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An Overview of Optical Fibre Sensors for Medical Applications

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Abstract— ***Optical techniques developed for sensing purposes proved to be completely realized in many application fields, ranging from aerospace, industry, process control and medical. The capabilities of these sensors are generally enhanced when a bulk-optical configuration is replaced by optical fibre technology. There is a growing need for real-time and low cost technology because of the expense and time constraints associated with modern laboratory analysis. This is certainly due to the growing interest in optoelectronics, but also to the very satisfactory performance and reliability that optical fibre sensors are now able to provide. This paper focuses on the advantages that optical fibre sensors offer to the biomedical field, recalls the basic working principles of sensing, and discusses some examples.***

Keywords— Fibre optic, Optical sensors, Cladding, Light illumination, Communication systems

I. INTRODUCTION

Optical fibres were becoming widespread in their commercial use with the telephone transmission systems and other communication systems. There are also widely used in medical imaging and mechanical engineering inspection but purely as light illumination light guides. Biological recognition elements have attracted superior interest in recent years, because of the key role they play in the progress of highly sensitive and selective chemical analysis [1]. In the medical field, the opportunities offered by optical fibres have always been beneficial feat. A great deal of research in optical fibres has been dedicated to sensing, and again the medical field found good opportunities for developing very promising sensors.

Two classes of clinical care procedures can be distinguished, in which conventional methods present some drawbacks [2]:

- In vitro laboratory tests of blood or tissue samples, which means frequent sample takings for continuous checking, thus placing the patient under stress. In addition, therapeutic intervention is delayed, and errors can also occur, due to sample handling and photo degradation;
- In vivo measurements of many physical and chemical parameters performed by electrical devices (thermocouples, CHEMFET, semiconductor or piezoelectric elements), which are fragile and expensive, and expose the patient to electrical connections.

Specificity and sensitivity should be the main properties of any proposed biosensor. The first depends entirely on the inherent binding capabilities of the bio receptor molecule whereas sensitivity will depend on both nature of the biological element and the type of transducer used to detect this reaction [3].

An overview of fibre optic sensors for biomedical applications is given, with particular attention to the sensors developed for in vivo monitoring, and to the advantages that these sensors are able to offer in different fields of application such as cardiovascular and intensive care, angiology, gastroenterology, ophthalmology, oncology, neurology, dermatology and dentistry.

II. FUNDAMENTAL OF FIBRE OPTICS

The working principle of fibre optic sensors (FOSs) is based on the modulation of the fibre-guided light produced in one of the optical properties (phase, intensity, wavelength, polarization state) by the parameter under investigation. The basic structure of a conventional optical fibre is shown in Fig. 1 and it is made of the following parts [4]:

- Core - thin centre of the fibre where the light travels.
- Cladding - outer optical material surrounding the core that reflects the light back into the core
- Buffer coating (optional) - plastic or polymer coating that protects the fibre from damage and moisture.

Fibre optics for biomedical sensing applications mostly using intensity modulation type thus the low cost of their components and the simplicity of their architectures. They can be either intrinsic or extrinsic, according to whether the intensity modulation is produced by the fibre, which is sometimes modified, or by an external transducer connected to the fibre.

A single mode optical fibre is capable of transmitting trillions of bits per second when the signals are wavelength multiplexed. In addition to their broad transmission capacity, optical fibres also offer many further advantages over electricity and copper wire. A few advantages of optical fibre are highlighted in Table I below and they relate to those for sensing purposes [4].

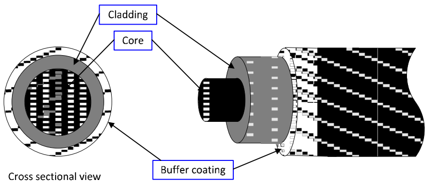

Fig. 1 Optical fibre structure

Table 1 Optical Fibre Advantages

Optical Fibre Advantages
• Less signal loss than copper transmission • Fibre is lighter, smaller in diameter and can be less expensive than copper lines • There is no electromagnetic interference. • High security, it is not possible to 'tap' an optical line as easily as a copper line • Fibre system are useful in hazardous environments where electrical signals might cause sparks • The fibre cable can be bent or twisted without damaging it if adequate precautions are taken

III. TYPE OF BIOSENSOR

In medical practice, there are two types of parameter which are physical parameters and chemical parameters. The parameters of medical interest have been measured are shown in Table II.

Table 2 Medical Parameters

Physical parameter	Chemical parameter
Pressure Temperature Blood flow Humidity Cataract onset Radiation dose Biting force	Bile pH Oxygen Carbon dioxide *Lipoproteins* Lipids

A. Sensors for Physical Parameters

1) *Blood Flow: Laser Doppler Flowmetry (LDF) is an accurate and reliable method for assessing microcirculatory function, and the use of optical fibres enhances the possibility of both invasive and contact measurements. The basic scheme of fibre-optic LDF is illustrated in fig. 2. The light of a He–Ne laser is guided by an optical fibre probe to the tissue or vascular network being studied. The light is diffusely scattered and partially absorbed within the illuminated volume. Light hitting moving blood cells undergoes a slight Doppler shift. The blood flow rate is derived by the spectrum-analysis of the back-scattered signal, which presents a flow-dependent Doppler-shifted frequency [2].*

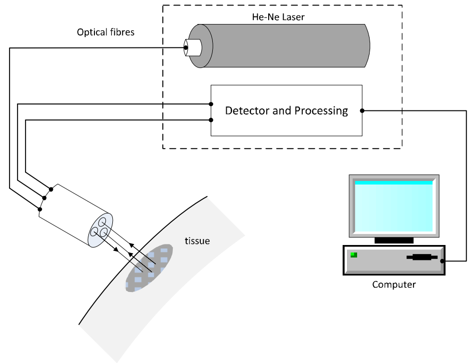

Fig. 2.Basic scheme of fibre-optic laser Doppler flowmetry.

2) *Radiation dose:* The success of radiotherapy is related to the on-line monitoring of the dose to which the tumour and the adjacent tissues are exposed. Conventional thermo-luminescence dosimeters only provide off-line monitoring, since they determine the radiation exposure after completing irradiation. A short length of heavy metal-doped optical fibre coupled to a radiation resistant fibre is an optimal system for the continuous monitoring of radiation dosage in both invasive and non-invasive applications. The light propagating in the doped fibre section undergoes intensity attenuation in the presence of radiation, since the attenuation is nearly linear to the radiation dose. Differential attenuation measurement compensates for insensitivity due to cable and connector losses [5].

B. Sensor for Chemical Parameters

In fibre-optic chemical sensors the light transported by the fibre may be directly modulated either by the parameter being investigated (spectrophotometric sensors), or by a special reagent connected to the fibre, whose optical properties vary with the variation in the concentration of the parameter under study (transducer sensors). The probe is often called optrode, as it represents an optical electrode. The main physical phenomena exploited for the realization of chemical sensors are fluorescence and absorption, even if chemical optical fibre sensors have been realized by exploiting other physical phenomena, such as chemical luminescence, Raman scattering, evanescent-wave coupling and plasmonics resonance.

1) *Blood pH:*Real-time monitoring of pH in the blood should be always accompanied by measurement of the oxygen and carbon dioxide partial pressures, pO2 and pCO_2respectively. Continuous and real-time knowledge of these parameters is of paramount importance in operating rooms and intensive-care units, in order to determine the quantity of oxygen delivered to the tissues and the quality of the perfusion. Conventionally, these parameters are measured by bench top blood-gas analysers on manually-withdrawn blood samples. In any case, significant changes may occur in blood samples after their removal from the body and before measurement is carried out by means of a blood-gas analyser.

Thanks to their ability to provide continuous monitoring, FOSs represents a welcome improvement in patient management. A different approach, recently proposed but still not tested in vivo [5], makes possible simultaneous multi-analyte detection with a single bundle of imaging fibres (1500 individual 10 μm fibres with an overall diameter of 400 μm). Spatial discrimination is obtained by creating, at the distal end of the bundle, separate portions with different indicating chemistry obtained by means of the photo-polymerization process.

2) *Bile:* The demand for FOSs for in vivo monitoring of foregut functional diseases is notably on the increase. The first and, to-date, only FOS available on the market for such an area of application is the Bilitec 2000.The instrument evaluates the logarithm of the ratio between the light intensities collected by the detection system. Since, according to the Lambert–Beer law, the difference in the logarithms measured in the sample and in pure water is proportional to the bilirubin concentration, said difference is related to the bile-containing reflux in the stomach and/or oesophagus. The method has been validated on numerous patients by inserting the optical fibre bundle into the stomach or oesophagus via the nasal cavity [6].The sensitivity of the sensor is 2.5 μmol/L (bilirubin concentration), and the working range is 0÷100 μmol/L. This range fits well with the range which can be encountered in the stomach or in the oesophagus: even if the bilirubin concentration in pure bile can be as high as 10 mmol/L, It is progressively diluted to its final concentration in the refluxate by pancreatic enzymes, duodenal secretion and, lastly, by the gastric content. Clearly, the characteristics of the above mentioned sensor refer to in vitro tests; as for in vivo measurements, since the gastric content is inhomogeneous with both mucus and solid particles suspended, although the absorbance values could numerically express the bilirubin concentration, they can only make possible an approximate quantitative assessment of the overall bile reflux concentration.

IV. CONCLUSIONS

Biosensors have advanced substantially in recent years. Nowadays, biosensor research is directed toward the development of simple applications that can solve specific problems. The FOSs described above has given good results in in vivo testing. Some of these are already commercially available, while others are being developed in response to have demands from medical profession and encouraging market studies. T he utilization of FOSs is increasing continuously, and this fact makes it feasible to imagine their more and more widespread diffusion for in vivo monitoring. The possibility of FOSs, in some cases already exploited [7, 8, 9, 10, 11], of monitoring several parameters using optical fibres with single instrument to make them still more competitive with the other techniques. It also continuously encouraged by physicians, who greatly appreciate the possibility of having a multi test portable unit with low-cost disposable probes, that can be easily managed by both doctors and patients

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REFERENCES

1. M. D. Marazuela and M. C. Moreno-Bondi "Fiber-optic biosensors – an overview," Analytical and Bioanalytical Chemistry, vol. 372, pp. 664-682, 2002.
2. A. G. Mignani and F. Baldini, "Biomedical sensors using optical fibres," *Reports on Progress in Physics*, vol. 59, pp. 1-28, Jan. 1996.
3. M. P. Byfield and R. A. Abuknesha,"Biochemical aspects of biosensors",*Biosens Bioelectron*, vol.9, pp. 373–400, 1994.
4. H. Manap, "An Ultra Violet Optical Fibre based Sensor for Ammonia Detection in the Agricultural Sector," PhD. thesis, University of Limerick, Ireland, Jan. 2011.
5. H. Bueker, F. W. Haesing and E. Gerhard, "Physical properties and concepts for applications of attenuation based fiber optic dosimeters for medical instrumentation," in *Proc. SPIE 1992 Fiber Optic Medical and Fluorescent Sensors and Applications*, 1648, p. 63.
6. P. Bechi, F. Pucciani, F. Baldini, F. Cosi, R. Falciai, R. Mazzanti, A. Castagnoli, A. Passeri and S. Boscherini, "Long-term ambulatory enterogastic reflux monitoring. Validation of a new fiber-optic technique", *Digestive Diseases Sci.,* vol. 38, pp. 1297–306, 1993.
7. R. Wolthuis, G. Mitchell, J. Hartl and E. Saaski, "Development of dual function sensor system for measuring pressure and temperature at the tip of a single optical fiber," *IEEE Trans. Biomed. Eng*., vol. 40, pp. 298–302, 1993.
8. J. L. Gehrich, D. W. L¨ubbers, N. Opitz, D. R. Hansmann, W. W. Miller, K. K. Tusa and M. Yafuso, "Optical fluorescence and its application to an intravascular blood gas monitoring system", *IEEE Trans. Biomed. Eng.*, vol. 33, pp. 117–32, 1986.
9. D. R. Walt and K. S Bronk, "Spatially resolved photo-polymerized image-ready single fiber sensor for blood gas analysis", in *Proc. SPIE 1992 Fiber Optic Medical and Fluorescent Sensors and Applications*, 1648, p.12.
10. C. D. Anderson, D. Vokovich and M. T. Wlodarczyk, "Fiber optic sensor for simultaneous oxygen saturation and blood pressure measurement", in *Proc. SPIE 1992 Fiber Optic Medical and Fluorescent Sensors and Applications,* 1648, p. 116.
11. M. Sun and A. Kamal, "A small single sensor for temperature, flow, and pressure measurement", in *Proc. SPIE 1991 Optical Fibers in Medicine VI*, 1420, p. 44.