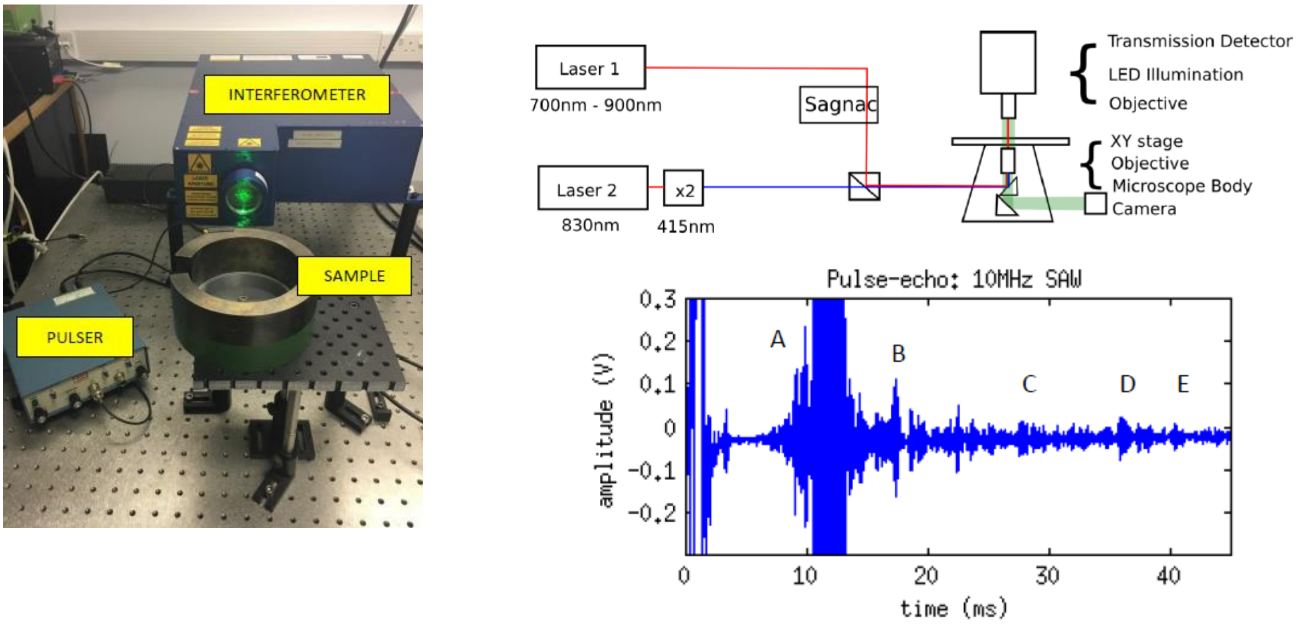
A combination of conventional contact and laser-ultrasonic methods was used to inspect three industrial samples with different coatings.

Both contact and laser-ultrasonic inspection of sample 1 (4MHz) successfully detected the presence of the machined slots on the coated and coating-free halves of the sample, although the signal (echo) amplitudes were consistently lower on the coated sides at equal conditions.

The test of sample 2 with picosecond ultrasonics revealed the sensitivity of the method to the variations in the coating. However, the exact relations between the coating structure and the characteristics of the recorded signal are not clear at present and would require modelling and further experimental work.

Contact inspection of sample 3 at 1MHz and 4MHz did not indicate the presence of the defect, with the inspection at 10MHz producing a promising but hard-to-repeat result. Although the presence of the crack was not detected by the visualisation of the propagating acoustic field at 1MHz, significant differences in the SAW amplitude on the coated and the coating-free regions were revealed indicating the damping effect of the coating.

The geometry of the sample 3 presented some difficulties when using the transducer wedges with little space for transducer attachment and movement (narrow, coated/uncoated surface steps close to the region of interest). The visualisation of the acoustic field at 10MHz with the fixed transducer setup could be used to validate the results of the contact pulse-echo inspection.



Top left: combined contact and laser ultrasonic detection of surface acoustic waves. Top right: optical setup of the picosecond ultrasonics setup. Bottom right: detection of 0.8mm crack under coating (feature B).

Control of Rayleigh wave propagation with a resonant metawedge: a practical concept demonstration of seismic metamaterials

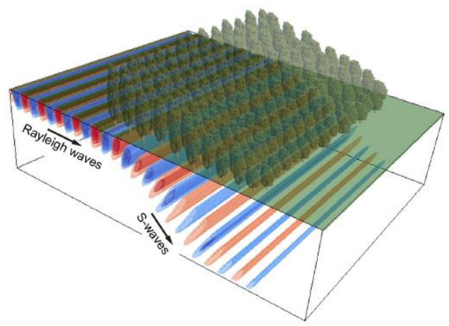
Victoria Ageeva[1], Andrea Colombi[2], Adam Clare[1], Richard V. Craster[2], Rikesh Patel[1], Philippe Roux[3], Richard J. Smith[1], Matt Clark[1]

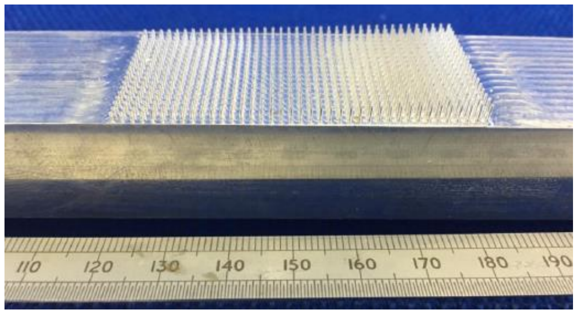
[1] Optics & Photonics Group, University of Nottingham
[2] Dept. of Mathematics, Imperial College London
[3] ISTerre, CNRS, Universite Grenoble Alpes, Grenoble, France

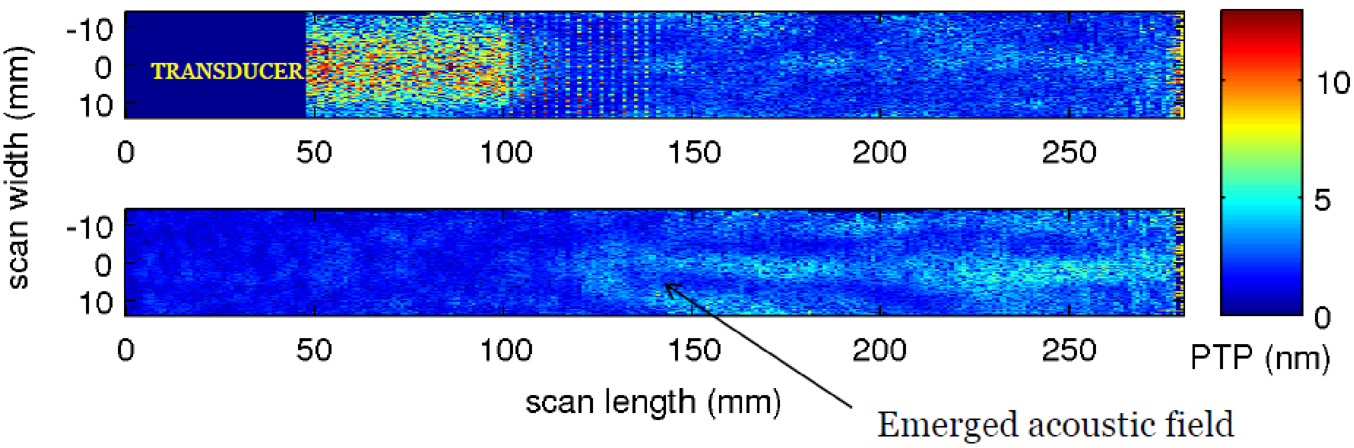
The devastating effects of the seismic waves generated during an earthquake range from tsunamis and landslides to the destruction of infrastructure or entire cities, and are often associated with the loss of life. The control of seismic surface waves (where amplitudes can reach several centimetres) offers promising prospect for seismic protection in civil engineering applications.

At the geophysical scale, the modification of the surface topology with an array of subwavelength resonators (elastic metamaterial) enables wavefront control via local modification of the dispersion properties of the Earth surface. A large-scale experiment demonstrated the use of forest-trees as a natural elastic metamaterial at frequencies < 100 Hz in sedimentary soil.

This work demonstrates the physics of a more sophisticated metamaterial, made of spatially graded array of vertical resonators. The experiment realisation at the laboratory scale allows precise control of the resonator's height and full spatial sampling of the wavefield.







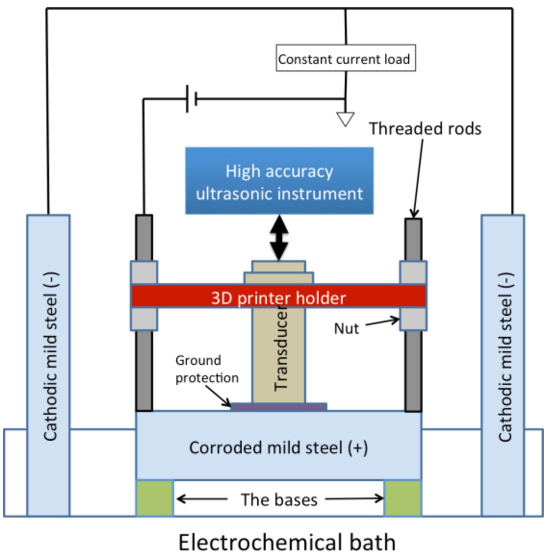
Top left: Metawedge concept, with model overlayed. Top right: Manufactured lab-scale metawedge. Bottom: laser ultrasonic detection of surface waves on top and bottom surfaces, showing successful deflection of acoustic energy away from the top surface.

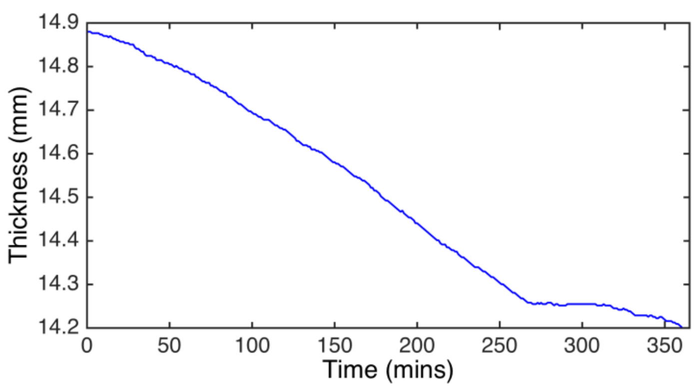
Ultrasonic instrumentation for automated assessment of corrosion in sea vessels

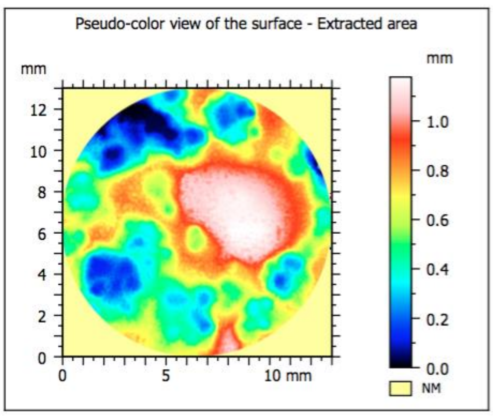
Nutthawut Suchato, Roger Light, Steve Sharples

Continuous measurement of the thickness of a ship hull has the potential of reduce the maintenance and service costs associated with surface corrosion, provided that the cost of instrumentation and transducers is low enough for their permanent installation in situ, and the recorded echo waveforms can be interpreted to determine corrosion penetration. In this research, we develop a high accuracy ultrasonic instrument and evaluate a signal processing method for estimating thickness of a steel plate under corrosive environment.

We have designed the test rig for ultrasonic monitoring of accelerated corrosion. Accelerated (uniform and pitting) corrosion is carried out using the reversed electroplating technique and continuous ultrasonic monitoring is carried out using the high accuracy ultrasonic waveform acquisition instrument, combined on-the-fly averaging with accurate interleaved sampling. We have also modelled an ultrasonic wave propagating through a corroding sample using K-Wave, an acoustic toolbox for Matlab. Confirmed by experiment and simulation, an adaptive cross-correlation (AXC) technique is the first choice for the online thickness measurement when the thickness of the sample decreases uniformly with gradual change in RMS surface displacement.







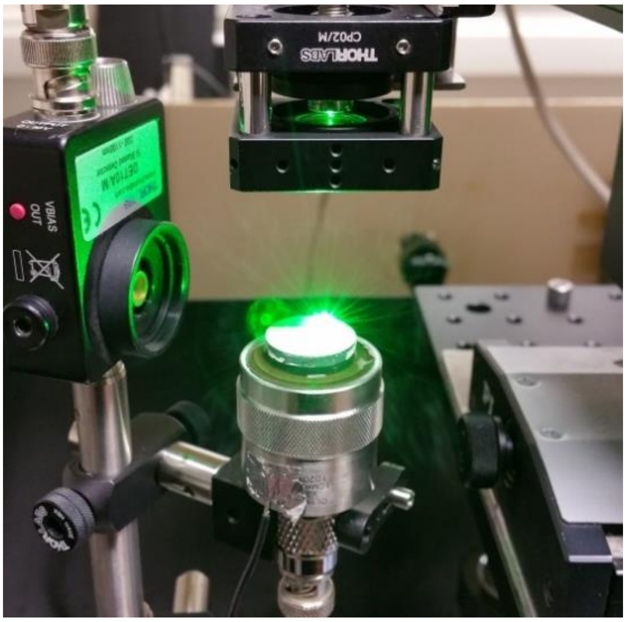
ISO 25178		
Height Parameters		
Sq	0.282	mm
Ssk	0.0818	
Sku	2.23	
Sp	0.572	mm
Sv	0.606	mm
Sz	1.18	mm
Sa	0.233	mm

Top left: Accelerated corrosion test rig. Top right: plate thickness versus time extracted from ultrasonic measurement with applying AXC algorithm during accelerated corrosion. Bottom right: contour plot with surface profiles of the extracted area corroded where ultrasonic probes were placed on the opposite side.

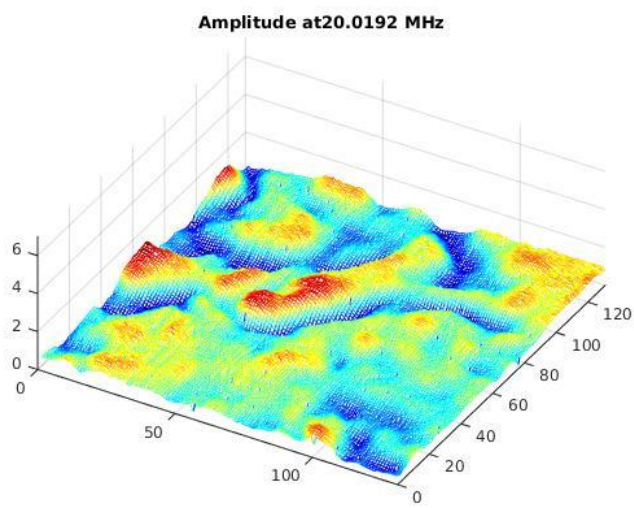
Photoacoustic imaging of thermal barrier coating

Bo Tan, Wenqi Li, Steve Sharples

High temperature ceramic coatings may generate stress concentration during their applications, which results in serious delamination and coating failure. Regular inspection of their quality condition has received increasing attention. The idea of LPAI is using green laser to penetrate the ceramic layer, generate bulk waves at the interface, and detect the by an ultrasonic transducer. The laser head is fixed on a 2D translation stage which gives an amplitude response of a square of area at certain frequencies. Samples thermal cycled at 1150°C for different numbers of times were tested, as a result samples with longer oxidation times have lower amplitude and less energy was transferred. This indicates the increased thickness and roughness of thermal growth of the oxidation layer.



Laser Photoacoustic imaging experimental setup.



Amplitude at 20MHz.

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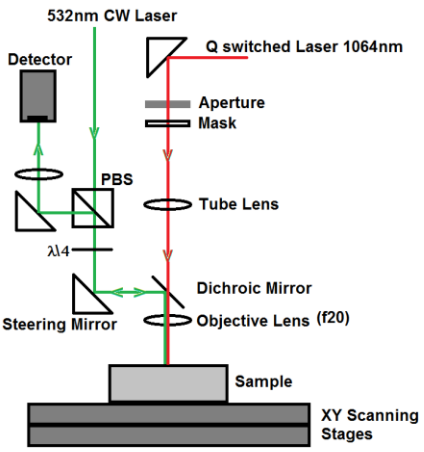
SRAS: spatially resolved acoustic spectroscopy for materials characterisation

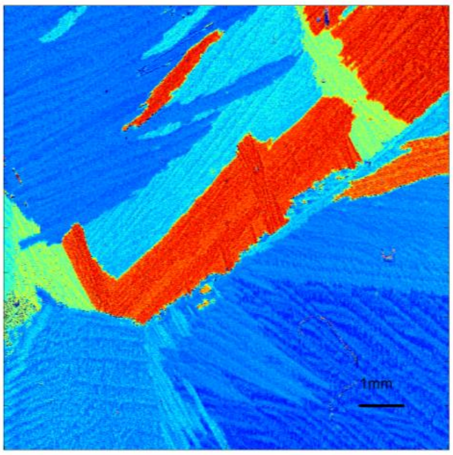
Wenqi Li, Richard Smith, Paul Marrow, Matt Clark, Steve Sharples

Measuring the grain structure of aerospace materials is very important to understand their mechanical properties and in-service performance. Spatially resolved acoustic spectroscopy is an acoustic technique utilising surface acoustic waves to map the grain structure of a material. When combined with measurements in multiple acoustic propagation directions the grain orientation can be obtained by fitting the velocity surface to a model. The research instrument based in our lab can take thousands of acoustic velocity measurements per second. The spatial resolution (~25-100µm) and velocity resolution (<1% single shot) can be adjusted by simple modification to the system optics.

The instrument has been used extensively over the past few years, on both a commercial and a research basis. We continue to develop the instrumentation itself, but more recently focusing on the interpretation of the data for quantitative texture and orientation determination.

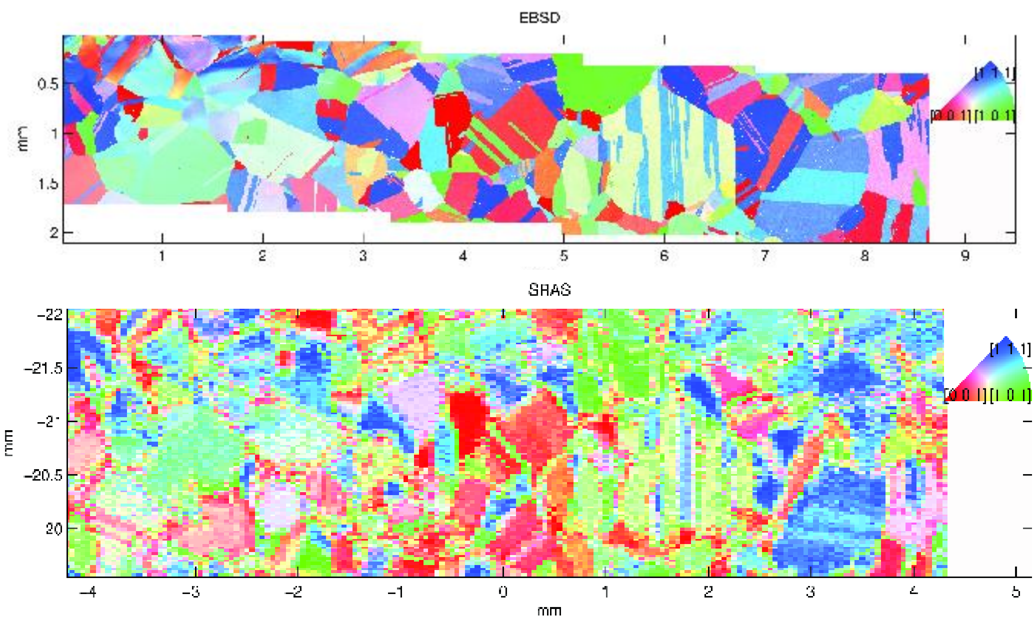


Optical configuration of the SRAS instrument.



Left: image of Ti LG685 showing internal structure within the large grains, the crystallites are clearly visible, spatial resolution ~50µm.

Below: inverse pole figure of a large grained Inconel sample, using EBSD (top) and SRAS (bottom).

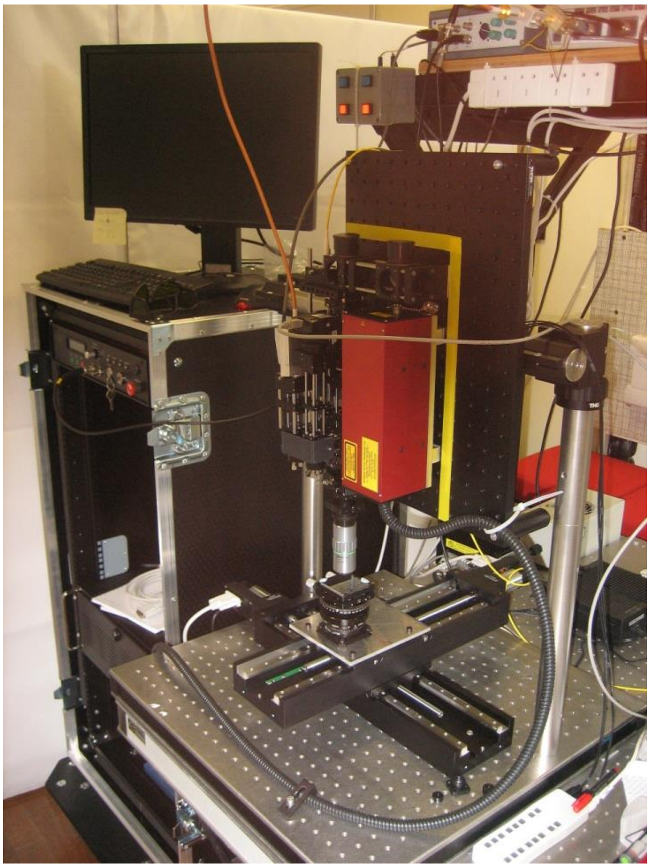


Technology transfer: SRAS from lab to commercial prototype

Jethro Coulson[1], Steve Sharples[2], Colin Bulled[1]

[1] Renishaw plc [2] Optics & Photonics Group

SRAS has remained a mainly laboratory based technique limited to fairly small samples moved by linear stages. Until recently, only one fully capable SRAS instrument existed and available for use. This project is a collaboration between the University of Nottingham and Renishaw plc to assess the viability of SRAS as a commercial product, and to develop the technique into a marketable scientific instrument. The ultimate goal is to produce a SRAS instrument, coupled to existing Renishaw motion platforms, which can be deployed autonomously on complex geometry parts, of unlimited size, as a quick and quantitative quality check.



The current laboratory based SRAS instrument.

The Renishaw Equator platform, a possible motion solution for SRAS.

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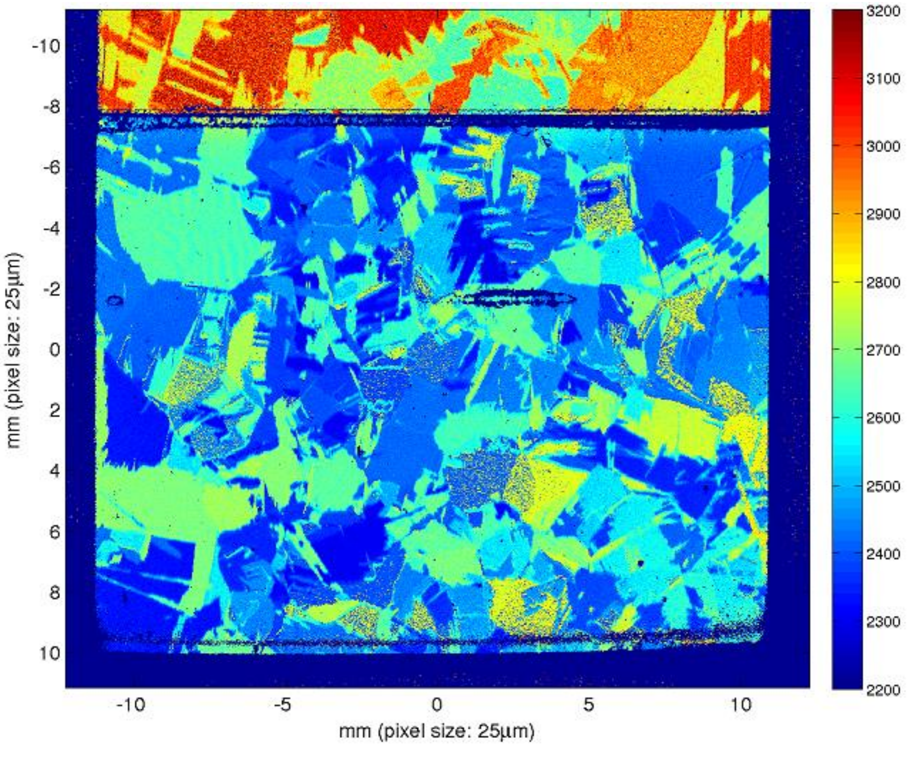
Advanced spatially resolved acousto-spectroscopic imaging

Paul Marrow, Wenqi Li, Matt Clark, Steve Sharples

Spatially resolved acoustic spectroscopy (SRAS) is a microscopy technique that uses surface acoustic waves (SAWs) to image the microstructure of multi-grain industrial materials. SRAS uses lasers to generate and detect ultrasonic surface acoustic waves (SAWs) to reveal the microstructure of the materials by looking at changes in the ultrasonic velocity of the metal alloys.

The primary goal of this research is to expand the capabilities of the SRAS technique, by utilising the incredible benefits that multiple acoustic wavelength afford. First example of this is to image the SAW velocity of and under isotropic coating on industrial relevant multi-grain anisotropic material substrate, and subtract the effect of the coating from the microstructure to reveal information of, and underneath the coating.

Another possibility is to probe the higher order elastic constants to get a more thorough determination of crystallographic orientation on hexagonal crystal structures. To do this, a large amount of uniform elastic stress of a known value will be introduced into the material statically. The effects of the anisotropy will be determined by looking at the subtle changes in the ultrasonic velocity with respect to propagation direction.



Velocity image of CP titanium block, with the bottom half coated in 500nm of gold The change in colour indicates a bulk change in velocity, which can be used to quantitatively determine coating properties.

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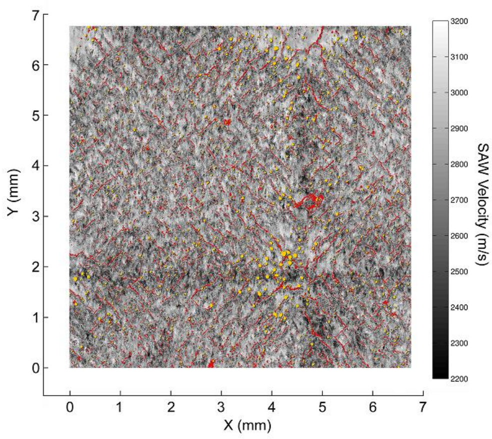
Non-destructive evaluation of additive manufactured parts

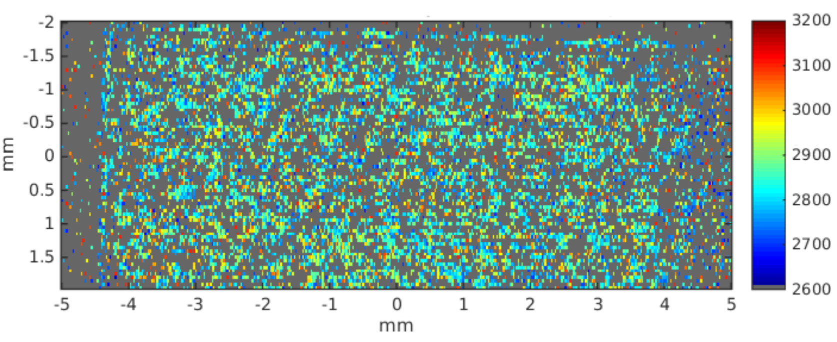
Rikesh Patel, Matthias Hirsch, Richard Smith, Adam Clare, Matt Clark, Steve Sharples

Additive manufacturing (AM) or 3D printing is a cost-efficient method of producing precision and complex parts that may not be producible any other way. Currently however, AM parts are often not fit for purpose as they contain defects (e.g. pores, cracks) or do not conform to design (e.g. incorrect dimensions, unsuitable microstructure).

The motivation for this project is to measure AM parts as they print by incorporating laser ultrasonics into AM machines, such as the selective laser melting (SLM) machine, which prints metal parts by creating layers of laser fused metal powder. Spatially resolved acoustic spectroscopy has been used to image the material microstructure, but it can also indicated surface and subsurface defects through the loss of signal or a drastic change in signal amplitude/frequency.

The challenges in this project are both in the optical setup, such as measuring signals off rough surfaces, as well as mechanical integration, where atmosphere, temperature, interfering particles are all factors to overcome. By incorporating SRAS into an SLM printer, our overall goal is to indicate where repairs are required or if scrapping the part is an option.





Top left: SRAS velocity scan of a nickel part produced with SLM. Cracks and pores are highlighted in red and yellow, respectively to show common types of defects of AM processes.
Top right: SRAS scan of cube surface using the SKED rough surface detector.
Bottom: assembly of demonstration build chamber for SRAS integration.

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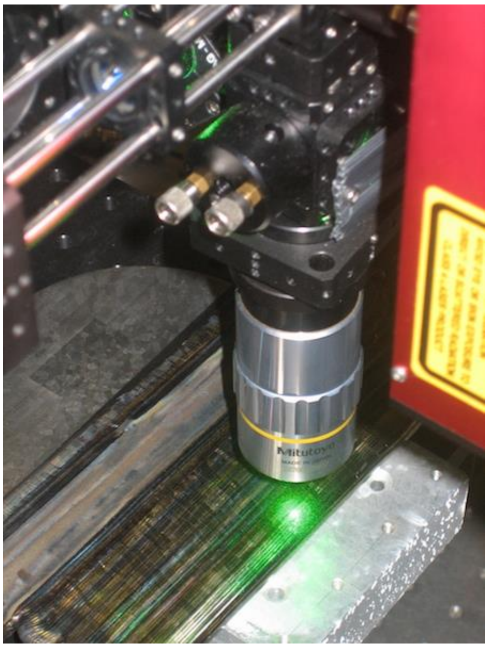
SRAS for high deposition rate additive manufacturing

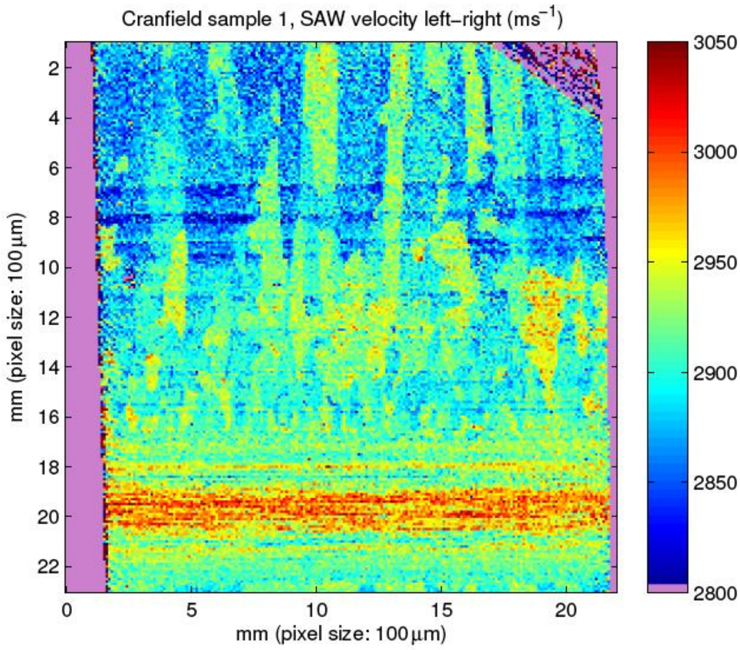
Wenqi Li[1], Steve Sharples[1], Supriyo Ganguly[2], Goncalo Rodrigues Pardal[2], Filomeno Martina[2], Stewart Williams[2]

[1] Optics & Photonics Group, University of Nottingham
[2] Welding Engineering and Laser Processing Centre, Cranfield University

Additive manufacturing (AM) is a process of building a component layer by layer, and has been identified as an emerging and transformational manufacturing technology. The technology is important because it is logistically and conceptually extremely simple with major benefits (e.g. reduce buy to fly ratio and able to create complex component architectures). During manufacturing, structure build errors occur but can be corrected if identified, also microstructure changing after cold rolling directly relates to the material properties. Hence an inspection technique, ideally non-destructive and operated online, is highly demanded. SRAS has been shown to be capable of providing microstructural details of AM parts non-destructively, and will be further developed to extract the requisite microstructural information needed to prove that the material properties are needed. The SRAS system will be combined with the wire feed metal AM system to demonstrate the capability for online monitoring of grain structure in the actual AM environment.



SRAS inspection of wire and arc additive manufactured sample.



SRAS scan of polished titanium wire and arc additive manufactured sample.

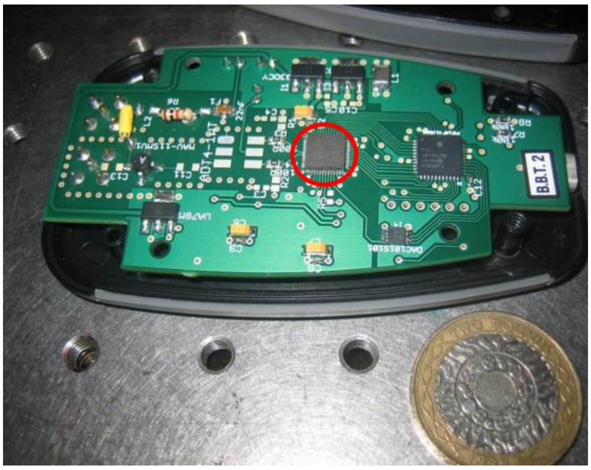
SKED: speckle knife edge detector for detection of ultrasound on rough surfaces

Samuel Achamfuo-Yeboah, Rikesh Patel, Roger Light, Steve Sharples

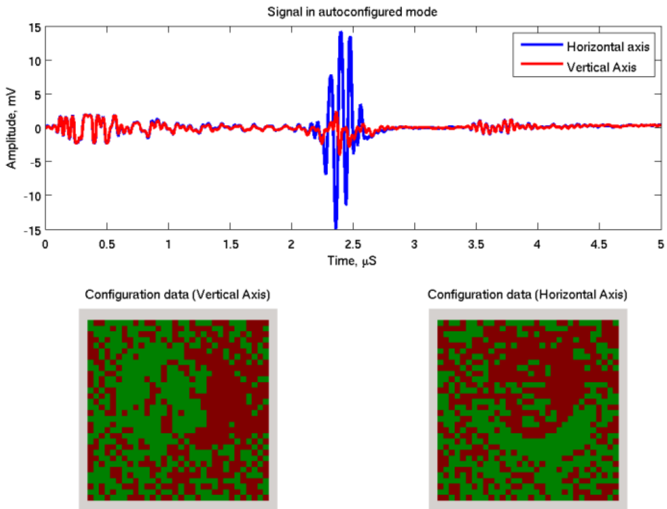
The optical detection of laser ultrasound from optically rough surfaces is severely limited using a conventional setup because the detected light is speckled. This means that complicated and expensive setups are required to detect laser ultrasound on rough surfaces. We present a CMOS integrated circuit that can detect laser ultrasound in the presence of speckle. The detector circuit is based on the simple knife edge detector. It is self-adapting and is fast, cheap, compact and robust.

The CMOS circuit is implemented as a widefield camera with 1024 pixels. Each pixel pairs up with one of two adjacent pixels and depending on the light intensity distribution over the array, a decision is made as to the output. The angular deflection of the surface due to the ultrasound preserves the speckle distribution whilst shifting it. The spatial disturbance of the speckle pattern due to the ultrasound is detected by considering each pair of pixels as a knife edge detector. The sensor can adapt itself to match the received optical speckle pattern in 0.1μS or even less, and then detect the ultrasound within 0.5μS of adaptation. This makes it possible to detect ultrasound from optically rough surfaces very quickly.

Because it is setup just like a camera, it is cheap, robust and easy to use. The detector is capable of independent operation controlled by a microcontroller (on the host printed circuit board), or it may be connected to a computer for more complicated configuration and control.



SKED printed circuit board, with SKED chip outlined.



Top: traces from a sample, showing sensitivity to orientation of the propagating surface acoustic wave depending on the axis of sensitivity set by the user.

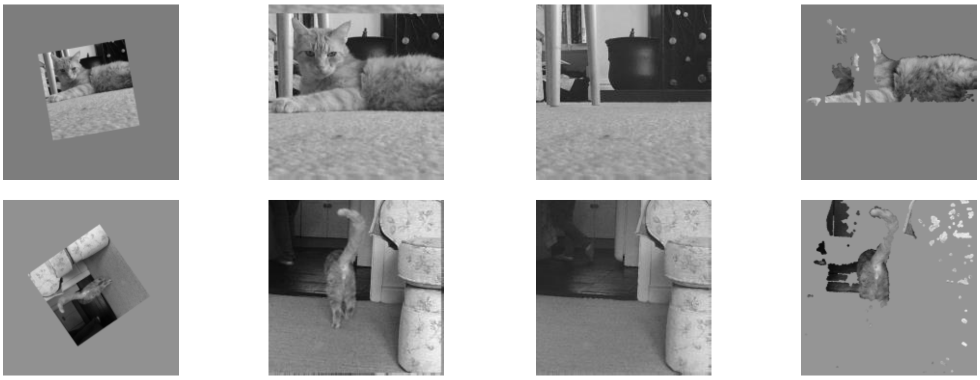
Visual recognition: identifying objects in linear subspaces

Nicholas Wells, Andrew Phillips, Chung W. See

State of the art computer vison is capable of assigning structural relationships between objects for the semantic description of real world scenes, *"There is a cat on a bed next to a child."* This inter-class relationship of the recognised objects is still far from competing with the capabilities of human vision, *"Our cat is lying on the unmade bed seeking the attention of my child."* State of the art is principally based on CNNs and deep learning strategies. However, their recognition performance error remains at the core issue in computer vision, the invariant nature of real world scenes and objects.

For enhancing visual signal content this research investigates signal processing techniques to improve non-parametric learning algorithms, and hidden structures of object features.

We have quantified the error of isolating an object invariant to translation and rotation. In development of this, we are investigating subordinate level categorisation to identify nonlinear structural relationships between intra-class object features cast into principal component space.



Invariant foreground detection. Two images of the same cat but at different views, the rotational and translational camera miss-alignment is corrected prior to background subtraction.

In support of recognition by parts, the similarity of features and structural relationships between object parts determines the probability of what the object is. The issue here is that a second cat would present the same feature space, hence; *how are they statistically different? What does this nonlinear relationship of intra-class feature space visually represent?* And, *is one my cat?*

Pressure measurements at single point using a fibre-optic Fabry-Pérot interferometer

Sergiy Korposh

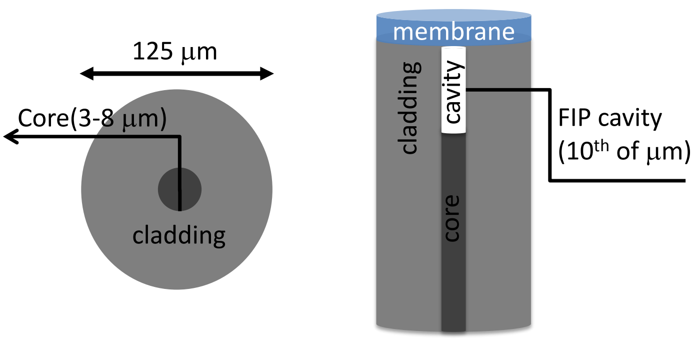
This work, which is undertaken in collaboration with Cranfield University and The University of Kitakyushu, Japan, focuses on the development of highly sensitive pressure sensors for bio-medical and industrial applications. The pressure sensor is formed at the tip of an optical fibre (typical outer diameter 125μm), offering compact device and flexible deployment.

The pressure sensor is formed by creating a Fabry-Pérot interferometer on the end of the optical fibre. A Fabry-Pérot interferometer (FPI) sensor consists of two partially reflecting surfaces separated by tens of micrometres, forming an *optical cavity*. The reflection spectrum of the FP is characterised by a sinusoidal channelled spectrum, the period of which depends on the cavity length. Small changes in the cavity length are characterised by a change in the phase of the sinusoid. A number of techniques may be employed to form an optical fibre FP cavity, ranging from complex machining and splicing to chemical etching using highly toxic reagents. One of the major drawbacks of the fabrication methods is low reproducibility.

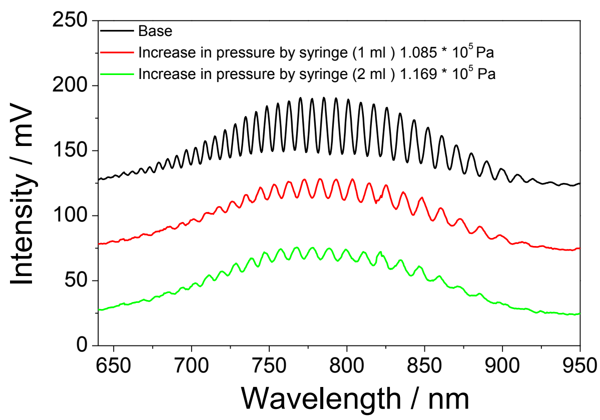
A novel method for the reproducible fabrication of a highly sensitive pressure sensor on the tip of an optical fibre is proposed. A narrow void is created at the end of a single optical fibre and a pressure sensitive membrane is attached directly to the end-face of the optical fibre. The interface between the core of the fibre and the cavity forms one of the reflecting surfaces while the flexible membrane forms the second, as illustrated in Figure 1a. Increasing the ambient pressure pushes the flexible membrane towards the fibre, thus changing FP cavity length, leading to wavelength shift of the channelled spectrum as shown in Figure 1b.

Here a free-standing thin film is used as the pressure sensitive membrane. The high sensitivity of the FPI is achieved as a result of the use of an ultrathin parylene membrane, with thickness ranging from 10s to 100s of nanometres. The free-standing membrane is directly and firmly attached to the tip of the optical fibre via electrostatic forces.

The dimensions of the pressure sensor are determined by the size of the optical fibre, typically 125μm. The sensitivity and dynamic range can be varied by changing the thickness of the pressure sensitive membrane.



Schematic illustration of the FP cavity in an optical fibre.

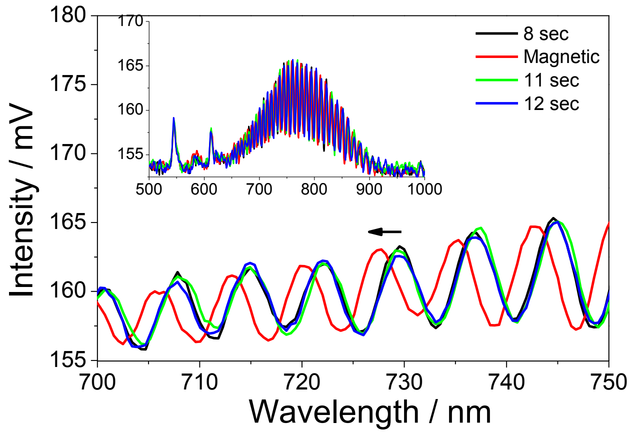


Typical response of the fibre optic FPI pressure sensor.

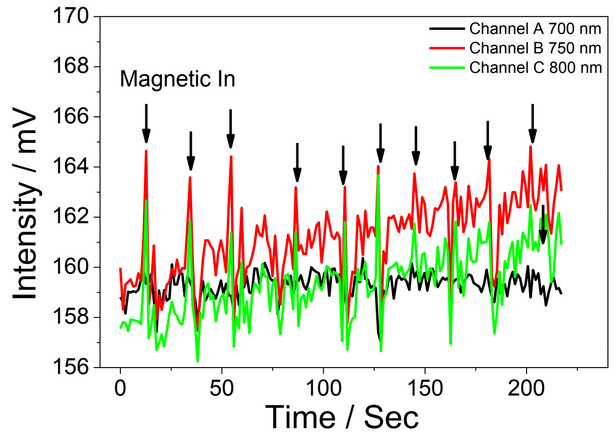
Ultra-miniature magnetic field sensor based on a fibre-optic Fabry-Pérot interferometer

Sergiy Korposh

This work, undertaken in collaboration with Cranfield University and The University of Kitakyushu, Japan, is aimed at the fabrication of miniature magnetic field sensors with highly sensitivity and fast response times. The principle of operation is based on the Fabry-Pérot interferometer (FPI), with the sensor consisting of a single optical fibre with a magnetic field sensitive membrane attached directly to the end-face of the optical fibre. The presence of the magnetic field leads to the deflection of the membrane thus changing the length of the optical cavity, which can be measured via changes in the reflection spectra, as shown in the figures.



Typical spectral response of the fibre-optic FPI sensor to the presence of the magnetic field.



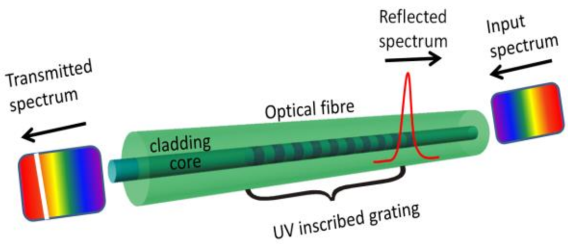
Dynamic response measured at single wavelength.

Measurements of the contact pressure at multiple locations using multiplexed optical fibre Bragg gratings

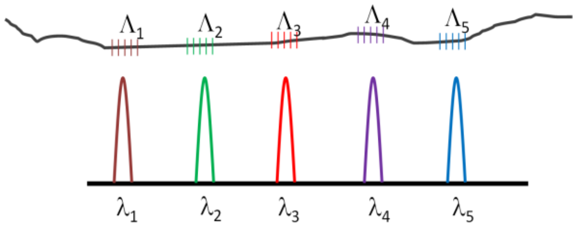
Sergiy Korposh

Fibre optic grating based sensors, fibre Bragg gratings, (FBGs), and long period gratings (LPGs), have been extensively investigated for the measurement of physical and chemical parameters.
An FBG consists of a periodic modulation of the refractive index of the core of the optical fibre with a period of the order of the wavelength of light. The FBG acts to reflect light of a specific wavelength (equal to twice the optical period of the grating) back along the fibre, see the figures below. The lengths of the FBG can vary from 0.5mm to 20mm [1].

A key feature of FBG sensors is the ability to wavelength-division-multiplex a serial array of sensors in a single optical fibre (right hand figure), and this is exploited in the measurement of strain, pressure and temperature across a wide range of industrial sectors. FBG sensor interrogation and data logging instrumentation is now available commercially.



Schematic illustration of an FBG inscribed inside the core of an optical fibre.



Wavelength-division-multiplexing of a serial array of FBG sensors in a single optical fibre; each grating has different grating period Λ with the corresponding reflection wavelengths λ.

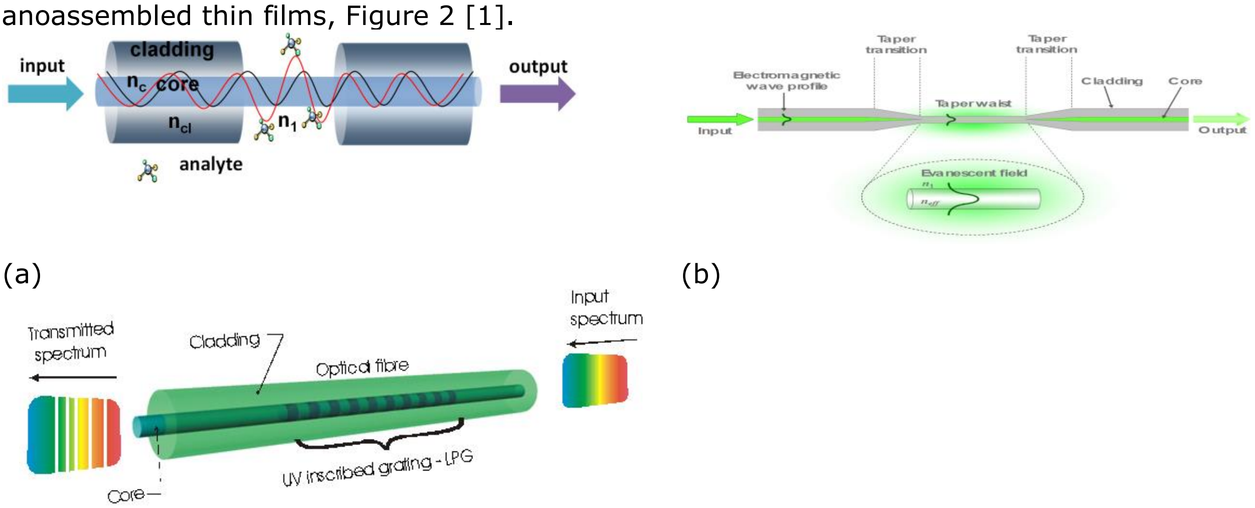
Reference

[1]. Sunita Ugale et. al., 2010, "Fiber Bragg Grating Modeling, Characterization and Optimization with different index profiles," *International Journal of Engineering Science and Technology*, **2** (9), 4463-4468.

Optical fibre chemical sensors modified with sensitive films for bio-medical applications

Sergiy Korposh

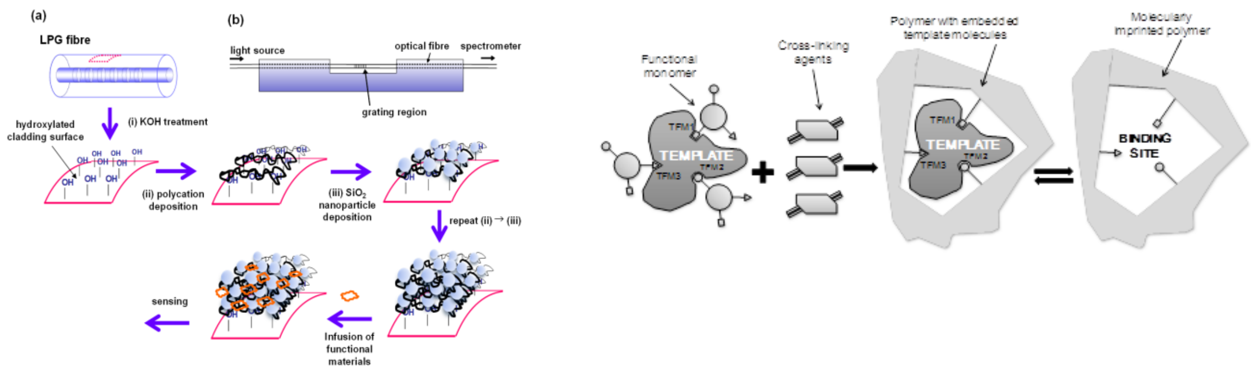
Sensing techniques based upon the use of optical fibre devices to probe the optical characteristics of nanomaterials that exhibit changes in their optical properties upon exposure to targeted chemical species are particularly attractive, due to their potential high sensitivity, selectivity, the ready ability to multiplex arrays of sensors, and the prospect for remote sensing. The variety of different designs and measurement schemes that may be employed using optical fibres provides the potential to create very sensitive and selective measurement techniques that can be deployed in real environments. In our work we have focussed on the development of fibre-optic chemical sensors utilising different measurement designs based on multimode optical fibres, (Figure 1a), tapered optical fibres (Figure 1b) and optical fibre long period gratings (Figure 1c) functionalized with nanoassembled thin films, Figure 2 [1].



(a) (b)

(c)

Figure 1: Schematic illustration of (a) an evanescent wave type sensor, (b) a tapered optical fibre sensorsensor and (c) an optical fibre LPG sensor.



(a) (b)

Figure 2: Schematic illustration of the (a) layer-by-layer (LbL) electrostatic deposition process; and (b), molecsular imprinting process.

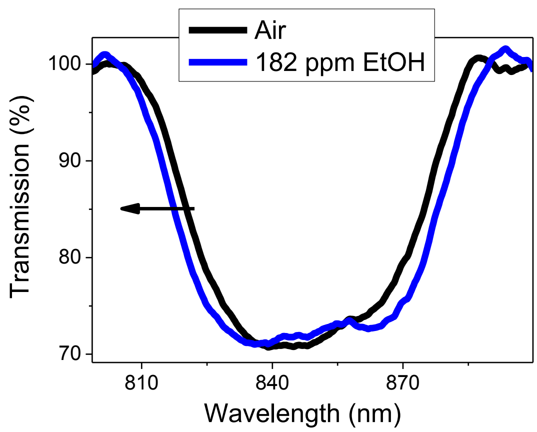
Reference

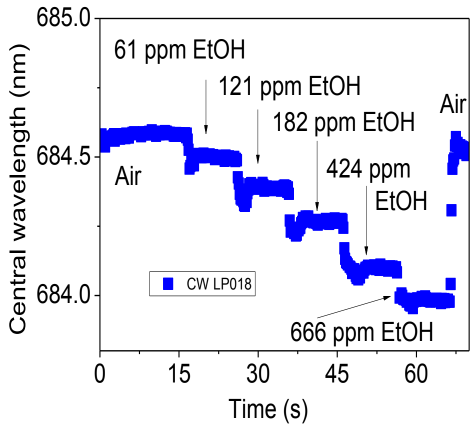
S. Korposh, S. James, R. Tatam, and S.-W. Lee, 2013, "Fibre-optic chemical sensor approaches based on nanoassembled thin films: A challenge to future sensor technology" in: *Current developments in optical fiber technology*, Dr. Sulaiman Wadi Harun (Ed.), ISBN: 978-953-51-1148-1, InTech, DOI: 10.5772/53399, 2013.

Fibre optic long period grating (LPG) chemical sensors modified with metal organic framework (MOF) thin films

Jiri Hromadka, Begum Tokay, Stephen James, Sergiy Korposh

Grating based fibre-optic sensors have attracted a lot of attention since they provide a useful platform for the development of multiparameter sensing system. Long period grating, LPG, consists of a periodic perturbation of the refractive index of the core of an optical fibre. The deposition of the functional coating endows an LPG with the sensitivity and selectivity to a particular compound. The sensor’s operation principle is based on the changes of the transmission spectrum induced by the measurand. An optical fibre LPG modified with a thin film of ZIF-8, a zeolitic immidazol framework, or HKUST-1, materials from metal organic framework family, was employed for the detection of organic vapours and carbon dioxide respectively. As an example the sensitivity to ethanol vapours is enough for the detection of 180 ppm of alcohol in breath providing the adequate sensitivity for the driver’s tests.





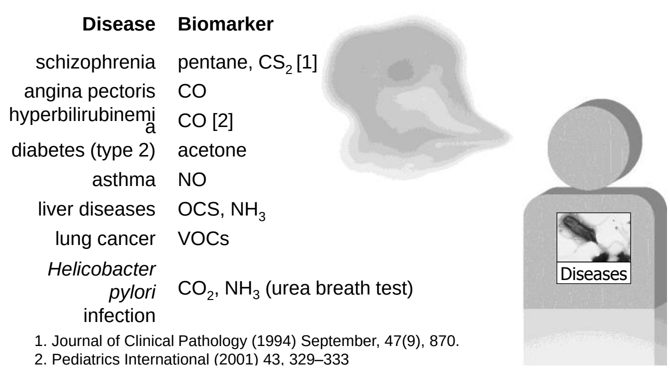
Left: transmission spectrum of optical fibre LPG in air (black) and the change induced by 182 ppm of ethanol vapour (blue). Right: dynamic response of the sensor to ethanol vapours at concentrations from 61 to 666 ppm.

Breath analysis using fibre optic sensors

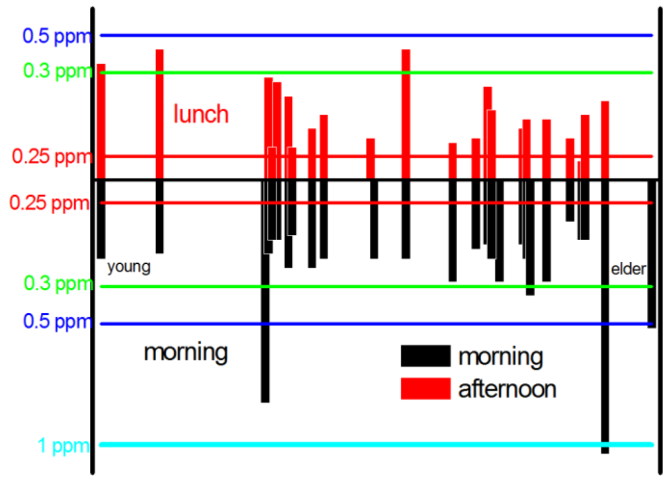
Sergiy Korposh

Chemical compounds excreted from the human body are believed to reflect certain metabolic conditions as well as the blood gas content, See left hand figure [1]. The changes in concentration of some compounds, referred to as biomarkers, and the chemical composition of human samples such as breath, blood, urine, sweat and saliva can be linked to particular diseases and have been intensively used in medicine for early and minimally invasive diagnosis [2]. There is considerable interest in the development of sensor devices to identify compounds both *in vivo* and *ex vivo* that can facilitate non-invasive diagnosis.

In collaboration with Cranfield University and The University of Kitakyushu, an optical fibre sensor for the measurement of ammonia, a known biomarker, in the breath of a patient has been demonstrated with the aim of developing point-of-care device, (right hand figure).



Biomarkers exhaled in breath.



Response of the fibre optical sensor modified with the sensitive film to ammonia measured using 50 healthy volunteers before and after lunch.

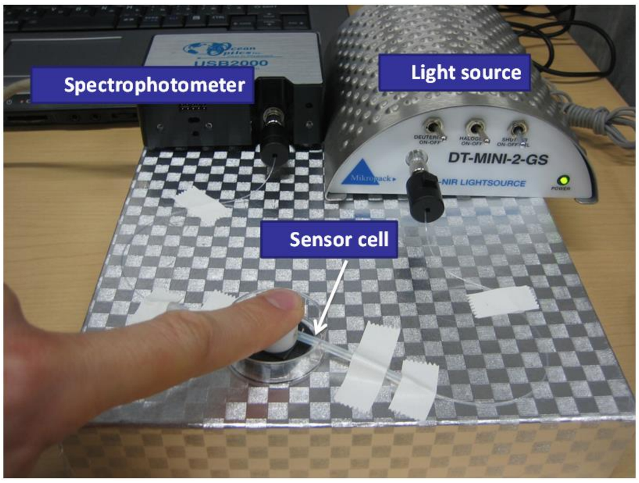
References
[1]. S Ohira, K Toda, 2008, "Micro gas analyzers for environmental and medical applications," *Anal. Chim. Acta,* **619**, 143.
[2]. C Probert, I Ahmed, T Khalid, *et al.,* 2009, "Volatile organic compounds as diagnostic biomarkers in gastrointestinal and liver diseases," *J Gastrointestin Liver Dis.* **18**, 337.

Skin gas analysis using fibre optic sensors

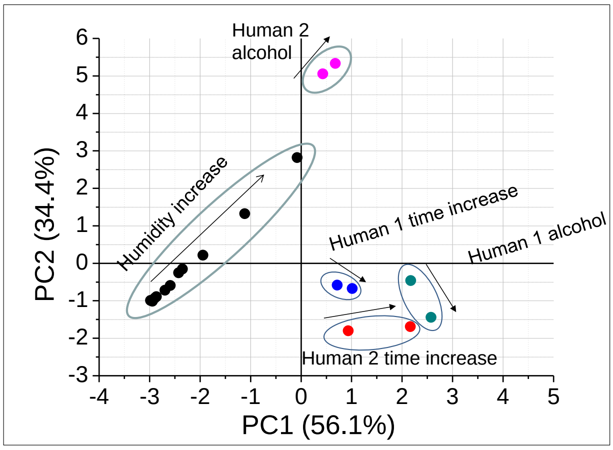
Sergiy Korposh

New diagnostic methods are of considerable interest in medicine. A lot of information about the chemicals excreted by human skin is available in the literature [1]. In gas chromatography (GC) based experiments, a variety of compounds such as acetone, ammonia, hydrocarbons, aromatics were shown to be emitted by human skin, with the quantity of some being correlated to blood content. Some studies suggested that it was that it was possible identify human subjects through the examination of their odour volatile organic compound (VOC) patterns, formulating the idea of a personal “smellprint” as analogue of fingerprint.

An evanescent-wave optical fibre sensor modified with tetrakis-(4-sulfophenyl) porphine (TSPP) and poly(allylamine hydrochloride) (PAH) bilayers using layer-by-layer (LbL) electrostatic self-assembly was tested to measure the gas emitted from human skin, shown in the left hand figure. Responses of the current optical sensor system could be considered as composite sensor array, where different optical wavelengths act as channels that have selective response to specific volatile compounds. Data obtained from the sensor system was analysed using principal component analysis (PCA). This approach enabled to distinguish skin odours of different people and their altered physiological conditions after alcohol consumption, (right hand figure).



Sensor used for the skin gas analysis.



Principal component analysis performed using the measured data.

References

[1]. S.I. Ohira, K. Toda, 2008, “Micro gas analyzers for environmental and medical applications,” *Anal. Chim. Acta* **619**, 143–156.

[2]. R. Selyanchyn, S. Korposh, W. Yasukochi, S.-W. Lee, 2011, “A preliminary test for skin gas assessment using a porphyrin based evanescent wave optical fiber sensor”, *Sensors & Transducers Journal*, **125** (2), 54-67.

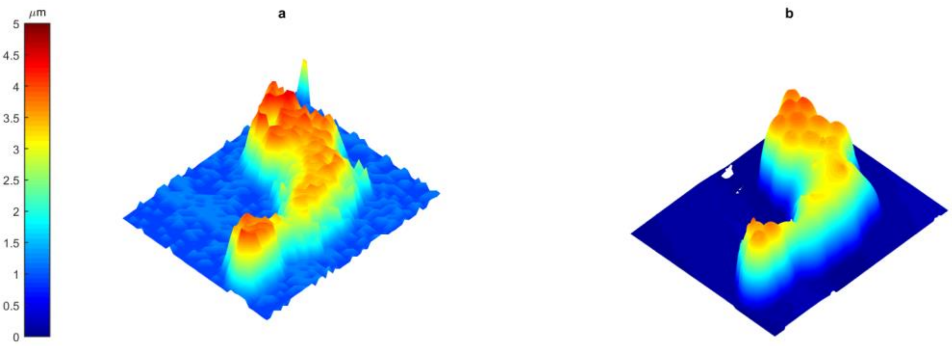
Imaging in three dimensions with picosecond laser ultrasound

Richard J Smith, Fernando Perez Cota, Leonel Marques, Matt Clark

The progress in picosecond laser ultrasound instrumentation, development of novel transducer substrates [1] and imaging modalities [2] has meant that imaging of micro sized structures, including living biological cells [3] is now possible. The time resolved nature of the measurements introduces the possibility of three dimensional imaging by use of different signal processing methods to monitor variations in the signal with depth in the sample. The ability to measure mechanical properties in 3D is a valuable tool for many applications, as most other high resolution mechanical imaging techniques only probe the surface of a sample (e.g. atomic force microscopy)

This project is investigating a number of different signal processing techniques including, signal fitting, zero crossing analysis, short time Fourier transforms and wavelet analysis to analyse the signals from several cell phantoms. The aim is to be able to reconstruct objects or section them in three dimensions to obtain a wealth of new information in the samples studied.

We are also investigating the limitations of the techniques with regards to transverse resolution – do time resolved high frequency acoustic measurements offer a viable way to achieve high z resolution compared to the current gold standard of optical microscopy?



(a) Reconstruction using zero crossing method of cell phantom profile.
(b) AFM image of the same phantom.

[1] R. J. Smith, F. P. Cota, L. Marques, X. Chen, A. Arca, K. Webb, J. Aylott, M. G. Somekh, and M. Clark, JASA, vol. 137, no. 1, pp. 219–227, Jan. 2015.
[2] T. Dehoux, M. A. Ghanem, O. F. Zouani, J.-M. Rampnoux, Y. Guillet, S. Dilhaire, M.-C. Durrieu, and B. Audoin, Sci. Rep., vol. 5, Mar. 2015.
[3] F. Pérez-Cota, R. J. Smith, E. Moradi, L. Marques, K. F. Webb, and M. Clark, Applied Optics, vol. 54, no. 28, p. 8388, Oct. 2015.

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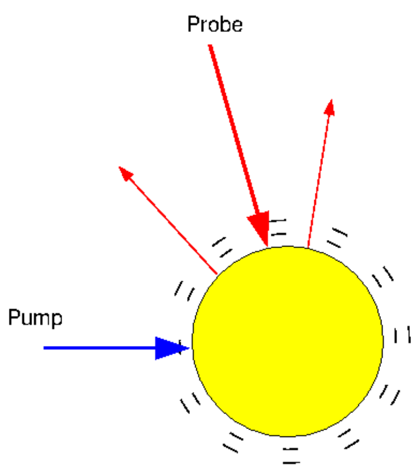
Nano-particle acoustic transducers

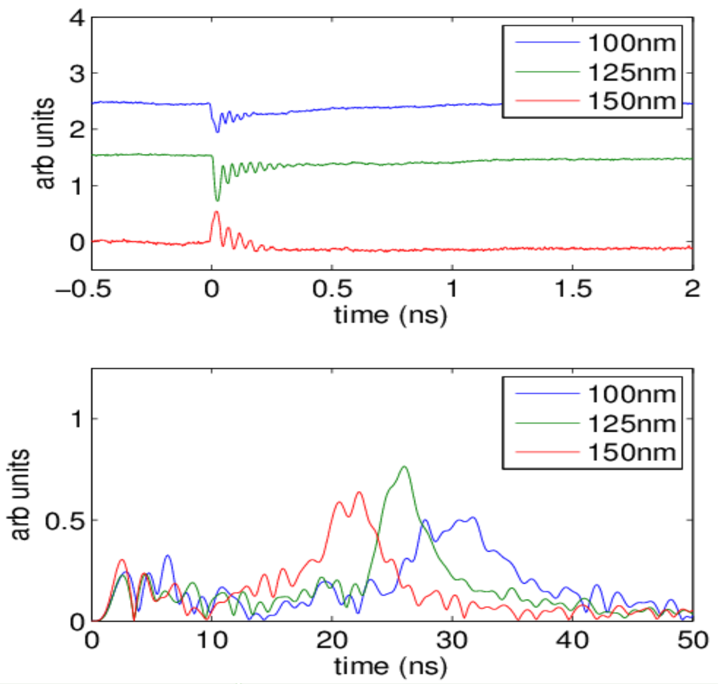
Rafael Fuentes Dominguez, Richard J. Smith, Leonel Marques, Fernando Perez Cota, Matt Clark

There has been much interest in the optical and mechanical properties of solid and core-shell nanoparticles. Our interest stems from the ability of such devices to interact with ultrasound of very short wavelength allowing the possibility of high resolution acoustic imaging.

There are a number of different fabrication approaches that could be adopted for making nano-ultrasonic transducers. Previously, a plate transducer for cell imaging has been developed [1], but making the lateral dimensions of the transducer smaller than one micron is challenging. An alternative approach to overcome this difficulty is to make transducers using nanoparticles. Nanoparticle transducers have some attractions, they are inherently small, can be made in large quantities, have an easy symmetry and for metal particles can exploit plasmonics to enhance the detection sensitivity.

This project has been developing both optical and mechanical models (analytical and FE models) to describe their behaviour. The optical model is based on Mie scattering [2] and allows us to choose a suitable size/material/medium of transducer to have good sensitivity at our probe wavelength. The mechanical model describes the expected main breathing mode frequency of the transducer.
The fabrication process of nanoparticles is an important area as making things the correct size is important for their operation and so we characterize the particles we make with TEM. Example results obtained from a pump-probe laser ultrasound on different sized particles is shown in figure 1.





Cartoon of a particle interacting with light and experimental signals and breathing mode frequencies of solid gold nanoparticles on sol-gel.

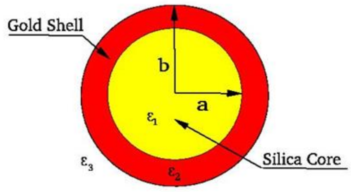
[1] F. Perez-Cota, R. J. Smith, E. Moradi, L. Marques, K. F. Webb and M. Clark, Appl. Opt., Vol. 54, No. 28, 8388-98 (2015)
[2] O. Pena and U. Pal, Computer Physics Communications, Vol. 180, No. 11, 2348-2354 (2009)

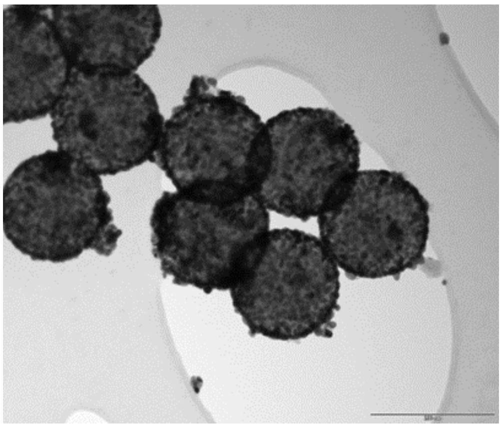
Development of core-shell nanoparticles as nanotransducer for ultrasonics

Leonel Marques, Richard Smith, Fernando Perez Cota, Matt Clark

At Prof. Clark's laboratory, the development of the smallest available nanotransducer devices in the market is made [1]. The devices are designed to operate at high frequencies and made within the size range of 100 to 500 nm. The fabrication process is based on chemical approach like self-assembly of different size nanoscale units. At the end of the fabrication process a core-shell spherical nanoparticle is generated, it is made of an inert and transparent core (silica or polystyrene) covered by a gold shell layer. The devices are easily fabricated with different size ranges, at low cost and in large quantities (200 ml batches containing ~millions of nanotransducers) and stable over time. The dimensions of the core and shell are modelled first and calculated to operate within a specific frequency output. The devices are excited and probed using femtosecond lasers. New applications in biomedical sensing and imaging can be developed using our nanotransducers.

(a) 

(b) 

(c) 

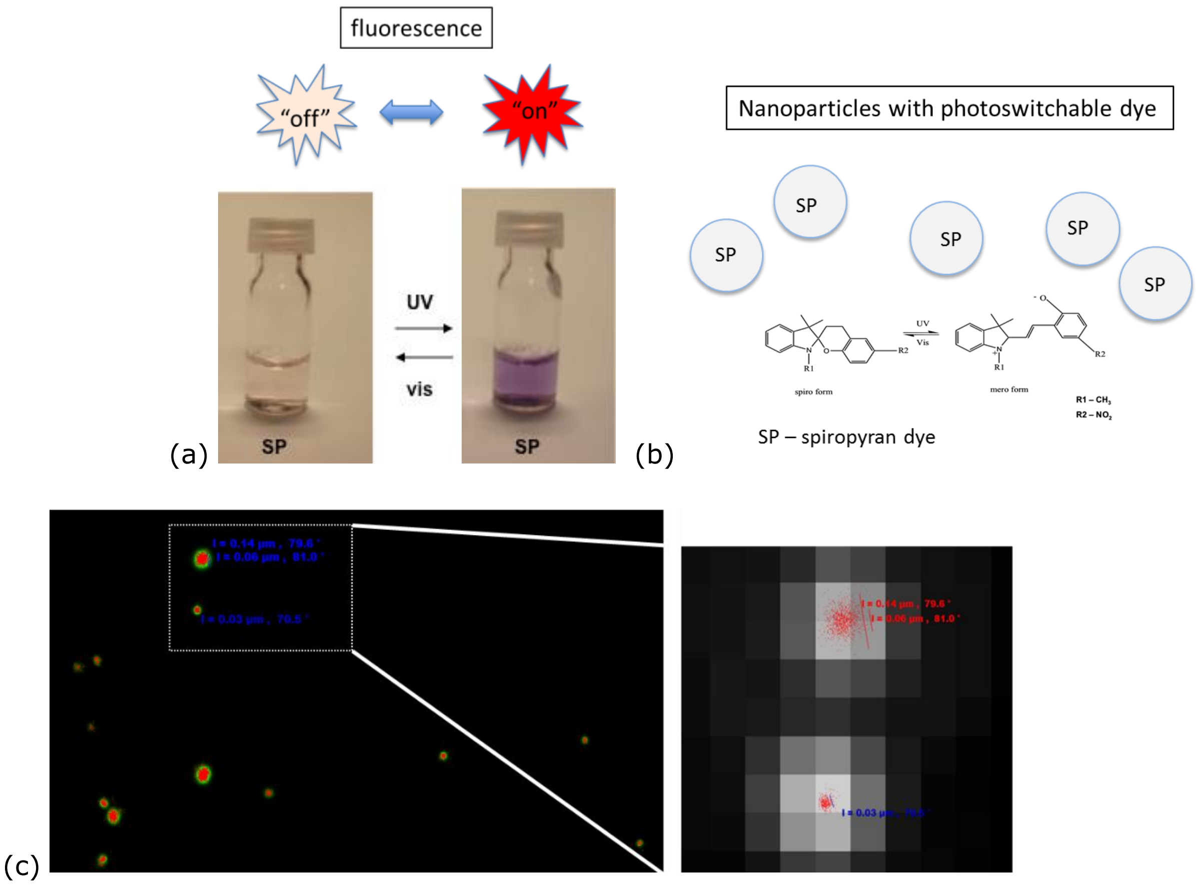
(a) Photograph of glass round flasks with core-shell nanotranducers; (b) schematic diagram of a core-shell nanoparticle structure; (c) TEM images of 200 nm core-shell nanotransducers (scale bar 200 nm).

[1] Richard Smith, Fernando Perez Cota, Leonel Marques and Matt Clark, "Optically excited nanoscale ultrasonic transducers, J. Acoust. Soc. Am. 137, 219 (2015).

Nanoparticles for super-resolution microscopy

Leonel Marques, Rikesh Patel, Robert Markus, Tim Self, Matt Clark

New techniques in the field of super-resolution microscopy, such as STED, PALM, and STORM, tackle the resolution limit by using a photoswitchable fluorescent signal. In our work we use spiropyran (SP) as the photo-switchable molecules incorporated into nanoparticles (and also complex polymer films). These molecules can be switched into fluorescent 'on' and 'off' states by using light with two different wavelengths. Our working samples are being tested with our collaborators, Robert Markus and Tim Self from the school of Life Sciences by using their new acquired super resolution microscope (Zeiss Elyra). The microscope has proven the efficacy of our system which allow for our nanoparticles to be resolved via PALM. Further research is ongoing to test our nanodevice with cells imaging.



(a) Schematic and photography of vials containing the spiropyran nanoparticles showing no fluorescent state ("off state") and fluorescent state ("on" state) as a coloured solution;
(b) chemical structure of the spiropyran molecule and a schematic diagram of the nanoparticles;
(c) a super-resolution microscope image resolving the nanoparticles containing the photoswitchable dye, spiropyran, and zoomed area showing the fluorescent events.

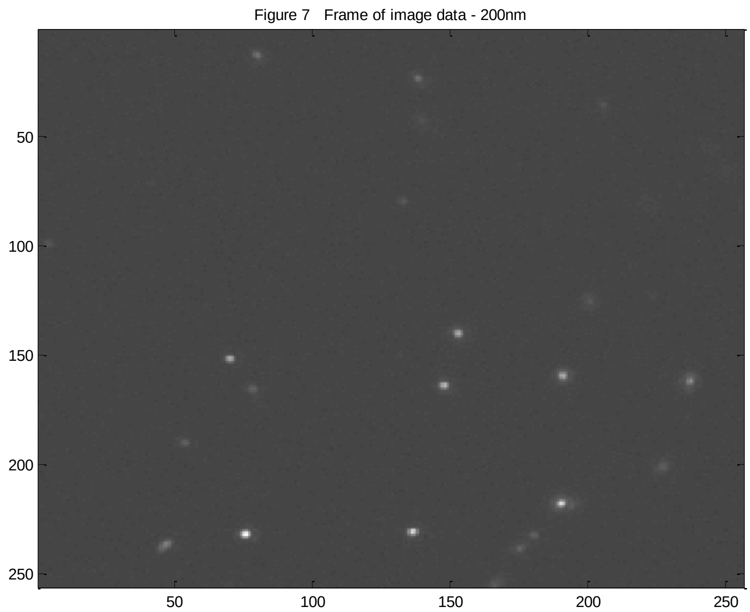
Nano-particle tracking analysis

John G Walker

The random displacements due to Brownian motion of a particle, suspended in a liquid, are dependent on the particle radius as well as the temperature and viscosity of the liquid. The Nano-particle tracking method uses images of particles to measure the random movements of individual particles. The images (see example in figure) are formed by illuminating a cuvette containing a suspension of particles with a thin sheet of light and then focussing the light scattered by this small volume onto a camera. The sheet of light is usually of a thickness similar to the depth of focus of the imaging lens so that only particles in the focal depth are strongly illuminated. A large number of images are recorded. The data processing consists in determining the positions of the individual particle images and by comparing these for adjacent frames, an estimate for the movement of individual particles can be obtained.

Nano-particle tracking is a method to estimate a particle size distribution by tracking the movements of individual particles, using multiple images of particles moving under Brownian motion. This project is looking at novel methods (e.g. maximum-likelihood) to recover a particle size distribution from Nano-particle tracking data. Unlike the conventional histogram method, the methods being investigated are able to account for the finite number of steps in each particle track and for the measurement uncertainty in the data. The work is based on algorithm development and Monte-Carlo computer simulation.

The work is done in collaboration with NanoSight (a subsidiary of Malvern Instruments), a manufacturer of particle sizing instrumentation.



A pixel frame of image data; the effective size of the pixels is approximately 1 micrometre. The particles are nominally 200 nm in radius polystyrene spheres.

Cell investigations of adipose cells differentiated from stem cells

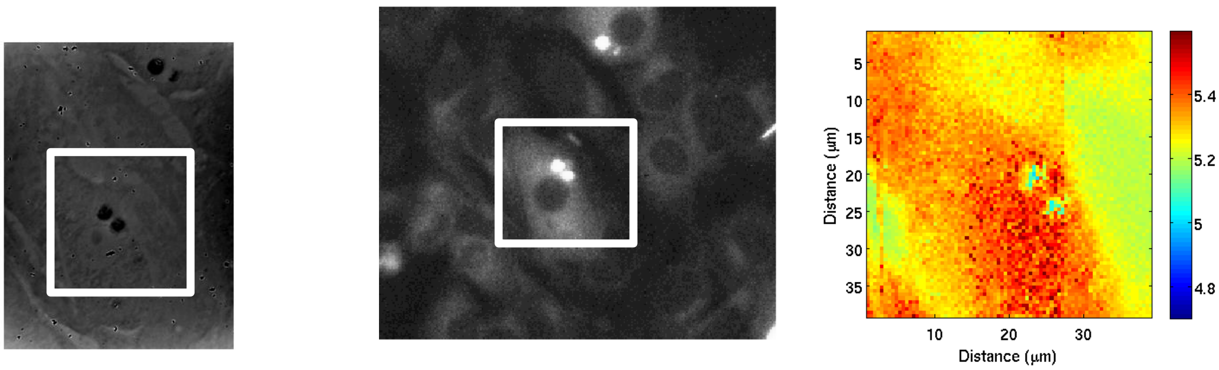
Fernando Perez, Richard Smith, Anaid Lugo*, Kevin Webb, Virginie Sottile*, Matt Clark

*School of Medicine

Adipose cells are the cells in the human body responsible for storing energy in the form of fat while regulating metabolism. There is a recent interest to understand such cells and their function in the body as it might provide insights to the current global obesity crisis.

Using a novel optoacoustic imaging technique, this project, in collaboration with the school of medicine, intends to look for new insights in adipose cells function and structure.

Preliminary results show that the fat globules that form inside the cells as they mature can be seen with high contrast from the main cell body, showing that the acoustics can provide useful information on not only the shape and size of the globules but also potentially the fat composition.



Imaging of adipose cells differentiated from stem cells. Left: bright field optical image. Centre: fluorescence labelling of lipids, the white spots show the location of the lipid drops. Right: acoustic image showing contrast between the cell body and forming lipid drops (green).

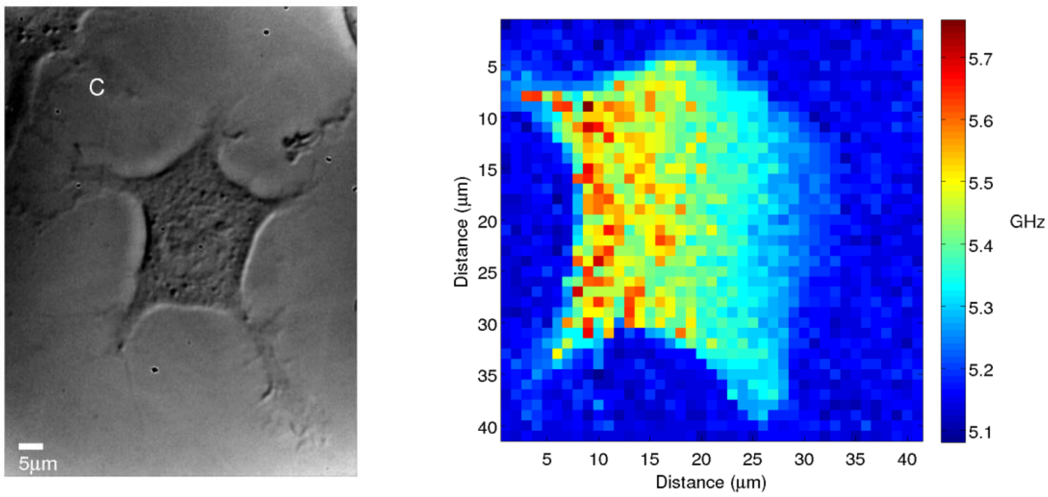
Live cell imaging with picosecond laser ultrasound

Fernando Perez, Richard Smith, Emilia Moradi, Leonel Marques, Kevin Webb, Matt Clark

Picosecond laser ultrasound offers a possibility for high-resolution non-invasive imaging of biological cells. This has great significance since there is a limited selection of techniques that can address imaging of living preparations and provide contrast related to the mechanical properties of the specimen.

Additionally, the high frequency of the ultrasound used (typically 5GHz+) means that the axial resolution is limited by the acoustic wavelength rather than the optical wavelength, which means that 3D sectioning with sub optical resolution should be possible.

In this project, a novel method of cell imaging is being developed, this involves the careful management of the light exposure and the local temperature so that the intense laser pulses used to generate and detect the sound waves do not damage the cells. We achieve this by engineering special thin film stacks which protect the cell from the laser pulses and conduct heat away from the cells. This has enabled us to image living cells in three dimensions using phonons instead of photons.



Live cell imaging of a 3t3 fibroblast cells. Left: bright field optical image. Right: acoustic image showing the change of Brillouin frequency across the cell as the cell dies.

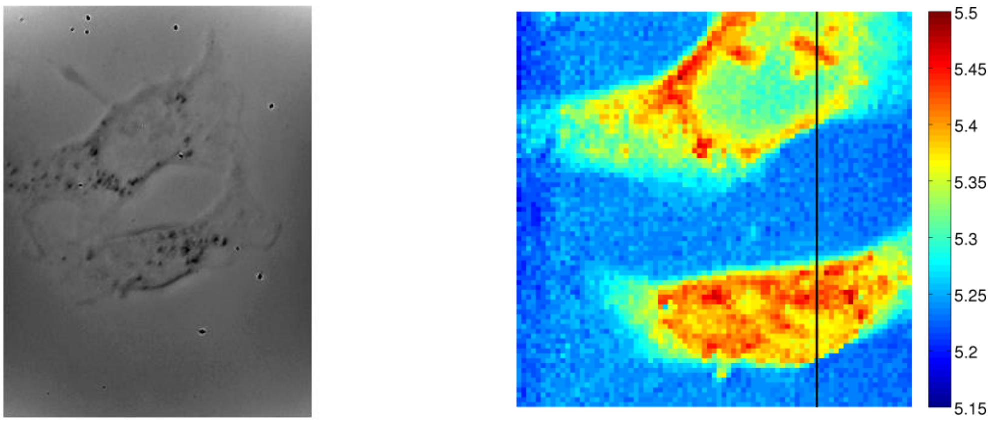
Label free Cell imaging of infectious microorganisms

Fernando Perez, Richard Smith, Kevin Webb, Hany Elsheikha*, Matt Clark.

*School of Veterinary Sciences

Using a novel high frequency acoustic imaging technique developed at the University of Nottingham, this project, in collaboration with the school of veterinary sciences, looks to investigate infectious organisms such as toxoplasmas or acanthamoebas in search for new insights in their structure and function.

These organisms affect millions of people globally, however their Biology is not fully understood. Toxoplasmas infect the brain cells of the host and are capable of modifying the behaviour of the host. Acanthamoebas are responsible for many eye infections and if untreated can lead to blindness.

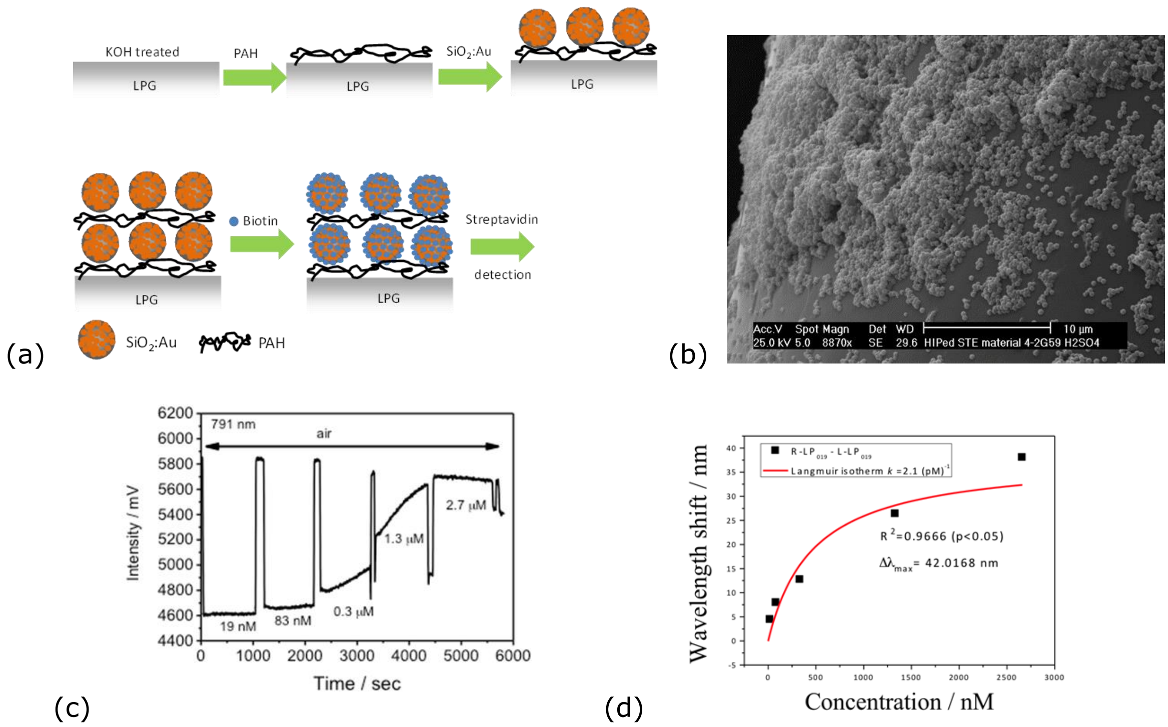


Acoustic imaging of toxoplasma infested cells. Left: bright field optical image. Right: acoustic image; the parasite is clearly visible in the top right of the acoustic image (red cross).

Development of biosensors using optical fibre long period gratings modified with core-shell nanoparticles

Leonel Marques, Ulises Hernandez, Steve Morgan, Matt Clark, Sergiy Korposh

A new optical biosensing device was made using an optical fibre long period grating (LPG) decorated with silica gold core-shell nanoparticles. The LPG is a core-cladding mode coupling device, where the in-fibre grating has a period of order within 100-500 um. The attachment of nanoparticles to the optical fibre LPG surface will enable a functional coating reflecting the refractive index changes over the detection of coupled analytes. We used a layer-by-layer approach using polyelectrolytes to electrostatically assemble the nanoparticles over the fibre surface. The metal layer of the core-shell nanoparticle enabled a surface plasmon resonance (SPR) like sensor sensitive to the attachment of model proteins like biotin and streptavidin (SV). The entire system proved to be sensitive enough to detect levels of SV proteins down to the concentration of 19nM. We are currently continuing with our study for further improvement of our sensing device and also testing relevant antibodies associated with cancer diagnosis.



(a) Schematic diagram of the nanoparticles assembly. (b) TEM image of the optical fibre LPG coated with nanoparticles. (c) Transmission values measured at 791 nm and different SV concentrations. (d) Langmuir isotherm fit of the sensor detecting the SV concentrations.

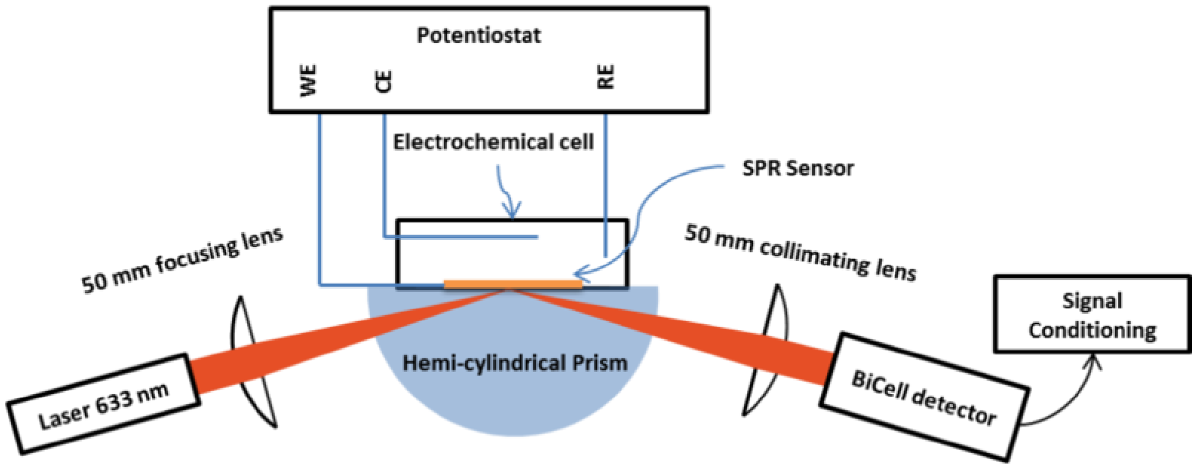
[1] L Marques, F.U. Hernandez, (….) S Korposh, “Highly sensitive optical fibre long period grating biosensor anchored with silica core gold shell nanoparticles”, Biosensors and Bioelectronics, 75,(2016), 222-231.

Sensing voltage dynamics with differential intensity surface plasmon resonance systems

Sidahmed Abayzeed, Richard Smith, Kevin Webb, Chung See

This project is directed at researching the capacity of surface plasmon resonance systems for label-free detection of electrical signals that are generated by excitable cells. Electrical signals are important in communication and control in biological systems. Therefore, accurate and reliable measurements of these signals at the cell level provide a valuable tool for physiological and pharmacological investigations. Unlike the popular fluorescent and micro-electrode techniques, surface plasmon resonance is a label-free, non-invasive way to measure localised signals at the cell-sensor interface.

Surface plasmon resonance (SPR) sensors are conventionally used to detect molecular interactions at the metal-dielectric interface. Additionally, they demonstrated the ability to detect the externally-applied voltage, which characterises them as electrodes with optical readout. As the project is motivated by resolving weak signals associated with dynamic processes, it aims to (i) estimate the limit of voltage detection of SPR using theoretical and experimental approaches and (ii) investigate the response time of the sensor to demonstrate the ability of the technique to resolve the transient electrical signals.



Surface plasmon resonance (SPR) sensing system combined with three-electrode electrochemical system. The potential of the working electrode (WE) is clamped with respect to the reference electrode (RE) by passing current between the counter electrode (CE) and the working electrode (WE). The applied voltage is detected simultaneously using the SPR system.

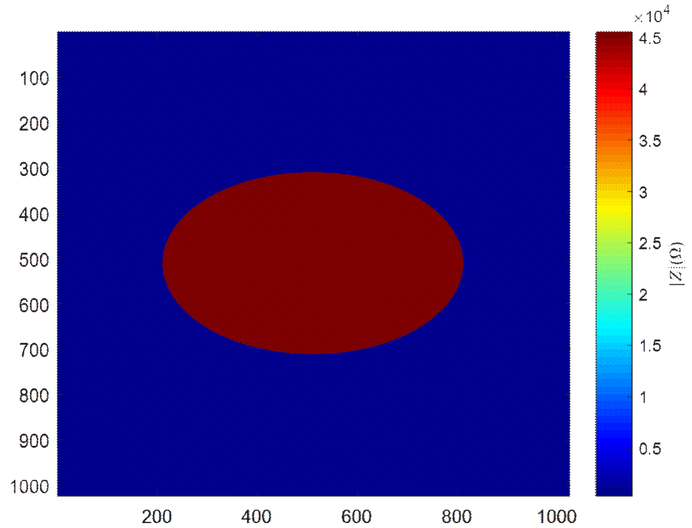
Advanced plasmonic-based impedance imaging of living cells

Sidahmed Abayzeed

This research is part of a two year postdoctoral fellowship, which is directed at developing an advanced optical imaging method to map the electrical impedance of biological cells. Measuring impedance at the cellular level is of a particular importance. Such measurements are utilized to understand key biological processes that are mediated by the cell membrane transporting ions and molecules from/to the cell.

The underpinning research aims to use plasmonic sensors which feature the ability to produce images of voltage or current. Therefore, they open new horizons in functional imaging of cells shifting the state of the art from low throughput microscopy-incompatible tools to high throughput that provides images of cell structure as well as retrieving rich information content about the cell function. Functional imaging of cell membrane, for example, is extremely important since it mediates normal and malfunctioning communications between the cell and the environment. It therefore provides a valuable future tool for understanding cellular interactions such as cell signalling, molecular transport or immune cell activation, in addition to pharmacological and drug screening applications.

This fellowship is funded by the EPSRC under the Doctoral Prize scheme and hosted by Prof Matt Clark within the Optics & Photonics Group.



Simulation of the electrical impedance of the cell membrane generated using input voltage signal at 2Hz. The background represents the impedance of the sensor.

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Cell optics

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Microscopy techniques for the life sciences

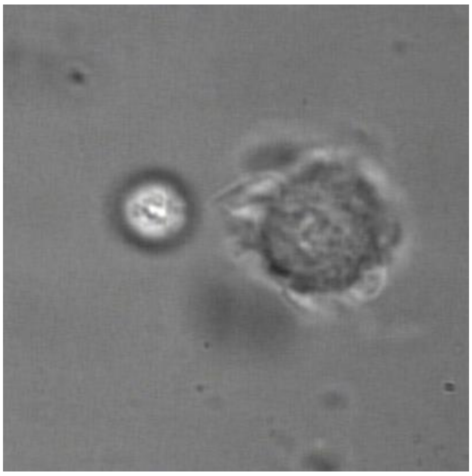
Amanda J Wright

My focus is on optical microscopy techniques that can be applied to life science research and I work closely with colleagues in the School of Life Sciences. The two techniques I am currently working on are optical trapping or optical tweezers and adaptive optics. Optical trapping involves using a laser beam and a high numerical aperture microscope objective lens to trap, manipulate and control micron sized cells/objects in three dimensions. It has been around since the early 1980s and has found application across the science and engineering disciplines. Examples of recent projects include:

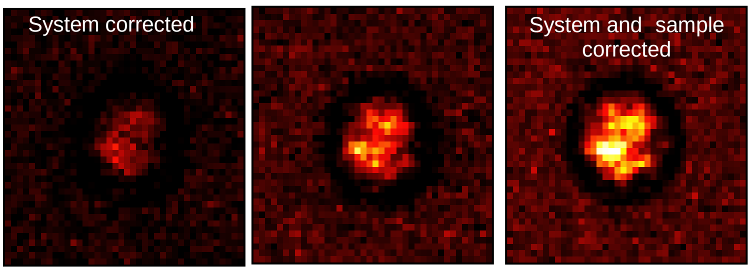
1) Using an optically trapped local probe to study the micro-rheology of the vitreous humour to aid the development of more effective drug delivery systems
2) Accurately quantifying the interaction force between individual immune cells and observing differences in force associated with therapeutic intervention

Adaptive optics was originally developed for optical astronomy to overcome the aberrations caused by the earth's atmosphere and to improve the quality of images. I specialise in transferring this technology to non-linear microscopy systems where image resolution and quality are known to greatly deteriorate with imaging depth. I have worked on confocal, multi-photon, CARS and second harmonic microscopes successfully installing adaptive optics systems leading to improved image quality at depth.

This work has been supported by the Royal Academy of Engineering, EPSRC, EU, Royal Society and Allergan.



Controlling and quantifying the interaction force between immune cells. Here the T cell is optically trapped and the dendritic cell is adhered to the coverslip.



A 10µm diameter polystyrene bead imaged at a depth of 592µm in a CARS microscope. Left to right: no aberration correction applied; correcting for only system induced aberrations; correcting for system and sample induced aberrations.

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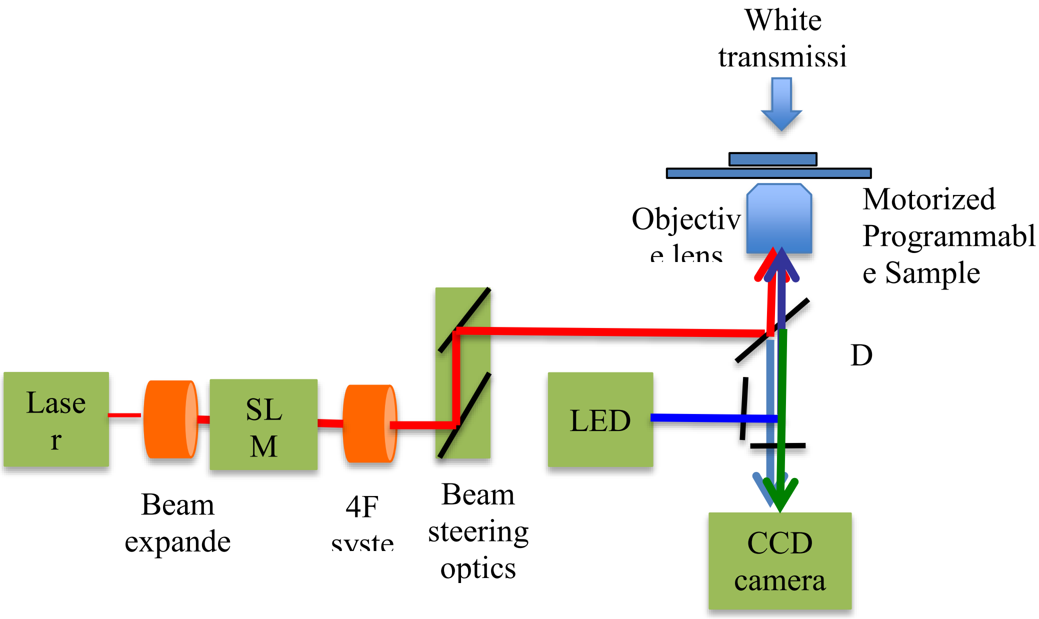
Optical trapping approaches for probing and modulating the mechanical properties of live cells

Aishah Mustapha, Joanna Richens, Jonathan Bramble, Melissa Mather, Paul O'Shea, Amanda Wright

The means to study and understand the mechanical properties of a cell have been of interest for many decades because they are linked to cell viability and function. To date, the characterisation of live cells in culture is done using conventional biological analysis techniques. These techniques are either destructive or involve modification of the cells.

In this research, optical tweezers have been used as a tool to trap and manipulate small objects without destructing them. The main aim of this study is to use optical tweezers and optical approaches to study the mechanical properties of live cells. At the moment, we have been working and experimenting on liposomes as model cells.

The liposomes were optically trapped in a single-beam gradient force trap operating at a wavelength of 1064 nm. With the liposome held in the trap, the sample stage was moved at a fixed velocity to exert a viscous drag force on the trapped liposome.



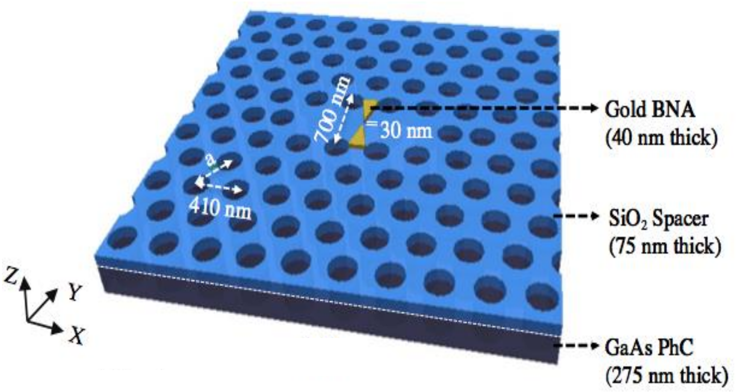
Optical trapping setup with 1064nm NIR laser. The sample stage is programmed in LabVIEW, and moved at a constant velocity to create an external force which cause the trapped object to deform. SLM is used to scale-up the deformation technique, and fluorescence turret is used to check the viability of cells.

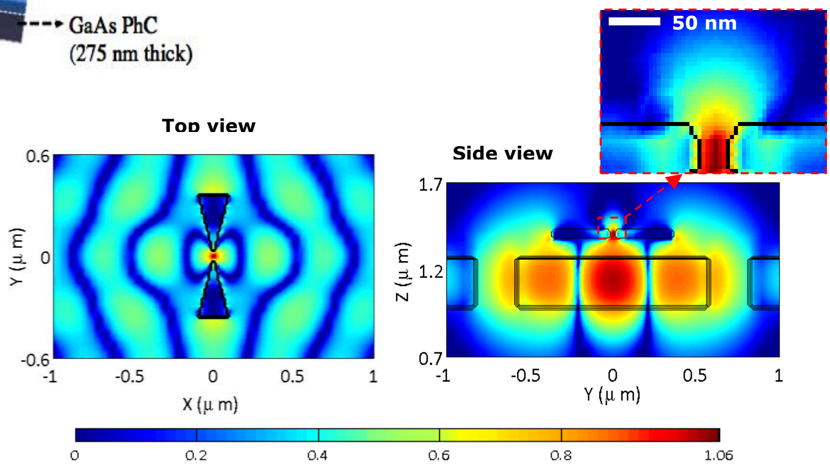
A hybrid photonic-plasmonic platform with high quality factor and external localization of light

Mina Mossayebi, [1] Alberto Parini, [2] Amanda J. Wright, [1] Mike G. Somekh, [3] Gaetano Bellanca, [2] Eric C. Larkins [1]

[1] Optics & Photonics Group, University of Nottingham
[2] Department of Engineering, University of Ferrara, Italy
[3] Department of Electronic and Information Engineering, Hong Kong Polytechnic University

We are focused on the design and characteristics of a hybrid photonic-plasmonic nanoresonator comprising of a L3 photonic crystal cavity coupled to a 700nm long, gold bowtie nanoantenna with a 100nm thick silicon dioxide layer as a realistic spacer between the two. Using 3D finite-difference time-domain simulations, we show that this hybrid device can achieve a hot spot outside the PhC cavity with a volume ~ 36,000nm^3 and an optical intensity enhancement > 15, while maintaining a high quality factor of ~20,000. We also show ability of integrating this device with platforms such as photonic integrated circuits by integration of this hybrid device with a W1 PhC waveguide. Future applications include nanosensing, near field optical trapping and manipulation of nanoparticles, Raman spectroscopy, and quantum interfacing.





Top left: illustration of the proposed hybrid photonic-plasmonic nanocavity comprising of an L3 PhC cavity (dark blue), a gold BNA (yellow) and the SiO_2 layer (light blue) separating the two. The PhC is based on a 275 nm thick GaAs slab with a triangular lattice of air holes (a = 410nm). The holes in the PhC are extended through the SiO_2 layer, to maintain a high quality factor. The gold BNA is 700 nm long and consists of two 40 nm thick isosceles triangles forming a bowtie with a tip width of 30 nm and a gap of 30 nm. Bottom right: Illustration of the optical intensity ($|E_y|^2$) profile of the hybrid device plotted in logarithmic scale.

Condenser-free phase contrast microscopy

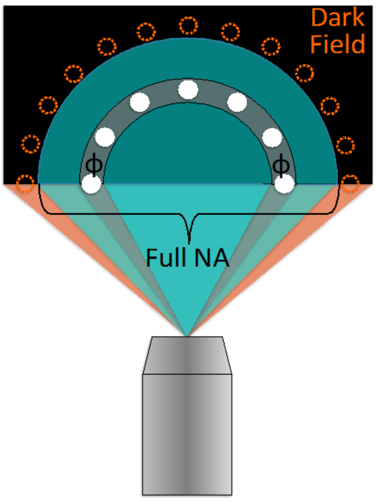
Flavius Pascut, Kevin Webb

Phase contrast microscopy allows the study of highly transparent yet detail-rich specimens by producing intensity contrast from phase objects within the sample. We have developed a generalised phase contrast illumination schema in which condenser optics are entirely eliminated, yielding a condenser-free yet highly effective method of obtaining phase contrast in visible light microscopy. A ring of light emitting diodes is positioned within the optical light-path such that observation of the objective back focal plane places this ring in appropriate conjunction with the phase plate.

We have demonstrated that true Zernike phase contrast is obtained, whose geometry can be flexibly manipulated to provide an arbitrary working distance between illuminator and sample. Condenser-free phase contrast has been demonstrated across a range of magnifications (4-100x), numerical apertures (0.13-1.65NA), and conventional phase positions. Also facilitated by the same schema is condenser-free darkfield microscopy, as well as the simultaneous application of condenser-free phase contrast in conjunction with scanning probe methods, such as scanning ion conductance microscopy (SICM).

By eliminating the condenser assembly, and thus providing enhanced working space above the preparation, a range of concurrent imaging and electrophysiological techniques are technically facilitated. The compact, versatile LED illumination schema further lends itself to novel next-generation transmitted-light microscopy designs, while the condenser-free illumination method using rings of independent emitters may be exploited in future in other electromagnetic wavebands, including X-rays or the infrared.

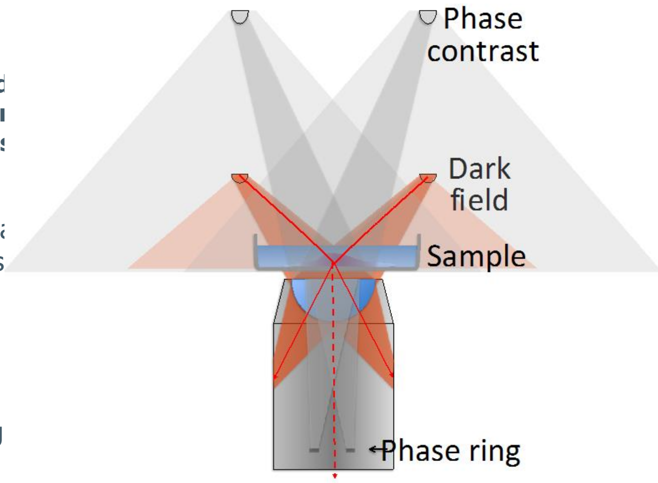
This work has been supported by the Royal Academy of Engineering and the EPSRC

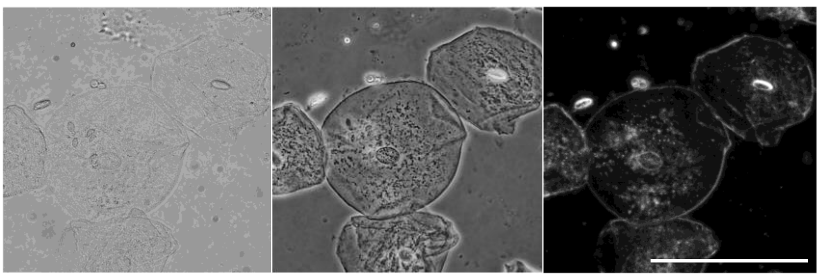


Condenser-free illumination schema phase contrast and d field imaging at arbit geometries, using ring LED's:

Left Illumination schem for condenser-free phas contrast and dark field imaging using rings of LED's

Right Back Focal Plane schema showing conjug of illumination sources





Condenser-free contrast enhancement in buccal epithelial cells:

Left **bright-field**
Middle **phase contrast**
Right **Dark field image**

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Direct imaging of epithelial fluid transport

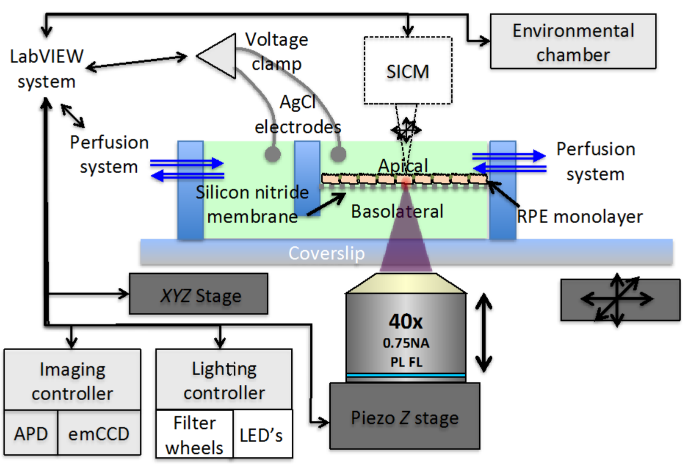
Flavius Pascut, Emilia Moradi, Kevin Webb

Epithelial fluid transport lies at the heart of bodily homeostasis; maintaining fluid and ion balance in response to normal physiology and to insult. Dysfunctions in epithelial transport are implicated in cystic fibrosis, kidney disease, and eye disease. The cornea, ciliary epithelium, and retinal pigment epithelium (RPE) are all important fluid transporting epithelial structures in the eye.

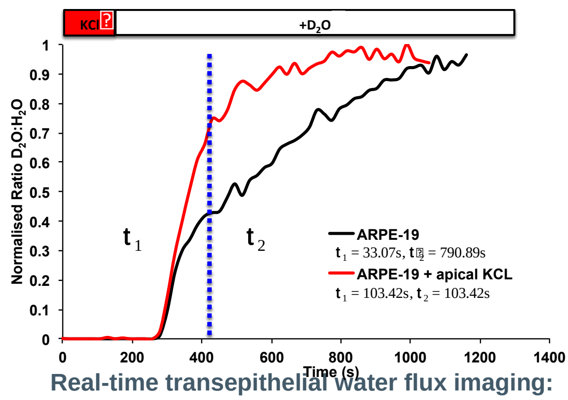
This programme of research addresses a fundamental limitation in the field; that of a lack of direct water transport measurements at the nano- to microscale within and across transporting epithelia. While it is known that the flow of solvent (water) is coupled to that of ions and other solutes, exactly how epithelia transfer fluid between two solutions of identical composition remains an enigma. A range of proxy measures of water flux have been employed, but water transport has yet to be imaged directly at the subcellular scale.

Our hybrid optical and electrophysiological system is being assembled to address the mechanistic foundations of epithelial fluid transport by providing multiscale, multimodal measurements of electrodynamic events at subcellular resolution. Confluent RPE layers have been established on nanopermeable silicon substrates which are highly permeable, incredibly thin (50nm) and optically transparent. Small (1mm^2) RPE cultures are held under voltage or current clamp for simultaneous high-resolution imaging of water flux using confocal Raman microspectroscopy. The resulting system is amenable to both apical and basolateral perfusion, allowing physiological and pharmacological manipulation. Optogenetics is further being applied for the first time to drive and manipulate epithelial transport in individual cells, non-invasively, using stimulus pulses of light.

This work is supported by the BBSRC and EPSRC



System schema showing geometry and control systems for perfusion, imaging, and positioning



Real-time transepithelial water flux imaging: Time evolution of ratiometric D_2O:H_2O Raman signals, under control conditions and in the presence of depolarising $[KCl]_o$ obtained 10µm above confluent ARPE-19 cells,

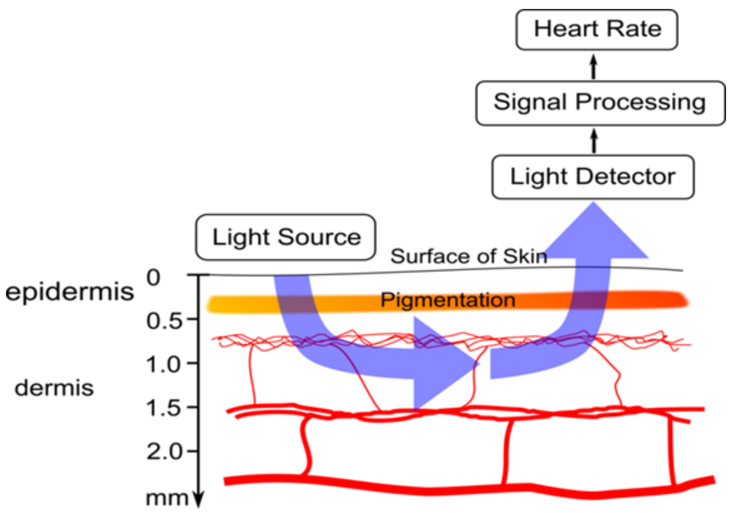
Heartlight: heart-rate sensing from miners to minors

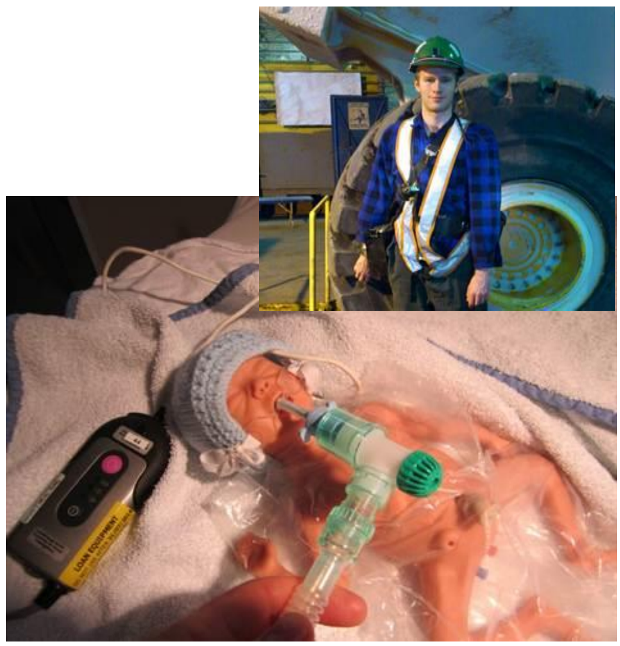
Barrie Hayes-Gill, John Crowe, Steve Morgan

A small optical non-invasive heart-rate sensor (Heartlight) has been developed by University of Nottingham academics. Started through a Rio Tinto EPSRC PhD CASE in 2004, the technology has been applied to multiple fields of use, including monitoring the health and wellbeing of miners working in hot environments and the assessment of newborn babies requiring resuscitation at the time of birth.

Miners can be exposed to temperatures exceeding 60 degrees Celsius, which means that many suffer from heat stress. This causes a number of problems such as fatigue, a decline in alertness and vigilance, muscle cramps and in the worst cases, heat stroke. A recent collaboration with a contract electronics manufacturer, Tioga Ltd, in the form of a KTP, has enabled the production of a wireless hard-hat incorporating Heartlight technology. The hard-hat has already undergone trials in underground mines with promising results.

A serendipitous meeting with a clinician in 2007 (Dr Don Sharkey) prompted the development of a Heartlight sensor suitable for use in newborn resuscitation. 10% of newborn babies require some form of resuscitation at birth and heart rate is the best indicator of the success of interventions. However the current heart-rate assessment technique, the stethoscope, is often inaccurate, and causes mismanagement and delays during the resuscitation. An improvement to resuscitation practice through the use of Heartlight will reduce short term morbidity and save on healthcare costs. Over 250 recordings have been performed on newborns to date, and future research will concentrate on clinical user needs and industrial prototyping. This work has recently been commercialised by the formation of a Joint venture between the University and Tioga to form a new spin out company called Heartlight Systems Ltd based in Derby. Subsequent to this company formation the team have benefited from the award of a £1.4M Biomedical Catalyst Innovate UK award to undertake clinical trials in readiness for product launch in 2018.





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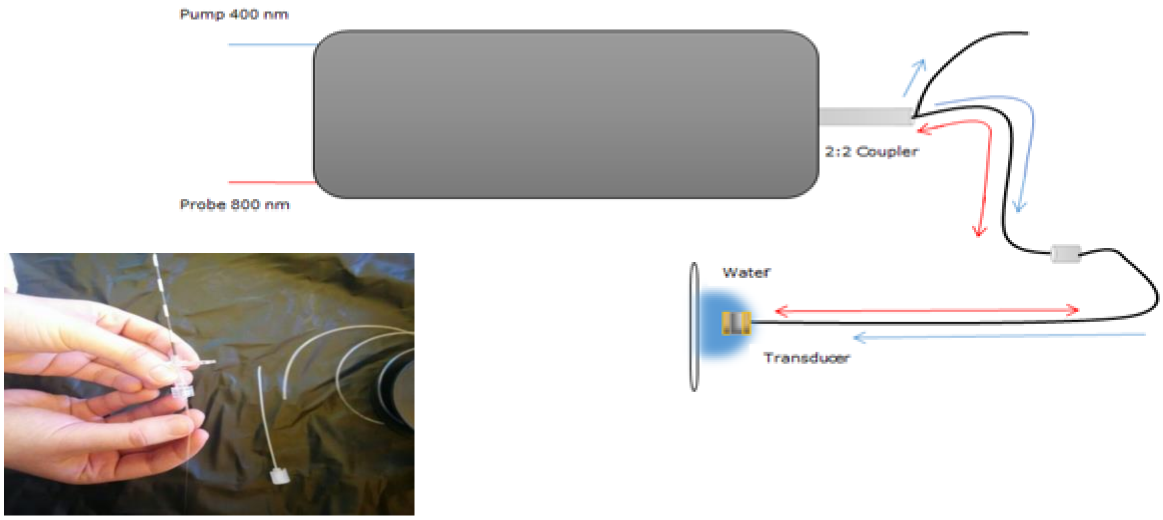
Needle compatible ultrasonic transducer for biomedical applications

Mitra Soorani, Richard J Smith, Fernando Perez Cota, Leonel Marques, Kevin Webb, Serhiy Korposh, Matt Clark

In so many circumstances in the field of medicine very small devices are needed to observe or monitor targets that are hard to access. Using technology originally developed for ultrasonic cell imaging it is possible to produce extremely small transducers, smaller than a grain of salt, which can be mounted at the end of optical fibres. Such small transducers have many potential applications in medicine, such as measuring tissue properties during needle biopsies or the ultrasonic guiding of needles during injections.

In this project, we are re-engineering plate transducers which were originally designed for nanoscale live-cell imaging to produce sub-mm^3 ultrasonic probes for deployment in needles. The aim is to produce tuneable transducers for producing a wide range of ultrasonic frequencies from the low 100’s of MHz to 10’s of GHz depending on specific application requirements. The transducers developed in this study are used to both generate and detect the presence of ultrasound. The generation is via optical absorption of the generation laser pulse which thermo-elastically generates an acoustic wave. In detection the transducers operate in a manner similar to a Fabry-Pérot interferometer allowing high sensitivity detection of the acoustic waves see figure. The thickness of the layer and the choice of materials in the device are determined by the two optical wavelengths of our laser system.



Cartoon of the concept, pump and probe laser beams are coupled into a fibre system. The transducer is at the tip of the fibre which can be inserted into a needle for use during medical procedures. Example early results of the transducer generating high frequency acoustic waves.

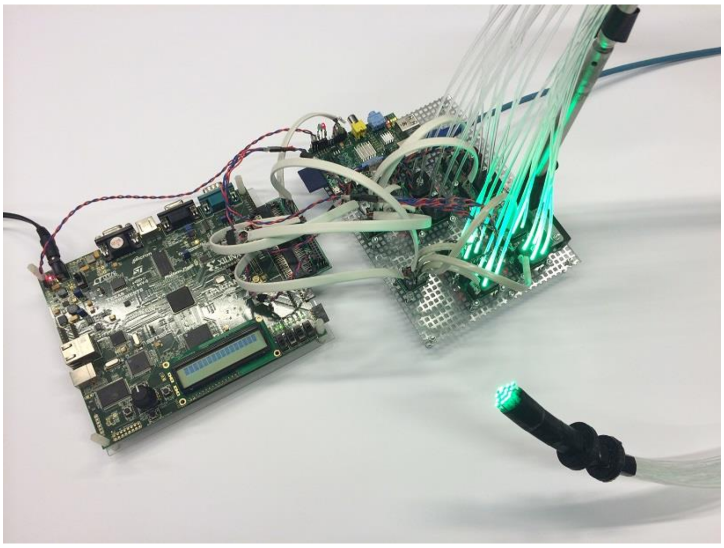
Motion artefact reduction for reflection-mode photoplethysmography

Matthew Butler, Barrie Hayes-Gill, John Crowe

The goal of this research is to minimise the effect of motion on the PPG when in reflection-mode. This has been achieved by taking multiple, simultaneous, measurements in a mechanically-coupled and optically-decoupled system, and exploiting redundancies in the resulting data. By calculating the differential effects of the movement on neighbouring channels, it can be more easily separated from the common signal, the PPG.

Photoplethysmography (PPG) is a technique that uses light to detect pulsatile blood from beneath the surface of the skin. This cardiac-synchronous, pulsatile, blood can be used to non-invasively determine the heart-rate and blood-oxygen saturation. This is used predominantly in clinical settings in ‘transmission-mode’, whereby the light enters one ‘side’ of the subject and leaves the other for detection. This, of course, limits the use to extremities with small dimensions. Additionally, during some illnesses and when cold, the body will restrict the blood-flow to these extremities, making the measurement more difficult, and where blood-oxygen-saturation is being measured, potentially inaccurate.

Reflection-mode systems, whereby the light that enters the skin scatters back to the same side, can be used anywhere on the body where a blood supply is present so does not suffer from these limitations. However, due to the poorer mechanical coupling with the subject, and the significantly different optical paths that exist, the technique is more susceptible to ‘motion artefacts’ – errors that occur in the measurement as a direct result of the subject (or sensor) moving.



The developed “Optical Matrix” that allows synchronous measurement of 16 regions of the subject's skin. Each ‘channel’ consists of a light source-sensor pair and can be controlled independently to allow for optically-differential measurements during movement.

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