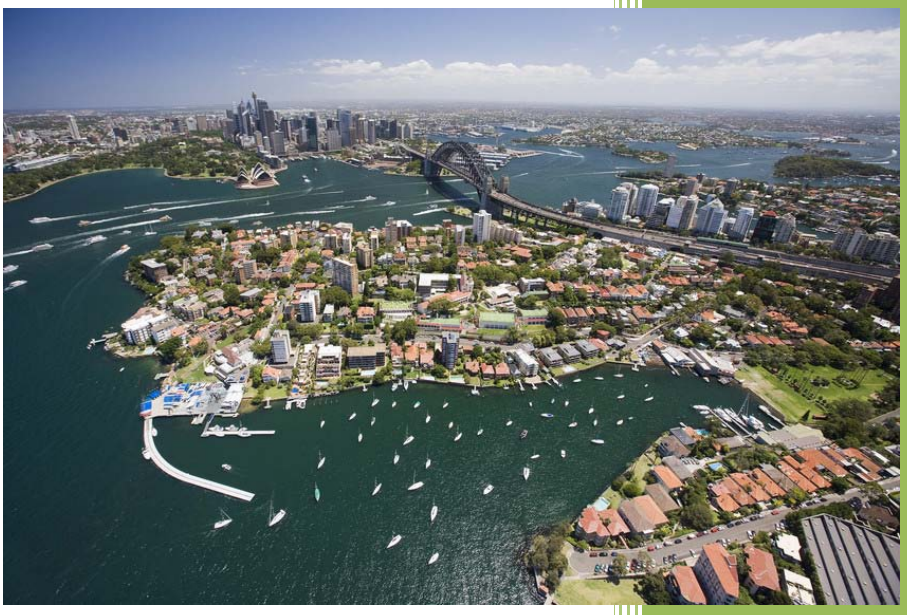
APOS 2012

3rd Asia Pacific Optical Sensors Conference

Sydney Australia



Hamilton Lund, Tourism NSW.

Conference 8351
Tuesday-Friday 31 January-3 February 2012
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History:
1st APOS2008 – Chengdu, China
2nd APOS2010 – Guangzhou, China
3rd APOS2012 – Sydney, Australia

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Welcome Message

The 3rd Asia-Pacific Optical Sensors Conference 2012 (APOS2012) is being held in Sydney, NSW, Australia, from January 31 to February 3, 2012. The conference is jointly organized by the University of Sydney and University of NSW and is the third in the series since the original founding conference in Chengdu, China.

The conference is a meeting point for academic researchers, technical and business professionals and end user industries to share and exchange their ideas and R&D experiences, from fundamental to applied spanning many diverse areas including structural health monitoring, environment, energy efficiency, extreme sensing, and more. The previous event focused quite strongly on optical fibre and grating technologies, emphasising their explosive growth in the region particularly in the energy and environmental sectors. This event will have an added component on biophotonics recognising the growth it too is experiencing in the region. The role of materials and interdisciplinary research is especially important in extending various optical and fibre optical sensing technologies, and as we begin this conference, we leave 2011 – the International Year of Chemistry and the Year of Humanitarian Engineering. These two celebrations recognise increasingly the role of materials and the increased emphasis on a humanistic perspective of what we do and why. Achieving and ensuring a stable and high quality of life for all is clearly a key driver for much of sensing work.

In short, the conference is the region's key forum for reporting the latest progress in optical and photonic sensing technologies. Holding it in Sydney, the first time outside of China, recognises the regional inclusiveness and status of this event and it is important that this inclusiveness continues strongly well into the future. It is also a symbolic acknowledgement of the centre stage the Asia-Pacific Region is assuming, in driving the fastest expansion of wealth, and therefore market growth, in human history. It is not coincidental that the growth of optical sensing in this region correlates with this rise in standard of living. As concerns for the environment translate across to increased demands in energy efificency and improved health, many are turning to optical sensing as the most favored technological approach for tomorrow's "healthy societies".

Tomorrow's optical sensing involves much more than the detection of a signal or preliminary diagnostics of an illness – it is increasingly integrated with communications into intelligent networks that will likely go well beyond the SmartGrid. They will be active and form the frontline of genuine artifical intelligence that, through "the internet of things", spans global networks actively monitoring many aspects of our societies and indeed our perosnal lives (the grand challenges this will pose can already be seen in the impact electroninc surveillane through social websites is already having). So the opportunites are immense, exciting and perhaps potentially worrying – so on that note, we hope you enjoy the conference whilst reflecting upon the brave new world we are entering, one where optical sensing is key. And in the midst of all the expert dialog, please take time to enjoy Sydney and its own wonders,.

We warmly welcome you to Sydney.

Conference Chairs:

Prof. John Canning & Prof. Gang-Ding Peng

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APOS2012 Technical Program overview

Tuesday, January 31st 2012

08:30 – 09:15	Registration
09:15 – 09:45	Welcome and Opening address
09:45 – 10:30	Technical SESSION **Tu-A**: **Plenary 1**
10:30 – 11:00	*Coffee Break*
11:00 – 12:00	Technical SESSION **Tu-B**: **Tutorial**
12:00 – 13:00	*Lunch Break*
13:00 – 14:45	Technical SESSION **Tu-C**: **Physical Sensing**
14:45 – 15:15	*Coffee Break*
15:15 – 17:30	Technical SESSION **Tu-D**: **Chemical and Environmental Sensing**
12:00 – 19:00	Exhibition
18:00 – 19:00	Welcome Reception

Wednesday, February 1st 2012

08:30 – 10:15	Technical SESSION **W-A**: **Plenary 2 and Invited Presentations**
08:30 – 09:15	Plenary Talk
09:15 – 10:15	Invited Presentations
10:15 – 10:45	*Coffee Break*
10:45 – 12:30	Technical SESSION **W-B**: **Integrated Technologies for Sensing**
12:30 – 13:30	Lunch Break
13:30 – 15:15	Technical SESSION **W-C**: **Grating and Component Technologies for Sensing**
15:15 – 15:45	*Coffee Break*
15:45 – 17:30	Technical SESSION **W-D**: **Distributed, Multiplexed and Networked Sensing**
17:30 – 18:30	Technical SESSION **W-E**: **Post deadline papers**
08:30 – 18:30	Exhibition
19:30 – 23:00	Conference Dinner

Thursday, February 2nd 2012

08:30 – 10:30	Technical SESSION **Th-A**: **Plenary 3 and Novel Materials for Sensing**
08:30 – 09:15	Plenary Talk
09:15 – 10:30	Novel Materials for Sensing
10:30 – 11:00	*Coffee Break*
11:00 – 12:45	Industry SESSION **Th-B**: **Industry Presentations**
12:45 – 13:45	*Lunch Break*
13:45 – 15:45	Technical SESSION **Th-C**: **Poster Presentations**
15:45 – 16:15	*Coffee Break*
16:15 – 18:00	Technical SESSION **Th-D**: **Poster Presentations**
08:30 – 18:00	Exhibition

Friday, February 3rd 2012

08:30 – 10:15	Technical SESSION **F-A**: **Industrial Applications and Field Trials**
08:30 – 13:30	Exhibition
10:15 – 10:45	*Coffee Break*
10:45 – 12:30	Technical SESSION **F-B**: **Biological and Biomedical Sensing and Imaging**
12:30 – 13:30	*Lunch Break*
13:30 – 15:15	Technical SESSION **F-C**: **Optical Fibres for Sensing**
15:15 – 15:45	*Coffee Break*
15:45 – 17:00	Technical SESSION **F-D: Invited Presentation, Awards and Closing**
15:45 – 16:15	Invited Presentation
16:15 – 17:00	Student Awards and Closing Ceremony

18:30 – late **Reception for the new optical fibre fabrication facility at UNSW**

Tuesday 31st January

Registration
On site..... 08.30 to 09.15

Welcome and Opening address
Room: Anchorage Room..... 09.15 to 09.45

Plenary Session Tu-A
Session Chair: TBA
Room: Anchorage Room..... 09.45 to 10.30

09.45: Tu-A1 **Human cancer imaging with optical coherence tomography microscope-in-a-needle technology**
(Plenary Talk) **David Sampson** University of Western Australia (Australia)
High-resolution optical imaging at the cellular level is a cornerstone of modern biology and medicine. It represents the gold standard in much medical diagnosis, which is conducted on collected specimens that have been carefully prepared for histological imaging. Such high resolution remains an elusive goal for medical imaging of living humans. Only optics has so far achieved such resolution in the living human, but only at very superficial depths in tissues – from the surface to a few millimetres at most. Endoscope and catheter technology has enabled optics to access hollow organ systems in the body, but general access to solid tissues has not been available. We have been working on microscope-in-a-needle technology to provide such access whilst retaining high resolution. Our work has mainly been based on optical coherence tomography, and has focussed on miniaturisation to avoid unacceptable levels of tissue damage and three-dimensional imaging. In this talk, I will describe our microscope-in-a-needle technology, including ongoing attempts to image human breast cancer during surgery.

Coffee Break
Room: Walsh Bay Room ..... 10:30 – 11:00

Tutorial Session Tu-B:
Session Chair: Prof. Reinhardt Willsch, Institute of Photonic Technology, Germany
Room: Anchorage Room..... 11.00 to 12.00

11.00: Tu-B1 **Fibre Optic Biomedical Sensors: Principles, Trends & Applications**
(Tutorial) **Alexis Mendez** MCH Engineering (USA)
Given their EM immunity, intrinsic safety, small size & weight, autoclave compatibility and capability to perform multi-point and multi-parameter sensing remotely, optical fibres and fibre-optic-based sensors are seeing increased acceptance and new uses for a variety of bio-medical applications—from laser delivery systems, to disposable blood gas sensors, to intra-aortic probes. This article will illustrate—through several application and product examples—some of the benefits and uses of bio-medical fibre sensors, and what makes them such an attractive, flexible, reliable and unique sensing solution. Key technical and industry trends will be identified along with relevant commercial opportunities and challenges.

Lunch Break and *Exhibition*
Walsh Bay Room..... 12:00 – 13:00

SESSION Tu-C: Physical Sensing
Session Chair: Dr. Scott Wade, Swinburne University of Technology, Australia
Anchorage Room ..... 13:00 – 14:45

13.00: Tu-C1 **Applications of advanced optical fibre sensors at UESTC**
(Invited Talk), Yun-Jiang Rao, Univ. of Electronic Science and Technology (China) [8351-164]
Based on many years research, a number of novel fibre-optic sensors and systems are developed by the Fibre Optics Group at University of Electronic Science & Technology of China (UESTC). This paper presents a review of the applications of these sensors and systems developed in recent years, including: (1) Micro fibre-optic Fabry-Perot interferometric sensors for high temperature strain measurement applications; (2) Fibre Bragg grating (FBG) sensors for safety monitoring applications in transportations industry; (3) Long-distance Brillouin optical time-domain analyzer (BOTDA) for high performance temperature/strain

measurement; (4) Fibre-optic fences based on FBG and phase-sensitive optical time-domain reflectometer (Φ -OTDR) for intrusion monitoring applications.

13.30: Tu-C2 **Field demonstration of 10-nano static strain resolution multiplexed FBG sensor for geophysical applications**, Qingwen Liu, Tomochika Tokunaga, Katsuro Mogi, The Univ. of Tokyo (Japan); Hiroya Matsui, Japan Atomic Energy Agency (Japan); Herbert F. Wang, Univ. of Wisconsin-Madison (United States); Teruyuki Kato, Zuyuan He, The Univ. of Tokyo (Japan) [8351-143]
We have developed an FBG sensor with a strain resolution better than 10 nano-strain for geophysics applications. The sensor consists of a pair of identical FBGs, one for strain sensing and the other for reference. A narrow linewidth tunable laser is used to interrogate the two FBGs simultaneously. Cross-correlation algorithm is utilized to extract the Bragg wavelength difference between the FBGs with high precision. Multiplexed sensing is achieved using WDM technique. With this sensor, the crustal deformation induced by oceanic tide at Aburatsubo Bay in Japan is clearly observed with a strain resolution better than 10 nε. This is the first that 10 nε order static strain resolution is demonstrated with FBG sensors, providing a potential tool for the geophysics applications.

13.45: Tu-C3 **Fibre laser hydrophone for low frequency signal detection**, Wentao Zhang, Fang Li, Yuliang Liu, Institute of Semiconductors (China) [8351-12]
A fibre laser hydrophone (FLH) based on a flat diaphragm and an L shaped lever is presented. This hydrophone uses an L shaped lever to transfer the acoustic pressure induced defection of the flat diaphragm to the axial elongation of the fibre laser. The curve where the L shaped lever contacts the diaphragm is a segment of an Archimedes spiral, which is used to enhance the responsivity. To compensate the hydrostatic pressure, a capillary tube is fixed at the end of the hydrophone. Both theoretical and experimental investigations are presented in this paper. The result shows that the proposed design has a high sensitivity of a flat frequency response below 1 kHz.

14.00: Tu-C4 **Digital resonator fibre optic gyro based on a miniature laser source**, Huilian Ma, Xuhui Yu, Zhonghe Jin, Zhejiang Univ. (China) [8351-31]
A resonator fibre optic gyro (RFOG) based on a fibre-coupled semiconductor DFB-LD with an FPGA-based digital processor is set up. A bias stability of 23deg/h over one hour is successfully demonstrated. This is the best result in long time stability reported to date, to the best of our knowledge, for the RFOG based on a miniaturized laser source.

14.15: Tu-C5 **Hydrostatic pressure sensing using a polymer optical fibre Bragg gratings**, Ian P. Johnson, David J. Webb, Aston Univ. (United Kingdom); Kyriacos Kalli, Cyprus Univ. of Technology (Cyprus) [8351-74]
The sensitivity of a fibre Bragg grating sensor fabricated in polymer optical fibre (POF) to hydrostatic pressure was investigated for the first time. In this initial investigative work a reflected Bragg response of a FBG fabricated in multimode microstructured POF was monitored, whilst the hydrostatic pressure was increased to 10MPa. Positive sensitivities were observed, as opposed to negative sensitivities monitored when using a silica FBG sensor. The polymer FBG sensors gave fractional changes in wavelength and hence sensitivities of at least 64.05×10-6/MPa, which is some 25 times larger than the -2.50×10-6/MPa sensitivity of a silica FBG sensor.

14.30: Tu-C6 **Tunable Yagi-Uda-type plasmonic nanoantennas: implications for nanoscale optical sensing**, Ivan S. Maksymov, Andrey E. Miroshnichenko, Yuri S. Kivshar, Australian National Univ. (Australia) [8351-39]
We introduce broadband and tunable Yagi-Uda-type plasmonic nanoantennas created by arrays of metal nanorods of varying length, and explore their use for nanoscale optical sensing.

Coffee Break and *Exhibition*

Walsh Bay Room ..... 14:45 – 15:15

SESSION Tu-D: Chemical and Environmental Sensing

Session Chair: Prof. Wei Jin, The Hong Kong Polytechnic University, Hong Kong, China
Anchorage Room ..... 15:15 – 17:30

15.15: Tu-D1 **Photon density wave spectroscopy: fibre-optical sensing of highly turbid materials** *(Invited Talk)* Oliver Reich Potsdam University (Germany)
The increasing importance of materials that contain nano- to micrometer-sized particles creates a strong demand for sensing their physical-chemical properties. Additionally, the incorporation as so-called process analytical technologies (PAT), that are able to monitor chemical or physical changes during the production

process, is of great benefit. Photon density wave (PDW) spectroscopy has been successfully introduced as a fibre-optical sensing approach for the characterization of the absorption and scattering properties without any sampling or sample preparation. Based on the analysis of the propagation of intensity-modulated laser light in these multiply scattering materials, PDW spectroscopy can be used to determine the particle or droplet sizes and concentrations of the chemical constituents. Among fundamental investigations of polymer-based model samples, on-line and in-line applications in polymer and food industry are discussed.

15.45: Tu-D2 **Plasmonic-photonic resonances in nanostructured metallo-dielectric quasi-crystals: tuning and sensitivity analysis**, Armando Ricciardi, Alessio Crescitelli, Marco Consales, Vincenzo Galdi, Univ. degli Studi del Sannio (Italy); Emanuela Esposito, Insituto di Cibernetica, CNR (Italy); Andrea Cusano, Univ. degli Studi del Sannio (Italy) [8351-17]
We report the evidence of plasmonic-photonic resonances in hybrid metallo-dielectric quasi-crystal nanostructures composed of aperiodically-patterned low-contrast dielectric slabs backed on a metal layer. Via both experimental and numerical studies, we characterize these resonant phenomena with specific reference to the Ammann-Beenker tiling lattice geometry. In particular, we show that, by comparison with standard periodic structures, a richer spectrum of resonant modes may be excited. Such modes are characterized by a distinctive plasmonic or photonic behavior, discriminated by their field distribution. We explore the structure functionalization via high refractive index overlays, as well as its surface sensitivity to deposition of nanolayers of materials mimicking bio-molecular binding. Overall, our results indicate the possibility of exciting a wealth of resonant modes of potential interest for the development of optical devices for communications, energy and sensing applications.

16.00: Tu-D3 **A microstructured optical fibre sensor for ion-sensing based on the photoinduced electron transfer effect**, Andrew C. Richardson, Tze Cheung Foo, Florian V. Englich, Heike Ebendorff-Heidepriem, Christopher J. Sumby, Tanya M. Monro, The Univ. of Adelaide (Australia) [8351-144]
We employ the photoinduced electron transfer (PET) effect within suspended-core microstructured optical fibre to authenticate a new type of fluorescence based sensor for ion detection. A sensor design based on a simple model PET-fluoroionophore system and small core microstructured optical fibre is shown and the operational performance of the sensor to different concentrations of sodium is investigated. Future approaches to improving the sensor's signal stability and sensitivity are discussed.

16.15: Tu-D4 **Edge gold-coated silver nanoprism [Ag@(Au nanoframe)] for H_20_2 detection**, M. M. Shahjamali, Nanyang Technological Univ. (Singapore); E. Martinsson, Linkoping Univ. (Sweden); W. Marcello, L. Yin, Nanyang Technological Univ. (Singapore); B. Liedberg, Linkoping Univ. (Sweden); F. Boey, C. Xue, Nanyang Technological Univ. (Singapore) [8351-179]
In this paper we describe a facile method for synthesizing gold triangular nanoframe from edge gold-coated silver nanoprism [Ag@(Au nanoframe)] with controlled ridge thickness and interior hollow diameter via chemical etching of silver from the gold coated Ag nanoprism with Hydrogen peroxide. Our process involves two major steps: (1) Formation of Ag@(Au nanoframe) by deposition of gold on the edges of Ag nanoprisms in room temperature (2) Etching of Ag atoms from the gold fame via H_2O_2 oxidation. The optical properties of the resulting nanoframe can be easily tailored in a broad range by controlling the ridge thickness or hole diameter by amount of H_2O_2 added into the reaction. Due to the changes to the optical spectra during etching, the nanoframe formation can be employed to detect H_2O_2 in a broad range of concentration down to 1 μM.

16.30: Tu-D5 **Additional enhancement in surface-enhanced Raman scattering due to excitation geometry**, Lorenzo Rosa, Sasani Jayawardhana, Swinburne Univ. of Technology (Australia); Saulius Juodkazis, Swinburne Univ. of Technology (Australia) and Melbourne Ctr. for Nanofabrication (Australia); Paul R. Stoddart, Swinburne Univ. of Technology (Australia) [8351-147]
Surface-enhanced Raman scattering (SERS) substrates based on metal island films exhibit higher levels of enhancement when excited through a transparent base material than when excited directly through air. However, the origin of this enhancement has not been satisfactorily explained to date. Finite difference time domain modelling shows that the electric field intensity between metal particles is higher for "far-side" excitation. The results are comparable with the observed enhancement for silver islands on silica and are in agreement with a simple physical model based on Fresnel reflection at the interface. This finding has important implications for SERS-based sensors.

16.45: Tu-D6 **Fibre optic hydrogen gas sensor utilizing surface plasmon resonance of indium-tin oxide (ITO) thin films**, Satyendra K. Mishra, Banshi D. Gupta, Indian Institute of Technology Delhi (India) [8351-80]
We present an experimental study of a fibre optic hydrogen gas sensor which works on the phenomenon of surface plasmon resonance. The sensor operates in intensity modulation scheme. The fibre optic probe was fabricated by removing a small section of the fibre cladding and symmetrically depositing a thin layer of

indium tin oxide (ITO) by thermal evaporation technique onto the fibre core. The presence of hydrogen in the air around the ITO changes the dielectric function of ITO. The SPR spectra were obtained for 100% nitrogen as well as for a mixture of 4% hydrogen and 96% nitrogen. A sharp dip in the transmittance spectrum was observed in the case of mixture of 4% hydrogen and 96% nitrogen. The transmittance corresponding to the resonance wavelength was found to decrease with the increase in the exposure time of the hydrogen gas to ITO. The present sensor can be used for the online monitoring of hydrogen gas in various environments.

17.00: Tu-D7 **Surface plasmon resonance based fibre optic sensors**
(Invited Talk), B. D. Gupta, Indian Institute of Technology Delhi (India) [8351-193]
Surface plasmon resonance (SPR) is one of the most promising optical techniques that find applications in sensing of various chemical and biochemical parameters. In SPR technique, a TM (transverse magnetic) or p-polarized light causes the excitation of electron density oscillations (known as surface plasmon wave, SPW) at the metal-dielectric interface. When the energy as well as the momentum of both, the incident light and SPW, match a resonance occurs which results in a sharp dip in the reflected light intensity. The resonance condition depends on the angle of incidence, wavelength of the light beam and the dielectric functions of both the metal as well as the dielectric. To excite surface plasmons, generally, a prism is used. The prism based SPR sensing device has number of shortcomings which can be overcome if an optical fibre is used in place of prism. In recent years, surface plasmon resonance based optical fibre sensors have drawn lot of attention. Both experimental and theoretical investigations have been reported in the literature. The performance of these sensors is, generally, evaluated in terms of sensitivity and signal to noise ratio (or, detection accuracy). In the present talk we shall discuss the principle of the sensing technique including the description of the performance parameters of the sensor: sensitivity and signal to noise ratio or detection accuracy. Various designs of the fibre optic SPR probes that have been studied to enhance the performance of the fibre optic sensor will be discussed. The advantages of bimetallic coatings, addition of dopants in fibre core and the choice of the metals and semiconductors for coating will also be presented. In addition, we shall also discuss fibre optic SPR sensors for the detection of naringin, pesticide, ethanol in water, urea etc

Welcome Reception

Anchorage Room ..... 18:00 – 19:00

Wednesday 1st February

SESSION W-A: Plenary 2 and Invited Presentations

Session Chair: Prof. Yunjiang Rao, University of Electronic Science and Technology of China, China
Room: Anchorage Room ..... 08.30 to 10.15

08.30: W-A1 **The potential of embedded sensor technologies in NASA's aerospace applications** *(Plenary Talk)*, A. K. T. Lau, Univ. of Southern Queensland (Australia) [8351-185]
In order to mitigate structural failures and therefore the catastrophic failures to aerospace structures, NASA has been at the forefront developing of real-time on-board monitoring capabilities using a large range of advanced sensors. Optical sensors have taken a significant share in the context of structural health monitoring system. Further, advanced optical sensor systems have great potential in NASA's effort of developing smart structures for orbital vehicles and other space hardware. This talk will critically discuss the use of optical sensors in NASA's space and aircraft applications.

09.15: W-A2 **Lab on fibre technology: perspectives and challenges** *(Invited Talk)*, A. Cusano, Univ. degli Studi del Sannio (Italy) [8351-186]
The "Lab on Fibre" concept envisions novel and highly functionalized technological platforms completely integrated in a single optical fibre that would allow the development of advanced devices, components and sub-systems to be incorporated in modern optical systems for communication and sensing applications. The realization of integrated optical fibre devices requires that several structures and materials at nano and micro scale are constructed, embedded and connected all together to provide the necessary physical connections and light-matter interactions. This paper reviews the strategies, the main achievements and related devices in the "Lab on Fibre" roadmap discussing perspectives and challenges that lie ahead.

09.45: W-A3 **Integrated planar Bragg grating sensors** *(Invited Talk)*, P. G. R. Smith, Univ. of Southampton (United Kingdom) [8351-187]
Planar Bragg grating sensors have developed over the last decade and offer a powerful set of features and capabilities for a wide range of sensor applications. This talk will provide an overview of planar Bragg grating devices and will cover basic operation, fabrication and measurement principles. Advantages of such devices include operation at 1550nm using telecomm technology, the ability to provide accurate self-referencing for temperature compensation, and chemical robustness allowing use of aggressive reagents for surface chemistry. Specific applications will be highlighted including chemical and biologically based detection, and physical measurement (pressure, temperature and fluid flow). Recent results will be highlighted including work on incorporating planar Bragg sensors within cantilevers and novel work utilising physical micromachining and plasmonic-dielectric hybrid mode sensors.

Coffee Break and *Exhibition*

Walsh Bay Room ..... 10:15 – 10:45

SESSION W-B: Integrated Technologies for Sensing

Session Chair: Prof. Martin Kristensen, Aarhus University, Denmark
Anchorage Room ..... 10:45 – 12:30

10.45: W-B1 **Low-cost fully integrated fibre Bragg grating interrogation system**, B. Van Hoe, E. Bosman, J. Missinne, S. Kalathimekkad, Ghent Univ. - Imec (Belgium); G. Lee, Z. Yan, K. Sugden, D. J. Webb, Aston Univ. (United Kingdom); G. Van Steenberge, P. Van Daele, Ghent Univ. - Imec (Belgium) [8351-54]
We present a dynamic low-cost interrogation system for fibre Bragg gratings which can be integrated with the fibre itself, limiting the fragile optical coupling interfaces and providing a compact, unobtrusive driving and read-out unit. The reported system is based on an embedded Vertical Cavity Surface Emitting Laser which is tuned dynamically and an embedded photodiode. Fibre coupling is provided through a dedicated 45° micromirror limiting the total thickness of the fibre coupled optoelectronic package to 550 µm. A few-mode fibre with fibre Bragg gratings at 850 nm is used to prove the feasibility of this low-cost and ultra-compact interrogation approach.

11.00: W-B2 **Tubular optical waveguide-based particle plasmon resonance biosensor for label-free and real-time detection**, Hsing-Ying Lin, Chen-Han Huang, Yu-Chia Liu, Shin-Huei Chen, Lai-Kwan Chau, National Chung Cheng Univ. (Taiwan) [8351-65]
A novel tubular optical waveguide-based particle plasmon resonance (TOW-PPR) device for chemical and

biochemical sensing is presented. The sensor is based on intensity measurement of consecutive total internal reflections (TIRs) along the wall of the gold nanoparticles-modified glass vial at a fixed wavelength from a miniaturized light emitting diode (LED). In comparison with other evanescent wave based optical sensors, the TOW-PPR sensor possesses merits of being a wavelength-selectable optical waveguide sensor to fit application needs, microchamber of a defined sample volume, and itself of being a mechanical support for sensor coatings. The sensor resolution is estimated to be 2.7x10-6 RIU.

11.15: W-B3 **High speed random accessibility of brillouin optical correlation domain analysis with time division pump-probe generation scheme**, K. Hotate, M. Numasawa, M. Kishi, Z. He, The Univ. of Tokyo (Japan) [8351-99]
High speed random accessibility to multiple points along a fibre is realized by a Brillouin Optical Correlation Domain Analysis system. In the BOCDA, correlation between continuous pump and probe lightwave is synthesized by frequency modulation, so that the stimulated Brillouin scattering takes place only at one selected point. An important feature of the system is random accessibility to an arbitrary point to be measured. In this paper, speed of the random accessibility is enhanced by introducing a time-division pump probe generation scheme, and simultaneous dynamic strain measurement at four points is demonstrated with a total sampling rate of 200 samples/s.

11.30: W-B4 **Generating and sensing signals for quantum cryptography using phase encoding in compact silica-on-silicon Mach-Zehnder circuits with Bragg gratings**, M. Kristensen, T. Balle, J. Selchau, K. B. Sigvardt, N. Groothoff, Aarhus Univ. (Denmark) [8351-59]
We have realized phase encoding and sensing of signals for quantum cryptography in compact circuits made with standard silica-on-silicon technology. The circuits include Bragg grating filters allowing multichannel cryptography with dense channel spacing, and they are thermally balanced to avoid crosstalk

11.45: W-B5 **Integrated interferometer for measuring three-dimensional vibrations based on spherical cooperative target**, Xuejie Zhang, Dean Liu, Tao Feng, Fang Liu, Jie Miao, Jianqiang Zhu, Shanghai Institute of Optics and Fine Mechanics (China) [8351-72]
This paper proposes a new method for measuring three-dimensional vibrations. By a spherical cooperative target, the system realizes interference from a spherical wave and a plane wave. It solves the problem of complex changes in interference fringes when two spherical waves are used to measure three-dimensional vibration. And the vibration calculation is very simple. Meanwhile, the interferometer integrates two interference arms into a beamsplitter by coating design and can monitor the stability of the system itself. Theoretical analysis and experiment are performed. The experiment results indicate that the method can monitor three-dimensional vibrations accurately.

12.00: W-B6 **Optical whispering gallery mode resonators for unlabelled nanoparticle sensing** *(Invited Talk)*, W. Bowen, The Univ. of Queensland (Australia) [8351-188]
There is a growing need for technologies that can detect and characterize nanoparticles in gaseous and liquid environments, due to their relevance to areas such as drug delivery, atmospheric pollution, and biodefense. Optical whispering gallery mode resonators enable parallel label free detection of nanoparticle mass, refractive index, and size. Their strong spatial and temporal optical confinement provides, in principle, ultrahigh sensitivity in an on-chip platform in both liquid and gaseous environments. In this talk I will discuss progress towards the development of the whispering gallery mode sensors at the University of Queensland. This includes an interferometric technique to characterise particle size and refractive index, insensitive to laser frequency noise and many sources of environmental noise; plasmonic enhancement of the sensors response, in principle enabling sensing at the level of a single BSA protein; and the possibility of mass sensing with attogram precision by regenerative excitation of mechanical vibrations within the resonator.

Lunch Break and *Exhibition*

Walsh Bay Room ..... 12:30 – 13:30

SESSION W-C: Grating and Component Technologies for Sensing

Session Chair: Prof. Bai-Ou Guan, Jinan University, China
Anchorage Room ..... 13:30 – 15:15

13.30: W-C1 **Full-spectrum FBG analysis of inhomogeneous, fast-varying strain effects** *(Invited Talk)*, Kara Peters, North Carolina State Univ. (United States) [8351-159]
In this paper we summarize some recent advances derived from full-spectral interrogation of FBG sensors for structural health monitoring and damage identification in composites. In particular we present signals from the FBG reflected spectra that have been correlated to the progression of delamination due to multiple

low-velocity impacts in woven composite laminates and foam-core sandwich composites. We also discuss recent advances in interrogation systems for these sensors which have permitted dynamic evaluation of these parameters.

14.00: W-C2 **Regenerated femtosecond fibre Bragg gratings**, K. Cook, The Univ. of Sydney (Australia); C. Smelser, Communications Research Ctr. Canada (Canada); J. Canning, The Univ. of Sydney (Australia); G. le Garff, M. Lancry, Univ. Paris Sud 11 (France); S. Mihailov, Communications Research Ctr. Canada (Canada) [8351-127]
We demonstrate the thermal regeneration of fibre Bragg gratings inscribed by direct writing using a femtosecond, infrared laser into standard SMF-28 and pure silica core fibres. Post-H2 loading was used. The regeneration process is shown to extend the temperature operation of these gratings up to 1200°C. The temperature durability of regenerated 193nm-written gratings in SMF-28 fibre is presented for comparison. The ability to enhance the temperature durability of femtosecond inscribed index changes has significance beyond fibre Bragg gratings; for example, the micromachining of photonic components such as planar waveguides.

14.15: W-C3 **Tailored draw tower fibre Bragg gratings for various sensing applications**, Eric Lindner, Institut für Photonische Technologien e.V. (Germany) and FBGS Technologies GmbH (Germany); Julia Mörbitz, Christoph Chojetzki, FBGS Technologies GmbH (Germany); Martin Becker, Sven Brückner, Kay Schuster, Manfred Rothhardt, Reinhardt Willsch, H. Bartelt, Institut für Photonische Technologien e.V. (Germany) [8351-22]
The idea of fabricating fibre Bragg gratings during the drawing process of an optical fibre dates back almost 20 years. The application of a transverse holographic writing method on a fibre draw tower offers a promising solution for a highly effective Bragg grating production. Because of the high technology requirements it took more than 10 years to develop the method into a reliable process. The improvements in the technical development during the last five years enable today a cost efficient industrial production of draw tower grating (DTG®) arrays. In this paper we report about new possibilities of the improved process with respect to the grating type (type I gratings, type II gratings), the coating type (2ORMOCER®, metals) and the fibre diameter (125µm, 80µm and below). Furthermore, we present an example for the application of draw tower fibre Bragg gratings in sensing technologies for medical applications.

14.30: W-C4 **Microfibre bragg grating inscribed using 193nm excimer laser for refractive index sensing**, Yang Ran, Yan-Nan Tan, Li-Peng Sun, Shuai Gao, Zhan Quan, Jie Li, Long Jin, Bai-Ou Guan, Jinan Univ. (China) [8351-115]
The inscription of fibre Bragg gratings was demonstrated by 193 nm ArF excimer laser in microfibres drawn from the standard single mode telecommunication fibre. Fibre Bragg gratings are directly inscribed in a series of microfibres with diameter ranged from ~10µm to 3.3µm without any treatment to photosensitize the microfibres. Four reflection peaks are observed where three correspond to high order mode resonances. The gratings are characterized for their response to ambient refractive index. The higher order mode resonance exhibits higher sensitivity to refractive index.

14.45: W-C5 **Modeling of bend effects on fibre Bragg gratings**, Peter J. Cadusch, Alexander C. Thompson, Paul R. Stoddart, Scott A. Wade, Swinburne Univ. of Technology (Australia) [8351-129]
In this work the basis of the centre wavelength shift of fibre Bragg gratings due to bending is investigated by modeling the effects of several potential causes for standard and depressed cladding fibre designs. The majority of the expected affects, including bend induced stress and mode field deformation, were found to result in small wavelength shifts in the opposite direction to those observed experimentally. However, a new account of the shift, based on simplistic geometrical optics, does show wavelength changes in the observed direction, of up to -0.15 nm, which is in the range of the experimentally measured shifts.

15.00: W-C6 **Noise analysis in a fibre Bragg grating accelerometer using allan variance method**, Matheus M. Carvalho, Rogério M. Cazo, Instituto de Estudos Avançados (Brazil) [8351-100]
This article presents the application of Allan Variance Method to determine the noise coefficients for a fibre Bragg Grating Accelerometer (FBGA) at static operation. FBGA mechanical structure is described, as well as the embedded optical and electronic circuits used to acquire the experimental data.

Coffee Break and *Exhibition*

Walsh Bay Room ..... 15:15 – 15:45

SESSION W-D: Distributed, Multiplexed and Networked Sensing

Session Chair: Prof. Xiaoyi Bao, University of Ottawa, Canada

Anchorage Room ..... 15:45 – 17:30

15.45: W-D1 **Let's put FBGs to work: sensing in exotic power and energy applications** *(Invited Talk)*, P. Niewczas, Univ. of Strathclyde (United Kingdom) [8351-189]
The Advanced Sensors Team within the Institute for Energy and Environment at the University of Strathclyde, Glasgow, Scotland, has been involved in photonic sensors research with the key objective to harness the benefits of fibre optic sensing and develop solutions for specific measurement problems within power and energy sectors. The team has carried out a unique portfolio of research programmes, mainly focussing on spectrally encoded sensors, and addressing such issues as sensor design, fabrication, packaging, deployment, and interrogation. This presentation will highlight specific examples of the measurement needs within the power and energy sectors and report on our recent progress in the established and novel approaches in fibre sensing to address these needs. In particular, I will discuss such applications as downhole and subsea electrical plant monitoring; voltage and current measurement for power system protection in the context of distributed generation; force and magnetic field monitoring in the context of thermonuclear fusion research; and, measurement of the loss of loading within concrete prestressing steel tendons in nuclear power plant applications. As the potential good solutions to these respective measurement needs, I will introduce and discuss such emerging technologies as the hybrid FBG voltage and current sensors; novel FBG interrogation schemes utilizing WDM and TDM architectures, not requiring tunable spectral filters or lasers; and novel FBG sensors and interrogation schemes utilizing some promising intrinsic sensing mechanisms capable of measuring such quantities as magnetic and electric fields or bend.

16.15: W-D2 **External feedback DFB fibre laser sensors in the weak reflection regime**, Scott Foster, Defence Science and Technology Organisation (Australia) [8351-163]
An analysis of the effect of weak feedback on Bragg grating fibre laser output parameters is presented and a simple sensor arrangement based on monitoring intensity fluctuations of a DFB fibre laser with a weak external reflector is considered. Calculations suggest that it may be possible, under certain conditions, to resolve changes to the length of the external cavity at close to the thermal noise limit. This introduces the possibility of achieving strain resolution in the sub-picostrain regime in the low frequency domain where resolution of conventional fibre laser sensors is limited by 1/f noise.

16.30: W-D3 **Fast and distributed dynamic sensing of strain using Sweep-Free Brillouin Optical Time-Domain analysis (SF-BOTDA)**, Asher Voskoboinik, The Univ. of Southern California (United States); Yair Peled, Tel Aviv Univ. (Israel); Alan E. Willner, The Univ. of Southern California (United States); Moshe Tur, Tel Aviv Univ. (Israel) [8351-62]
A frequency-sweep-free method for distributed Brillouin sensing is used to reconstruct the Brillouin gain spectrum of optical fibres at high speed. We experimentally demonstrate distributed strain measurements induced by 140Hz vibrations, with a spatial resolution of 5m.

16.45: W-D4 **Distributed fibre optic sensor for mapping of intense magnetic fields based on polarization sensitive reflectometry**, Luca Palmieri, Andrea Galtarossa, Univ. degli Studi di Padova (Italy) [8351-149]
We describe a novel distributed fibre optic sensor, which is able to map both strength and orientation of intense static magnetic fields in the area spanned by the fibre. The sensor is based on Faraday rotation and on polarization analysis of the field backscattered by the fibre due to Rayleigh scattering. Owing to a specific theoretical model, it is possible to isolate and measure the effect of magnetic field along the fibre, independently of its intrinsic birefringence. The small Verdet constant of standard silica fibres makes the proposed technique most suited to intense magnetic fields. Two different sensors based on this approach have been built and successfully tested in a 1.5 T magnetic resonance imaging scanner.

17.00: W-D5 **BOTDA measurements in the presence of fibre vibrations**, Avi Motil, Yair Peled, Lior Yaron, Moshe Tur, Tel Aviv Univ. (Israel) [8351-140]
The ramifications of optical fibre vibrations on the calibration phase of slope-assisted fast distributed Brillouin optical time-domain analysis, is studied. It is theoretically and experimentally found that for not too severe vibrations the Brillouin gain spectrum, as determined by classical BOTDA, is only negligibly broadened, still enabling the correct estimation of its -3dB frequency points along the fibre.

17.15: W-D6 **Strain and temperature discrimination using concatenated fibre grating lasers**, Yan-Nan Tan, Dalian Univ. of Technology (China) and Jinan Univ. (China); Yang Zhang, Dalian Univ. of Technology (China); Long Jin, Bai-Ou Guan, Jinan Univ. (China) [8351-108]
We propose and experimentally demonstrate a novel simultaneous strain and temperature fibre optic sensor

based on radio-frequency measurement. The sensing head is formed by two concatenated ultra-short distributed Bragg reflector lasers that operate in single longitude mode with two polarization modes. The total length of the sensing head is only 18 mm. The two lasers generate two polarization mode beat notes in the radio-frequency range which show different frequency response to strain and temperature. Simultaneous strain and temperature measurement can be achieved by radio-frequency measurement. This approach has distinctive advantages of ease of interrogation and avoidance of expensive wavelength detection.

SESSION W-E: Post Deadline Papers

Session Chair: Prof. Andrea Cusano, University of Sannio, Italy

Anchorage Room ..... 17:30 – 18:30

Conference Dinner

Anchorage Room ..... 19:30 – 23:00

Thursday 2nd February

SESSION Th-A: Plenary 3 and Novel Materials for Sensing

Session Chair: Dr. Brant Gibson, University of Melbourne, Australia
Anchorage Room ..... 08:30 – 10:30

08.30: Th-A1 **The non-uniformity and dispersion in SBS-based fibre sensors**
(Plenary Talk), Xiaoyi Bao, Shangran Xie, Xuan Liu, Liang Chen, Univ. of Ottawa (Canada) [8351-169]
For a fibre with complex index profile, its density fluctuations change with position and it also introduces birefringence, hence Brillouin frequency changes with position due to variation of modal index and sound velocity has a range instead of being a constant. As a result, single mode fibres support multiple Brillouin resonances varying in position, even with polarization scramblers of pump and probe waves. For BOTDA, at a specific location, because of the spatial resolution the measured Brillouin frequency still gives a range, although PS can reduce this fluctuation as the spatial resolution is much smaller than the beat length. The measured Brillouin frequency variation in one position and its location dependence reflect fibre non-uniformity rather than systematic error. The beat of different Brillouin peaks and their magnitudes change with temperature and strain, which can be used to measure temperature and strain simultaneously in LEAF fibre without sweeping Brillouin spectrum.

09.15: Th-A2 **Fabrication of self-assembled microwires from silica nanoparticles for sensing**, Masood Naqshbandi, John Canning, Maxwell J. Crossley, The Univ. of Sydney (Australia) [8351-124]
A simple method of fabricating low loss microwire waveguides from silica nanoparticles via evaporative self-assembly is demonstrated. Light guidance within the microwires is characterised. The photonic microwires assemble into rectangular slab waveguides with a typical cross-sectional dimension of (20×10) μm and are up to 15 mm in length. Rhodamine B was incorporated into the structures and characterized with fluorescent microscopy, absorption spectroscopy and scanning electron microscopy (SEM). We discuss the relevance of these structures to sensing.

09.30: Th-A3 **Fabrication of 2D metal nanoparticle array encapsulated by anodic aluminum oxide and its applications to surface-enhanced Raman scattering**, Chen-Han Huang, Hsing-Ying Lin, National Chung Cheng Univ. (Taiwan) [8351-136]
The verification of a reproducible, highly sensitive, robust, and reliable SERS active substrate composed of periodic silver nanoparticle arrays encapsulated within large-area (1 in2) anodic aluminum oxide films is reported. The well-organized spherical silver nanoparticles are electro-deposited at the interior bottom of alumina nanochannels. After chemically removing the residual aluminum, the exposed bottom alumina layer can be adopted as a sensitive SERS sensor but can avoid the oxidation and sulfidation corrosion of embedded silver. The encapsulated nanoparticle arrays provide strong and reproducible SERS signals of probe R6G and adenine molecules.

09.45: Th-A4 **Green fluorescent protein-doped sol-gel silica planar waveguide to detect organophosphorus compound**, Y. Enami, Hiroshima Univ. (Japan); S. Suye, Univ. of Fukui (Japan) [8351-75]
We report novel living protein-doped planar waveguide, and real-time detection of an organophosphorus compound using a sol-gel silica planar waveguide doped with a green fluorescent protein and an organophosphorus hydrolase on a yeast-cell surface. The waveguide was pumped at 488 nm, and emitted green fluorescence at the far field. The green fluorescent light at 550 nm changed by 50% from the original power 1 min after application of the organophosphorus compound. The results enable the real-time detection of biochemical weapon and insecticide harmful for human body by using an in-line fibre sensor network.

10.00: Th-A5 **Distributed hydrophone array based on liquid crystal cell**, Zourab Brodzeli, Francois Ladouceur, Leonardo Silvestri, Univ. of New South Wales (Australia); Andrew Michie, Smart Digital Optics Pty. Ltd. (Australia); Vladimir Chigrinov, Grace Qi Guo, The Hong Kong Univ. of Science and Technology (China); Eugene P. Pozhidaev, P.N. Lebedev Physical Institute (Russian Federation); Alexei D. Kiselev, Institute of Physics (Ukraine) [8351-146]
We describe a fibre optic hydrophone array system that could be used for underwater acoustic surveillance applications e.g. military, counter terrorist and customs authorities in protecting ports and harbors, offshore production facilities or coastal approaches as well as various marine applications. In this paper we propose a new approach to underwater sonar systems using voltage-controlled Liquid Crystals (LC) and simple multiplexing method. The proposed method permits measurements of sound under water at multiple points along an optical fibre using low cost components (LC cells), standard single mode fibre, without complex interferometric measurement techniques, electronics or demodulation software.

10.15: Th-A6 **Surface plasmon resonance based multi-channel and multi-analyte fibre optic sensor**, Roli Verma, Sachin K. Srivastava, Banshi D. Gupta, Indian Institute of Technology Delhi (India) [8351-85]
Surface plasmon resonance (SPR) based fibre optic sensor has been studied for multichannel and multianalyte sensing. Simulations have been carried out for a fibre optic sensor having two sensing regions coated with silver and gold for multichannel and multianalyte sensing. To support the simulations optical fibre SPR probes with two sensing regions coated with silver and gold have been fabricated. SPR spectra for these sensors have been recorded for aqueous sucrose solutions of varying refractive indices. The refractive index of the liquid samples around both the gold and silver coated regions was kept the same to see the potential of SPR based fibre optic multichannel sensing, while it was kept different for studies related to multianalyte sensing. Both the theoretical and experimental results match qualitatively. The SPR resonance wavelengths for gold and silver being different, these sensors can be utilized for both multichannel and multianalyte sensing.

Coffee Break and *Exhibition*

Walsh Bay Room ..... 10:30 – 11:00

SESSION Th-B: Industry Presentations

Session Chair: Zuyuan He, University of Tokyo, Japan
Anchorage Room ..... 11:00 – 12:45

11.00: Th-B1 **Continuous monitoring of mining induced strain in a road pavement using fibre Bragg grating sensors**
(Invited Talk), B. E. Whelan, M. Brunton, Monitor Optics Systems Ltd. (Australia); G. Nosenzo, Monitor Optics Systems Ltd. (Ireland); D. Kay, Mine Subsidence Engineering Consultants (Australia); H. Buys, AECOM (Australia) [8351-173]
This paper describes the application of fibre Bragg grating (FBG) based sensors for monitoring road pavement strains caused by mining induced ground subsidence as a result of underground longwall coal mining beneath a major highway in New South Wales, Australia. After a lengthy planning period, the risks to the highway pavement were successfully managed by the highway authority and the mining company through a technical committee. The technical committee comprised representatives of the mining company, the highway authority and specialists in the fields of pavement engineering, geotechnical engineering and subsidence. An important component of the management strategy is the installation of a total of 840 strain and temperature sensors in the highway pavement using FBG arrays encapsulated in glass-fibre composite cables.

11.30: Th-B2 **Fibre Fusion and Glass Processing Technologies for Fibre Sensing Applications**
B. S. Wang, Vytran LLC (United States) [8351-190]
We review fibre fusion and glass processing technologies for fibre sensing applications, in which dissimilar fibres need to be fused together with low loss and high strength to ensure long-term performance stability and high performance fused fibre components, such as fused couplers and polarization-maintaining (PM) components, are important integral part for both coherent and incoherent detection. We describe fundamental optics, present solutions using various fibre devices, and also discuss potential challenges. We will show some application examples and also available fibre processing hardware for fabricating these fibre devices.

11.45: Th-B3 **Nuisance alarm suppression techniques for fibre-optic intrusion detection systems**, Seedahmed S. Mahmoud, Yuvaraja Visagathilagar, Jim Katsifolis, Future Fibre Technologies Pty Ltd. (Australia) [8351-138]
A level crossings algorithm is presented for suppressing torrential rain-induced nuisance alarms in a distributed fibre-optic Mach Zehnder fence-based perimeter intrusion detection system. Results show that rain-induced nuisance alarms can be suppressed for rainfall rates in excess of 100 mm/hr, and intrusion events can be detected simultaneously during rain periods. The use of a level crossing based detection and novel classification algorithm is also presented demonstrating the suppression of nuisance events and discrimination of nuisance and intrusion events in a buried pipeline fibre-optic intrusion detection system.

12.00: Th-B4 **To Be Confirmed**

12.15: Th-B5 **R&D on optical fibre sensors at the National Engineering Laboratory for Optic Fibre Sensing Technologies: fundamental and industrial aspects**
(Invited Talk), M. Yang, D. Jiang, Wuhan Univ. of Technology (China) [8351-176]
In this article, we review R&D on optical fibre sensors at the National Engineering Laboratory for Optic Fibre Sensing Technologies at Wuhan University of Technology, both from industrial and fundamental

aspects. New concepts of optical sensors combined micro-machining of novel fibre structure with sensitive thin film are also proposed and discussed.

Lunch Break and *Exhibition*

Walsh Bay Room ..... 12:45 – 13:45

SESSION Th-C: Poster SESSION 1

Anchorage Room ..... 13:45 – 15:30

Th-C1 **Refractive index sensing by a periodical pressure on a single-mode fibre**, Xiaojun Zhou, Shenghui Shi, Zhiyao Zhang, Xiaoyun Li, Yong Liu, Univ. of Electronic Science and Technology (China) [8351-06]
A refractive index sensor using a pressure-induced long-period grating is proposed and demonstrated. The sensing element is made of a composite optical waveguide based on a single-mode fibre. The experimental results show that the sensitivity for LP14 mode resonance is 72nm/RIU (refractive index unit) when the medium refractive index varies from 1.33 to 1.43.

Th-C2 **Raman spectroscopy is a novel tool for bacteria fingerprint discrimination: preparation a disk-like SERS substrate**, C. C. Lin, Tunghai Univ. (Taiwan) [8351-08]
Novel disk-like surface-enhanced Raman scattering (SERS) substrate for bacteria fingerprint discrimination is described. A simple synthesis method for dispersion gold nanoparticles (NPs) in the mesoporous silicas matrix with tunable size and concentrations are also reported. Prepared NP-embadded complex matrix was thermal treated at 600°C for cleaning protecting agent and impurity chemicals to obtain the bare gold NPs (~40 nm) embedded matrix. These prepared matrix present high surface area (≈ 300 m2g-1), large pore size (> 5.0 nm) and high metal NPs content (≈30 wt.%). Moreover, a filter-like substrate contains higher water permeability to filter out targets from sample solution and the substrates can also perform highly SERS signal compared with normal Raman. Specially, SERS signals can be further adjusted by controlling the size of NPs.

Th-C3 **Bend response of weakly tilted Bragg grating inscribed in all-solid photonic band-gap fibres**, Yinping Miao, Tianjin Univ. of Technology (China); Bo Liu, Nankai Univ. (China); Kailiang Zhang, Xiaoyun Zhu, Tianjin Univ. of Technology (China); Yan Liu, Xingya Chen, Hao Zhang, Nankai Univ. (China) [8351-10]
In this paper, weakly tilted fibre Bragg gratings (W-TFBGs) with a certain tilted angle are inscribed in the Ge-doped cladding rods of all-solid photonic band-gap fibres (AS-PBGF) by UV illumination. There are couplings not only forward-propagating LP01 mode to counter-propagating LP01 mode but also the couplings to counter-propagating high order supermodes based on tilted refractive index modulation. The responses of the W-TFBGs to temperature and bend are investigated. The results indicate that the resonance peaks will shift red-side with increasing temperatures, and the sensitivities of different resonance peaks are very close in the same grating. When the bending is applied, the grids of W-TFBG will be compressed or stretched. Two resonance peaks will shift with increasing curvatures, which is related to the orientation of curvature. Therefore, it is potential to work as a directional bending sensor.

Th-C4 **Interferometric closed-loop fibre-optic gyroscopes**, Yuri N. Korkishko, Vyacheslav &. Fedorov, Victor &. Prilutskii, Vladimir G. Ponomarev, Ivan V. Morev, Sergey M. Kostritskii, Optolink RPC, Ltd. (Russian Federation) [8351-11]
Fibre optic gyroscopes are desirable devices for many navigation and guidance applications because, being solid state devices, they have several major advantages including light weight, long working lifetimes, no moving parts and operate using low voltage power.
The Optolink's single-axis and three-axis fibre optic gyroscopes are described. The results illustrate the versatility of the technology, showing its potential to meet both the low-cost, compact sized needs of tactical guidance, as well as the very high performance needs of inertial navigation and precision applications. The optical and electronic blocks of closed-loop gyroscopes with integrated optic components are considered.

Th-C5 **Optical voltage sensor based on Mach-Zehnder $LiNbO_3$ interferometer and fibre-optical technology**, S. M. Kostritskii, Yu. N. Korkishko, V. A. Fedorov, RPC Optolink Ltd. (Russian Federation) [8351-20]
An optical voltage sensor is proposed that exploits the electric field dependence of transmission of a Mach-Zehnder interferometer fabricated on basis of the channel waveguides in electro-optic LiNbO3. The device works in a transmission scheme, utilizing the long fibre transmission lines for input and output optical signals. The sensor has been used to measure AC electric fields in a range from 0.005 to 56 kV/cm, resulting in a linear sensitivity that may be further improved by tailoring of the optical and geometrical parameters.

Th-C6 **Regenerated single pulse fibre Bragg gratings for high temperature sensing**, Eric Lindner, Institut für Photonische Technologien e.V. (Germany) and FBGS Technologies GmbH (Germany); Christoph Chojetzki, Julia Mörbitz, FBGS Technologies GmbH (Germany); Sven Brückner, Martin Becker, Manfred Rothhardt, Hartmut Bartelt, Institut für Photonische Technologien e.V. (Germany) [8351-21]
Regeneration of fibre Bragg gratings has been shown to be an effective method for improving the temperature stability well beyond the limit of conventional gratings. Strong gratings, which require a high number of laser pulses, have been used mostly in the past for the additional regeneration process. Specific production methods such as draw tower inscription allow only single laser pulse illumination. Such a process can provide, however, versatile and cost effective Bragg grating arrays for sensor applications. Therefore, a combination of single pulse gratings and a regeneration process is of great practical interest. We have demonstrated that an increase of the temperature stability up to 800°C for arrays of single pulse gratings is possible.

Th-C7 **Refractive-index gradient sensor based on the structured fibre Bragg grating**, Bin-bin Luo, Chongqing Univ. of Technology (China) and Univ. of Electronic Science and Technology of China (China); Ming-fu Zhao, Chongqing Univ. of Technology (China); Xiao-jun Zhou, Sheng-hui Shi, Univ. of Electronic Science and Technology of China (China); Xi Han, Ying Wang, Chongqing Univ. of Technology (China) [8351-23]

Th-C8 **Analysis and study of static pressure distribution in an optical cable spool using distributed fibre Bragg gratings**, Liyong Ren, Xi'an Institute of Optics and Precision Mechanics (China); Chengju Ma, Xi'an Institute of Optics and Precision Mechanics (China) and Xi'an Shiyou Univ. (China); Feng Tang, Xi'an Institute of Modern Control Technology (China); Enshi Qu, Xu Han, Xi'an Institute of Optics and Precision Mechanics (China) [8351-27]
A theoretical model was given to study the static pressure distribution among the layers of an optical fibre cable spool. Using the distributed FBG sensing technique, the pressures within the fibre cable layers of the spool were measured according to the Bragg wavelength shifts of the FBGs embedded in the cable. Theoretical simulations coincide with experimental results.

Th-C10 **Side-polished fibre Bragg grating hydrogen sensor with different sensitive thin films**, Minghong Yang, Jixiang Dai, Wuhan Univ. of Technology (China); Kun Cao, Junsheng Liao, Pengcheng Zhang, China Academy Engineering Physics (China) [8351-32]
WO3-Pd and Pd-Ag composite films were deposited on the side-face of side-polished fibre Bragg grating as sensing element by magnetron sputtering process. Compared to common FBG coated with same hydrogen sensitive film, side-polished FBG significantly increase the sensor's sensitivity. When the hydrogen concentration is 4% and 8% in volume percentage, the maximum wavelength shift of side-polished FBG is about 25 and 55 pm respectively. The experiment results show the sensor's hydrogen response is reversible, side-polished FBG hydrogen sensor has great potential in hydrogen's measurement.

Th-C11 **Fibre optic sensor for detection of ground vibrations**, Tsair-Chun Liang, Yung-Li Lin, National Kaohsiung First Univ. of Science and Technology (Taiwan) [8351-33]
The paper describes a new fibre optic sensor based on the Mach-Zehnder and Sagnac hybrid interferometer to measure the ground vibrations is investigated. The frequency characteristic of vibration signal is analyzed via fast Fourier transform (FFT) and Gabor transform. It provides highly sensitive for low frequency measurement. The fibre optic vibration sensing system presented in this research is appropriate to utilize for sensing ground vibration between 10 ~ 200Hz frequency range.

Th-C12 **Design and fabrication of a debris flow sensor using a fibre optic interferometer**, Yung-Li Lin, Tsair-Chun Liang, National Kaohsiung First Univ. of Science and Technology (Taiwan) [8351-34]
In this paper, we study the debris flow monitoring system. Two kinds of sensing system are studied and compared with their performance. The first sensor is a traditional geophone, while the second one is a fibre optic sensor. This sensing system is composed of a fibre optic sensor and a Sagnac interferometer. The optical sensor is constructed by a mandrel wrapped with fibre. We compare the characteristic of those two sensor heads. The results indicate that the fibre optic interferometric sensor head (fibre optic geophone) has high resolution and its frequency response highly match with the traditional geophone. The results of experiments show that the performance of fibre optic geophone sensing system work well for low frequency range. According to our preliminary test, the dynamic range detected by the optic fibre sensor is 45 dB, while the frequency ranges is between 10 ~ 300 Hz.

Th-C13 **A cost effective FBG-based security fence with fire alarm function**, H. J. Wu, S. S. Li, X. L. Lu, Y. Wu, Y. J. Rao, Univ. of Electronic Science and Technology of China (China) [8351-35]
Fibre Bragg grating (FBG) is sensitive to the temperature as well when it is measuring the strain change, which is always avoided in most measurement applications. However, in this paper strain/temperature dual

sensitivity is utilized to construct a special security fence with a second function of fire threat prediction. In an FBG-based fibre fence configuration, only by characteristics analysis and identification method, it can intelligently distinguish the different effects of personal threats and fires from their different trends of the wavelength drifts. Thus without any additional temperature sensing fittings or other fire alarm systems integrated, a normal perimeter security system can possess a second function of fire prediction, which can not only monitor the intrusion induced by personal actions but also predict fire threats in advance. The experimental results show the effectiveness of the method.

Th-C14 **Non-local effect in long-distance Brillouin optical time-domain analyzer based on bi-directional Raman amplification**, Xin-Hong Jia, Yun-Jiang Rao, Univ. of Electronic Science & Technology of China (China) [8351-36]
The influence of the non-local effect on sensing performance in long-distance Brillouin optical time-domain analyzer (BOTDA) based on bi-directional Raman amplification has been investigated theoretically. The results show that, the system error induced by non-local effect worsens with increased powers of probe and Raman pump waves.

Th-C15 **Surface plasmon resonance based fibre optic hydrogen sensor utilizing wavelength interrogation** Priya Bhatia, B. D. Gupta, Indian Institute of Technology Delhi (India) [8351-37]
We present an experimental study on the surface plasmon resonance (SPR) based fibre optic sensor for the detection of hydrogen. Wavelength interrogation mode of operation has been used for sensing. The probe is fabricated by coating silver, silicon and palladium layers over unclad core of the fibre. The fact that the presence of hydrogen in the air around the palladium changes the dielectric functions of palladium is utilized. The SPR spectra are obtained for 100% nitrogen as well as for a mixture of 4% hydrogen and 96% nitrogen. A shift in resonance wavelength is obtained. The silicon layer enhances the shift in resonance wavelength.

Th-C16 **Enhancing the temperature sensitivity of fibre Bragg grating sensor using bimetallic strip**, P. Saidi Reddy, K. Srimannarayana, R. L. N. S. Sai Prasad, D. Sen Gupta, M. Sai Shankar, P. Kishore, National Institute of Technology, Warangal (India) [8351-38]
This paper presents theoretical and experimental results carried out on a simple structure based on bimetallic cantilever to enhance temperature sensitivity of fibre Bragg grating (FBG) sensors. Two metals of equal length and width but having different coefficients of thermal expansion (CTE) are bonded with electric arc welding to form the bimetallic strip and FBG was longitudinally affixed to that metallic strip having larger coefficient of thermal expansion. It was observed that the temperature sensitivity of the proposed FBG sensor has increased 5 times more compared to the bare FBG sensor.

Th-C17 **Measurement of Rhodamine B absorption in self-assembled silica microwires using a Tablet as the optical source**, John Canning, Masood Naqshbandi, Maxwell J. Crossley, The Univ. of Sydney (Australia) [8351-40]
A simple demonstration utilising the optical light source of an Android tablet to obtain the absorption spectra of Rhodamine dye stained self-assembled silica microwires is demonstrated. The spectrum is collected using a portable Spectrometer. This highlights the potential of tablet technology as portable optical hardware in its own right and we discuss how to potentially achieve complete integration of spectrometer onto the tablet.

Th-C18 **Four-layer d-shaped optical fibre surface plasmon resonance sensor for high-sensitivity strain measurement**, Yu-Lung Lo, Chin-Ho Chuang, Zheng-Wei Lin, National Cheng Kung Univ. (Taiwan) [8351-41]
A four-layer D-shaped optical fibre surface plasmon resonance (SPR) for high-sensitivity polarimetric strain sensor is proposed. In contrast to existing SPR-based sensors, which are based on changes in the refractive index of the over-layer, the sensor proposed in this study is based on the change in the refractive index of the fibre core in response to the application of an axial load. The experimental results show that the sensitivity of the proposed sensor is around 2.19×104 Deg./ϵ, i.e., degree/strain.

Th-C19 **Sensor-less aberration correction in optical imaging systems using blind optimization**, Mohammad R. N. Avanaki, Univ. of Kent (United Kingdom); R. Mazraeh Khoshki, Univ. of Razi (Iran, Islamic Republic of); S. A. Hojjatoleslami, A. Gh. Podoleanu, Univ. of Kent (United Kingdom) [8351-42]
The imperfection of optical devices in an optical imaging system deteriorates wavefront which results in aberration. This reduces the optical signal to noise ratio of the imaging system and the quality of the produced images. Adaptive optics composed of wavefront sensor (WFS) and deformable mirror is a straightforward solution for this problem. In this paper, we describe a blind optimization technique with an in-expensive electronics without using the WFS to correct the aberration in order to achieve better quality images. The correction system includes a DM with 52 actuators which are controlled by particle swarm

optimization (PSO) algorithm. The results of the application of simulated annealing (SA), and genetic algorithm (GA) techniques.

Th-C20 **Study on the all-fibre wind direction sensor and its application**, Jiasheng Ni, Chang Wang, Tao Lei, Jiqiang Wang, Zhihui Sun, Yanjie Zhao, Xiaohui Liu, Jun Chang, Shandong Academy of Sciences (China); Gangding Peng, Univ. of New South Wales (Australia) [8351-43]
An all-fibre wind direction sensor that used in wind power generation is introduced in this paper. The system based on Interferometer technology. The probe is designed as a fabry-perot cavity, which cavity length is changed with the wind directions. The system can calculate the wind direction by interference fringe period. The results of experiment showed that this sensor can monitor wind direction more exactly. The method is simple, sensitive with a good reproducibility.

Th-C21 **Photonic crystal surface plasmon waveguides sensor for high and accurate temperature measurement**, Rajan Jha, Indian Institute of Technology Bhubaneswar (India); Triranjita Srivastava, Delhi Technological Univ. (India); Ritwick Das, National Institute of Science Education and Research (India) [8351-44]
Highly sensitive, accurate and stable high temperature (800 K) sensor based on Photonic Crystal Surface Plasmon Waveguides is proposed. The PCW is based on widely used lithographic and nano-fabrication compatible materials like TiO2 and SiO2. Gold has been used as a SPR active metal. Employing coupled mode theory, the sensitivity is found to be as high as ~66 pm/K.

Th-C22 **Dynamic digital holography applied to three-dimensional imaging of droplet evaporation process**, Shiping Li, Jingang Zhong, Jiawen Weng, Cuiying Hu, Jinan Univ. (China) [8351-48]
Understanding the evaporation behavior of water droplets on a flat substrate is very important for applications of many areas. In order to obtain quantitative three-dimensional imaging of droplet evaporation process, the dynamic digital holography has been employed. The off-axis holograms are recorded by a camera and the object waves are numerical reconstructed. The method can simultaneously provide an amplitude-contrast image and a quantitative phase-contrast image. The theory of digital holography is introduced and the experiment of water droplet evaporation is presented.

Th-C23 **A high sensitive fibre Bragg grating(FBG) geophone detecting system**, Jin-Yu Wang, Hai-Feng Qi, Guang-Dong Song, Chang Wang, Key Lab. of Optical Fibre Sensoring Technology of Shandong Province (China) and Shandong Academy of Sciences (China); Tong-Yu Liu, Key Lab. of Optical Fibre Sensoring Technology of Shandong Province (China) and Shandong Academy of Sciences (China) and Shandong Micro-Sensor Photonics Ltd. (China) [8351-49]
A high sensitive fibre Bragg grating (FBG) geophone detecting system based on narrow line width distributed feedback (DFB) laser is realized by using filtering demodulation. Sensitivity of FBG geophone lies on the structure of the sensor shell and the shape of the reflectivity spectrum of FBG. Experiments on the detecting system's frequency character have been done. Results show that this geophone can detect the smallest acceleration of 1mm/s2 with a flat response from 5Hz to 40Hz. The experiments on coal mine exhibit that the geophone can be used to measure micro-seismic signals. The detecting system shows great prospect in micro-seismic detection, and geological disasters detecting.

Th-C24 **1-cm spatial resolution with large dynamic range in strain distributed sensing by Brillouin optical correlation domain reflectometry based on intensity modulation**, Sitthipong Manotham, Masato Kishi, Zuyuan He, Kazuo Hotate, The Univ. of Tokyo (Japan) [8351-51]
We experimentally demonstrate distributed strain measurement with a high spatial resolution and a large dynamic range by proposing a system for Brillouin optical correlation domain reflectometry with an intensity modulation scheme. With the optimized intensity modulation, the optical power spectrum of the light source is properly modified so that the accumulated background noise in the Brillouin gain spectrum is significantly reduced. It is confirmed that the proposed system enables us to extend the maximum measurable strain up to ~7000 με, which is sufficient for practical applications of a distributed sensing, with 1-cm spatial resolution. This resolution is the best result ever reported in reflectometries based on spontaneous Brillouin scattering by using a conventional single mode fibre.

Th-C25 **Modeling and experimental investigation of the coupling efficient of a fibre-capillary fluorescent sensor**, Zhong Pan, Min Li, Li Hua, Wuhan Univ. of Technology (China); Yulin Li, Wuhan Haomai Photonics Technology Co., ltd. (China) [8351-53]
An evaluation model is proposed to estimate the fluorescence coupling efficiency of a small, capillary-shape fibre sensor, which takes advantage of the analysis approach for the coupling efficiency from a point lightsource to a fibre. Both simulation and experiment results show that a triangle-arrangement of two excited fibres and one receiving fibre gives the best coupling efficiency of a capillary-shape fibre probe with a fixed diameter. The coupling efficiency is inversely proportion to the refractive index and attenuation

coefficient of the fluorophore solution, besides being direct proportion to the core diameter R and the N.A., i.e., sin θ (θ is the receiving angle), of the receiving fibre within the distance from the fibre end to the limit decided by R/tan θ , and a fluorescence efficiency of 0.8% is demonstrated.

Th-C26 **Birefringence analysis of a two elliptical cores hollow fibre based on finite element method**, Fengjun Tian, Libo Yuan, Qian Dai, Zhihai Liu, Jianzhong Zhang, Harbin Engineering Univ. (China) [8351-55]
We design and fabricate a two elliptical cores hollow optical fibre. Based on the finite element method the birefringence characteristics are analyzed numerically at 200nm-1800nm wavelength. We expect that the two elliptical cores hollow fibre has some potential applications in in-fibre interferometers with polarization maintaining, poling fibre and Bio-sensor based on evanescent wave field.

Th-C27 **Fibre Laser methane sensor with the function of self-diagnose**, Yan-fang Li, Yu-bin Wei, Ying Shang, Chang Wang, Tong-yu Liu, Shandong Key Lab. of Optical Fibre Sensor (China) and Shandong Academy of Sciences (China) [8351-58]
Using the technology of tunable diode laser absorption spectroscopy and the technology of micro-electronics, a fibre laser methane sensor based on the microprocessor C8051F410 is given. We use the DFB Laser as the light source of the sensor. By tuning temperature and driver current of the DFB laser, we can scan the laser over the methane absorption line, we realize the methane detection. It makes the real-time and online detection of methane concentration to be true, and it has the advantages just as high accuracy, immunity to other gases , long calibration cycle and so on. The sensor has the function of adaptive gain and self-diagnose.

Th-C28 **A high temperature sensor based on a peanut structure-based Michelson interferometer**, Tao Zhu, Di Wu, De-Wen Duan, Chongqing Univ. (China); Kinseng Chiang, City Univ. of Hong Kong (China) and Chongqing Univ. (China); Yun-Jiang Rao, Univ. of Electronic Science and Technology of China (China) and Chongqing Univ. (China) [8351-60]
A novel fibre temperature sensor with high sensitivity based on a Michelson interferometer in a single-mode fibre is constructed and demonstrated. The sensor consists of a peanut-shape structure and we demonstrated that the peanut-shape structure can couple the light energy of the core mode into the cladding and re-couple the light in the cladding into the core. The experimental results show that the device can be heated up to 900°C; with the sensitive of 0.096nm/°C when the sensor length L is ~21mm. Such kind of simple, low-cost, and highly sensitive fibre-optic temperature sensor would find applications in sensing fields.

Th-C29 **Online fabrication of compact and asymmetrical DFB fibre laser**, Haifeng Qi, Shandong Academy of Sciences (China) and The Univ. of New South Wales (China); Zhiqiang Song, Chang Wang, Jun Chang, Shandong Academy of Sciences (China); Gangding Peng, The Univ. of New South Wales (Australia) [8351-63]
The online fabrication of distributed feedback (DFB) fibre laser with a compact and asymmetrical cavity structure was presented.

Th-C30 **Study of photorefractive properties of liquid crystal hybrid thin film by side polished fibre sensor**, Jianhui Yu, Xiaoqing Li, Yao Du, Jun Zhang, Zhe Chen, Jinan Univ. (China) [8351-67]
Using a side polished standard fibre (SPF) as a sensor which is very sensitive to external refractive index, liquid crystal hybrid film mixed with Azobenzene(AZO) and ZLI811 is overlay on the polished region of the SPF, and the photorefractive effect of the film with UV light irradiation is studied. The mixture composed of liquid crystal, AZO, and ZLI811 was coated on the polishing area after the SPF was calibrated. The optical power transmission of the SPF changes when the photosensitive film on the SPF is under UV irradiation. Through curve of optical power transmission which functions as refractive index, refractive index change of liquid crystal hybrid film is measured. Our experimental result shows that the photosensitive thin film is a negative photosensitive material, and the refractive index changes from 1.474 to 1.470 under UV light irradiation. This photosensitive film material can be potentially used to create a new all-fibre optical-controllable components and sensors.

Th-C31 **Interrogation of intensity modulation fibre Bragg grating sensor based on loss-tunable corrugated long period fibre grating filter**, Chia-Chin Chiang, Min-Yuan Hsieh, National Kaohsiung Univ. of Applied Sciences (Taiwan) [8351-70]
Current study utilizes the corrugated long period fibre grating (CLPFG) edge filter and fibre Bragg grating (FBG) strain sensor to configure the high speed strain sensing system by intensity modulation. For static calibration, the FBG wavelength shift is linear with the modulated intensity by CLPFG while the linearity (R2) of the FBG intensity and strain is 0.994. For dynamic strain sensing, the performance of this system is good as the strain gage at 500Hz under the various strain fields. Experimental results also indicate that the optimal sensitivity is 11.08 mV/με.

Th-C32 **Research of fibre carbon dioxide sensing system based laser absorption spectrum**, Yubin Wei, Tingting Zhang, Yanfang Li, Yanjie Zhao, Chang Wang, Tongyu Liu, Shandong Academy of Sciences (China) [8351-71]
Carbon dioxide is one of the important gas need to be detected in coal mine safety. In the mine limited ventilation environment, Concentration of carbon dioxide directly affects the health of coal miners. Carbon dioxide is also one of important signature Gas in spontaneous combustion forecasting of coal goaf area, it is important to accurately detect concentration of carbon dioxide in coal goaf area. This paper proposed a fibre carbon dioxide online sensing system based on tunable diode laser spectroscopy. The system used laser absorption spectroscopy and optical fibre sensors combined, and a near-infrared wavelength 1608nm fibre-coupled distributed feedback laser (DFB) as a light source and a 7cm length gas cell, to achieve a high sensitivity concentration detection of carbon dioxide gas. The technical specifications of sensing system can basically meet the need of mine safety.

Th-C33 **Study of DFB fibre laser intensity noise and its suppression**, Yanjie Zhao, Chang Wang, Jiansheng Ni, Shandong Academy of Science (China); Jun Chang, Pengpeng Wang, Shandong Univ. (China); Gangding Peng, Univ. of New South Wales (Australia); Tongyu Liu, Shandong Academy of Science (China); Qingpu Wang, Shandong Univ. (China) [8351-73]
We proposed an experimental investigation into the low-frequency intensity noise characteristics of erbium-doped distributed feedback fibre lasers (DFB-FL). And the paper presented a simple self-injection locking (SIL) configuration of DFB fibre laser to suppress the intensity noise. One of the reasons caused intensity noise is the existence of multimode in the DFB-FL. SIL inhibits other modes while enhances dominant mode. Process of locking mode occurred in the DFB-FL was measured in this paper. Comparison of the output powers with and without injection gives a sufficient proof, that it can realize the stable lasing by injecting the feedback laser into the cavity again. When the current of 980nm pump is about 175mA, the intensity noise is suppressed about 25 dB, and relaxation oscillation frequency decreased from 126.5 KHz to 60 KHz in this paper. The results have potential application in high sensitive fibre sensors and optical communication.

Th-C34 **Closed loop resonator fibre optic gyro with precisely controlled bipolar digital serrodyne modulation**, Xijing Wang, Masato Kishi, Zuyuan He, Kazuo Hotate, The Univ. of Tokyo (Japan) [8351-76]
A closed-loop resonator fibre optic gyro (R-FOG) with a precisely controlled bipolar digital serrodyne phase modulation scheme is experimentally demonstrated. A precise amplitude adjustment method using a gain variable amplifier and the oversampling technique is utilized to improve the backscattering suppression efficiency. Compared with the amplitude control via adjusting the digital gain of the function generator, improved bias stability is achieved. Moreover, the closed-loop operation is realized by superimposing an additional bipolar digital serrodyne waveform with gentle slope on the original bipolar digital serrodyne waveform. Measurement results of different rotation speeds show good linearity for the adoption of closed-loop operation.

Th-C35 **Fibre Bragg grating acceleration sensor incorporating a taper fibre**, K. Ni, China Jiliang Univ. (China) and Nanyang Technological Univ. (Singapore); C. Chan, X. Dong, Nanyang Technological Univ. (Singapore); L. Li, China Jiliang Univ. (China) [8351-77]
An intensity-modulated optical fibre Bragg grating (FBG) acceleration sensor incorporating a taper fibre is proposed and experimentally demonstrated. The sensing mechanism is based on the measurement of the reflected optical power of a single FBG. An 8 mm long, 125μm single-mode fibre is tapered and connected with the fibre Bragg grating. In taper section, the light attenuation is affected by microbending. When the acceleration is applied to the sensor, the core mode energy would decrease with the acceleration. Hence the reflected optical power changes with the acceleration. So we can measure the power change in reflection to get acceleration. This power detection method reduces the cost and complexity of the sensor system with respect to method of wavelength interrogation, It shows a static range of 5 g and sensitive of 4.85 nW / g. Vibration measurements have been achieved and the measured frequency is from 0 to 20 Hz.

Th-C36 **FBG application in monitoring the liquid-solid and gas-liquid phase transitions of water**, Chai Quan, Khalil Later, Lijie Yang, Shijun Peng, Anna Zhang, QianQian Hao, Jianzhong Zhang, Weimin Sun, Libo Yuan, Harbin Engineering Univ. (China); G. D. Peng, Univ. of New South Wales (Australia) [8351-82]
We propose to monitor the liquid-solid and gas-liquid phase transition of water based on FBG sensors. The naked FBGs and the packaged FBG temperature sensors are used to monitoring the liquid-solid phase transition of water at the same time in order to find its characteristics, including the supercooling state and the strain and pressure change introduced by the phase transition. Fourteen FBGs are packaged and arranged in a steam boiler in order to monitor the gas-liquid phase transition, including the temperature and pressure change inside the steam boiler and the strain of the boiler wall. The preliminary experimental results are demonstrated here.

Th-C37 **The dual-parameter sensor based on the SMS fibre structure with an off-axis welding**, Yanan Liu, Shijun Peng, Baoyong Li, Jianzhong Zhang, Harbin Engineering Univ. (China) [8351-90]
A novel sensing scheme to measure strain and temperature simultaneously by using an off-axis single mode-multimode-single mode (SMS) fibre optical structure is proposed in this article. The dual-parameter measurement is achieved based on the obviously different strain and temperature responses of two loss peaks in the off-axis SMS transmission spectrum. In experimental, the sensitivities value of temperature and strain of two loss peaks are measured to -8.2pm/με, -2.3 pm/με and 41.2pm/°C, 16.0pm/°C, respectively.

Th-C38 **Control system for optic-fibre coating process based on photoelastic effects**, Alejandro Hernández, Victor Velasco, Miguel Orozco, Alfredo Márquez, Ctr. de Investigación en Materiales Avanzados A.C. (Mexico) [8351-91]
The coating process, of optic-fibres into a polymer matrix is a very difficult and delicate process due to the fragility of the fibres, which can get broken by the stresses and temperature imposed during processing. In this paper we introduce a new control system which is based on measurement of specific power changes in the laser transmitted signal thought the fibre. Those changes are produced by mechanical or thermal stresses on the fibre during processing. Those stresses normally generated by photoelastic effects on the fibre when it is pulled or heated, changing its optical properties. By a meticulous characterization of those effects we are able to establish a real time control system for the coating process, avoiding the deformation or even breaking of the fibre during coating.

Coffee Break and *Exhibition*

Walsh Bay Room ..... 15:30 – 16:00

SESSION Th-D: Poster SESSION 2

Anchorage Room ..... 16:00 – 18:00

Th-D1 **Facile fluorescent rhodamine-based sensor for selective detection of Pb2+**, Heeyoung Ju, Kyung Hee Univ. (Korea, Republic of); Min Hee Lee, Korea Univ. (Korea, Republic of); Jungahn Kim, Kyung Hee Univ. (Korea, Republic of); Jong Seung Kim, Korea Univ. (Korea, Republic of); Joohoon Kim, Kyung Hee Univ. (Korea, Republic of) [8351-92]
Rhodamine-based chemosensors were synthesized and self-assembled on glass surface for the selective fluorescent sensing of Pb2+. The immobilized chemosensors showed fluorescent response that is turned-on selectively with Pb2+ over various metal ions in CH3CN. The Pb2+ selective fluorescent switch of the immobilized chemosensors was also reversible, which allows their repeated use for Pb2+ detection.

Th-D2 **The weak optical feedback effect of DFB fibre laser and its sensing applications**, Yanshuang Zhao, Touati Amine, Jianzhong Zhang, Harbin Engineering Univ. (China); G. D. Peng, Univ. of New South Wales (Australia) [8351-93]
We present the transfer matrix based analysis of the distributed feedback (DFB) fibre laser with an extra weak optical feedback introduced by a fibre end facet directly. The lasing frequency and output power could be modulated by the modulation of the weak feedback parameters, including the phase and intensity of the feedback light. A corresponding simple intensity based DFB fibre laser vibrometer is proposed according to the analysis and the experimental results are given to prove it feasibility. With the advantages of simple and compact structure, the sensing scheme is expected to have broad applications.

Th-D3 **Fibre optical vibrometer based on a phononic crystal filter**, Sijing Lin, Quan Chai, Jianzhong Zhang, Harbin Engineering Univ. (China) [8351-95]
We propose that phononic crystals could be used as a packaging method in a fibre optical vibrometer system to filter the vibration at unwanted frequency range. A simple FBG based vibrometer and a aluminum-silicone rubber based 1D phononic crystal with the designed phononic band gap are built up, and the corresponding experimental results are demonstrated to show the feasibility of our proposal. Our proposal also points out that optical fibre sensors could be an excellent candidate to research the inner acoustic response of more complex phononic crystals.

Th-D4 **Gas detection with evanescent-wave quartz-enhanced photoacoustic spectroscopy**, Yingchun Cao, Wei Jin, Hoi Lut Ho, The Hong Kong Polytechnic Univ. (Hong Kong, China) [8351-96]
Evanescent-wave gas sensing with tapered optical fibres (TOFs) and quartz-enhanced photoacoustic spectroscopy (QEPAS) is reported. The evanescent field of TOFs with diameter down to sub-wavelength is utilized for photoacoustic excitation in photoacoustic spectroscopy. A quartz tuning fork (QTF) with resonant frequency about ~32.75 kHz is used to detect the generated pressure wave. A normalized noise equivalent absorption coefficient of 1.5×10-6 cm-1 W/ √ Hz is achieved for acetylene detection with a fibre taper with a waist diameter of 1.1 μm. It is found that QEPAS with TOFs of sub-wavelength diameters

exhibit comparable sensitivities with open path QEPAS but with additional advantages of lower insertion loss, easier alignment, and multiplexing capability.

Th-D5 **A new real non-invasive single fibre tweezers**, Yu Zhang, Zhihai Liu, Jun Yang, Libo Yuan, Harbin Engineering Univ. (China) [8351-97]
A new real non-invasive two-core single fibre optical tweezers is proposed and fabricated by fibre grinding and polishing technology. The yeast cells trapping performance of this special designed truncated cone tip fibre probe is demonstrated and investigated. The distributions of the optical field emerging from the truncated cone fibre tip are simulated by Beam Prop Method. Both axial and transverse trapping forces are calculated by FDTD method. This new optical tweezers can realize truly non-invasive remote trapping and manipulating bio-cells.

Th-D6 **Performance investigation of erbium-doped fibre ring laser for intra-cavity absorption gas detection**, Mo Li, Univ. of New South Wales (Australia) and Harbin Institute of Technology (China); Jingmin Dai, Harbin Institute of Technology (China); Kun Liu, Univ. of New South Wales (Australia) and Tianjin Univ. (China); Gang-Ding Peng, Univ. of New South Wales (Australia) [8351-98]
The performance of an erbium-doped fibre (EDF) ring laser based intra-cavity gas sensor is investigated theoretically and experimentally. A theoretical model for analyzing the effects of the EDF parameters and the system parameters on the performance of this gas sensor was established using coupled rate equations and propagation equations. We investigated a number of specific cases and suggested practical choices of their parameters. Experiments with two cavity losses were conducted to test the system sensitivity enhancement and the trend of the results matched well with the theoretical prediction. The results showed sensitivity enhancement factors ranged from 17-20 in the experimental system can be achieved.

Th-D7 **Implementation of highly sensitive refractometers with rectangular microfibres**, Jie Li, Li-Peng Sun, Shuai Gao, Zhan Quan, Yong-Liang Chang, Yang Ran, Long Jin, Bai-Ou Guan, Jinan Univ. (China) [8351-101]
A new kind of highly-sensitive refractometer is demonstrated utilizing the polarimetric interference of rectangular microfibre, with the obtained sensitivity as high as 18,987nm per refractive index unit around refractive index of 1.33. The calculation is in good agreement with the experimental results. Our device exhibits the performance of high sensitivity, easy implementation, high stability and repeatability.

Th-D8 **Optical humidity sensor based on hollow core fibre**, M. Y. Mohd Noor, N. Khalili, G. D. Peng, The Univ. of New South Wales (Australia) [8351-103]
We propose a novel relative humidity (RH) sensor based on hollow core fibre using direct absorption spectroscopic method in this paper. The wavelength scanning around water vapour absorption peak around 1368.59 nm is realized by injecting saw-tooth modulated current to a DFB laser diode. We demonstrate that a length of 5 cm hollow core fibre with a fixed small air gap between SMF and hollow core fibre as an opening achieves a humidity detection resolution of around 0.02%RH over the range 0 to 50%RH.

Th-D9 **Enhanced working distance of fibre lens with low refractive index material**, Jaemyoung Lee, Korea Polytechnic Univ. (Korea, Republic of) [8351-105]
We proposed a new structure for fibre lens to extend the working distance by applying polymer layer to the fibre lens. The simulation result shows that the working distance can be extended to larger than 10 times than a fibre lens without a coated layer. In simulation, the proposed structure extended the working distance up to about 2,110 micron by using polymer layer with a refractive index of 1.3.

Th-D10 **New theory of femtosecond induced changes and nanopore formation**, John Canning, The Univ. of Sydney (Australia); Matthieu Lancry, Univ. Paris Sud 11 (France); Kevin Cook, The Univ. of Sydney (Australia); Bertrand Poumellec, Univ. Paris Sud 11 (France) [8351-106]
Recent results confirm the presence of molecular oxygen proving that recombination of dissociated silica bonds does not occur. This combined with the observation of nanopores within the nanograting structure in silica, leads to a new interpretation of femtosecond processing based on the unusual characteristics of quenching of tetrahedral silica compared to other glasses. This new approach suggests very different directions and implications for devices, including sensors, based on femtosecond laser processing of glasses.

Th-D11 **Surface treatment of silicate based glass: base Piranha treatment versus 193nm laser processing**, J. Canning, I. Petermann, K. Cook, The Univ. of Sydney (Australia) [8351-107]
Contact angle measurements of water on pathology grade borosilicate glass microscope slides before and after base piranha treatment are compared to treatment with 193nm laser irradiation. 193nm irradiation in the presence of hydrogen was also explored. Within experimental resolution, the observed changes in contact angle as a result of treatment either with base Piranha solution or with laser processing are identical.

Th-D12 **FBG tread wear detecting lines**, Weilai Li, Xin Dai, Jie Liu, Jianjun Pan, Qin Wang, Yanxiao Zhang, Wuhan Univ. of Technology (China) [8351-111]
FBG strain sensing technology is used to dynamically detect tread wear of railway train wheels. Dozens of FBG track strain sensors are installed as lines along railway tracks in crosstie sections. Wheels one by one roll on the track and load the sensors, groups of strain peak are taken. The strain curve of defective wheel appears a gap or with serration. By means of strain pulse processing program, tread wear and wheel health condition are obtained. FBG strain gauge is employed to increase the measuring sensitivity. The examples of detecting results are given to show the validity of this FBG application.

Th-D13 **Liquid level measurement sensor using a long-period fibre grating**, Barerem-Melgueba Mao, Bin Zhou, Zhejiang Univ. (China) [8351-116]
A liquid level sensor based on a long-period fibre grating is proposed. The principle of this type of sensor is based on the refractive index sensitivity of long-period fibre grating. By monitoring a given attenuation band's resonant wavelength shifts, one can measure the immersed lengths of long period fibre gratings and then the liquid level. The long-period fibre grating was immersed in two solutions which have different refractive indexes. A maximum shift of 7.69 nm for 50 mm of solution which has the highest refractive index has been observed.

Th-D14 **Double-fibre Fabry-Perot Interferometry optical fibre liquid level sensor**, Bin Tong, Min Li, Wuhan Univ. of Technology (China); Yulin Li, Wuhan Haomai Photonics Technology Co., Ltd. (China) [8351-119]
This paper presents a liquid level sensor with a double-fibre Fabry-Perot (F-P) cavity and a diaphragm serving as the sensing element. The end surfaces of the two fibres that integrated in a ferrule serve as the front surfaces of the F-P cavities, and the diaphragm (one of the standard components of a manometer) as the rear surface. The random difference in position between the two fibre ends makes a phase difference between the two F-P interferometers, and is used to interpret the direction of the pattern shifts with the variation of the F-P cavity length, which leads to a much lower technological requirement for the cavity manufacture and a more stable sensor.

Th-D15 **Application of fibre grating-based acoustic sensor in progressive failure testing of e-glass/vinylester curve composites**, Asrul Izam Azmi, Raju Raju, Gang-Ding Peng, The Univ. of New South Wales Sydney (Australia) [8351-120]
This paper reports an application of phase shifted fibre Bragg grating (PS-FBG) intensity-type acoustic sensor in a continuous and in-situ failure testing of an E-glass/vinylester top hat stiffener (THS). The narrow transmission channel of the PS-FBG is highly sensitive to small perturbation, hence suitable to be used in an effective acoustic emission (AE) assessment technique. The progressive failure of THS was tested under transverse loading to experimentally simulate the actual loading in practice. Our experimental tests have demonstrated, in good agreement with the commercial piezoelectric sensors, that the important failures information of the THS was successfully recorded by the simple intensity-type PS-FBG sensor.

Th-D16 **Optical methane detection sensor using an interferometric-structured optical planar waveguide**, Myoung Jin Kim, Sung Hwan Hwang, Woo-Jin Lee, Eun Joo Jung, Byung Sup Rho, Korea Photonics Technology Institute (Korea, Republic of) [8351-122]
We present an optical methane sensor that employs a Mach-Zehnder interferometer formed on a planar waveguide. The overclad of only one arm of the interferometer is partially etched up to the boundary between the core and clad. Then, the etched region is coated by SnO2 thin layer and the sensor module is annealed at high temperature. When the fabricated sensor module is exposed to methane gas, the interferogram is changed and quickly saturated in 10 seconds.

Th-D17 **Narrow-linewidth photonic crystal fibre laser with DBR construction**, Xue-jing Liu, Wei-hong Bi, Xue-qiang Liu, Feng Wang, Yue-feng Qi, Chun-ling Hou, Yanshan Univ. (China) [8351-123]
A narrow-linewidth photonic crystal fibre (PCF) laser operating at room temperature with two Bragg gratings integrated directly is demonstrated. Fabrication of the Bragg grating in a photonic crystal fibre is investigated experimentally by phase mask method. Under the optimal experiment condition, we fabricate the optical fibre grating with four obvious peaks. Moreover, a continuous-wave all fibre laser operation at 1549.6nm of a diode-pumped PCF laser is fabricated. A constrained bandwidth of 50 pm is formed through locking the laser on the overlapping peak of one Bragg grating with the side lobes of the other. It is possible to achieve a high stability and beam quality laser, which has a great application potential in optical communication field in future.

Th-D18 **High strain FBG sensors for structural fatigue testing of military aircraft**, S. Tejedor, J. Kopczyk, T. Nuyens, C. Davis, Defence Science and Technology Organisation (Australia) [8351-126]
This paper reports on a series of tests investigating the performance of Draw Tower Gratings (DTGs) combined with custom-designed broad area packaging and bonding techniques for high-strain sensing applications on Defence platforms. The sensors and packaging were subjected to a series of high-strain static and cyclic loading tests and a summary of these results is presented.

Th-D19 **Periodic array of nanoholes on gold-coated optical fibre end-faces for surface plasmon resonance liquid refractive index sensing**, Huy Nguyen, Fotios Sidiroglou, Stephen F. Collins, Gregory Baxter, Victoria Univ. (Australia); Ann Roberts, The Univ. of Melbourne (Australia); Timothy J. Davis, Commonwealth Scientific and Industrial Research Organisation (Australia) [8351-128]
Focused ion beam (FIB) lithography was used to inscribe a periodic array of nanoholes directly on gold-coated optical fibre end-faces. The excitation of the surface plasmon polaritons of the nanohole arrays on the optical fibre end-faces provided the basis of a refractive index sensor for liquids. This optical fibre based surface plasmon resonance sensor is compact and has the potential to be used in biomedical applications. A sensitivity of approximately 294 nm per refractive index unit (RIU) has been demonstrated for this sensor.

Th-D20 **Wavelet transform based de-noising method for self mixing interferometry signals**, Yuan Sun, Yanguang Yu, Jiangtao Xi, Univ. of Wollongong (Australia) [8351-130]
Self-mixing interferometry (SMI) signals are observed from a laser diode (LD) with optical feedbacks induced by an external target. SMI signals carry information related to both of the target and parameters of the LDs. However, the noise contained in SMI signals greatly degrades the applications of the SMI systems. This paper proposes a wavelet transform based de-noising method which can effectively eliminate noise while keeping an SMI waveform less changed. The proposed method is verified by both simulations and experiments

Th-D21 **MFI-type zeolite functional liquid phase sensor coated on the optical fibre end-face**, Yaoxin Hu, Fotios Sidiroglou, Victoria Univ. (Australia); Matthew R. Hill, Commonwealth Scientific and Industrial Research Organization (Australia); Stephen F. Collins, Mikel Duke, Victoria Univ. (Australia) [8351-131]
In this work, we demonstrate a simple technique to coat the end face of an optical fibre with the microporous MFI-type zeolite. The exposure of the zeolite films from air to water or to aqueous solutions of ethanol and isopropanol causes a distinct change in the film's refractive index. This change was then detected using a simple fibre optic refractive index sensor by monitoring the signal intensity reflected back from the coated fibre endface and as the zeolite is transferred between air, water and solutions containing ethanol and isopropanol. The zeolite coating was developed using the in-situ templated growth technique to grow the zeolite crystals on the cleaved endface of an optical fibre.

Th-D22 **Michelson Interferometer characterisation of noise reduction in DFB fibre lasers**, Albert Canagasabey, The Univ. of Sydney (Australia); David Jones, David Mann, Thales Underwater Systems (Australia); John Canning, Simon Fleming, The Univ. of Sydney (Australia); John Holdsworth, Univ. of Newcastle (Australia) [8351-132]
A comparison is made between unpackaged and packaged distributed feedback (DFB) fibre lasers using the Michelson interferometer configuration for delayed self-heterodyne interferometery (MI-DSHI) to ascertain the improvements to the external environmental noise, quantified by reductions in the Gaussian linewidth. Voigt fitting is used to extract and separate out the Lorentzian and Gaussian linewidth contributions and therefore the associated sources of noise. Significant improvements in the Gaussian linewidth were achieved as a result of significant reductions in the sensitivity of the DFB laser to external perturbations using packaging. However, a broadening of the laser Lorentzian linewidth was observed.

Th-D23 **Water vapor absorption spectrum measurements and its application in concentration measurement**, Jun Chang, Shandong Univ. (China); Kun Chen, School of CPC Shandong Provincial Party Committee, Jinan (China); Guoqing Zhou, Guangping Lv, Cunguang Zhu, Zhongliang Wang, Fujun Song, Haiyong Song, Junqiang Tian, Wenjia Hou, Jiaqing Huang, Shandong Univ. (China) [8351-133]
Wavelength tunable distributed feedback laser diode (DFB-LD) were utilized to measure line 1368.597nm and line 1367.862 nm absorption character of water vapor, based on it, water vapor concentration can be measured by peak absorption rate according to Beer-Lambert law. Besides, we observe that the overlap between the line 1368.597nm and line 1367.862 nm appears and become serious with the increase of gas pressure, this agrees well with the theoretical prediction, and the overlap cause difficulty to determine the absorption peak value, a scheme is presented to cope with the difficulty, it takes advantage of the peak absorption difference between 1368.597nm and 1367.862 nm, and the difference value is used to calculate the water-vapor concentration.

Th-D24 **Sol-gel surface functionalisation by cold-processing for optical sensor applications**, George Huyang, The Univ. of Sydney (Australia); Ingemar Petermann, The Univ. of Sydney (Sweden); John Canning, Maxwell J. Crossley, The Univ. of Sydney (Australia) [8351-134]
The structure and physical properties of a thin titania sol-gel layer, prepared on silicon and silica surfaces by cold processing and spin-coating techniques, were examined. A series of spectroscopic (FTIR, UV-VIS spectroscopy and ellipsometry) and microscopic (light microscopy, SEM and EDS) techniques were used to examine the chemical and physical uniformities of the sol-gel layers. Conditions were established to generate uniform layers reproducibly. The high refractive index, selective binding to organic functional groups and the light and gas transmission properties of the titania layers can be successfully fabricated suitable for new optical sensor applications.

Th-D26 **Voltage sensor based on Deformed Helix Ferroelectric Liquid Crystal**, Zourab Brodzeli, Francois Ladouceur, Leonardo Silvestri, Toan Phung, Univ. of New South Wales (Australia); Andrew Michie, Smart Digital Optics Pty. Ltd. (United States); Vladimir Chigrinov, Grace Qi Guo, The Hong Kong Univ. of Science and Technology (China); Eugene P. Pozhidaev, P.N. Lebedev Physical Institute (Russian Federation); Alexei D. Kiselev, Institute of Physics (Ukraine) [8351-145]
In this paper we propose a new approach to fibre optic voltage sensors via voltage-controlled Liquid Crystals (LC), which would allow direct measurement of up to 400 kV/m electric fields at multiple points. In addition, a novel polarization independent fibre optic sensor configuration is presented that exhibits a linear electro-optic (EO) response to variations of the electrical field under test.

Th-D27 **CO_2-laser induced long-period fibre gratings in nano-engineered bend insensitive single-mode fibre**, Yunjiang Rao, Wenhua Wang, Zinan Wang, Kin Seng Chiang, Yuan Gong, Univ. of Electronic Science & Technology of China (China) [8351-148]
Long-period fibre gratings (LPFGs) written in nano-engineered bend insensitive single-mode fibre (NEBI-SMF) were reported. It is found that, only when the pitches of the gratings are in two wavelength ranges (270-305 μm and 420-480 μm), obvious resonance peaks can be obtained within the band of 1200-1650 nm, due to the cladding mode separation caused by the nano-engineered ring in the fibre cladding. The strain sensitivity of the LPFG with a pitch of 295μm in the range of 270-305 μm is 2.8 pm/ με , while the LPFG with a pitch of 470 μm in the range of 420-480 μm is insensitive to strain. The temperature sensitivities of the two LPFGs are 0.145 nm/°C and 0.098 nm/°C, respectively.

Th-D28 **Fibre laser sensor interrogation system development and test**, Zhihui Sun, Jinyu Wang, Laser Institute of Shandong Academy of Sciences (China); Jun Chang, Shandong Univ. (China); Jiasheng Ni, Li Min, Chang Wang, Laser Institute of Shandong Academy of Sciences (China); Gangding Peng, The Univ. of New South Wales (Australia) [8351-150]
In this paper, fibre laser sensor digital PGC interrogation system has been developed and tested. PGC interrogation principle and overall interrogation system are described. The components of the interrogation system including digital PGC demodulation algorithm, data acquisition, PD amplifier and low-pass filter, PGC phase carrier generation and unbalanced Michelson interferometer are discussed in detail. Standard wavelength shift signal generator is set up and it can be used for unbalanced Michelson interferometer performance test, PGC demodulation algorithm development and interrogation system calibration. And the frequency response of the uncoated DFB fibre laser for detecting acoustics signal in water is obtained.

Th-D29 **Reflection from gold-coated deformed-helix ferroelectric liquid crystal cells: theory and experiment**, Leonardo Silvestri, Zourab Brodzeli, Francois Ladouceur, The Univ. of New South Wales (Australia); Andrew Michie, Smart Digital Optics Pty. Ltd. (Australia); Vladimir G. Chigrinov, Grace Qi Guo, The Hong Kong Univ. of Science and Technology (Hong Kong, China); Eugene P. Pozhidaev, P.N. Lebedev Physics Institute of Russian Sciences (Russian Federation); Alexei D. Kiselev, National Academy of Sciences of Ukraine (Ukraine) [8351-152]
Liquid crystal (LC) cells can be used in conjunction with optical fibres to develop cheap and efficient sensors, such as voltage sensors or hydrophones. In this paper we apply an effective tensor model to describe reflection from gold-coated deformed-helix ferroelectric liquid crystal (DHFLC) cells. We show that, depending on the polarisation of the incident light, it is possible to obtain a linear electro-optical response to the voltage applied to the cell. Theoretical results are compared with experimental results yielding accurate agreement.

Th-D30 **Experimental and technical research on fibre Bragg grating vibration measuring based on two matching gratings demodulation**, Zheng-fang Wang, Qing-mei Sui, Jing Wang, Jun Chang, Shandong Univ. (China); Gang-ding Peng, Univ. of New South Wales (Australia); Hai-yong Song, Shandong Univ. (China) [8351-154]
The analysis of a novel demodulation technique for fibre Bragg grating (FBG) vibration sensors based on two parallel matching gratings has been carried out both theoretically and experimentally. The lineally

model between transformed formula of optical power and the central reflection wavelength of sensing grating has been obtained. In addition, the FBG vibration sensor based upon cantilever with equalized strength is designed and the natural frequency of sensor has been obtained by calculations. The vibration experiment have been carried out to verify the feasibility of the modulation approach and the performance of the sensor, the results show that frequency measured by the FBG vibration sensor is agreement with the setting value. Moreover, the experiment also indicate that the sensor have a excellent frequency response at the measuring range of 0~30Hz, and the demodulation technique with two parallel matching gratings work well in the vibration sensing system.

Th-D31 **Surface plasmon resonance based fibre optic glucose biosensor**, Sachin K. Srivastava, Roli Verma, Banshi D. Gupta, Indian Institute of Technology Delhi (India) [8351-155]
A surface plasmon resonance (SPR) based fibre optic biosensor has been fabricated and characterized for the detection of blood glucose. Optical fibre sensor was fabricated by first coating a 50 nm thick gold film on the bare core of optical fibre and then immobilizing glucose oxidase (GOx) over it. Aqueous glucose solutions of different concentrations were prepared. SPR spectra for the sensor were recorded for these glucose solutions. When the glucose comes in contact to glucose oxidase, chemical reactions take place and as a result, the refractive index of the immobilized GOx film changes, giving rise to a shift in the resonance wavelength. Unlike electrochemical sensors, the present sensor is based on optics and can be miniaturized because of optical fibre. The present study provides a different approach for blood glucose sensing and may be commercialized after optimization of certain parameters.

Th-D32 **Surface-enhanced Raman spectroscopy of mouse serum using silver colloid substrate**, Shupeng Liu, Hongfei Zhu, Shaofeng Chen, Zhenyi Chen, Na Chen, Tingyun Wang, Shanghai Univ. (China) [8351-156]
In this paper, the Raman spectra of the cancer nude mouse serum were measured using surface-enhanced Raman scattering (SERS) with the silver colloid substrate. The result indicated that the SERS spectra of the serum increased several peaks compared with conventional Raman spectra. More ever, these peaks were so crucial for analysis of the serum component and structure so that the information of the protein, carbohydrate, lipid and other trace amounts component could be analyzed through SERS spectra. Therefore, SERS technique is reliably used to compare relative intensity shifts and to investigate the adsorption of biological molecular proteins on Ag nanoparticles.

Th-D34 **A sensitivity enhanced gas sensor based on carbon nanotubes around microfibre**, Lan Jia, Yu Wu, Baicheng Yao, Feiya Yang, Yunjiang Rao, Univ. of Electronic Science and Technology (China) [8351-161]
In this paper, a carbon nanotubes (CNTs) films around microfibre gas sensor is reported. The CNTs films are deposited uniformly on the surface of microfibre with Langmuir-Blodgett(LB) coating technology. The CNTs which are rank tightly perform as cladding of microfibre and show the well absorption characteristic when they are used for gas sensing. The experimental results have shown the variations of intensity of transmitting light while the concentration of acetone and xylene around CNTs films based microfibre are different, The changes of light intensity are 3.1dB and 9.5dB respectively, when acetone and xylene concentrations reached 1200ppm. As the gas vaporizing freely, the results also show the fine characteristic with real-time response. The results demonstrate that this type of CNTs films around microfibre structure has great potential applied in trace gases detecting in micro-scale.

Th-D35 **Low coherence interferometry modelling using combined broadband Gaussian light sources**, Paul Jansz, Graham Wild, Steven Richardson, Steven Hinckley, Edith Cowan Univ. (Australia) [8351-162]
Using an OCT simulation model, a comparison of broadband single-Gaussian and multi-Gaussian OCT light sources has been undertaken. For single-Gaussian sources, the axial resolution improved with source bandwidth, as expected. However, narrow bandwidth light sources, resulted in interferograms with overlapping strata peaks and the loss of strata information. For multiple-Gaussian sources with the same bandwidth, spectral side lobes increased, reducing A-scan reliability to show accurate layer information, without eliminating the side lobes. Our simulations show the conditions needed for resolution of strata information for broadband light sources using both single and multiple Gaussian models. Future applications are envisaged.

Th-D36 **Sensitivity investigation of intra-cavity absorption gas sensors based on erbium-doped fibre ring lasers**, Tie-gen Liu, Kun Liu, Jun-feng Jiang, Yi-mo Zhang, Tianjin Univ. (China) and Ministry of Education (China) [8351-165]
The sensitivity is an important issue for intra-cavity absorption gas sensors (ICAGS). In this paper, the ICAGS based on erbium-doped fibre ring lasers (EDFRL) are modeled using propagation equations, from which the expressions of the signal-to-noise ratio (SNR) and the sensitivity of the system are deduced. The influence of the pump power and the total attenuation of the system on the performance of the ICAGS are

simulated theoretically and measured experimentally. The absorption signal of acetylene is detected by adjusting the state of the system. And concentration calibration of acetylene is realized finally.

Th-D37 **Optically stimulated luminescence in fluoride phosphate glass optical fibres for radiation dosimetry**, Christopher A. G. Kalnins, Heike Ebendorff-Heidepriem, Nigel A. Spooner, Tanya M. Monro, Univ. of Adelaide (Australia) [8351-170]
A novel approach to distributed radiation dosimetry is presented. Our approach uses optically stimulated luminescence in optical fibres to detect ionising radiation. This system is unique in that the optically stimulated luminescence mechanism occurs within the optical fibre itself, which then guides the resulting optical signal to a detector.
Fluoride phosphate glass was identified as a suitable material, showing a strong optically stimulated luminescence response to ionising radiation. Optical fibres were fabricated from this glass and radiation-detection measurements performed. Detection of optically stimulated luminescence produced within the optical fibres is demonstrated. The capacity of the fibres to provide continuous and real-time detection is demonstrated.

Th-D38 **Surface Plasmon resonance based fibre optic refractive index sensor utilizing cobalt metal,** Sarika Singh, Banshi D. Gupta, Indian Institute of Technology Delhi (India) [8351-171]
In this work, we have experimentally studied the surface plasmon resonance (SPR)-based fiber-optic refractive index sensor introducing a layer of cobalt in addition to gold layer. The sensor is based on wavelength interrogation method. The advantage of cobalt is that it possesses both SPR and magnetic properties and hence can also be used for magnetic field sensing. Addition of a thin layer of cobalt to the SPR probe enhances the sensitivity of the sensor. Further, the operating wavelength can be tuned by varying the thickness of the cobalt layer. Experimental results show a red shift in the resonance wavelength with the increase in the refractive index of the sensing layer for a given thickness of the cobalt layer. Further, as the thickness of the cobalt layer increases, the sensitivity of the sensor increases. Use of cobalt in place of gold reduces the cost of the probe. In the bilayer metallic structure that has been studied, the ferromagnetic material (cobalt) induces the magnetooptic activity and the noble metal allows the excitation of non damped plasmons, which increases the electromagnetic field intensity inside the cobalt layer and enhances the sensitivity of the sensor.

Th-D39 **Sensitivity of cavity optomechanical field sensors** J. Knittel, University of Queensland (Australia); S. Forstner, University of Queensland (Australia) and TU Muenchen (Germany); J. D. Swaim, H. Rubinsztein-Dunlop and W. P. Bowen, University of Queensland (Australia) [8351-177]
This article presents a technique for modelling cavity optomechanical field sensors. A magnetic or electric field induces a spatially varying strain across the sensor. The effect of this strain is accounted for by separating the mechanical motion of the sensor into eigenmodes, each modelled by a simple harmonic oscillator. The force induced on each oscillator can then be determined from an overlap integral between strain and the corresponding eigenmode, with the optomechanical coupling strength determining the ultimate resolution with which this force can be detected.

Th-D40 **Condition monitoring of tapered roller bearings: A photogrammetric approach** Sylvester A. Aye, University of Pretoria (South Africa) and University of Agriculture (Nigeria); S. Heyns, University of Agriculture (Nigeria) [8351-178]
The study evaluated damage detection of a tapered roller bearing using a non-contact photogrammetric approach. Customized round tape was pasted on the bearing housing and GOM Pontos was used to measure the radial accelerations from the bearing housing. The data obtained from the photogrammetric techniques was processed to detect damage of the bearing using statistical tools such as RMS, kurtosis. It was established that the photogrammetric approach detects bearing damage excellently.

Friday 3rd February

SESSION F-A: Industrial Applications and Field Trials

Session Chair: Dr. Jim Katsifolis, Future Fibre Technologies, Australia
Anchorage Room ..... 08:30 – 10:15

08.30: F-A1 **Fibre optical sensors in power generation**
(Invited Talk), M. Willsch, Siemens AG (Germany) [8351-174]
The raising demand for increase of efficiency and reduction of costs in power generation causes a mind change and promotes the commercial use of fibre optical sensors for health monitoring and control purposes.

09.00: F-A2 **Progressive failure monitoring of E-glass/vinylester curve composites using embedded FBG sensors**, Asrul Izam Azmi, Raju Raju, Gang-Ding Peng, The Univ. of New South Wales (Australia) [8351-84]
In this paper, we report our recent work in an application of fibre Bragg grating (FBG) sensors in progressive failure monitoring of E-glass/vinylester top-hat stiffener (THS) composites. FBG sensor arrays were embedded at strategic points within the THS to monitor the onset and progress of failure modes as the THS undergone a transverse loading. Techniques to embed FBGs in-situ during composite structure fabrication are developed. Our experiments demonstrated that key structural failure information can be obtained from the analysis and assessment of data, such as average strain, strain gradient and full spectrum measurements, collected by the embedded FBG sensors.

09.15: F-A3 **Development and application of subminiature multipoint FBG displacement sensor**, Jing Wang, Qing-mei Sui, Zheng-fang Wang, Jun Chang, Shandong Univ. (China); Gang-ding Peng, Univ. of New South Wales (Australia); Jun-qiang Tian, Shandong Univ. (China) [8351-153]
A novel subminiature multipoint FBG displacement sensor is designed especially for the model test based on analysis of displacement detecting principle. It mainly consists of several FBGs, springs, crusts and the bases. FBGs which are sensitive device connect with springs in series. When key point moves, stretching deformation of spring will occur, so that FBG will receive axial force which will make central wavelength of FBG drifts. According to drift of center wavelength of the sensor, displacement of several points can be detected simultaneously. Calibration experiments of several sensors are carried out, in which it could get the conclusions that the sensitivity is about 1.3nm / mm and the linearity is over 0.99. FBG displacement sensors are embedded in the tunnel wall rock symmetrically to monitor precursory information of disaster. In the process of tunnel excavation, displacement increased gradually, and the detecting results had a strong symmetry.

09.30: F-A4 **Experience of developments and applications of intelligent optical fibre sensors in industries of Russia**, Grigory Y. Buymistryuk, Intel-Systems Instruments Ltd (Russian Federation) [8351-18]
Results of R&D of intelligent optical fibre sensors, in particular Fabry-Perot interferometer-based, Bragg grating-based and Doppler frequency-based sensors are presented. Advantages of using the intelligent OFS as self-checking pressure gauges, acoustic emission sensors and sensors of other physical quantities are considered. Presentations of the applications intelligent optical fibre measuring systems in nuclear, oil& gas industries of Russia are given.

09.45: F-A5 **Use of FBG sensors in SHM of aerospace structures**, Gayan C. Kahandawa, Jayantha Epaarachchi, Hao Wang, Univ. of Southern Queensland (Australia) [8351-168]
This paper discusses the use of fibre Bragg grating sensors (FBG) in structural health monitoring (SHM) of fibre reinforced polymer (FRP) aerospace structures. The diminutive sensor provided the capability of embedding inside FRP structures in order to monitor vital potential locations for damage. Some practical problems associate with manufacturing process of FRP with embedded FBG sensors, interrelation of distortion to FBG spectra with damage, and interpretation of FBG spectral responses for identifying the damage will be discussed.

10.00: F-A6 **A calibration method based on look-up-table for cryogenic temperature fibre Bragg grating sensors**, Andrea Saccomanno, Univ. degli Studi di Napoli Federico II (Italy); Giovanni Breglio, Univ. degli Studi di Napoli Federico II (Italy) and Optosmart s.r.l. (Italy); Andrea Irace, Univ. degli Studi di Napoli Federico II (Italy); Marta Bajko, European Organization for Nuclear Research (Switzerland); Zoltan Szillasi, European Organization for Nuclear Research (Switzerland) and Institute of Nuclear Research of the Hungarian Academy of Sciences (Hungary); Salvatore Buontempo, European Organization for Nuclear

Research (Switzerland) and National Institute for Nuclear Physics (Italy); Michele Giordano, Institute for Composite and Biomedical Materials, CNR (Italy) and Optosmart s.r.l. (Italy); Andrea Cusano, Univ. degli Studi del Sannio (Italy) and Optosmart s.r.l. (Italy) [8351-117]
A calibration method for fibre Bragg grating (FBG) cryogenic temperature sensors based on look-up-table was proposed and demonstrated experimentally. The operating principles of different kind of FBG cryogenic temperature sensors are introduced. A statistical characterization of the data was carried out to verify the quasi-static condition of the measurement system by checking the stability of the measurement. Once verified this condition, the sensitivity curves of the sensors were determined by correlating the wavelength shift of the FBGs with the reference sensor measurements. On the basis of the sensitivity curves, the look-up-table (LUT) have been determined. The experimental data shows that the LUT fitting approach provides good and reliable performance in terms of accuracy and processing time.

Coffee Break and *Exhibition*

Walsh Bay Room ..... 10:15 – 10:45

SESSION F-B: Biological and Biomedical Sensing and Imaging

Session Chair: Prof. Kyriacos Kalli, Cyprus University of Technology, Cyprus

Anchorage Room ..... 10:45 – 12:30

10.45: F-B1 **Plasmonic field enhancement and hot spot generation for sensor applications** *(Invited Talk)*, Byoungho Lee, Seung-Yeol Lee, Junghyun Park, Il-Min Lee, Sookyoung Roh, Seoul National Univ. (Korea, Republic of) [8351-167]
[Invited paper]
Based on recent studies of our group, we will present various methods of plasmonic field enhancement and hotspot generation. Especially, we will focus on the potential of utilizing localization of propagating surface plasmon polaritons (SPPs) for the sensor applications. The advantage of using localization of propagating SPPs instead of using directly excited localized SPPs will be investigated.

11.15: F-B2 **Lanthanide upconversion nanocrystals within microstructured optical fibres; a sensitive platform for biosensing and a new tool for nanocrystal characterisation**, E. P. Schartner, The Univ. of Adelaide (Australia); D. Jin, Macquarie Univ. (Australia); H. Ebendorff-Heidepriem, The Univ. of Adelaide (Australia); J. A. Piper, Macquarie Univ. (Australia); T. M. Monro, The Univ. of Adelaide (Australia) [8351-151]
We investigate a powerful new sensing platform based on upconversion luminescence in NaYF4: Yb/Er nanocrystals loaded inside a suspended-core microstructured optical fibre. The use of a NIR source enables autofluorescence from the glass to be reduced compared to using visible sources for excitation of fluorescence. We demonstrate a substantial improvement in the detection limit that can be achieved in a suspended-core fibre sensor, with detection limits as low as 660 fM achieved. This is a factor of 15× better than the best results previously reported using Quantum dots in a similar fibre.

11.30: F-B3 **Real-time detection of α-thrombin binding to single-strand DNA aptamers by a highly sensitive Si-based waveguide SPR biosensor**, Chi-Chieh Huang, Hsin-Feng Hsu, Sz-Hau Chen, Kun-Yu Tsai, Yang-Tung Huang, Chih-Sheng Lin, Shih-Hsin Hsu, National Chiao Tung Univ. (Taiwan) [8351-135]
In this paper, real-time characterization of **α**-thrombin binding to single-strand DNA (ssDNA) aptamers by novel Si-based waveguide SPR biosensors has been investigated. The gold nanoparticles (AuNPs) modified with anti-thrombin antibodies were employed to bind with **α**-thrombin via strong antibody/antigen affinity for SPR signal amplification. The detection limit of 1 pM for **α**-thrombin detection was achieved.

11.45: F-B4 **Multiplex fibre-optic biosensor using multiple particle plasmon resonances**, Hsing-Ying Lin, Chen-Han Huang, Yu-Chia Liu, Kuo-Wei Huang, Lai-Kwan Chau, National Chung Cheng Univ. (Taiwan) [8351-69]
Multiplex fibre-optic biosensor implemented by integrating multiple particle plasmon resonances (PPRs), molecular bioassays, and microfluidics is successfully demonstrated. The multiple PPRs are achieved by chemical immobilization of silver nanoparticles (AgNPs) and gold nanorods (AuNRs) separately on two unclad portions of an optical fibre. The difference in morphology and material nature of AgNPs and AuNRs are exploited to yield multiple plasmonic absorptions at 405 and 780 nm in the absorption spectrum. Through the coaxial excitation of LEDs with 405 and 800 nm wavelengths, the distinct PPRs are advantageous for real-time and simultaneous detection of multiple analyte-probe pairs.

12.00: F-B5 **On-chip SERS analysis for single mimic pathogen detection using Raman-labeled nanoaggregate-embedded beads with a dielectrophoretic chip**, Chen-Han Huang, Hsing-Ying Lin, I-Ting Kuo, Wen-Hsin Hsieh, Ping-Ji Huang, Tzyy-Schiuan Yang, Lai-Kwan Chau, National Chung Cheng Univ.

(Taiwan) [8351-79]
The integration of Raman-labeled nanoaggregate-embedded beads (NAEBs) for high performance SERS analysis of single mimic pathogen on a self-designed dielectrophoretic chip is demonstrated. The Raman tags called NAEBs are silica-coated, dye-induced aggregates of a small number of gold nanoparticles (AuNPs). In this work, NAEBs consisting of a Raman dye tetramethyl-rhodamine-5-isothiosyanate (TRITC) are chemically functionalized with streptavidin to detect biotin-functionalized polystyrene (PS) microspheres which mimic as pathogens.

12.15: F-B6 **Optical-fibre biosensors using plasmons excited tilted fibre gratings**, Tuan Guo, Baiou Guan, Jinan Univ. (China); Yanina Y. Shevchenko, Jacques Albert, Carleton Univ. (Canada) [8351-102]
Plasmon based optical-fibre biosensors created from gold coating tilted Bragg gratings have been demonstrated. Plasmon resonances in the transmission are used to detect the binding of single stranded DNA (aptamer) and the further binding of target DNA (matched one).

Lunch Break and *Exhibition*

Walsh Bay Room ..... 12:30 – 13:30

SESSION F-C: Optical Fibres for Sensing

Session Chair: Dr. Adrian Carter, Nufern, USA
Anchorage Room ..... 13:30 – 15:15

13.30: F-C1 **Smart aircraft composite structures with embedded small-diameter optical fibre sensors** *(Invited Talk)*, N. Takeda, The Univ. of Tokyo (Japan) [8351-191]
This talk describes the embedded optical fibre sensor systems for smart aircraft composite structures. First, a summary of the current Japanese national project on structural integrity diagnosis of aircraft composite structures is described with special emphasis on the use of embedded small-diameter optical fibre sensors including FBG sensors. Then, some examples of life-cycle monitoring of aircraft composite structures are presented using embedded small-diameter optical fibre sensors for low-cost and reliable manufacturing merits.

14.00: F-C2 **Influence of core diameter and length of polymer optical fibre on Brillouin scattering properties**, Yosuke Mizuno, Tokyo Institute of Technology (Japan); Takaaki Ishigure, Keio Univ. (Japan); Kentaro Nakamura, Tokyo Institute of Technology (Japan) [8351-166]
We investigate the influence of fibre core diameter and length on Brillouin gain spectra in perfluorinated graded-index polymer optical fibres (PFGI-POFs). First, we show that smaller core drastically enhances Stokes power using PFGI-POFs with 62.5-μm and 120-μm cores. Then, we demonstrate that PFGI-POF length has little influence on BGS when the length is longer than 50 m. We also predict that, at 1.55 μm, it is difficult to reduce the Brillouin threshold of PFGI-POFs below that of long silica fibres even if their core is sufficiently reduced to satisfy the single-mode condition. Finally, we observe linewidth narrowing effect.

14.15: F-C3 **Fibre ring laser incorporating a pair of rotary long-period fibre gratings for torsion measurement**, Leilei Shi, Tao Zhu, Fangyuan Chen, Chongqing Univ. (China); Kinseng Chiang, City Univ. of Hong Kong (China) and Chongqing Univ. (China); Yunjiang Rao, Chongqing Univ. (China) [8351-61]
We demonstrate a fibre ring laser for high-resolution torsion measurement, where the laser cavity consists of a MZI formed with a pair of long-period fibre gratings written in a twisted SMF. The emitting wavelength of the laser provides a measure of the rate of the torsion applied to the grating pair, while the direction of the wavelength shift indicates the sense direction of the applied torsion. The torsion sensitivity achieved is 0.084 nm/(rad/m) in the torsion range ±100 rad/m, which corresponds to a torsion resolution of 0.12 rad/m, assuming a wavelength resolution of 10 pm for a typical optical spectrum analyzer.

14.30: F-C4 **Cryogenic temperature response of long-period fibre gratings inscribed on standard photosensitive single-mode fibres**, Daeho Choi, Jihoon Kim, Yong Wook Lee, Pukyong National Univ. (Korea, Republic of) [8351-46]
In this paper, we have investigated cryogenic temperature response of long-period fibre gratings (LPFGs) inscribed on standard photosensitive single-mode fibres without any polymeric coatings. The resonance wavelength of the fabricated LPFG, which was ~1530.778 nm at room temperature (296 K), was monitored under various temperatures ranging from 77 K to 296 K. The temperature sensitivity of the resonance wavelength was measured as ~402.4 pm/K, and the adjusted R-square value of the linear fit of the temperature response curve was evaluated as 0.98144.

14.45: F-C5 **High-sensitivity stress sensor based on Bragg grating in BDK-doped photosensitive polymer optical fibre**, Tongxin Wang, Univ. of Science and Technology of China (China); Yanhua Luo, Univ. of Science and Technology of China (China) and The Univ. of New South Wales (Australia); Gang-Ding Peng, The Univ. of New South Wales (Australia); Qijin Zhang, Univ. of Science and Technology of China (China) [8351-09]
Bragg grating in a single-mode photosensitive polymer optical fibre (POF) with BDK-doped in core has been inscribed through the Sagnac ring interference method. The Bragg wavelength of grating is about 1570nm. The stress and strain response of fibre Bragg grating (FBG) has been studied. The strain sensitivity of FBG in POF has been found to be almost same to that of silica FBG. However, its stress sensitivity is measured to be 421pm/MPa, which is 28 times higher than silica FBG. Such high stress sensitivity makes FBG fabricated here appear to be very attractive for constructing stress sensor with high resolution.

15.00: F-C6 **In-ground optical fibre Bragg grating pressure switch for security applications**, Gary Allwood, Graham Wild, Steven Hinckley, Edith Cowan Univ. (Australia) [8351-78]
A fibre Bragg grating (FBG) was embedded beneath three common flooring materials acting as a pressure switch for in-ground intrusion detection. This is achieved using an intensiometric detection system, where a laser diode and FBG were optically mismatched so that there was a static DC offset from the transmitted and reflected optical power signals. As pressure was applied, in the form of a footstep, a strain induced wavelength shift occurred that could then be detected by converting it into an intensity change. The change in intensity caused a significant change in the DC offset which behaved as on optical switch.

Coffee Break

Walsh Bay Room ..... 15:15 – 15:45

SESSION F-D: Invited Talk, Student Awards and Closing Ceremony

Session Chair: Prof. Graham Town, Macquarie University, Australia
Anchorage Room ..... 15:45 – 17:00

15.45: F-D1 **Microstructured optical fibre sensors for strain, pressure and temperature measurement** *(Invited Talk)*, W. Jin, The Hong Kong Polytechnic Univ. (Hong Kong, China) [8351-192]
Several novel types of optical fibre sensors will be reported. These includes fibre-tip micro-cavity sensors for pressure and temperature measurement, high temperature photonic crystal fibre and sapphire fibre grating sensors, highly sensitive strain and bent sensors based on structural long period fibre gratings, and sensitive acoustic pressure sensors with hollow core photonic bandgap fibres.

16.15: *SPIE and IEEE student Awards and Closing Ceremony*

Session Chairs: Prof. Desheng Jiang, Wuhan University of Technology, China
Prof. Kazuo Hotate, University of Tokyo, Japan

16.45: Conference close (Prof. John Canning and Prof. Gang Ding Peng)

18.30: **Special Event:**

Cocktail reception and Opening Celebration of the Joint National Fibre Facility at UNSW

For catering purposes please let the Conference Secretariat or Prof. Gang-Ding Peng know if you would like to attend.