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COMPARATIVE STUDY OF FIBER OPTIC BIO-MEDICAL SENSORS AND THEIR CONFIGURATION

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ABSTRACT

In this paper, comparative study of two fiber optic Bio-medical sensors and their configuration are presented. Both sensors are related to bio-medical field. First is the Fibre Optic Sensors for Blood Pressure Measurements in a Swine Model and secondly textile fiber optic micro bend sensor for heartbeat and respiration monitoring.In the, first Fiber optic sensors are potential techniques for diagnosis of coronary artery disease by measuring the blood pressure difference across a coronary artery stenosis. A complete packaging solution to a miniature fiber optic sensor was designed accordingly, including fiber pretreatment, coating, tubing, and coil assembly, so that the packaged fiber optic sensor can work effectively and robustly in the coronary artery of a swine model and in other sensorcan be used to measure heartbeat and respiration rate simultaneously during standing and sitting position. Researchers combined the product outgrowths of fiber optic telecommunications with optoelectronic devices to emerge fiber optic sensors. Numerous researches have been conducted in past decades using fiber optic sensors with different techniques. Intensity, phase, and wavelength based fiber optic sensors are the most widely used sensor.

Keywords: Fiber Optics, Optical Fiber Sensing, Fiber Bragg Gratings (Fbgs), Interferometry, Microbending, Textile Heartbeat, Respiration, Smartstructures, Biomedical, Fiber Optic Sensor, Intravascular Pressure, Packaging.

I. INTRODUCTION

Invention of laser, researchers motivated to study the potential of fiber optics for data communications, sensing, and other applications. Laser systems could send a much larger amount of data than microwave, and other electrical systems. Glass fibers soon became the preferred medium for transmission of light [1].

In 1969, several scientists concluded that impurities in the fiber material caused the signal loss in optical fibers. By removing these impurities, construction of low-loss, optical fibers was possible [1].

Recent advances in fiber optic technology have significantly changed the telecommunications industry. The ability to carry gigabits of information at the speed of light increased the research potential in optical fibers. Simultaneous improvements and cost reductions in optoelectronic components led to similar emergence of new product areas.

Last revolution emerged as designers to combine the product outgrowths of fiber optic telecommunications with optoelectronic devices to create fiber optic sensors.

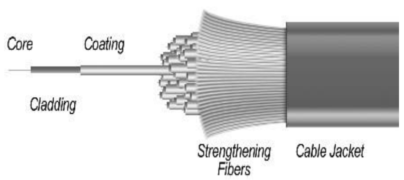
Soon it was discovered that, with material loss almost disappearing, and the sensitivity for detection of the losses increasing, one could sense changes in phase, intensity, and wavelength from outside perturbations on the fiber itself. Hence fiber optic sensing was born [2].

Fiber optic sensors have been widely used to monitor a wide range of environmental parameters such as position, vibration, strain, temperature, humidity, viscosity, chemicals, pressure, current, electric field and several other environmental factors [3].

II. OPTICAL FIBER BASICS

Fibre optics is nothing but bunch of fibre in which light wave propagating inside the fibre on the phenomenon of total internal reflection which occurs in the guide medium. It is very thin wire like human hair which is made of glass or silica. It consists of three parts; the core, the cladding, and the coating or buffer. The basic structure is shown in Figure 1.

The core is a cylindrical rod of dielectric material and is generally made of glass. Light propagates mainly along the core of the fiber [1].



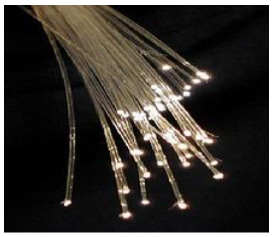


Fig. 1. Basic structure of optical fibre **Optical Fiber**

The cladding layer is made of a dielectric material with an index of refraction. The index of refraction of the cladding material is less than that of the core material. The cladding is generally made of glass or plastic [1].

The coating or buffer is a layer of material used to protect an optical fiber from physical damage. The material used for a buffer is a type of plastic. The buffer is elastic in nature and prevents abrasions [1].

The light-guiding principle along the fiber is based on the “total internal reflection”. The angle at which total internal reflection occurs is called the critical angle of incidence. At any angle of incidence, greater than the critical angle, light is totally reflected back into the glass medium (see Figure 2). The critical angle of incidence is determined by using Snell's Law. Optical fiber is an example of electromagnetic surface waveguide [1].

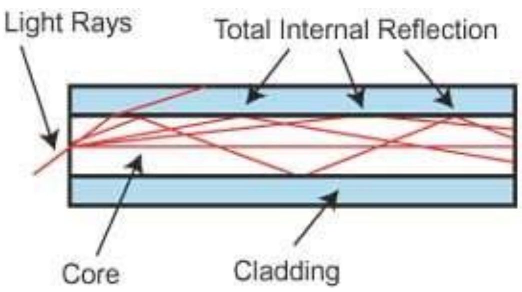


Fig 2. Total internal reflection in an optical fiber.

Optical fibers are divided into two groups called single mode and multimode. In classifying theindex of refractionprofile, we differentiate between step index and gradient index. Step index fibers have a constant index profile over the whole cross section. Gradient index fibers have a nonlinear, rotationally symmetric index profile, which falls off from the center of the fiber outwards [4]. Figure 3 shows the different types of fibers.

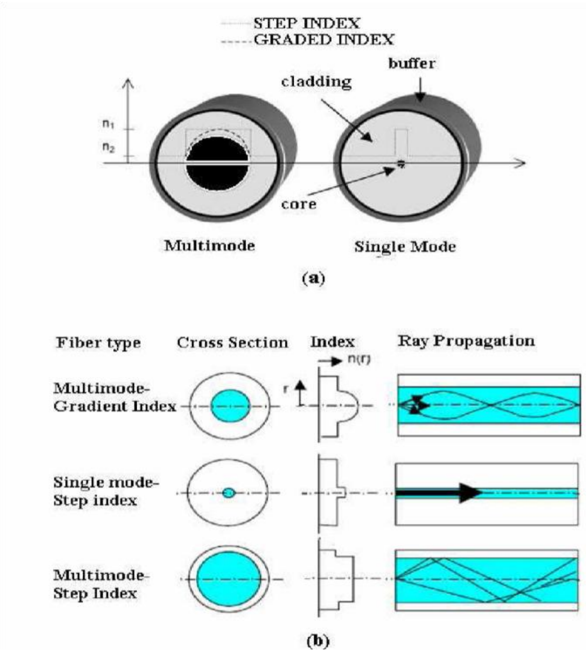


Figure 3. Different types of optical fibers.

III. FIBER OPTIC SENSOR PRINCIPLES

The basic concept of sensors is that the data which has to send in the other location is in form of electrical signal and sensors sense it and convert it in to light form.The general structure of an optical fiber sensor system is shown in Figure 4. It consists of an optical source (Laser, LED, Laser diode etc.) optical fiber, sensing or modulator element (which transduces the measured to an optical signal), an optical detector and processing electronics (oscilloscope, optical spectrum analyzer etc.)

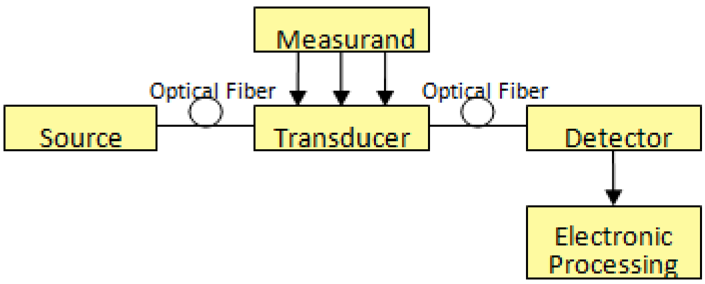


Fig 4. Basic components of an optical fiber sensor system.

Fiber optic sensors can be classified under three categories: The sensing location, the operating principle, and theapplication.

Based on the sensing location, a fiber optic sensor can be classified as extrinsic or intrinsic. In an extrinsic fiber optic sensor (see Figure 5), the fiber is simply used to carry light to and from an external optical device where the sensing takes place. In this cases, the fiber just acts as a means of getting the light to the sensing location.

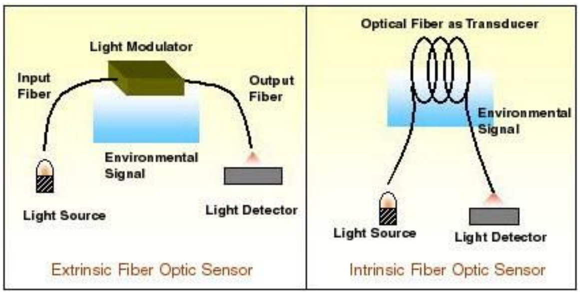


Figure 5. Extrinsic and intrinsic types of fiber optic sensors.

On the other hand, in an intrinsic fiber optic sensor one or more of the physical properties of the fiber undergo a change (see Figure 5). Perturbations act on the fiber and the fiber in turn changes some characteristic of the light inside the fiber [5].

Based on the operating principle or modulation and demodulation process, a fiber optic sensor can be classified as an intensity, a phase, a frequency, or a polarization sensor. All these parameters may be subject to change due to external perturbations. Thus, by detecting these parameters and their changes, the external perturbations can be sensed [6].

Based on the application, a fiber optic sensor can be classified as follows:

- Physical sensors: Used to measure physical properties like temperature, stress, etc.
- Chemical sensors: Used for pH measurement, gas analysis, spectroscopic studies, etc.
- Bio-medical sensors: Used in bio-medical applications like measurement of blood flow, glucose content etc.

IV. FIBER OPTIC SENSOR TYPES

Bio-medical sensors

4.1 Fibre Optic Sensors for Blood Pressure Measurement in Swine Model.

Fiber optic sensors may be widely used for diagnosis of coronary artery disease; however, there is no available packaging method to accelerate the device. The packaging requirements summarized below should be taken into

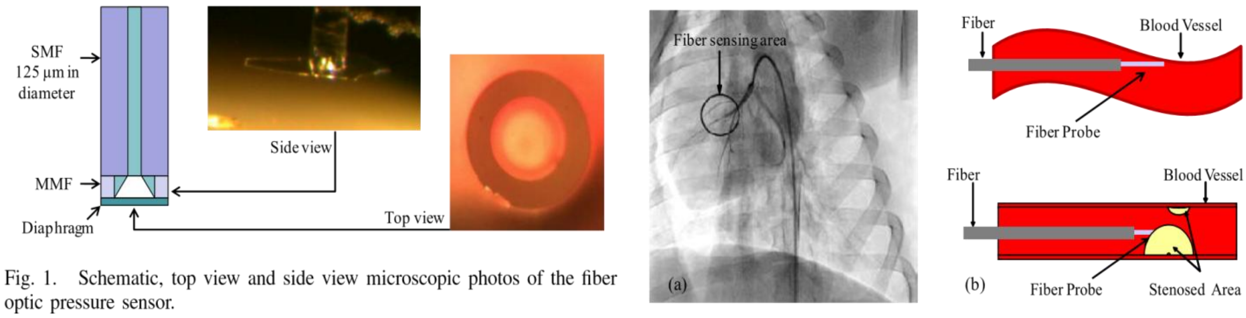


Fig. 6. Schematic top view and side view microscopic photos of the fiber optic pressure sensor.

Consideration:

1) There should be a covering layer around the stripped bare fiber to protect it from external forces.

2) There should be an enclosure around the delicate fiber tip to prevent surrounding contact.

3) There should be an opening for the enclosure to allow the outside blood pressure to interact with the fiber sensing element

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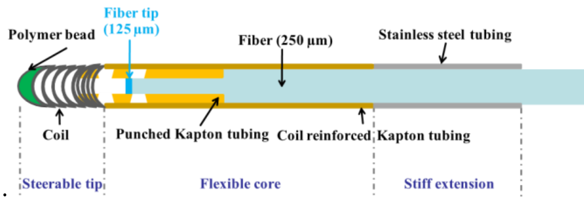

Fig. 7Overviewof the packaging design.

5) The mechanical properties of the different sections of the packaged device should vary from the steerable tip to the flexible core and to the stiff extension in order to improve maneuverability and to prevent bending loss.

6) A fiber glass pretreatment should be performed before packaging to repair the fiber surface cracks.

7) The packaging length should be longer than 1.5 m for human use.

8) The final outer diameter (OD) should be uniform and approximately 355.6 μm, which is close to the dimensions of commercial guide wires for artery use.

A complete packaging solution for the fiber optic sensors used in *in-vivo* blood pressure measurements. A typical guide wire consists of three main segments: steerable tip, flexible core and stiff extension. Proper flexibility, steerability and stiffness across different sections of the fiber optic sensor are considered for related applications and tested at various vessel locations inside a swine model.

Fiber optic sensor was designed accordingly, including fiber pretreatment, coating, tubing, and coil assembly, so that the packaged fiber optic sensor can work effectively and robustly in the coronary artery of a swine model. For blood pressure measurements, the tip section of fiber optic sensors needs to be flexible, while the main section needs to be sufficiently stiff to prevent the sensors from over-bending. The steerable tip makes it easy to deliver the guide wire to the desired position in a blood vessel, while the stiff extension provides the guide wire with excellent torque control and helps the sensor excellent torque control straighten the net force pushing it forward.

The Kapton tubing has openings that allow the blood pressure outside to interact with the fiber sensing area. Steerability is a critical issue for fiber optic, blood pressure sensors. Fig. 6(a) shows an X-ray image of an animal test using a swine model conducted at University of Massachusetts Memorial Medical Center [7]. The encircled region is the fiber sensing area that shows a long fiber that needs to be inserted through a tortuous, blood vessel path to reach the very thin blood capillaries. Fig. 6(b) shows two cases in which a fiber probe may injure the blood vessel when it is outside the catheter.

The cavity inside an optical fiber was thermally bonded with a thin silica diaphragm (1.5 μm or 3 μm thick). The fragile diaphragm, on which blood flow directly impacts, is the critical fault of the pressure sensor. A protection mechanism for the fiber tip area is necessary to prevent its physical damage.

The schematic design for a fiber optic sensor that is fully packaged to meet the biomedical application requirements for blood pressure measurements is shown in 7.Kapton tubing is used to cover the stripped, bare fiber to protect it from external forces, similarly, the coil reinforced Kapton tubing works together with the Kapton tubing as an enclosure around the delicate fiber tip to prevent the area from contacting its surrounding. Additionally, the Kapton tubing has openings that allow the blood pressure outside to interact with the fiber sensing area. All covering materials are either made of biocompatible polyimide or coated with polytetrafluoroethylene (PTFE).The packaging length is longer than 1.5 m for clinical use. The uniform OD is approximately 355.6 μm, which is suitable for blood vessel use.

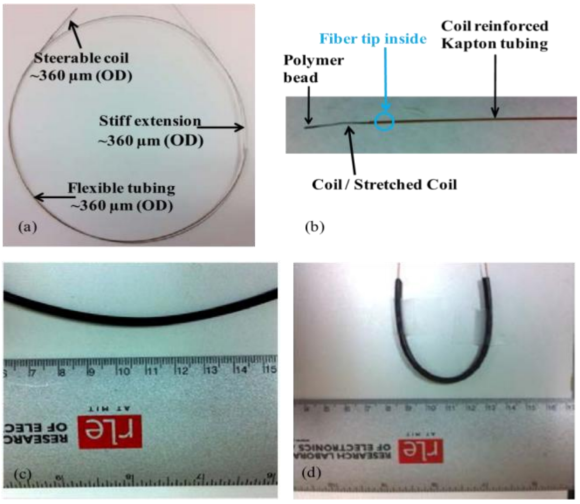

Fig. 8. (a) Photo of a packaged fiber-optic blood pressure sensor; (b) Zoomin photo of the packaged tip section; (c) Bare, burned fiber tip damage in the plastic tubing at bending radius of 20 cm; (d) Packaged fiber pass-through of the plastic tubing at bending radius of 2.5 cm.

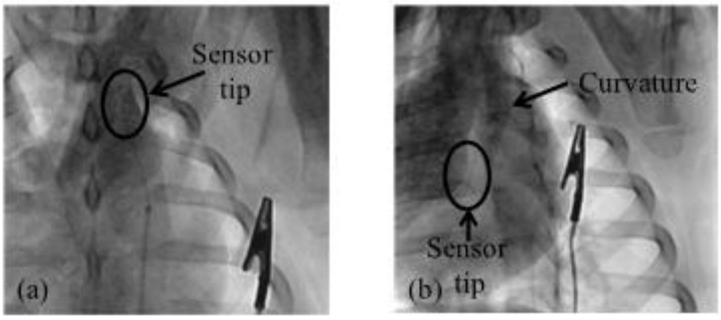

Fig. 9. (a) X-ray photo when the fiber optic sensor was measuring at the aortic arch; (b) X-ray photo when the fiber optic sensor was measuring at the right coronary artery

4.2 Textile fiber optic microbend sensor for heartbeat and respiration monitoring.

The textile fiber optic micro bend sensor used for heartbeat and respiration monitoring simultaneously during standing and sitting position. It can help toidentify heart and lungdiseases such as: heart failure, heart attack, stroke and apnea [9].

Its design is based on fiber micro bending effects a section of multimode optical fiber sandwiched between parallel strips acting as a micro bender is being integrated onto an elastic substrate. In other word we can say thatin this sensor, the elastic substrate and the sinusoidal pattern of the optical fiber makes the period of the bent fiber change with the breathing action and heartbeat of the wearer [10].

It designed and demonstrated a novel textile fiber micro bend sensor for heartbeat and respiration monitoring simultaneously. The heart rate and respiration rate were verified using a commercial SpO2 and golden standard. The frequency characterization of the sensor was tested with a simulation setup with an electronic motor, and the sensitivity of the sensor was found to decrease with the increase of the motor speed (rpm) from 6.9rpm to

105rpm. Textile fiber optic sensor possesses merits of simple fabrication, low cost and high sensitivity and is suitable /comfortable enough for continuously monitoring of the vital signs in daily life activities [11].

The micro bend fiber optic sensors developed for the measurement of vital signs are studied and were embedded in pillows/cushions or on bed [8]. By virtue of its simplicity and low cost for implementation, It can measure the breathing rate, heart rate, and body movement simultaneously and non-invasively, and it is suitable for long term continuous monitoring with no constrain on the user's activity and without the need for skin contact.

When this sensor wraps the upper body of a person, the breathing action and heartbeat of the person will exert force on the optical sensing fiber from the lateral and tangential direction.

The textile fiber sensor sheet was tested on healthy adults to measure the heartbeat and respiration activities. We wrapped the elastic textile sensing belt around the upper body of the volunteer who sits or stands as in Fig 10. The sensing optical fiber is in the middle section of belt we call sensing area. The belt can wrap

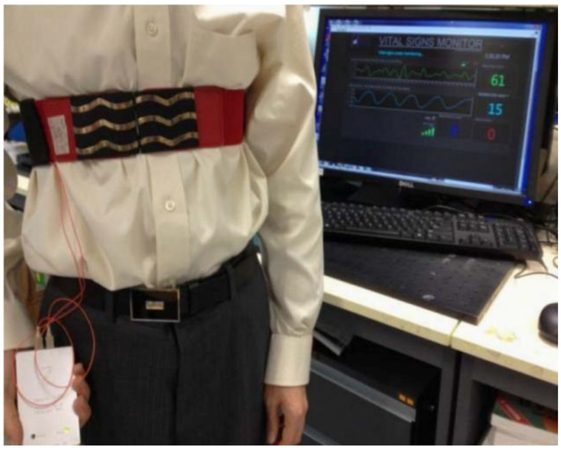

Fig.10 Heartbeat and respiration measurement.

Heart beat and respiration measurement in standing position

Around the upper body (thorax or waist position) of a person to measure the cardiac and breathing activities and the sensing area can be on the back or chest position. The mechanical activities of cardiac muscle and respiration are applied to the sensing optical fiber which modulates the light in the fiber. The light received by an optical receiver reflects the heartbeat and respiration action. In this measurement, the sensing area was on the back of the volunteer. The initial length of the whole belt is about 70 cm.

Electronic motor, and the sensitivity of the sensor was found to decrease with the increase of the motor speed (rpm) from 6.9rpm to 105rpm. Textile fiber optic sensor possesses merits of simple fabrication, low cost and high sensitivity and is suitable /comfortable enough for continuously monitoring of the vital signs in daily life activities[12] W. B.

V. CONCLUSION

Over view of comparative study,we find that Both sensors are bio-medical but first is used for Blood Pressure measurement in swine model and may be widely used for diagnosis of coronary artery disease in animals.it is complete packaging solution and other one is used for heart beat and respiration monitoring for human beings. It can help to identify heart and lung diseases such as: heart failure, heart attack, stroke and apnea. This sensors is in form of belt.

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