CARBON BASED SENSING NANOSTRUCTURES IN ENGINEERING EDUCATION

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INTRODUCTION

The design and development of different projects have been established and implemented for photonics engineering education, towards a multidisciplinary network engineering culture. They aim to be an added value to physical, electrical and biomedical engineering education, providing an important training on nanotechnology and photonics.

In the present work, Bragg sensors have been explored in many different applications such as the monitoring of wine production processes and the measurement of pulse waveforms directly in the carotid artery, without requiring the application of transfer functions from data obtained in peripheral arteries. Their potential applications in real-time measurements of internal temperature and pressure of lithium batteries have also been successfully explored. Recently, various carbon- based nanomaterials and nanostructures have been studied for high advanced sensing applications.

The design and development of these different projects have been established for the integrated master degree in physical engineering, at Aveiro University, Portugal. It is a 5 year degree course, based on 41 disciplines of 6 ECTS, a 3rd year project of 12 ECTS and a final year thesis of 42 ECTS. In the last two years of the course, the students can choose disciplines from different areas, namely materials, optoelectronics, energy, physical medicine and instrumentation. Typically, this project approach is focussed on the 3^{rd} year project and final year thesis and on the promotion of technology transfer and interaction with small and medium enterprises, at national and international level.

1 OPTICAL SENSORS

1.1 Vinification monitoring

Recently, one of the major applications of the optical sensing has been the monitoring of different processes in food industry, aiming the improvement of the characteristics of many different products. For example, optical sensing technology has been increasingly used in wine industry. Several studies of physical parameters with interest to the vinification process and its control have been reported in literature, namely turbidity, density and colour.

In particular, the Madeira winemaking is based on a unique heating process which happens after the fortification step, where the fermentation is stopped by the addition of a grape spirit. This process was introduced in the XVIII century and it consists in a controlled heating of the wine. Typically, the wine is put in stainless steel tanks with serpentines that heat the wine up to 55ºC for at least three months. This controlled heating process has a significant impact on wine flavour, colour and formation of undesirable volatile compounds [1].

A pilot scale facility has been installed, where the heating tanks can be controlled independently. The development of a dedicated optical platform has been carried out for real time monitoring of the operating conditions and the wine evolution during all process.

1.2 Central arteries stiffness measurement

Cardiovascular diseases are one of the major causes of death in developed and developing countries. The arterial elasticity loss has been considered the major early event on cardiovascular disease generation. Typically, it can be assessed by pulse wave velocity and form analysis [2].

The available electromechanical equipment commonly used for a non-invasive measurement has several difficulties in the pulse acquisition. The fibre optic sensors, due to its unique characteristics, are becoming an important alternative. In particular, Bragg sensors have been considered a solution with a high potential of applicability due to its high sensitivity and immunity to electromagnetic interference. In fact, they are suitable for assessing the pulse wave in hospital environments, including magnetic resonance imaging and computerized tomography rooms.

In the present work, Bragg sensors have been explored to obtain the pulse waveform directly in the carotid artery, without requiring application of transfer functions from data obtained in peripheral arteries. During the acquisition process the sensor is placed in the neck over the carotid artery. This sensor is able to sense the micrometric displacements of the artery walls, with the detection of a clear carotid pulse constant in time [3].

1.3 Lithium batteries studies

In the last decade, lithium batteries have been widely used in portable electronics and pursued as power sources for hybrid and electric vehicles. The primary challenge in designing a scaled up system is the safety warranty under abuse and normal operating conditions [4]. Thermal stability and internal pressure are the relevant parameters. Under abuse conditions such as over charge/discharge and short circuit, explosion and combustion of batteries may occur due to the high internal temperature and pressure. Hot-spots can appear in an individual battery, causing rapid capacity fading. Bragg sensors can be an excellent solution due to their high sensitivity and accuracy. In fact, they have been widely used to measure local, static and fluctuating temperatures, pressure, refractive index, strain and bending, among others [5].

The integration of Bragg sensors in lithium batteries to measure real-time temperature and pressure has been under development. The desired measurement can be achieved at various charge and discharge conditions. Furthermore, the thermal behaviours of lithium battery with different cathode materials can also be studied and the multiplexing possibility in a single optical fibre explored. The electrochemical performance, temperature and pressure variations will greatly benefit from the understanding of the stability of cathode material and electrolyte under various voltages.

2 NANOSTRUCTURED SENSING

2.1 Nanodiamond coated sensors

Research efforts have been put on the use of nanocoatings for modifying the response of optical fibre Bragg gratings. It can be expected that nanodiamond coatings can significantly extend the capability of sensors, such as enhancing its mechanical strength, protecting it from chemical erosion, increasing its high temperature limit and increasing its lifetime, especially for high temperature applications. It has also been shown that due to its fine grain and smooth surface, nanocrystalline diamond is an excellent choice for life science and bio-sensor applications [6].

In preliminary work, microcrystalline and nanocrystalline diamond coatings on optical fibres have been obtained using a hot-filament chemical vapour deposition system [7]. However, the sensitivity of the conventional sensor disappeared after diamond deposition. This reveals that they cannot survive in the typical diamond deposition temperatures (600-1000 ºC). Presently, a novel type of Bragg sensor is under development. The major tasks are being focussed on the nanodiamond deposition onto optical fibres, the fabrication of high temperature resistant sensors and subsequent growth and characterization.

2.2 Composite filaments based sensors

Carbon based nanoparticles present unique electrical, mechanical and thermal properties. Their applications are usually conditioned by their physical form, the dispersion in solvents, monomers or polymer melts being usually required [8]. The carbon particles are typically chemically modified in order to evaluate the influence of nanoparticle surface modification on the dispersion aptitude and to analyse the role of the interface on the final composite properties. Composite filaments need to be produced under the best possible conditions established by the dispersion studies. Monofilaments are currently produced by melt processing and nano/micro filaments processed by electrospinning of polymer/nanoparticle suspensions [9].

The sensing ability of these filaments is being tested. Preliminary results show that they may have a significant rule on the design of very high sensitive fibre Bragg grating sensors for advanced applications. For example, recent studies have already been demonstrating the feasibility of using single-walled carbon nanotubes as sensitive coatings of optical fibre sensors for the detection of chemical traces in water at room temperature.

3 PROJECT APPROACH IN PHOTONICS ENGINEERING EDUCATION

Photonics has been increasingly considered one of most relevant enabling technologies for the development of new approaches and solutions of currently main socio-economics challenges. In particular, nanophotonics and carbon based devices have been allowing extremely relevant improvements in sensing, imaging and energy issues. In terms of education and training, it requires new concepts and practices for a more efficient studying and teaching.

The above described study cases have been designed within a project approach in order to promote self-study and to strengthen societal perspectives. An active participation of the students and the establishment of useful and efficient dialogues between teachers and students can be achieved. It can also allow to adequate work materials to individual needs and different speeds of learning. On the other hand, they can facilitate individual and group learning assessment and seem to have great impact on learning efficiency. In general, they have been considered an adequate education tool for the development of the required competences on photonics engineering.

4 SUMMARY AND ACKNOWLEDGMENTS

Bragg sensors have been used to acquire pulse waveforms directly in the carotid artery and to measure real-time internal temperature and pressure of lithium batteries under high current rates, short circuit and over-charge. Their potential applications in wine studies and high temperature measurements have also been explored. Recently, the design and fabrication of high sensitive polymer coated fibre Bragg grating sensors has been studied and developed.

The different study cases have been focussed on a project approach. Its impact on photonics education has been successfully explored, towards a multidisciplinary engineering culture. Its use in physical and related master engineering courses will be fostered, aiming the development of new education tools and the establishment of innovative networks.

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