

# A review on optical fiber sensors for biomedical sensing.

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**Abstract:** The development of optical technology for sensing purpose is growing extensively. Its applications are varied, ranging from field like aerospace equipment, military, security, process control and in later years, in health and medicine. Tremendous research work and advancement has led to the development of various optical sensors which is suitable for biomedical industries. This paper gives an overview of optical sensing technologies and advantage that it provides to biomedical field. Study of characteristics of biomedical optical sensors and different parameter like temperature, pressure, humidity etc, which have been successfully measured using fiber optical sensor.

**Keywords:** optical fiber sensor, physical parameter, sensing technologies, diagnosis, health care, biocompatibility

## I. INTRODUCTION

Numerous research and advancement has led to the development of various sensors which are capable of biomedical monitoring. Actually the application of optical fibre bundle in medicine has started in sixties when it was premiered in endoscopy both for illumination and for imaging. Later dermatology and plastic surgery, eye surgery, endovascular surgery, and foot and ankle, gastro-intestinal tract, oral and dental surgery were made possible using fiber which witnessed to be most flexible and a low attenuation delivery system inside the auxiliary channels of endoscope and inside human being. Researches done in eighties and nineties has contributed a lot in biomedical area, where sensing was a great application of optical fibre. This characteristic of fiber has given recent researchers a room to develop sensors for medical field as well as varied aspect of life.

Optoelectronics and fiber optical communication collaborative evolution have resulted in better products which can replace those traditional sensors by optimization of cost and components. Earlier in 1960's fiber optic sensor made for medical use was mostly intensity modulation based, but they were very bulky in size so arduous to construct and implement, and pricy too. They included more than one fiber or fiber bundles to direct light, this made the sensing arrangement an elaborate one[1].

## II. OPTICAL SENSING TECHNOLOGY FOR MEDICAL FIELD

Due to recent advances in optoelectronics field, there is a great excitement in medical device companies, industries and institute to use optical technologies for sensing and diagnostic purpose of biochemical and biophysical parameters. These parameters are physical which include are body temperature, intracranial pressure, blood flow, radiation dose for cancer detection, and chemical parameters composition of blood and tissue PH are already being detected by optical sensor using fiber optic probe placing remotely in patients body. The fiber optic has got its own advantage as they have good biocompatibility for near and visible infrared wavelength, it also provide scope of miniaturization and also faster speed which light offers and safe as no electrical connection involved in human body. In this section we will briefly describe the latest mechanism being explored for biomedical sensing for biomedical optical sensing today including interferometry, infrared absorption, scattering, luminescence and polarimetry.

*Intensity modulated sensing (fotonic sensors):* It is the most simplest technique among the other sensing techniques using optical fiber. Here the intensity of modulated light is being measured at the receiver end. Many parameters can be measured using this technique such as pressure, temperature, heart rate monitoring, except for those which cannot create intensity losses in guided beam of light. Benefit of using this technique is that its implementation just requires a source, a receiver and a detector which makes it cheaper and less complex though it works as real distributed sensor [r1]. Further more these distributed sensors has two methodologies on which they work the first one is Brillouin scattering and the other one is optical time domain reflectometry (OTDR). Brillouin scattering occurs when light, transmitted by a transparent carrier interacts with that carrier's periodic spatial & temporal variations in refractive index. As in optics, the index of refraction of a transparent material changes under deformation. The result of the interaction between the light-wave and the carrier-deformation wave is that a fraction of the transmitted light-wave changes its momentum in preferential directions.

OTDR uses an inner back scattering properties of optical fiber to detect and categorize its condition by sending high power pulse of laser light down into the fiber and capturing the reflected light. This is useful technique to determine the losses and learn about the defect in the fiber. However this technique

determines the changes on relative basis, a cross referencing system is a must for its reliability [2].

**Spectrometric or quasi-distributed fiber sensors:** This sensor is based on alteration of wavelength of light. Sensing based on converted wavelength results makes multiplexing easy. Hence every periodic segments of fiber acts as sensors and the periodic formation is acquired when the fiber is grating.[3] Fiber Bragg Grating (FBG) based sensing systems has distinctive characteristics which has made this technology very capable and dependable for long term sensing furthermore suitable for various health assessment in medical field. In FBG a photorefractive effect of optical has been utilized, where period of grating depends on reflection wavelength.[10].

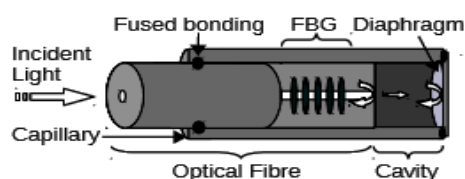


Figure 1. Layout of a combined Fiber Bragg Grating and an Extrinsic Fabry Perot Interferometer, forming an Optical Fiber Pressure and Temperature Sensor.

In construction of Bragg grating, small segments of fiber reflects for every unique wavelength however to achieve this variation are added to refractive index of core of the optical fiber, which as a result creates wavelength specific dielectric mirror. Therefore fiber Bragg grating can block specific wavelength acting as filters. There are many applications of Fiber Bragg grating technique in this new age of communication system. They are already utilized in developing temperature and strain sensor and also in quasi distributed Fiber Bragg grating pressure sensors. Specifically fiber Bragg grating optical sensor delivers exceptional operational results along with additional benefits like low noise, wide range, high sensitivity. Figure 1, consists of a miniature diaphragm based all-silica Extrinsic Fabry-Perot Interferometric (EFPI) Fibre Optic Pressure Sensor (FOPS) which additionally incorporates a Fibre Bragg Grating (FBG) temperature sensor highly suitable for in-situ patient monitoring.

**Interferometric fiber sensors (sensing using phase):** Basic principle of these sensor is that it works on modulation of phase of light coming out of single mode fiber. This relative change of phase are transformed into intensity utilizing interferometric strategies such as Sagnac forms, ring resonators, Mach-Zehnder, Michelson, Fabry- Perot or dual mode, polarimetric, grating and Etalon based interferometers.[4-6] Frequently used instrument is Mach-Zehnder. The Michelson interferometer is currently being investigated for sensing other biophysical parameters such as

tissue thickness, particularly for corneal tissue as feedback for the radial keratectomy procedure, which is laser removal or shaving of the cornea to correct vision [7-8]. Optical coherence tomography is also interferometric based technique which provides non invasive diagnostic image. Its importance are increasing in the field of medical science. In this technique we measure the intensity of infrared light which is reflected back. It helps in diagnosis of disease like macular disease, genetic retinal disease, retinal detachment and retinoschisis, choroidal tumors, optic nerve disorders, and glaucoma [9].

One example of a fiber optic based interferometric sensor is the commercially available intracranial fluid pressure monitoring system for patients with severe head trauma or a condition known as hydrocephalus, which is an increased amount of cerebral spinal fluid in the ventricles and/or subarachnoid spaces of the brain.

**Polarization modulated sensor:** Polarization property of light has been utilized glucose and tissue characterization particularly cancer diagnosis.[11-14]. Single mode fibers are slightly noncircular and under non symmetrical thermal stress distribution, its elemental mode split into two independent polarized states. The modes travels with bit different propagation constants and therefore fibers are known for having modal birefringence. Due to birefringence and retardation of the polarized light along with cell and tissue's polarized scattering results a signal, helps in tissue characterization. Application of polarimetry is non invasive health diagnosis where the potential of polarized light are utilized in identifying the tissue disorder or damage due to cancer[15]. Also used for detection of glucose concentration of aqueous humor of the eye.

### III. ADVANTAGE IT PROVIDES OVER ELECTRICAL SENSOR

Researcher in fiber optics are constantly working with sensing and again and again into biomedical sensor. They have succeeded in developing very promising sensors. A drawback of non optical sensors has over biomedical fiber optics sensors.

**Clinical care procedure:** In vitro: Examination of blood and tissue samples in laboratory are much painful and if needs frequent monitoring then patients undergo into great stress. Chances of occurring error are also there due to sample handling.[ In vivo: electrical device( piezoelectric element and thermo coupler) for physical and chemical parameter measurement make patient exposed to electrical connection. They are costly as well as delicate.

Fiber optics sensors for biomedical monitoring easily overcome these drawbacks due to optical fibre very much known for its vital characteristics. **Geometrical ability:** optical fiber is known for its miniaturization, lightness, modifiability which makes it capable of installing it in needles and catheters

and therefore helps in attaining localized measurement of tissue and blood.

*Suitability of material:* optical fibers are made up of either glass or plastic. They are sturdy, non toxic and biocompatible which makes it suitable for continuous measurement. Dielectric nature and consumption of low light power of fiber optics gives it an additional vantage for using it in biomedical monitoring. There is no crosstalk between closed fiber thus we can implant more than one sensors in a catheter [16 -17]. Low attenuation make possible of use of long wire for connecting electronic equipment kept away from patient’s bed. A biomedical sensors should be reliable as measurement may have to be repeated there is no heating of component and its also very accurate and stable in the long run. It is also immune to environmental temperature changes.

IV. PARAMETER MEASURED BY FIBER OPTICAL SENSOR IN MEDICAL FIELD

The use of biomedical instrumentation based on optical fibre application is playing a key role in increasing the longevity of humans such applications aid in diagnosis , monitoring and treatment with minimum invasive surgery[25]. There by increasing the demands for ever availability of constantly diminishing the size of sensors by miniaturisation.

The fibre optical biomedical sensors cab be classified into the following types (a) physical (b) imaging (c) chemical (d) biological. *Physical:* this type of sensors basically measures parameters like temperature [18-19], blood pressure, muscle displacement etc. *Imaging:* imaging sensors basically include endoscopic equipments for imaging and observation of internal organ. It also includes latest techniques and procedures such as OCT (optical coherence tomography) which is an established technique to generate 3D images from optical interferometer[21,22]. Also photo acoustic imaging is trending due to its minimal intrusive technology. *Chemical:* A chemical sensor basically identifies the specific chemical specified for diagnostic purpose. It mainly relies on fluorescence, spectroscopic and various indicative techniques to examine various parameters like pH, blood O2 level or sugar level [23]. *Biological:* Such sensors mainly rely on antigen antibody and various enzymes for identification of biological molecules. In the present day sensors although , the optical fibre sensors has been demonstrated other than imaging sensors, which are in the their very advanced stage of development, the other sensors like biological and chemical are in very recent stage.

Physical	Chemical	Biological	Imaging
Body temperature	pH	Antigens	Endoscopy
Blood pressure	pO <sub>2</sub>	Antibodies	Optical coherence tomography (OCT)
Blood flow	PCO <sub>2</sub>	Electrolytes	Photodynamic therapy (PDT)
Heart rate	Oximetry (SaO <sub>2</sub> , SvO <sub>2</sub> )	Enzymes	
Force	Glucose	Inhibitors	
Position	Bile	Metabolites	
Respiration	Lipids	Proteins	
Shape sensing			

Table 1.classification of biomedical sensor by type showing various biomedical parameter of interest.

Latest development (a) a device called ICP (intracranial pressure) sensor , using miniature bellows transducer has been successfully developed and widely used by Camino Labs (San Diego CA) in 1984. Various fibre optic based temperature and pressure sensors have been developed by Luxtron (American company and FISO technologies ( Canada). FISO’s sensors especially work on white light interferometry using EFPI devices[17,18]. Further, companies like Neoptix, Opsono, Samba sensors are constantly working not only towards development of new fibre optic sensors but also reducing the cost for increased application.

Parameter	Company
Temperature	Fiso, LumaSense, Neoptix, OpSens, RJC
Pressure	Fiso, Maquet, OpSens, Samba Sensors, RJC
Coronary imaging	InfraRedx
Oxygenation	ISS
Pulse oximeter	Nonin
Blood flowmeter	ADInstruments
Shape/position	Hansen Medical, Intuitive Surgical, Luna, Measurand, Technobis
Force	EndoSense
EKG/EEG	Srico

Table2. Example of fiber-optic biomedical sensors commercially available by type

Another latest development is the fabrication of shape sensing system using FBG that will respond to the strain and curvature stress during bending. this achieved by multimode and single mode fibre which determine the exact location and shape of instruments and robotic arms during minimal invasive surgeries[24]. Companies like Measurand, Technobis, Hansen medical etc are constantly working on these technologies and improving them.

## V. CONCLUSION

For fibre optical sensor, biomedical sensing is very profitable and growing opportunity particularly in the context of disposable probes. Variety of minimally invasive medical device for a single use as well as small size, that can be well attached to catheters and endoscopes are perfect suit for optical sensor. Fiber optic sensors are compatible to EMI that helps during use of MRI and it is also useful in RF treatments. Not only fiber optics sensor is known for its high potential but its well capable and its feature cannot be obtained otherwise. Expensiveness of these sensors is at times a barrier. Lengthy development process and regulatory process makes the device costly. Excellent sense of material selection and biocompatibility and design as well as patient safety should be kept in mind. Though there are many successful device in the market but many are yet to come.

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