A brief study on Fiber Optics Sensors and its few applications

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Abstract - Optical fiber sensor (OFS) technologies have been developed rapidly over the last few decades, and various types of OFS have found practical applications in the various fields such as civil engineering, medical field, gas sensing era etc. Various OFS are developed to extremely well suitable for different applications.

In this paper, we discussed briefly about basics of optical fibers, basics of optical fiber sensors and few of its glorious applications, which are very helpful for the betterment of mankind.

Index Terms - FOS (optical fiber sensors), sensing, braggs grating, intensity modulation etc.

I. INTRODUCTION:

A new branch in fiber optics [1, 2, 10] developed in parallel with the communication which is well known and interesting called as ‘FIBER OPTIC SENSORS’ [3-7,10]. With the invention of the laser in 1960’s, a great interest in optical systems for data communications began. The inventions of lasers,, motivated researchers to study the potentials 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. Initially, the existence of large losses in optical fibers prevented coaxial cables from being replaced by optical fibers. Recent advances in fiber optic technology have significantly changed the 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. Due to its small size, low cost and ease of fabrication, leading it to replace traditional sensors which were used frequently before the birth of 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 types. In this paper, a brief study of fiber optic sensors and their applications is made and presented. Optical fiber sensor (OFS) technologies have developed rapidly over the last few decades, and various types of OFS have found practical applications in the various fields such as civil engineering, medical field, gas sensing era etc.

II. BASICS OF OPTICAL FIBERS [1-3, 10]:

An optical fiber is a flexible, fiber made of high quality extruded glass or plastic, slightly thicker than a human hair. It can function transparent as a wavelength, or light pipe to transmit light between the two Ends of the fiber. The field of applied science and engineering concerned with the optic design and application of optical fibers is known as fiber optics. Optical fibers are widely used in fiber-communications, which permits transmission over longer distance and at the higher bandwidths than other forms of communication. Fibers are used instead of metal wires because signals travel along them with less loss and are also immune to electromagnetic interference. Fibers are also used as sensors and fiber lasers. They are used as light guides in medical and other applications where bright light needs to be shown on a target without a clear line-of-sight path. Many microscopes use fiber optic light sources to provide intense illumination of samples being studied.

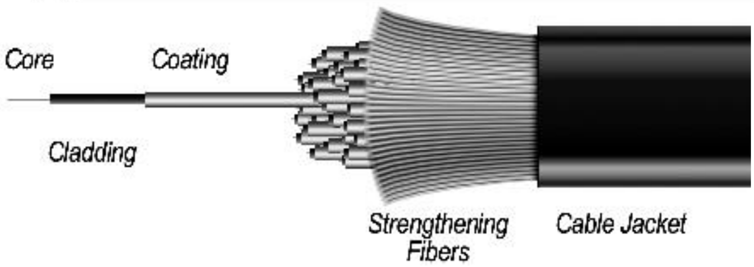


Fig.1: Basic Structure of Optical fiber

An optical fiber is composed 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. 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. The cladding executes such functions as decreasing loss of light from core into the surrounding air, decreasing scattering loss at the surface of the core, protecting the fiber from absorbing the surface contaminants and adding mechanical strength.

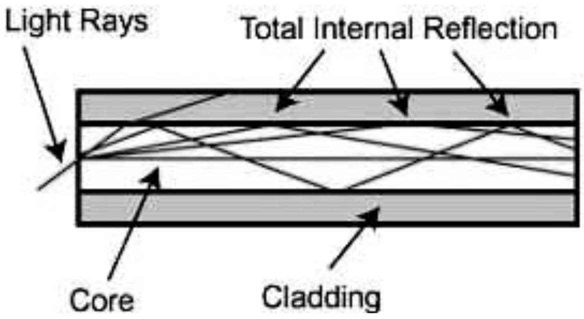


Fig.2: Total internal reflection in optical fiber.

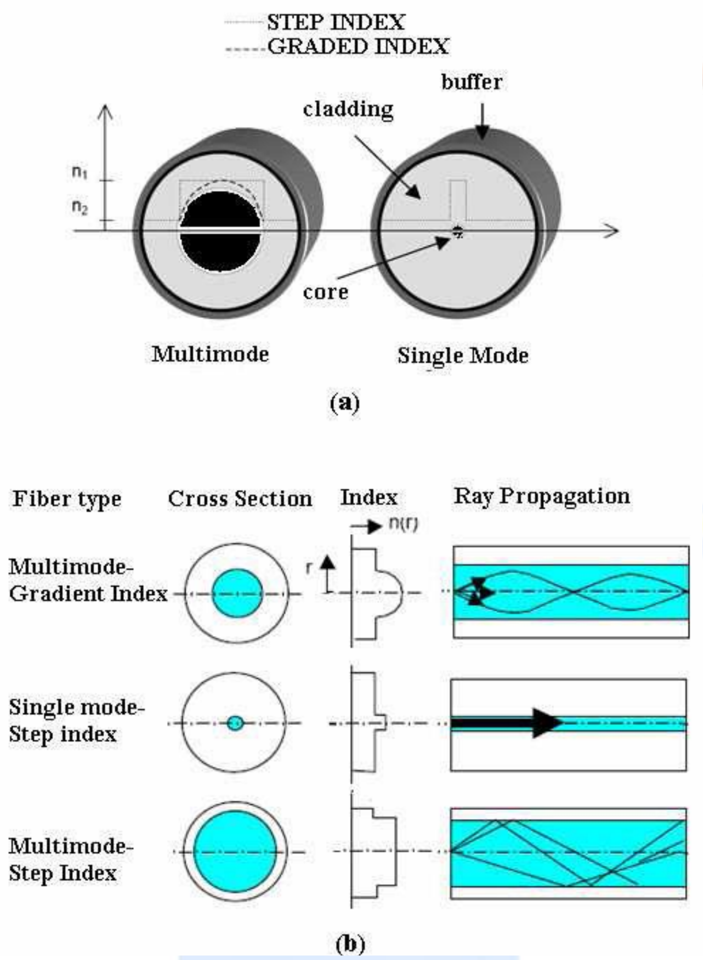


Fig.3: Different types of fibers and ray propagation through each type

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. 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 fig. 2). The critical angle of incidence is determined by using Snell's Law. Optical fiber is an example of electromagnetic surface waveguide. Optical fibers are divided into two groups called single mode and multimode. In classifying the index of refraction profile, 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. Figure 3 shows the different types of fibers.

III. FIBER OPTIC SENSOR PRINCIPLES AND THEIR CLASSIFICATIONS:

Basic Principle: 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 measurand to an optical signal), an optical detector and processing electronics (oscilloscope, optical spectrum analyzer etc).

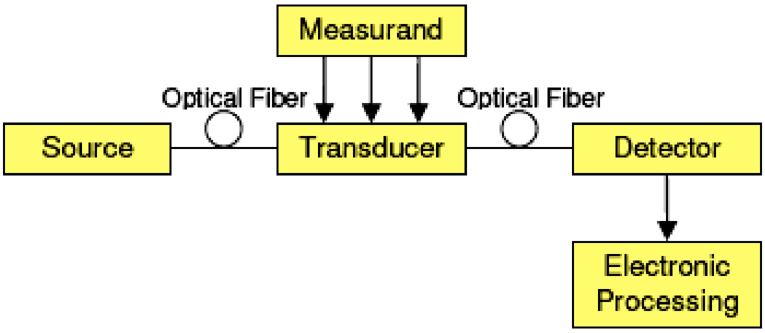


Fig.4: Basic component of optical fiber sensor system

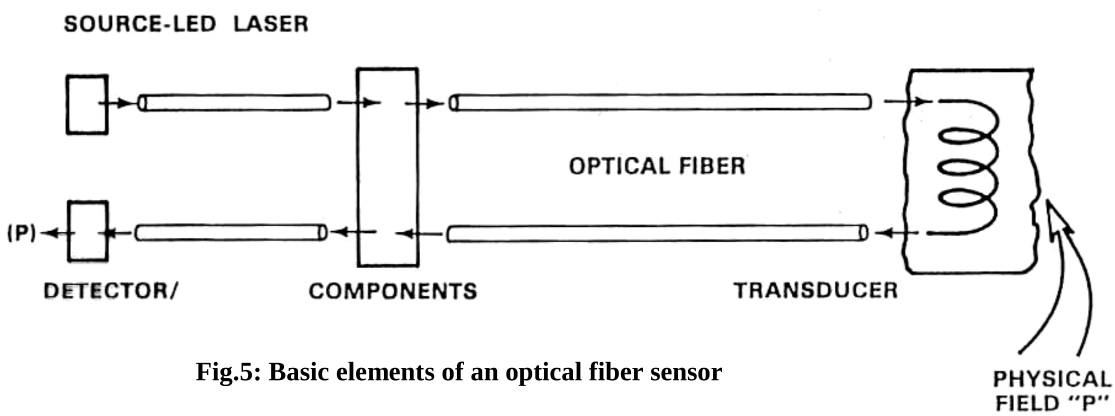


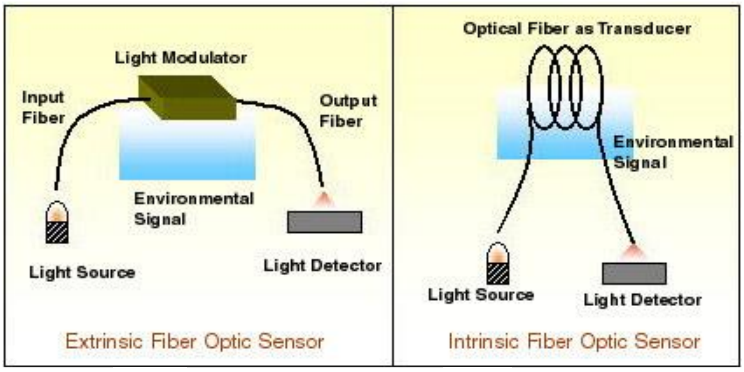
Fig.5: Basic elements of an optical fiber sensor

The principle of operation of a fiber sensor is that the sensing elements modulates some parameter of the optical system (intensity, wavelength, polarization, phase, etc.) which gives rise to a change in the characteristics of the optical signal received at the detector.

Classifications of Fiber Optics Sensors [4, 5]:

Fiber optic sensors are classified as: The sensing location, the operating principle, and the application.

A) **Based on the sensing location,** a fiber optic sensor can be classified as extrinsic or intrinsic. In an extrinsic fiber optic sensor (fig. 6(a)), the fiber is simply used to carry light to and from an external optical device where the sensing takes place. In this case, the fiber just acts as a means of getting the light to the sensing location. On the other hand, in an intrinsic fiber optic sensor one or more of the physical properties of the fiber undergo a change (see fig. 6(b)). Perturbations (Change in physical parameter such as change in pressure or temperature) act on the fiber and the fiber in turn changes some characteristic of the light inside the fiber [3]. The fiber sensor can be either an intrinsic one if the modulation takes place directly in the fiber or it is extrinsic, if the modulation is performed by some external transducer as shown in fig. 7. Hybrid FOS is also a possible classification.



(a) (b)

Fig.6: Extrinsic and intrinsic types of fiber optic sensors.

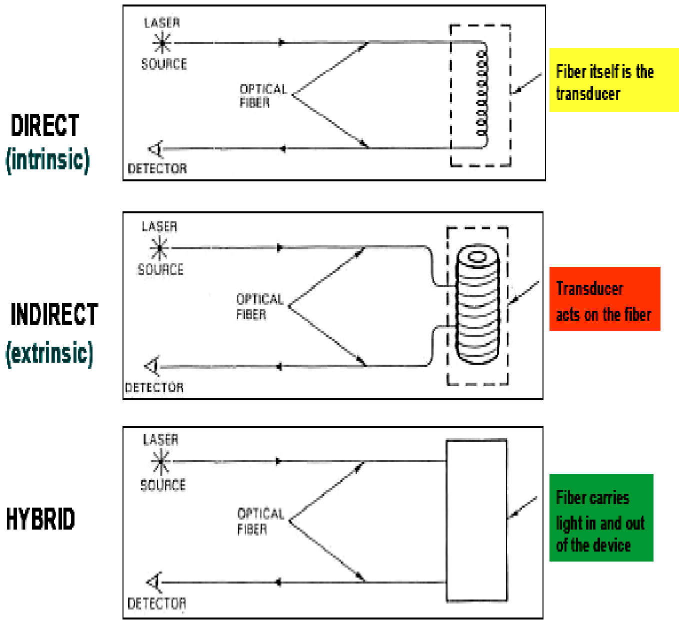


Fig.7: Classification of FOS on the basis of sensing location

B) 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 [4].

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

i. Physical sensors: Used to measure physical properties like temperature, stress, etc.

ii. Chemical sensors: Used for pH measurement, gas analysis, spectroscopic studies, etc.

iii. Bio-medical sensors: Used in bio-medical applications like measurement of blood flow, glucose content etc.

D) Based on response at the measurement point, the fiber optic sensor can be classified as, point to point sensors, multiplex sensors, distributes sensors.

Each of these above mentioned classes of fibers in turns has many subclasses that consist of large number of fiber optic sensors.

➢ **Intrinsic fiber optic sensors:**

Such type of sensor is shown in fig.6 (a). In such type of sensors, sensing takes place within the fiber itself. These type of sensors have their dependency on the optical fiber properties itself to convert an environmental action into a modulation of the light beam passing through it. Virtually, any environmental effect can be converted to an optical signal to be interpreted .Each environmental effect may be measured by dozens of different fiber optic sensors approaches. It has been designed in such a way that it sensed only the environmental effects. The most important characteristic of intrinsic fiber optic sensors is that it provides distributed sensing over long distances.

Some examples of intrinsic sensors are described below-

Pressure Sensor:

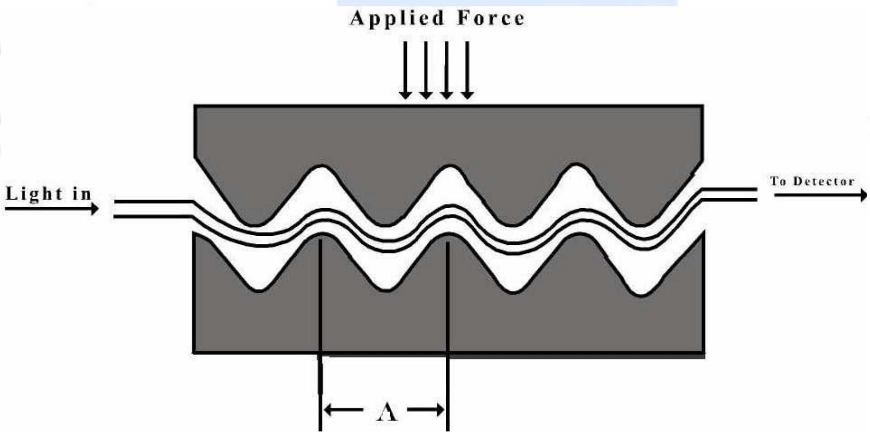


Fig. 8: Intrinsic fiber optic sensor: Pressure Sensor

It is intensity based fiber optic sensor. It is micro bend sensor. Suppose a light of known intensity is allowed to pass through a fiber optic line. And the intensity of output light of the fiber is noted. It is found that, when the fiber bents, there may be intensity losses arising due to this bending. This bending is called micro bending. Thus, the output light intensity is proportional to the amount of micro bending. Therefore, by detecting the changes of output light intensity, the micro bending can be measured.

A schematic diagram of such type of sensor is shown in fig.8. The sensor is comprised of two grooved plates and between them an optical fiber passes. In such type of sensors a fiber is sandwiched between a pair of toothed plates to induce micro bending. When pressure is applied to these toothed pairs, there is a redistribution of guided power between modes of fiber occurs, which changes the power at output end. Once we calibrate such change in optical power with applied pressure we can easily use such system as a pressure sensor. In this type of sensors, intensity of light changes because of the measuring quantity, hence it is also called as intensity modulated fiber optic sensor.

- **Extrinsic fiber optic sensors**:

Such type of sensor is shown in fig.6 (b). In such type of sensors, sensing takes place in a region outside of the fiber and essentially fiber serves as a medium for the to and fro transmission of light to the sensing region efficiently and in a desired form. These sensors may be used strictly as information carriers that lead up to a black box to impress information on a light beam that propagates to a remote receiver. The black box may contain mirrors, a gas or liquid cell, a cantilevered arm or dozens of other mechanisms that may generate modulate or transform a light beam. The most important advantage of using these sensors is that their ability to reach places which seems to be unreachable.

- **Temperature (or Pressure) sensor:**

It is an intrinsic type sensor. Here optical fiber is used to sense the temperature. It works under the principle of interference. It is shown fig. 9. A LASER source is used. Light obtained from it passes through a beam splitter. The beam splitter is kept at 45^{o} with incident beam from LASER source. The beam form LASER source is divided in to two similar parts; one part transmitted through beam splitter and the other part reflected and send perpendicular to the incident beam. The reflected beam is allowed to incident on the lens 2 and the converged beam is allowed to pass through the measurable optical fiber. The transmitted beam is allowed to incident on the lens 2 and the converged beam is allowed to pass through the reference fiber. The measurable optical fiber is kept in the environment whose temperature (pressure) is to be measured. The reference optical fiber is isolated or kept away from the environment whose temperature (or pressure) is to be measured. Due to variation in temperature (pressure) of the environment, changes the refractive index of measurable optical fiber, which in turn changes phase of beam passing through it. The light from measurable optical fiber and the light form reference fiber passes through the lens 3. The light from measurable optical fiber and the light form reference fiber have a phase difference due to various changes in temperature (or pressure). Due to this phase difference, interference pattern occurs. With the help of the interference pattern we can accurately measured change in temperature (or pressure). In this type of sensors, phase of light changes because of the measuring quantity, hence it is also called as phase modulated fiber optic sensor.

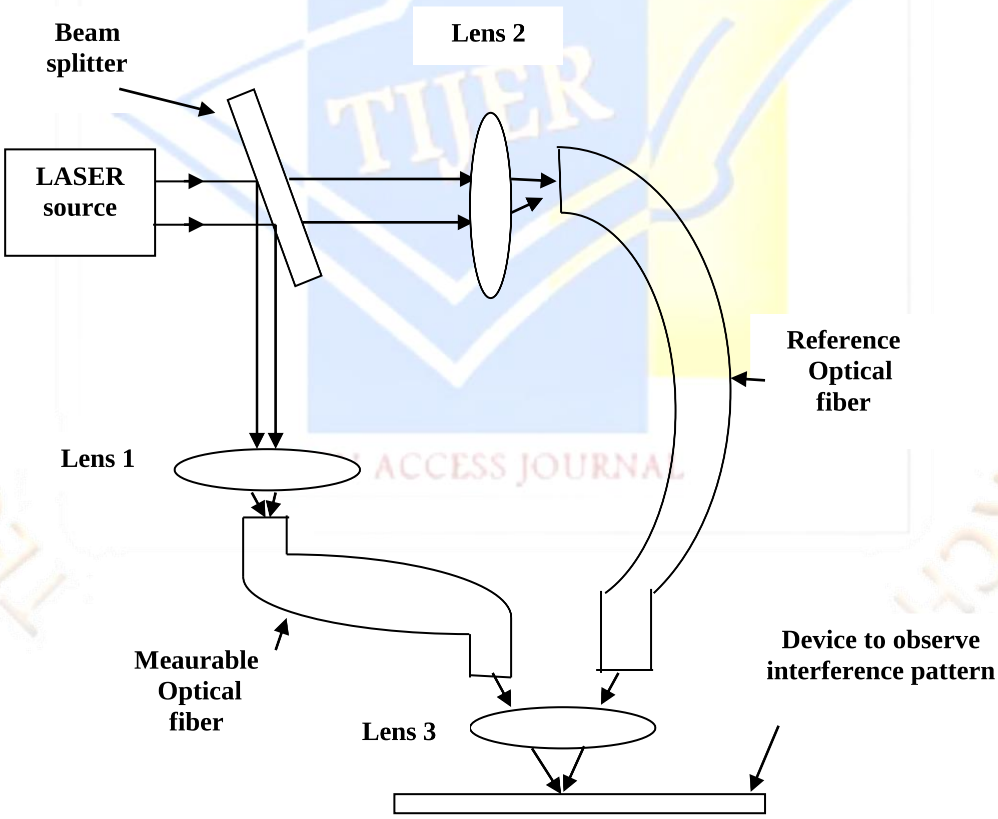


Fig. 9: Temperature (pressure) sensor using FOS based on interference principle

- **Displacement sensor:**

It is an extrinsic type sensor. Here optical fiber is used to sense the displacement of certain object. It is shown fig. 10. It consists of a bundle of transmitting optical fiber and a bundle of receiving optical fiber. A LASER source is used as source of light. When light from the LASER source passed through the transmitting optical fiber and strikes the moving target (object). After striking the moving target, the light get reflected back and it is received by receiving optical fiber and travel through it and fed to a photo detector for detection.

With the help of change in intensity, we can find the displacement of moving target. If the intensity of receiving light is less, then the moving target is going away from optical fiber. If the intensity of receiving light is high, then the moving target is coming towards the optical fiber. In such a way the displacement of a moving object can be obtained by the optical fiber sensor.

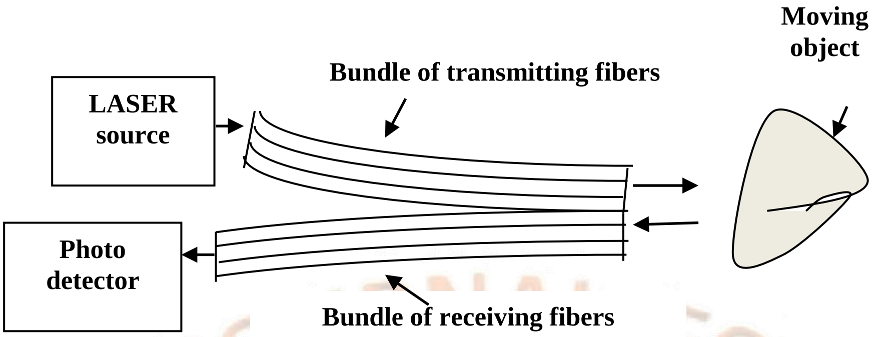


Fig. 10: Displacement Sensor

IV. FIBER OPTIC SENSOR USED IN MEDICAL FIELD [6-8]:

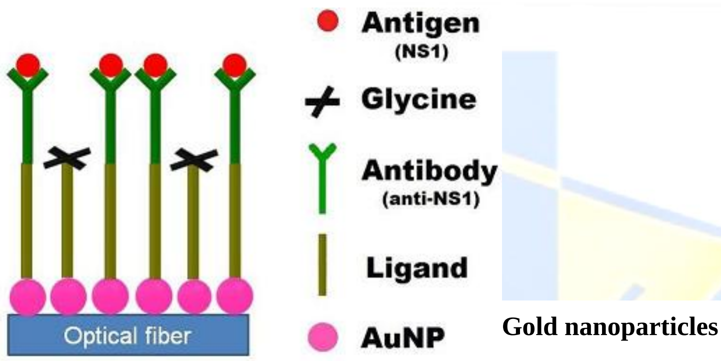


Fig.11: Fiber optic sensor tip for to detect dengue (NS1) antigen

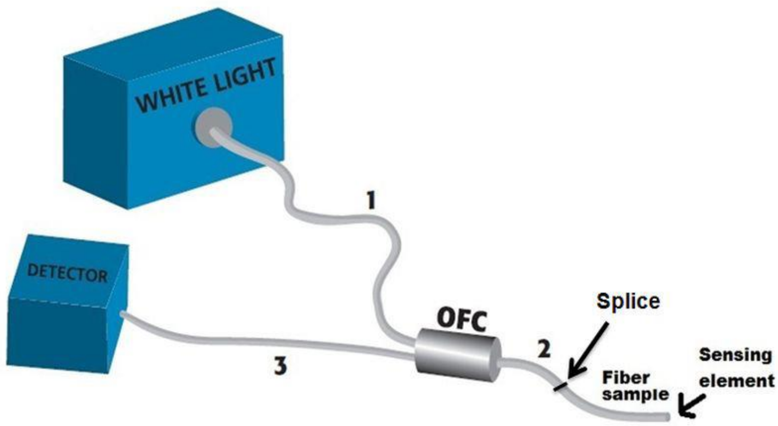


Fig. 12: LSPR-based all-optical fiber sensor to detect dengue (NS1) antigen

There is a huge research and evolution in the medical field. Fiber optic sensor is used in invasive or noninvasive. The small size of sensor is allows to inject into body tissue and their non-galvanic nature makes them genetically electrically protect. Fiber optic sensor has many applications in medical area. Dengue fever is a viral disease that affects millions of people worldwide. Dengue fever is a tropical disease caused by the dengue virus, transmitted mainly by the female 'Aedes aegypti mosquito'. Many laboratorial tests are available to detect this disease but all are taking a long time, having laborious procedure and need highly knowledgeable person to test and analyze. A fast good and simple method to diagnosis this diseases is optical fiber sensors. Localized Surface Plasmon Resonance (LSPR) phenomenon used in optical fiber sensors to detect dengue.

A special sensor is developed with the help of optical fiber to detect antigen of dengue in the sample collected from patient (fig.11). A special sensing element is located at the tip of each optical fiber. It shows a good correlation between wavelength shifts for dengue (NS1) antigen concentration, as well as negligible wavelength shift for zero concentration of dengue (NS1) antigen. The sensor element is dipped for specific time in a saline solution without dengue (NS1) antigen and reflected wavelength is noted. Then the sensor element is dipped for specific time in a saline solution with a sample collected from patient and reflected wavelength is noted. If the collected sample has dengue (NS1) antigen, then there will be shift in the wavelength of reflected light is observed.

Fig.12. shows LSPR based optical fiber sensor system to detect dengue (NS1) antigen. The system consists of a white light source, a detector (spectrum analyzer) and a 2x1 optical fiber coupler (OFC) with standard multimode fiber (62.5μm/125μm). The fiber sample was spliced to Fiber 2 of the OFC such that the sensing element was located on the free end (not spliced). Light coupled into Fiber 1 propagated through the coupler and Fiber 2, and into the fiber sample. The light back-reflected from its end face, where the sensing element is located, propagated back though the optical fiber coupler and into Fiber 3, which was connected to the detector/spectrum analyzer. The detected light contained the LSPR signal with information from the sensing element. The definite spectral changes will occur in the incoming and reflected light due change in refractive index of optical fiber sensor (fiber 2) which get deposited by **dengue (NS1) antigen** [6]. This is the dengue (NS1) antigen detection procedure with the help of optical fiber sensor.

V. FIBER OPTIC SENSOR USED IN AMMONIA GAS SENSING [9, 10] :

Ammonia is a coluorless gas produced by humans and by nature, is readily biodegradable and has a characteristic penetrating odour. This chemical substance is used in smelling salts, many household and industrial cleaners; for the manufacture of fertilizers for agricultural crops, lawns and plants; is a highly corrosive substance and the main effects of exposure occur in the skin, eyes, mouth, respiratory and digestive systems. Due to its potential hazard to human beings, even at small concentrations, real time environmental monitoring of ammonia is a critical issue in closed environments. Optical fibers sensors (OFS) are an attractive option due to their inherent characteristics.

Sensor element to detect ammonia gas:

Some part of optical fiber line is coated with a suitable pH indicator, which is sensitive to ammonia gas. The pH indicator is mixture of the indicators Methyl Red, Methyl Yellow, Bromothymol Blue, Thymol Blue and Phenolphthale. If it is coated on optical fiber line then it acts as a fiber optic sensor.

Fig.13 shows fiber optic sensor element to detect ammonia. It consists of a optical fiber line, coated with pH indicator sensitive film near one end, which is sensitive to ammonia gas.

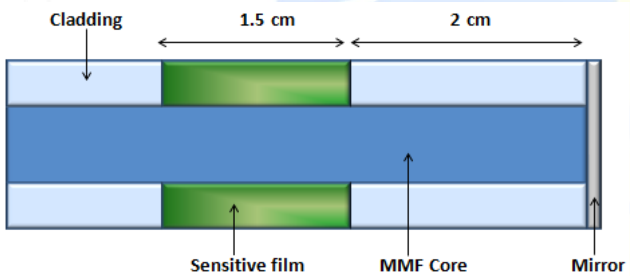


Fig.13: Optical fiber coated with an pH indicator acts as fiber optic sensor to detect ammonia gas

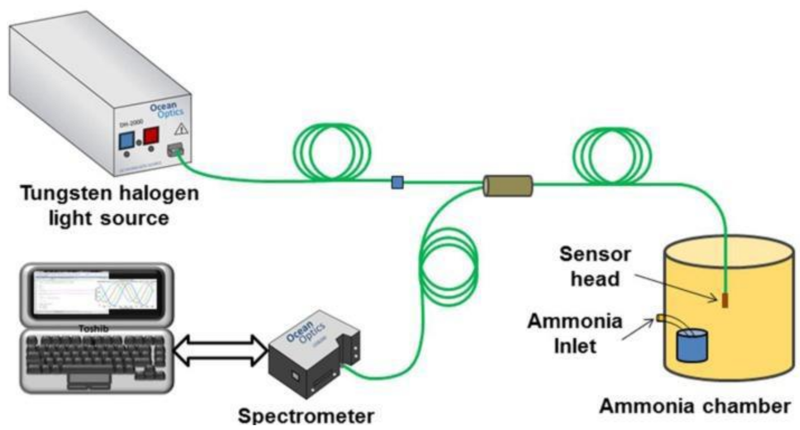


Fig.14: Experimental set up to test FO ammonia gas sensor

Light is allows to pass through such sensor element and reflected back from the mirror present at the end. If ammonia is present nearby the sensitive film of pH indicator changes its color and hence refractive index of core. Due to there is absorption of light within the film region. The incident and reflected beam are compared and analyzed by detector and determine the presence of ammonia gas with its concentration. Fig.14.Shows experimental set up to test FO ammonia gas sensor.

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