LAUDATIO

pentru acordarea titlului onorific

DOCTOR HONORIS CAUSA
al
UNIVERSITĂŢII DIN ORADEA

Domnului Profesor

KENNETH GRATTAN

Royal Academy of Engineering and George Daniels Professor of Scientific Instrumentation
City University of London, United Kingdom

Oradea
16 iunie 2014

Professor Kenneth Grattan

Royal Academy of Engineering and George Daniels Professor of Scientific Instrumentation

City University of London, United Kingdom

"Concordia res crescunt"

ROMÂNIA
UNIVERSITATEA DIN ORADEA

In nomine
Senatus Universitatis Varadiensis,
Praesidens Senatus Sorin Curilă,
Professor Publicus Ordinarius,

summo omnium plausu decrevit ut
excellentissimus atque illustrissimus vir,

Professor Publicus Ordinarius

KENNETH THOMAS VICTOR GRATTAN

Honoris Causa in Corpus Doctorum
huius Universitatis reciperetur.

In cuius rei fidem hoc Diploma ad omnium
quibus expedit notitiam conscribendum iussit.

Datum 16.06.2014 Urbs Varadinum

Praesidens Senatus
Sorin Curilă

Rector Magnificus
Constantin Bungău

Seria :466

LAUDATIO

for

Professor KENNETH GRATTAN

Royal Academy of Engineering and George Daniels Professor of Scientific Instrumentation - City University of London

cu ocazia acordării Titlului de

Doctor Honoris Causa al Universităţii din Oradea

Este o tradiţie ca Senatul Universităţii din Oradea să onoreze marile valori ale ştiinţei şi culturii universale prin conferirea titlului de DOCTOR *HONORIS CAUSA* al Universităţii din Oradea. Astăzi, 16 iunie 2014, acest titlu se acordă unei personalităţi ştiinţifice internaţionale de excelenţă, unui om de ştiinţă cu o activitate remarcabilă – Domnului Profesor KENNETH GRATTAN.

Domnul Profesor KENNETH GRATTAN este un reputat fizician, cu o operă ştiinţifică de excepţie şi cu o relevanţă internaţională deosebită, recunoscut şi apreciat pe întreg mapamondul ca un strălucit cercetător şi o autoritate incontestabilă în domeniul fizicii laserilor. Domnia sa este un adevărat deschizător de drum în organizarea şi dezvoltarea cercetării fundamentale într-un domeniu inovator, de vârf, aflat într-o incontestabilă ascensiune prin prisma aplicaţiilor practice pe care le prezintă.

On the award of the Academic Title of

Doctor Honoris Causa of the University of Oradea

It is a tradition that the Senate of the University of Oradea honours the important values seen in science and contributions to international culture by conferring the Academic Title of DOCTOR *HONORIS CAUSA* of the University of Oradea. Today, June 16, 2014, this title is awarded to a personality of international scientific excellence, a scientist with a remarkable record of activity in his field – Professor KENNETH GRATTAN.

Professor KENNETH GRATTAN is a renowned physicist, having undertaken scientific work of great distinction and of major international relevance and is recognized and appreciated throughout the world as a brilliant researcher and an indisputable authority in the field of optical physics. He has demonstrated real leadership in organizing and developing fundamental research in an area of major innovation, underpinning the development of the field through the practical applications he has espoused.

Personalitate complexă, Profesor KENNETH GRATTAN reuneşte, într-o generoasă conexiune, cercetătorul pasionat şi creativ, autorul unor impresionante lucrări de referinţă în domeniul fizicii laserilor şi profesorul cu o viziune perfecţionistă, interdisciplinară, ridicată la rang de internaţionalitate.

Activitatea sa ştiinţifică este una cu totul remarcabilă, având ca reper anul 1979, când a susţinut teza de doctorat în domeniul Fizicii laserilor la Universitatea Queen's din Belfast.

A continuat cariera academică în următorii cinci ani ca cercetător post-doctoral, la „Imperial College of Science & Technology", din Londra, activitatea de cercetare fiind sponsorizată pentru studiul unor noi sisteme laser, de către Laboratorul Rutherford al Marii Britanii.

Ulterior, domeniile sale de cercetare au fost extinse asupra utilizării laserilor, a sistemelor optice şi a fibrelor optice bazate pe sisteme de măsurare senzoriale. Una dintre direcţiile sale majore de cercetare o reprezintă modelarea numerică a sistemelor optice pe calculator, în vederea obţinerii unor dispozitive laser şi fotonice de înaltă precizie, a fibrelor optice şi a cristalelor fotonice, utilizate în cercetarea experimentală, cu aplicaţii industriale de vârf.

In anul 1983, devine "New Blood"-Lector la City University din Londra, contribuind astfel la dezvoltarea unui domeniu de cercetare inovator, cel al instrumentelor şi fibrelor optice. Ulterior, în anul 1991 devine Profesor universitar şi Şef al Departamentului de Inginerie Electrică, Electronică şi Informatică.

Through the many facets of his scientific approach, Professor KENNETH GRATTAN brings together the characteristics of a passionate and creative researcher, the author of a body of impressive reference works in the field of optical physics and a Professor with a breadth of vision and an interdisciplinary approach, as well as an international reputation.

The body of scientific work from Professor KENNETH GRATTAN is indeed remarkable; from the benchmark year of 1979 when he defended the PhD thesis in Laser Physics at Queen's University Belfast.

His academic career continued over the next five years as a postdoctoral researcher at the Imperial College of Science & Technology, London, through the study of new laser systems in research activity sponsored by the Rutherford Laboratory of Great Britain.

Subsequently, his research has extended to the use of lasers, optics and fiber optics with a focus on instrumentation and measurement and sensory systems. One of his major research directions has been the numerical modeling of optical systems using computer-based methods in order to design laser and photonic devices and high precision conventional and photonic crystal optical fibres, used in a breadth of experimental research and extending to a range of industrial applications.

In 1983, he became a "New Blood" Lecturer at City University London, helping to develop a range of innovative research projects in the field of instrumentation and optical fibers. Further, in 1991, he became Professor of Measurement & Instrumentation and Head of the Department of Electrical Electronic and Information Engineering.

În anul 2001 este numit Decan asociat al Facultăţii de Inginerie, iar în 2006, Prodecan al Facultaţii de Ştiinţe Matematice şi Inginereşti. În anul 2008, Domnia sa devine simultan Decan atât al Facultaţii de Informatică, cât şi al Facultaţii de Ştiinţe Matematice şi Inginereşti de la City University Londra.

Activitatea sa academică este axată atât pe dezvoltarea şi extinderea activităţii de cercetare pe plan internaţional, cât şi pe organizarea unor programe de masterat de înaltă specializare, precum şi de creşterea calitativă a gamei de cursuri universitare de licenţă.

O deosebită atenţie a fost mereu acordată schimburilor academice de cadre didactice şi studenţi, ca mijloc de cunoaştere, colaborare şi propagare a ştiinţei in lume.

Mai târziu, în anul 2012 Profesorul KENNETH GRATTAN a devenit primul Decan al Şcolii Doctorale din cadrul City University din Londra, conducând destinele acesteia şi activând pentru dezvoltarea domeniilor de cercetare interdisciplinară a studenţilor doctoranzi, din cadrul diverselor specializări academice ale universităţii.

Ca o personalitate intelectuală deplină, Profesorul KENNETH GRATTAN are o activitate deosebit de prodigioasă şi în cadrul comunităţii intra- şi extra-academice. Vasta experientă în conducerea universităţii este coroborată cu participarea activă într-un foarte mare număr de comitete academice din cadrul City University din Londra, ocupându-se de toate aspectele legate de viaţa universitară.

Domnia sa a activat ca Director al Centrului de Cercetare in Instrumentaţie si Senzoristică, Preşedinte al Diviziei de Ştiinţă, Educaţie şi Tehnologie al Institutului de Inginerie Electrică,

In 2001 he was appointed Associate Dean of the School of Engineering and, in 2006, Deputy Dean of the School of Engineering and Mathematical Sciences. In 2008, he was appointed the first Conjoint Dean of the School of Informatics and of the School of Engineering & Mathematical Sciences at City University London.

His academic work has focused on the development and expansion of the international dimension of his research and the growth and organization of both highly specialized Masters and a wide range of undergraduate courses.

Special attention has always been given to academic exchanges of teachers and students from overseas, as a means of the exchange of knowledge, building collaborations and the wider dissemination of science across the world.

Following that, in 2012, Professor KENNETH GRATTAN became the first Dean of the Doctoral School (the City Graduate School) of City University London, leading its direction and enabling the development of interdisciplinary PhD research students across a range of different academic specializations of the University.

Demonstrating a wide range of intellectual interests, Professor KENNETH GRATTAN has engaged in a breadth of particularly prodigious intra-and extra-curricular academic activity. Extensive experience in the management of the University has been complemented by active participation in a large number of academic committees of City University London, covering all aspects of university life.

Also he has served as Chairman of the Science, Education and Technology Division of the then Institution of Electrical Engineers (IEE, now the IET), was Chairman of the Applied Optics Division of the

Preşedinte al Diviziei de Optică Aplicată din cadrul Institutului de Fizică, Preşedinte al Institutului de Metrologie şi Control, precum şi în Consiliile şi Comitetele consultative ale acestor organizaţii.

Recunoaşterea academică şi de cercetare excepţională a determinat implicarea Profesorului KENNETH GRATTAN activităţi de consiliere politică şi finanţare, în numeroase comitete guvernamentale atât din Marea Britanie cât şi ale Uniunii Europene. A participat intens ca membru în Comitetul Consultativ de Standardizare, Calitate şi Metrologie din cadrul Departamentului de Comerţ şi Industrie, a prezidat grupurile de lucru ale Comitetului Consultativ de Metrologie din cadrul Oficiului Naţional de Metrologie şi recent, activează în Comitetul de Cercetare şi Inovare precum şi în Consiliul General al Confederatiei Internaţionale de Metrologie.

Profesorul KENNETH GRATTAN este una dintre personalităţile de seamă ale fizicii contemporane, având un impact major în dezvoltarea studiului laserilor şi a senzorilor optici, atât prin propriile sale rezultate prestigioase, cât şi prin contribuţia Domniei sale la dezvoltarea acestui domeniu în întreaga lume, cu aplicaţii practice deosebite in industrie.

Cercetările sale sunt excepţional de profunde şi de variate, fiind continuu finanţate prin granturi britanice şi europene, care se ridică la valori de peste 15 milioane de lire sterline. Amprenta sa ştiinţifică este absolut remarcabilă în toate abordările, atât teoretice cât şi experimentale, concretizate în peste 100 de granturi şi contracte de cercetare, realizate la nivel naţional şi internaţional.

Activitatea de cercetare, de o mare valoare ştiinţifică, s-a concretizat în publicarea a peste 700 de lucrări ştiinţifice în reviste indexate ISI Web of Science şi

Institute of Physics and was President of the Institute of Measurement & Control in 2000, as well as serving on many advisory boards and committees of these organizations.

In light of the exceptional academic and research activity in which he has been engaged, this has led Professor KENNETH GRATTAN to involvement in developing both policy and financial advice through numerous committees both of the UK Government and the European Union. He has served as a member of the Consultative Committee for Standardization, Quality and Metrology of the UK Department of Trade and Industry, chaired working groups of the Advisory Committee of the National Metrology Office and service on the General Council of IMEKO, the International Measurement Confederation.

Professor KENNETH GRATTAN is one of the outstanding personalities in contemporary optical physics with a major impact on the development of the study of optical and laser sensors, both through the prestigious results of his work and his contribution to the development of this area throughout the world and with a focus on its practical impact on industry.

His research is exceptionally deep and varied, being continually funded by British and European grants, of value amounting to over 15 million pounds. His scientific footprint is absolutely outstanding in all approaches, both theoretical and experimental, having resulting from success in over 100 grants and research contracts, funded nationally and internationally.

His research of great scientific value has resulted in the publication of over 700 scientific papers in ISI Web of Science-indexed journals and at international

congrese internationale, acumulând peste 4700 de citări. In ultimul an, Domnia sa a fost citat de peste 500 de ori.

Activitatea profesională a Profesorului KENNETH GRATTAN este reflectată printr-un indice Hirsch absolut remarcabil, cu o valoare de 31.

Lista de publicaţii ştiinţifice impresionează printr-o mare varietate şi originalitate de subiecte, precum şi prin implicaţiile lor practice, în special în domeniul senzorilor optici.

Profesorul KENNETH GRATTAN are o reputaţie internaţională remarcabilă, fiind invitat în comisii de doctorat în Marea Britanie, Australia, Canada, Irlanda, Africa de Sud, Hong Kong, Singapore, China, Olanda, India şi România. A coordonat peste 50 de doctoranzi şi mai mult de 30 de cercetători post-doctorat.Toata activitatea de cercetare a Domniei sale este pusă în slujba dorinţei de a crea puternice legături internaţionale, fiind implicat activ în contracte de cercetare cu ţări din Europa, Asia şi Australia.

Datorită recunoaşterii sale ştiinţifice este ales Editor-şef al Journal „Measurement" (publicat de editura Elsevier), cu un impact deosebit în comunitatea stiinţifică şi de cercetare, precum şi membru în consiliile editoriale al unor prestigioase reviste ştiinţifice internationale, ca de exemplu: Review of Scientific Instruments (USA), Sensors & Actuators A: Physical şi Optic & Laser Technology.

Pe baza rezultatelor ştiinţifice şi al ecoului acestora în literatura de specialitate, a fost invitat să facă parte din comitetele ştiinţifice şi de organizare a numeroase conferinţe internaţionale de prestigiu, precum:

- UK Applied Optics Divisional Conference in 1996 şi 1998;

congresses, accumulating over 4,700 citations. Last year his work was cited more than 500 times.

Professor Kenneth Grattan's professional activity is reflected in an absolutely remarkable Hirsch index, with a value of 31.

His list of publications is impressive through the great variety and originality of topics, as well as their practical implications, especially in the field of optical sensors.

Professor KENNETH GRATTAN has an outstanding international reputation, having being invited to doctoral committees in the UK, Australia, Canada, Ireland, South Africa, Hong Kong, Singapore, China, the Netherlands, India and Romania. He has supervised over 50 PhD students and more than 30 postdoctoral researchers. All his research activity has been focused on the desire to create strong international links, being actively involved in research contracts with countries in Europe, Asia and in Australia.

Due to the recognition of his scientific activity, he was elected Editor-in-Chief of the Journal "Measurement" (published by Elsevier), thereby making a significant impact on the scientific community and in research, and has served as a member of the Editorial Board of prestigious international journals such as the Review of Scientific Instruments (USA), Sensors & Actuators A: Physical and Optics & Laser Technology.

Based on the scientific results he has obtained and their reporting across the breadth of the literature, he had been invited to be part of the scientific and organizing committees of numerous prestigious international conferences such as:

- UK Applied Optics Divisional Conference in 1996 and 1998;

- UK Sensors and their Applications Conference 1991, 1993 şi 2001;
- UK International Conference on Optics and Laser Diagnostics 2002, 2005 şi 2007.

Pentru activitatea sa ştiinţifică, Profesorul KENNETH GRATTAN a fost distins cu numeroase premii şi medalii, printre care amintim:

- Medalia „Callendar" a Institutului de Metrologie şi Control al Marii Britanii în 1992;
- Premiul Institutului de Metrologie şi Control a Marii Britanii în 1987 şi 2000;
- Premiul „ICI" al Institutului de Metrologie şi Control al Marii Britanii în 1991;
- Medalia „Sir Harold Hartley", acordată de Institutului de Metrologie şi Control în anul 2013;
- Premiul „Applied Optics Divisional Prize", decernat de Institutul de Fizică al Marii Britanii în anul 2010.

Ca o recunoaştere a prodigioasei sale activităţi de către comunitatea academică, Profesorului KENNETH GRATTAN i s-a conferit în iunie 2013 titlul de „George Daniels Profesor în Instrumentație Ştiințifică", care a devenit „George Daniels Chair of Scientific Instrumentation" al Academiei Regale de Inginerie in 2014.

Calităţile profesionale şi umane de excepţie au fost certificate de-a lungul timpului prin alegerea domnului Profesor KENNETH GRATTAN în diferite societăţi ştiinţifice cu largă rezonanţă, fiind:

- Membru al Academiei Regale Britanice de Inginerie.
- Cetățean de onoare al orașului Londra;
- Membru al Companiei Producatorilor de Aparatura Stiintifica,
- Membru al Societatii de Inginerie şi Tehnologie a Marii Britanii;

- UK Sensors and Their Applications Conference 1991, 1993 and 2001;
- UK International Conference on Optics and Laser Diagnostics 2002, 2005 and 2007.

For his scientific work, Professor KENNETH GRATTAN has been awarded numerous awards and medals, including:

- The Callendar Medal of the Institute of Measurement and Control in 1992;
- The Honeywell Prize of the Institute of Measurement & Control in 1987 and 2000;
- The ICI Prize of the Institute of Measurement & Control in 1991;
- The Sir Harold Hartley Medal of the Institute of Measurement & Control in 2013;
- The Optics and Photonics Divisional Prize which was awarded by the Institute of Physics of Great Britain in 2010.

In recognition of his prodigious activities across the academic community, Professor Grattan was awarded the title George Daniels Chair in Scientific Instrumentation at City University London, in June 2013, becoming the Royal Academy of Engineering – George Daniels Chair of Scientific Instrumentation in 2014.

The professional and other qualities over a long period have been recognized in the nomination of Professor KENNETH GRATTAN for various honours with wide international resonance such as:

- Fellow of the Royal Academy of Engineering;
- Freeman of the City of London;
- Liveryman of the Worshipful Company of Scientific Instrument Makers;
- Fellow of the UK Institution of Engineering & Technology (IET, formerly IEE);

- Membru al Institutului de Metrologie şi Control al Marii Britanii;
- Membru al Institutului de Fizică al Marii Britanii.

Personalitatea Domniei Sale de leader, colaborator şi mentor se manifestă într-un spaţiu stiinţific internaţional academic, de cercetare şi industrial, cuprinsă într-o matrice profesională, educaţională şi individuală de înaltă calitate umană.

Inteligenţa inovativă şi abilităţile ştiinţifice deosebite sunt dublate de altruismul şi generozitatea împărtăşirii experienţei şi a cunoştintelor dobândite prin muncă asiduă, creând astfel contribuţii de o reală valoare ştiinţifică în fizica laserului.

Întreaga activitate a Domnului Profesor KENNETH GRATTAN este caracterizată de o extraordinară creativitate, contribuţia sa majoră la dezvoltarea fizicii datorându-se combinaţiei unice de abilităţi experimentale de excepţie, coroborată cu înţelegerea teoretică profundă şi cu o intuiţie ştiinţifică remarcabilă, legate într-un spirit altruist, împărtăşit pe altarul internaţional al ştiinţei.

Acordarea titlului de DOCTOR *HONORIS CAUSA* al Universităţii din Oradea Domnului Profesor KENNETH GRATTAN constituie o recunoaştere simbolică a marilor sale merite, un semn de aleasă preţuire pentru realizările de excepţie ale Domniei sale pe planul ştiinţific şi academic.

În numele Comisiei de Redactare,
Prof.univ.dr. Sanda Monica Filip
Decanul Facultăţii de Ştiinţe

Oradea,
16 iunie 2014

- Fellow of the UK Institute of Measurement & Control;
- Fellow of the UK Institute of Physics.

His personality as a leader, collaborator and mentor has been manifested in the international scientific academic community through research and industrial work which is exemplified through the professional dimension seen in high quality education and human qualities.

His innovative intelligence and outstanding scientific skills are coupled with selflessness and generosity in his experience and in sharing his knowledge, gained through hard work, creating real scientific value contributions in optical physics.

The entire activity of Professor KENNETH GRATTAN has been characterized by an extraordinary creativity, his major contribution to the development of physics has been due to the unique combination of outstanding experimental skills, combined with a deep theoretical understanding and a remarkable level of scientific intuition, linked in a selfless spirit, shared by the international “altar of science”.

Awarding the title of DOCTOR *HONORIS CAUSA* of the University of Oradea to Professor KENNETH GRATTAN is a symbolic recognition of his great merit and a sign of appreciation for a breadth of outstanding achievements of his scientific and academic activity in his field.

On the behalf of Editorial Committee,
Professor Sanda Monica Filip PhD
Dean of Science Faculty

Oradea, June 16 2014

Comisia de redactare

Preşedinţi:

Prof.univ.dr. **Constantin Bungău**
Rector al Universităţii din Oradea

Prof.univ.dr. **Sorin Curilă**
Preşedinte al Senatului Universitar

Membri:

Prof.univ.dr**. Sanda Monica Filip**
Decan al Facultăţii de Ştiinţe

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Director Şcoala Doctorală de Ştiinţe Inginereşti

Prof.univ.dr. **Radu Cătălin Ţarcă**
Director al Departamentului de Mecatronică

Lectio magistralis

Fibre Optic Sensors – key tools in modern scientific instrumentation

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Abstract

Optical Fibre Sensors were developed from advances in communications systems using optical fibre and laser technology in the late 1970s and since then there have been enormous developments in both physical and chemical sensing which were designed to meet a wide range of industrial needs and to compete effectively with conventional sensors on a number of important industrial applications. The paper will review the technical background to the field and report on several areas where these optical fibre sensors have made significant impact through the development of new fibre optic-based instrumentation for modern industrial needs.

Introduction to Optical Fibre Sensor Technology

An optical fibre is a strand of dielectric material which has been designed to trap radiation at one end and guide it to the other. The guidance is based on the simple principle given by Snell's Law:

$$n = c / v$$

where n is the material refractive index, c is the speed of light in vacuum and v is the velocity of light in the medium, taking advantage of the fact that light travels more slowly in materials with high value of n. The key requirements of the materials used are that they enable making long, thin, flexible fibres from the material, which must be transparent at the wavelength of interest and the materials forming core and cladding must be physically compatible to create stable fibre. Glasses and plastics fit these requirements well and silica (SiO2) is widely used as this low loss material is readily available. Plastic or polymer materials also used but they have a higher attenuation than silica, creating a practical limit to several hundred meters in the fibre length due to

attenuation, in spite of greater mechanical strength and greater flexibility of the fibre. Single or monomode fibre is mainly used for communications systems or interferometry and multimode fibre: step index is popular for many sensor applications with a wide variety of fibre diameters available. Greater dispersion not an issue for most sensors and there are easier light launch conditions from sources into such fibres than for monomode fibre and they are easier to install than monomode fibre in many cases.

There are several different types of optical fibre sensor that are used and can be considered:

Point sensors where the active component is located at the distal end of the fiber and the measurand field interacts with the sensitized tip of the fibre. Examples of such sensors include luminescent sensors for temperature measurement, Fabry-Perot cavity pressure sensors and chemical sensors relying upon interaction with an analyte at the distal end.

Quasi-distributed sensors where the sensor discriminates in the spatial mode and senses at predetermined points along the sensor length, but not in between. Such sensors are very useful for certain situations where the region of interaction in known in advance. This approach readily enables sensors to be multiplexed along the fibre length and is seen in particular in Fibre Bragg Grating (FBG) sensors or chemical sensors and they offer wide flexibility in use.

Fully ***Distributed sensors*** discriminate in the spatial mode and therefore are able to sense at any point along the sensor length, making such sensors useful for certain situations where the region of interaction is not known in advance as all points along the fibre are, in principle, sensitive. This approach works through the use of OTDR (Optical Time Domain Reflectometry) and relies upon time of propagation of light to determine position of interaction.

Multiplexing of sensor signals along a single optical fibre is an important advantage which enables multiple sensing channels to be created using the above techniques, especially quasi-distributed sensors. ***Time division multiplexing*** may be used where signals are combined along a single fibre and can be demultiplexed at the detector. Further, ***wavelength division multiplexing*** can be used where a number of wavelengths combined along the fiber and then demultiplexed at the receiver through use of a wavelength selective element.

Thus, in summary, fibre optic characteristics are based upon the fundamental physics of optical systems, where the fibre optic modal characteristics are important to indicate the way in which the light propagates in the fibre. Further, the coupling between fibres may be non-trivial, to avoid large losses in connections along multiple channels and the fibre fabrication depends upon a well-established chemical vapor deposition techniques and good fibre splicing methods are the key to wide acceptance of optical fiber technology in industry to connect systems ‘in-the-field’. Further, new fiber types being produced for different applications and add to the flexibility and scope of modern optical fibre sensors.

Fibre Bragg Grating-based sensors

Fibre Bragg Gratings are based on a periodic change in refractive index along the optical fibre, induced by light in a fibre whose core may be photosensitive, or made photosensitive e.g. through hydrogen loading and which acts as a longitudinal diffraction grating through a phase structure in the core of the fibre. They are widely used in optical communications systems and useful for changing the characteristics of pulses and thus for the development of communications systems. However the periodicity of the index modulation has a physical spacing one half that of the wavelength of light that will be reflected by the grating and thus high (approaching 100%) refelectivity of the grating(s) are possible, with bandwidths varying from 0.1 nm to tens of nanometers.

The ability to write such FBGs arises from the photosensitivity of Ge-doped fibre (from work of Hill et al dating back to 1978) where light from an Ar ion laser formed a weak standing wave pattern: this led to self-organized gratings through a two photon process. However, self-induced gratings are not practical as the basis of real sensor devices and in 1989 Meltz et al showed strong refractive index change occurred due to side exposure. Exposure is in the 240 – 250 nm region which coincides with absorption of germania-related defects – this is a single photon process where the periodic pattern indication produces grating and index changes of typically 2 x 10–3 are produced which were comparable to the core: cladding index difference. Figure 1 shows this schematically.

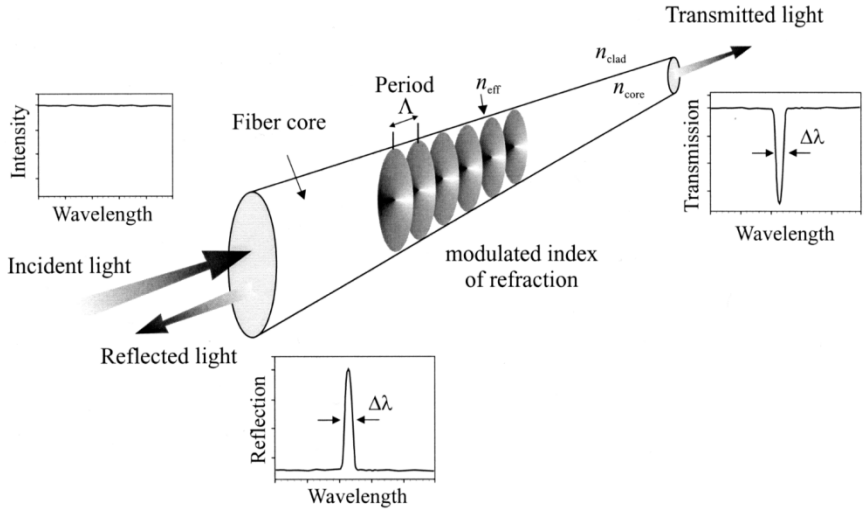

Figure 1: Schematic of a Fibre Bragg Grating written into the core of an optical fibre

The Bragg condition for a FBG in a fibre is given by:

$$\lambda B = 2neff\Lambda$$

where λB is the free space centre wavelength, Λ is the grating pitch and neff is the effective refractive index of the core of that wavelength. Fibre Bragg Gratings (FBGs) are used typically in sensor applications as is shown schematically in Figure 2.

The figure shows clearly how the measurand-induced FBG shift that can be calibrated to allow the monitoring of a wavelength shift in the grating to be related to the measurand e.g. temperature or strain.

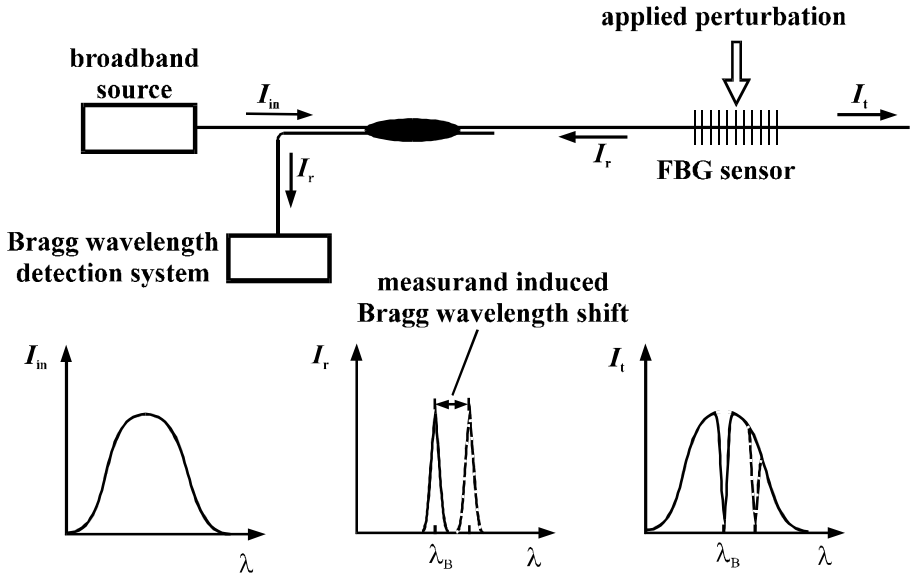

Figure 2: Schematic of a Fibre Bragg Grating sensor system

The centre wavelength of the grating is affected by strain and temperature which forms the basis of an effective sensor system and Figure 3 shows results for a Fibre Bragg Grating for a 1555.1 nm centre wavelength. Thermal effects result in an expansion of fibre and the grating (0.55 x 10-6 for silica) and a refractive index change (8.6 x 10-6 for silica) where the index change is the dominant mechanism. There is a need to deconvolve the two effects in practical sensors, as is discussed later.

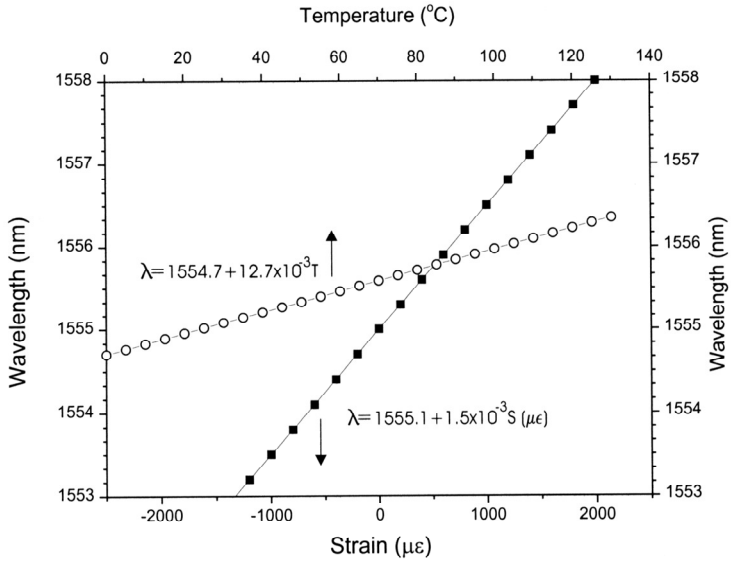

Figure 3: Characteristics of a typical Fibre Bragg Grating in terms of temperature and strain sensitivity as applicable to sensor applications

Multiplexing of a number of FBGs along a single fibre enables multiple sensors to be configured in quasi-distributed mode, as is shown schematically in Figure 4.

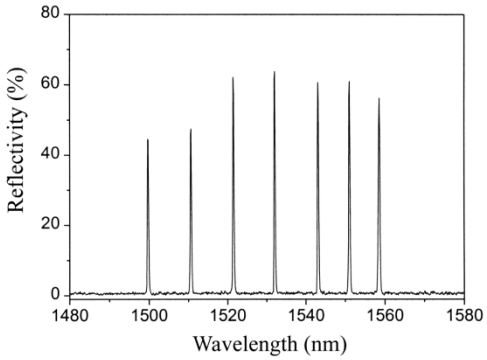

Figure 4: Illustration of the characteristics of seven FBGs across the spectral range 1500 – 1560 nm

There is a wide use of Bragg gratings in communications systems: involving wavelength stabilized lasers, filters, phase conjugators, Wavelength Division Multiplexers/Demultiplexers, dispersion compensators and gain equalization, for example. These techniques can be applied in excellent sensor elements which are good for both static and dynamic measurements where examples include temperature, pressure and strain in particular. Sensor data are wavelength encoded: therefore they are self referencing devices, not being intensity-measurement dependent and thus immune to losses in the system. Such systems have very low insertion loss and there is the major advantage that the fibre is highly transmitting at other wavelengths, allowing serial multiplexing and thus an in-line, in-fibre device. They can be embedded in materials, relatively easily retrofitted and attached and of small size – this opens up optical fibre "smart structures" concepts as discussed below.

An example of a simple practical FBG-based Strain and Temperature monitoring system is show in Figure 5 below.

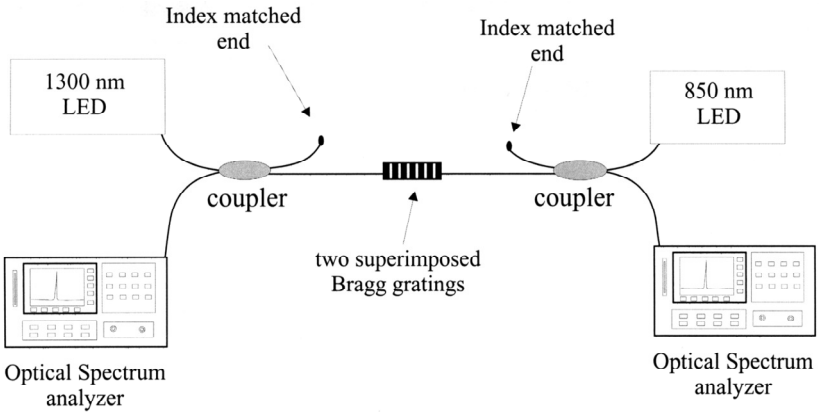

Figure 5: Illustration of a simultaneous FBG-based strain and temperature sensor system

FBGs are ideal for the above application as FBGs are sensitive to both parameters and here are overlapped spatially. Thus in the above figure, two superimposed gratings may be used allowing strain and temperature data to be extracted. It is interesting to note the sensitivities of the FBGs – they are about ten times more sensitive (per pm wavelength shift) to temperature than strain, which if not properly resolved can be a problem for strain monitoring.

Long Period Gratings (LPGs) were first reported in 1995 and use similar technology to FBGs, being also a photoinduced effect. The period, Λ, lies in the region of hundreds of micrometers to millimeters and they are of length of tens of millimeters with an index modulation of 10-4 or greater. The operation is different in that it couples light from core to cladding where the wavelength of operation is given by

$$\lambda lpg = \mid nco - ncl\ (m) \mid \Lambda$$

where nco is the core refractive index, ncl the cladding refractive index and m the cladding mode and they operate over a wide spectral range. The spectral features arise as light decays away quickly at the interface between the core and cladding, as shown in Figure 6.

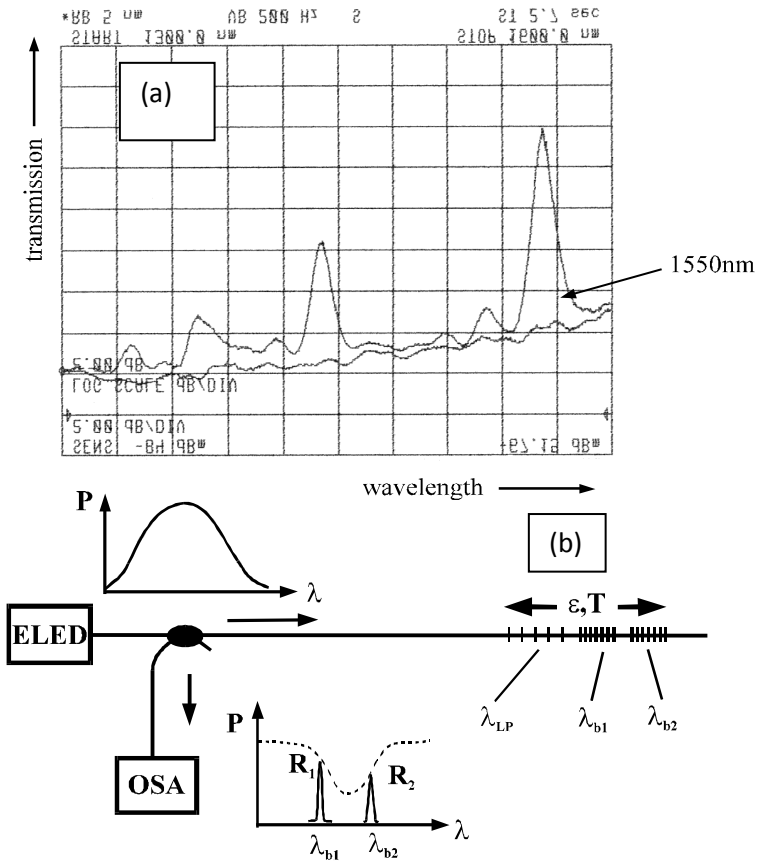

Figure 6: (a) Typical LPG Spectrum (b) Schematic of a sensor system using an LPG/FBG combination

Fibre Optic Sensor Applications for Industry today

A key question for industry today is 'Why use optical fibre sensors'?. The response to that can be summarized as follows:

- **When there are a large number of sensors to be placed:** If it is necessary to place a lot of sensors for complete monitoring of a system
- **When electrical temperature monitoring is impractical:** In a situation where there is a large amount of electromagnetic noise, the data being read from conventional sensors can be corrupted
- **When electrical monitoring is unsafe:** There is a risk of sparking inherent in all electrical systems. If the atmosphere in the area being monitored is in danger of becoming volatile, then the fact that a fibre optic system does not present a spark hazard can be a significant safety advantage
- **Where being lightweight and using an optical network is important:** this minimizes weight of the cables used and simplifies the set up

Some of the key application where Fibre Optic Sensors can be applied include:

- **Monitoring of our multi-billion dollar infrastructure** e.g.
  - Concrete/stone or composites
  - Steel in bridges and other metal structures
  - Marine structures exposed to wind and water
- **Physical monitoring of key parameters**
  - Bridges: retrofitting and during construction
  - Foundations: offer potential for reuse
  - Repair: monitoring effectiveness of repairs
- **Adverse situations**
  - In 'real world' situations - factories making structures
  - At high temperatures or during fires
  - At high voltage
  - Under water
  - Under irradiation

Work at City University London has focused on a number of key areas of Structural Health Monitoring including the following applications in 'real world' situations which are illustrative of the breadth of work in the field in areas such as:

- **Concrete platform bridges: Mjosund Bridge in Norway**
  - externally attached sensors retrofitted
  - Composite bridge: West Mill in UK
  - sensors incorporated within the composite during construction
- **Composite fibre reinforcements: Gronalds Bridge in Sweden**
  - Smart reinforcements using carbon fibre 'patches'
  - Monitoring strengthening of bridges: Frovi bridge in Sweden
  - Sensors mounted in 'smart reinforcements' retrofitted
- **Ornskoldsvik bridge: tests to destruction**

- Sensors mounted and results taken during extreme test
- Mounted in groves (tube) or in drilled holes (rod)

Illustrations of the above are seen below in work done by researchers at City University London working with industrial colleagues.

Figure 7 shows the performance of one of a suite of strain sensors installed, from a series of tests on a bridge – the Mjosund Bridge in Norway.

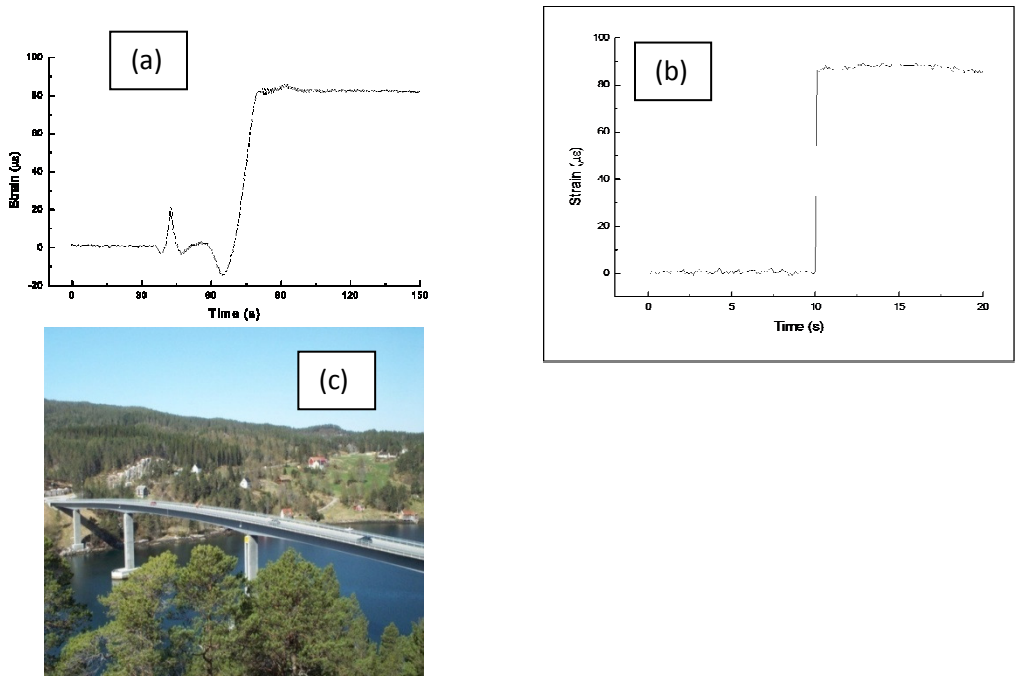

Figure 7: (a) Performance of an optical fibre sensor (b) Performance of a conventional strain sensor under the same circumstances of monitoring on the bridge (c) the Mjosund bridge itself

Fibre optic sensors can be installed in concrete samples, even during the pouring of the concrete, as shown below in tests carried out with an industrial company, Creagh Concrete, in Figure 8.

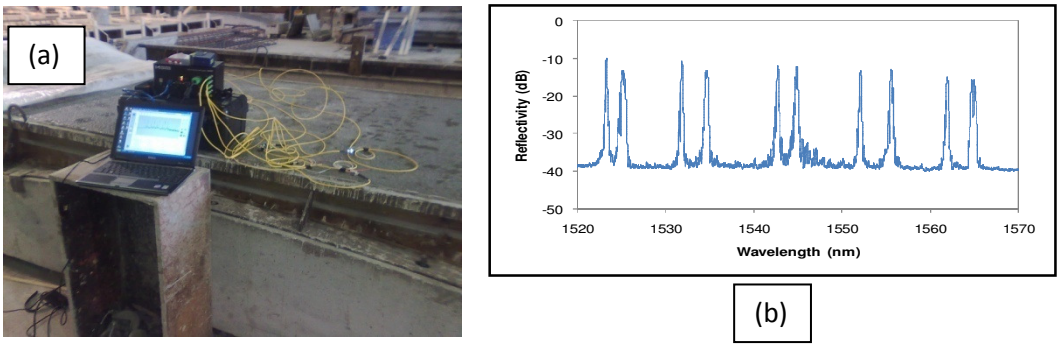

Figure 8: (a) Photograph of fibre optic sensors embedded in concrete and (b) response of the series of FBGs installed in the concrete sample showing 10 spectral peaks

A 'packaged' fibre optic strain and temperature sensor developed for structural monitoring for bridges is shown in Figure 9 below.

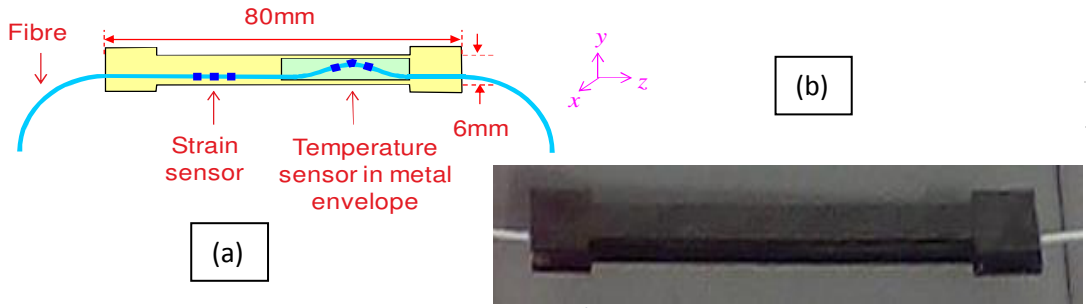

Figure 9: (a) Schematic of the dual strain/temperature sensor and (b) photograph of the device itself

A fibre optic laser sensor based on FBGs is shown schematically in Figure 10

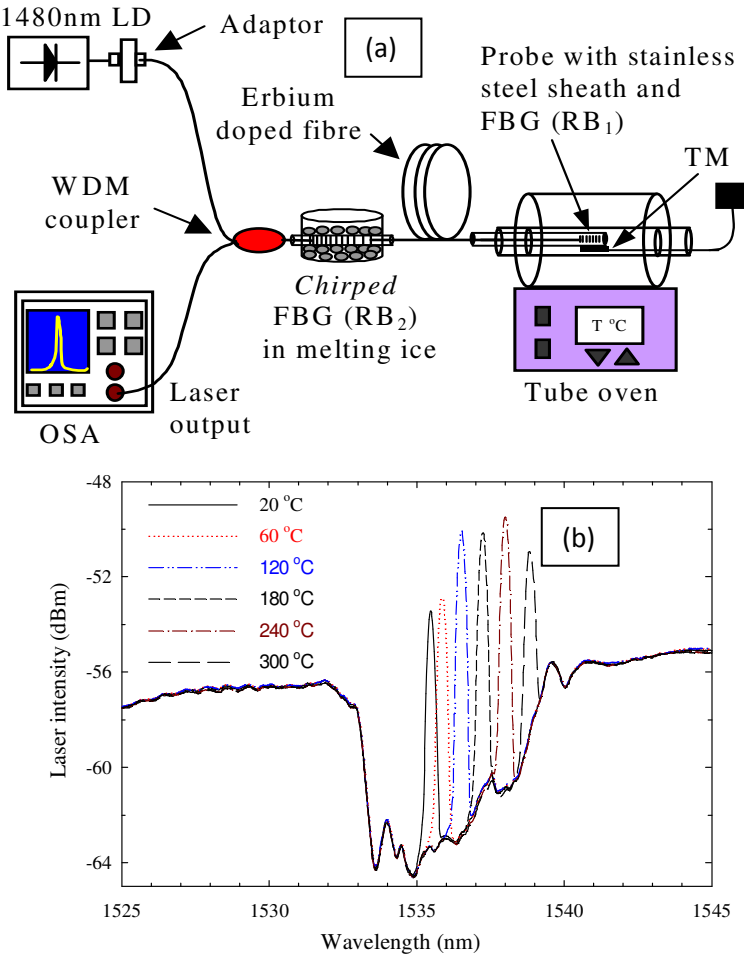

Figure 10: (a) Schematic of the fibre optic laser sensor and (b) performance of the device for temperature measurement over a wide range from 20 to 300 degrees C

A fibre optic humidity sensor based on a coated FBG and used for structural monitoring to investigate water ingress into materials is shown in Figure 11

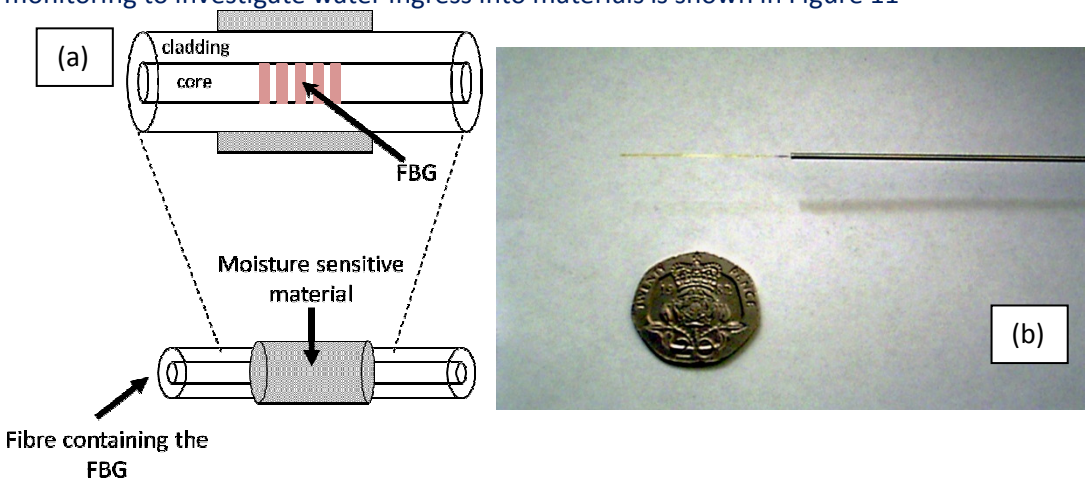

Figure 11: (a) Schematic of the sensor operation (b) photograph of the sensor itself

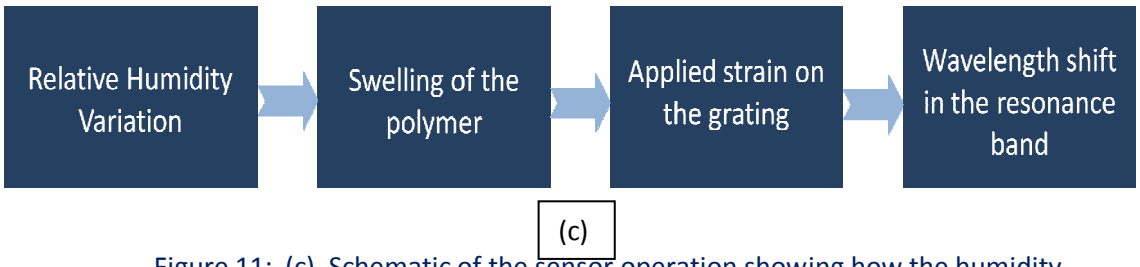

Figure 11: (c) Schematic of the sensor operation showing how the humidity change affects the wavelength measured by the sensor

Summary and Conclusions

Fibre optic sensor systems offer unique opportunities to make physical and chemical measurements across a range of environments and to meet a variety of industrial needs. As has been seen, sensors may be fitting during construction or retrofitted to existing structures to allow for effective measurements, often in 'niche' circumstances and environemnts. Results obtained, some of which are summarized above (but which can be seen from the literature [1]), compare well with those from conventional sensors and illustrate clearly that measurements are possible under adverse situations. Further, the sensors described, being largely FBG-based devices, are well suited to multiplexing as quasi-distributed fibre optic sensor systems. With fibre optic sensor networks, the opportunity for wide range monitoring applications exits, as illustrated in the foregoing.

Considerable future potential is evident as new systems are developed over future years, exploiting both current and future technologies. The field is exciting and dynamic and one where a wide range of opportunities will be seen, influencing policies in education, in industrial linkages and in creating new ways for support for people in an increasingly automated world.

Acknowledgements

The author would like to acknowledge the support of his many colleagues at City University London, without whom this work would not have been possible.

The support of the Royal Academy of Engineering and the George Daniels Educational Trust are greatly appreciated.

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CURRICULUM VITAE

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George Daniels Professor of Scientific Instrumentation

Dean, City Graduate School

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Email: k.t.v.grattan@city.ac.uk

Personal Information

Background

Professor Grattan graduated in Physics from Queen's University Belfast with a BSc (First Class Honours) in 1974, followed by a PhD in Laser Physics. His research involved the use of laser-probe techniques for measurements on potential new laser systems.

Following Queen's, in 1978 he became a Research Fellow at Imperial College of Science and Technology, sponsored by the Rutherford Laboratory to work on advanced photolytic drivers for novel laser systems. This involved detailed measurements of the characteristics and properties of novel laser species and a range of materials involved in systems calibration. In 1983 he joined City University as a "new blood" Lecturer in Physics, being appointed Professor of Measurement and Instrumentation in 1991 and Head of the Department of Electrical, Electronic and Information Engineering. From 2001 to 2008 he was the Associate and then Deputy Dean of the School of Engineering and from 2008 to 2012 the Conjoint Dean of the School of Engineering & Mathematical Sciences and the School of Informatics. In 2013 he was appointed the Inaugural Dean of the City Graduate School.

His research interests have expanded to include the use of fibre optic and optical systems in the measurement of a range of physical and chemical parameters. The work has been sponsored by a number of organizations including EPSRC, the EU, private industry and charitable sources, and he holds several patents for instrumentation systems for monitoring in industry using optical techniques. He obtained the degree of Doctor of Science (DSc) from City University in 1992 for his sensor work. Professor Grattan is

extensively involved with the work of the professional bodies having been Chairman of the Science, Education and Technology of the Institution of Electrical Engineers, the Applied Optics Division of the Institute of Physics and he was President of the Institute of Measurement and Control during the year 2000. He was awarded the Callendar Medal of the Institute of Measurement and Control in 1992, and the Honeywell Prize for work published in the Institute's journal as well as the Sir Harold Hartley Medal in 2012 for distinction in the field of instrumentation and control. He was awarded the Applied Optics Divisional Prize in 2010 for his work on optical sensing.

Professor Grattan has been Deputy Editor of the Journal Measurement Science and Technology for several years and currently serves on the Editorial Board of several major journals in his field in the USA and Europe. In January 2001 he was appointed Editor of the IMEKO Journal "Measurement" and also serves on their General Council. He is the author and co-author of over seven hundred refereed publications in major international journals and at conferences and is the co-editor (with Professor B T Meggitt) of a five volume topical series on Optical Fiber Sensor Technology.

Qualifications

DSc City University London, 1992
PhD Queen's University of Belfast, 1979
BSc Physics, Queen's University of Belfast, 1974

Employment

- to date City University London
  - George Daniels Professor of Scientific Instrumentation (since 06/2013)
  - Dean, City Graduate School (since 2013)
- 08/2012 - 07/2012 City University London, Inaugural Dean, City Graduate School
- 08/2008 - 07/2012 City University London, Dean, School of Engineering & Mathematical Sciences and School of Informatics
- 03/2006 - 07/2008 City University London, Deputy Dean, School of Engineering & Mathematical Sciences and School of Informatics
- 08/2001 - 03/2006 City University London, Associate Dean (Strategy & Resources), School of Engineering & Mathematical Sciences and School of Informatics
- 01/1991 - 07/2001 City University London, Head of Department of Electrical, Electronic & Information Engineering
- 01/1991 - 06/2013 Professor of Measurement & Instrumentation
- 10/1988 - 01/1991 City University London, Deputy Head of Centre for Measurement, Instrumentation & Applied Physics
- 10/1988 - 12/1990 City University London, Reader in Measurement & Instrumentation
- 10/1983 - 09/1987 City University London, "New Blood" Lectureship in Measurement & Instrumentation

- 04/1981 - 09/1983 Imperial College London, SERC sponsored Postdoctoral Research Assistant
- 11/1978 - 03/1981 Imperial College London, Rutherford Laboratory sponsored Postdoctoral Research Assistant

Other appointments

1994 - to date Huazhong University of Science & Technology, Visiting Professor
1995 - to date Chongqing University, Chongqing, China, Visiting Professor
1996 - to date Harbin Institute of Technology, Visiting Professor
2012 - to date Harbin Engineering University, Honorary Professor

Membership of Professional Bodies

- 2008 Royal Academy of Engineering, Fellow
- 1995 Worshipful Company of Scientific Instrument Makers, Liveryman
  - Assistant at the Court of the Company since 2011
- 1989 Institute of Measurement & Control, Member
  - Fellow since 1995
  - President since 2000
- 1985 Institution of Electrical Engineers (now Institution of Engineering & Technology since 1992), Chartered Engineer
- 1984 Institute of Physics, Member, Chartered Physicist and Chartered Scientist
  - Fellow since 1990

Research Interests

- Measurement and Instrumentation
- Fibre optic sensors for physical measurement
- Fibre optic sensors for high temperature measurement
- Applications of optical sensing techniques in industrial situations

Publications

- Journal Article 524
- Books 18
  - (Sep 2010). Proceedings of IMEKO TC1/7 Symposium on Measurement & Instrumentation. Bristol, UK: Institute of Physics Publishing.
  - (Mar 2008). Optics & Laser Diagnostics 2007. Bristol, UK: Institute of Physics Publishing.
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- Supervisor for 55 PhD students
- Conference papers 313

LAUDATIO
PENTRU PROFESORUL
KENNETH GRATTAN

Profesorul KEN GRATTAN de la City University London este membru al Academiei Regale de Inginerie (Royal Academy of Engineering) din Regatul Unit al Marii Britanii si membru al altor insitutii prestigioase din Marea Britanie, printre care UK Institute of Physics, UK Institute of Measurement and Control si UK Institution of Engineering and Technology.

Profesorul Ken Grattan a sustinut doctoratul in fizica laserilor in anul 1979 la Queen's University din Belfast si a obtinut titlul de doctor in stiinte in anul 1992 pentru lucrarile sale in domeniul masuratorilor si instrumentatiei. A studiat ca cercetator post-doctoral la Imperial College din Londra iar din 1983 lucreaza la City University of London, unde a devenit professor, sef al Depratamentului de Inginerie Electrica si Electronica, prodecan si apoi decan al Scolii de Inginerie si Stiintele Matematice si Informatica, actualmente fiind decanul Şcolii Doctorale.

LAUDATIO
FOR PROFESSOR
KENNETH GRATTAN

Professor KEN GRATTAN from City University of London is Fellow of the Royal Academy of Engineering from the United Kingdom of Great Britain and Fellow of other prestigious institutions in Great Britain, including UK Institute of Physics, UK Institute of Measurement and Control, and UK Institution of Engineering and Technology.

Professor Ken Grattan presented his Phd thesis in laser physics in 1979 at the Queen's University Belfast and obtained his PhD in Sciences in 1992 for his work in the field of measurement and instrumentation. He studied as a post-doctoral researcher at the Imperial College, London and from 1983 he works at the City University of London, as Lecturer, subsequently he becomes Professor Head of the Department of Electrical Engineering and Electronics, Vice-dean and then Dean of the School of Engineering and Mathematical Sciences and Informatics, currently being Dean of the City Graduate School.

Profesorul Ken Grattan a dezvoltat cercetari prestigioase in domeniul instrumentatiei bazate pe fibre optice, cu aplicatii importante in industrie, a condus peste 50 studenti doctoranzi si a pregatit peste 30 cercetatori post-doctorali, iar cercetarile sale au fost finantate permanent prin granturi britanice si europene care insumeza peste 15 milioane de lire sterline. A publicat peste 380 lucrari stiintifice si a fost invitat la numeroase conferinte internationale importante,

Professor Ken Grattan developed prestigious researches in the field of fiber optic instrumentation, with important applications in industry, he coordinated over 50 PhD students and prepared over 30 post-doctoral researchers and his researches have been continuously financed through British and European grants which add up to over 15 million pounds. He published over 380 scientific papers and has been invited at numerous important international conferences.

Profesorul Grattan se bucura de o remarcabila reputatie internationala fiind invitat in comisii de doctorat in Australia, Canada, Irlanda, Africa de Sud, Hong Kong, Singapore, China, Olanda si Romania. Este membru in colegiul de redactie al unor reviste stiintifice internationale prestigioase si a obtinut mai multe premii.

Professor Grattan has a remarkable international reputation being invited in PhD committees in Australia, Canada, Ireland, South Africa, Hong Kong, Singapore, China, Holland and Romania. He is member in the editorial board of some prestigious international scientific journals and has obtained several awards.

Cercetarile profesorului Grattan s-au concentrat asupra metodelor optice de masurare a unor parametri fizici si chimici ai materialelor, in special cu senzori bazati pe fibre optice si laseri, imbinand cercetarea fundamentala cu cea aplicativa.

The researches of Professor Grattan focused on the optical methods of measuring physical and chemical parameters of materials, especially with optical fiber based sensors, combining the fundamental research with the applied one.

A publicat aproape 700 lucrari stiintifice, in reviste si la congrese internationale, care au cumulat peste 4700 citari. Dupa anul 2000 are peste 150 citari in fiecare an ! Activitatea profesorului Grattan este reflectata intr-un remarcabil indice Hirsch a carui valoare este 31.

He published almost 700 scientific papers in journals and at international congresses and he accumulated over 4700 citations. After the year 2000 he has over 150 citations every year! The professional activity of Professor Grattan is reflected in a remarkable Hirsch index with a value of 31.

Parcurgerea listei de publicatii a profesorului Grattan impresioneaza prin varietatea si originalitatea subiectelor tratate si prin implicatiile lor practice, mai ales in domeniul senzorilor.

Running over Professor Grattan's list of publications impresses through the variety and originality of the subjects and their practical implications, especially in the field of sensors.

Rezultatele deosbite in cercetarea stiintifica, reputatia internationala si contributiile sale stiintifice il recomanda pe deplin pe profesorul Grattan pentru acordarea titlului de Doctor Honoris Causa al Universitatii din Oradea. Sustin cu caldura aceasta initiativa.

04.12.2013

Acad. Ionel Haiduc
Președintele Academiei Române
Profesor Universitatea Babes Bolyai, Cluj-Napoca

The outstanding results in scientific research, the international reputation and his scientific contributions fully recommend Professor Grattan to be awarded the title of Doctor Honoris Causa of the University of Oradea. I warmly support this initiative.

4th of Decembre 2013

Acad. Ionel Haiduc
President of the Romanian Academy
Professor at Babes Bolyai University, Cluj-Napoca

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Honorary Degree Recommendation

This reference is written to highlight the prodigious activity performed by Professor Ken Grattan during his career. Its purpose is to aid consideration for the award of an honorary degree from the University of Oradea.

Professor Grattan graduated with a PhD in laser physics in 1979; in 1992 he obtained a DSc for work in measurement and instrumentation. Ken undertook his PhD degree at Queen's University of Belfast and then spent 5 years as a post-doctoral Research Assistant at Imperial College, London. He joined City University London in 1983 as a Lecturer, subsequently became Professor and was Head of the Department of Electrical & Electronic Engineering from 1991-2001. He was then appointed Associate and then Deputy Dean, and in 2008 became Dean of the Schools of Engineering & Mathematical Sciences and of Informatics. In 2012 he became Dean, of the City Graduate School.

At City, since 1983, he built up research in the field of optical and fibre optic instrumentation achieving support for that from industry and the research councils, both in the UK and Europe, leading the Research Centre in Instrumentation & Sensing. He has supervised some 50 PhD students and over 30 post-doctoral fellows – most have gone on to successful careers in industry and academia. He has held over 60 different grants and awards, of value some £15M and has been continuously funded by the UK Research Councils since 1984. He has been a contributing author to more than 380 journal publications and has been an invited speaker to a significant number of influential international conferences.

Professor Grattan contributions to research have been repeatedly acknowledged by his peers through in particular being made a:

- Fellow of the Royal Academy of Engineering, the UK's national academy of engineering
- Fellow of the UK Institution of Engineering & Technology (IET, formerly IEE);
- Fellow of the UK Institute of Measurement & Control;
- Fellow of the UK Institute of Physics

His was a former Council member of the above Institutions and past-President (2000) of the UK Institute of Measurement & Control.

Ken has received prizes and awards including:

- Institute of Physics (UK) Applied Optics Divisional Prize 2010
- Institute of Measurement & Control Callendar Medal 1992
- Institute of Measurement & Control Honeywell Prize 1987 and 2000
- Institute of Measurement & Control ICI Prize 1991

He has been Conference Chair on a number of occasions including:

- UK Applied Optics Divisional Conference 1996 and 1998
- UK Sensors & their Applications Conference 1991, 1993 and 2001
- UK International Conference on Optics and Laser Diagnostics 2002, 2005 and 2007

Professor Grattan's active contributions to the professional community are further demonstrated by being a regular reviewer for many international journals and through editorial activity including:

- Editor of Journal Measurement (published by Elsevier)
- Editorial Board membership
    - Review of Scientific Instruments (USA) for 3 year term
    - Sensors & Actuators A
    - Optics & Laser Technology.

Further contributions to the profession are demonstrated through his activity as a PhD examiner in countries such as UK, Australia, China, Holland, Romania, Hong Kong, Ireland, Singapore and India. Similarly he has been a reviewer of grant applications originating from Australia, Hong Kong, Canada, Ireland, Singapore, South Africa and UK.

The description above is testimony to the breadth and depth of the prodigious research activity and professional contribution made Professor Grattan across his career. I would now like to describe the personal attributes he has consistently demonstrated in performing the activities described above.

Ken is innovative, creative, a leader, a collaborator and a mentor. The scope of his influence is truly international and includes industry, professional societies, educational institutions and individuals. He uses his knowledge, experience and networks to make contributions of real value to the each of the spheres of influence described above.

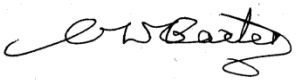
Being both innovative and creative means working with Ken results in a new idea being proffered on a regular basis. The activity around Ken is alive with exciting possibilities evolving into realisable opportunities. His warmth and generosity ensures that all players have access to those opportunities as he shares his depth of knowledge of funding schemes or potential industry partners who may wish to become involved in helping a small germ of an idea grow into a convincing well-articulated project. His command of the written form enables contributions to knowledge to be concisely stated

and understood both for the purpose of publication and also to advance an argument for funding. He is committed to having fun whilst maintaining high productivity.

These abilities have been applied not only for the betterment of his research endeavours but also shaped his leadership in academia and the professional societies.

It will be of no surprise then that on a personal, individual to individual level, Professor Grattan has powerfully influenced for the good many academics, researchers and industrialists; not least amongst these being his former PhD students and postdoctoral fellows. He regularly and repeatedly creates opportunities for others to prosper.

It is therefore with great confidence that I warmly recommend Professor Grattan to you as a person of utmost integrity whose professional impact as an academic researcher, administrator and leader has been consistent and at the highest level.



About the referee

Professor Greg Baxter is a researcher professor within the College of Engineering and Science at Victoria University, Melbourne, Australia. As a former Chair of the university's Academic Board he was a member of the University Council serving on the nominations committee that made recommendations on honorary awards. Until recently he served a 5 year term as Pro Vice-Chancellor (Academic and Students) having previously for 6 months acted as Pro Vice-Chancellor (Research). He has a great respect for the purpose and process of honorary awards.