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A conjectural presentation on use of optical fibers for sensing purpose

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Abstract
Fiber optic sensors are modern demand of present research and need of society due to their small size, high sensitivity, cost effectiveness and accuracy. They are taking in use for strain, stress, temperature, displacement, bio samples measurement in several structures. As no electrical power is needed to operate an optical fiber so at the remote location fiber optic sensor gives advantages to conventional electrical sensor in certain applications, like in too high temperature a semiconductor sensor is not useful. Similarly, in bio samples analysis where change in refractive index is very low $\sim 10^{-7}$ an optical fiber can sense using surface plasmon resonance (SPR) based technique. Likewise, by monitoring the change in intensity and phase of light with respect to reference signal an optical fiber sensor is applicable in various sensing purpose. Basically, Optical fibers areone kind of medium for illumination purpose that's why most commonly used as light guiding medium in medical and other applications where bright light needs to be brought to bear on a target without a clear line-of-sight path, most common example is medical and industrial endoscope. Some other examples of fiber optic sensor is in bridge monitoring and crack monitoring, like in a bridge or decks or roofs where crack openings beyond 0.15 to 0.2 mm is measure it cause of leakage of water result heavy chance of corrosion of steel or iron, a fiber optic senor is a good alternative of visual inspection. A fiber Bragg grating based sensor is also useful to make an optical fiber based humidity sensor which is a key tool to observe the variation in the moisture level of concrete. In this paper author have shown that optical fibers is not only useful for communication purpose but also an extraordinary tool for sensing application and give a review for use of optical fiber for different kind of sensing purposes.

Keywords: Optical fibers, optical sensors, small size, high sensitivity, cost effective

Introduction
An optical sensor converts light rays into electronic signals. It measures the physical quantity of light and then translates it into a form that is readable by an instrument. An optical sensor is generally part of a larger system that integrates a source of light, a measuring device and the optical sensor. Fiber optic sensors are excellent candidates for monitoring environmental changes and they offer many advantages over conventional electronic sensors like their integration into a wide variety of structures is easy, including composite materials, with little interference due to their small size and cylindrical geometry [1]. They are highly enabling to conduct electric current moreover Immune to electromagnetic interference and radiofrequency interference.as they use optical fibers so they are Lightweight, Robust, more resistant to harsh and ambient environment, Highly sensitive towards very minimum change in physical condition of external environment like change in refractive index. Multiplexing capability to form sensing networks and as optical fibers are reachable in remote areas for a long distance so they are useful in Remote sensing. Multifunctional sensing capabilities such as strain, pressure, corrosion, temperature and acoustic signals. To date, fiber optic sensors have been widely used tomonitor a wide range of environmental parameters such as position, vibration, strain, temperature, humidity, viscosity, chemicals, pressure, current, electric field and several other environmental factors. An optical fiber sensor system consists of an optical source (laser, LED, laser diode, etc.), optical fiber, sensing or modulator element transducing the measure and to an optical signal, optical detector and processing electronics (oscilloscope, optical spectrum analyser, etc.). a bock diagram of optical fiber sensor is given in fig. 1.

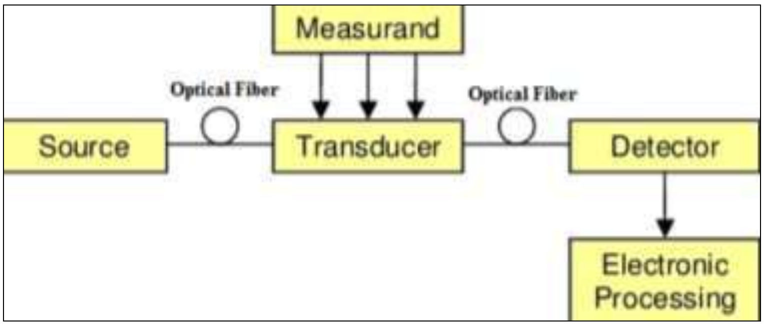

Fig 1: Basic components of a fiber-optical sensor system [2]

A fiber-optical sensor system consists of an optical source (laser, LED, laser diode, *etc*.), optical fiber, sensing or modulator element transducing the measure and to an optical signal, optical detector and processing electronics (oscilloscope, optical spectrum analyser, *etc*.) An optical fiber is one kind of light pipe composed of core, cladding, and buffer. The basic structure is shown in Fig.2. The core is a cylindrical rod of dielectric material and is generally made of glass. Light propagates mainly along the core of the fiber [3]. 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. 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 [4].

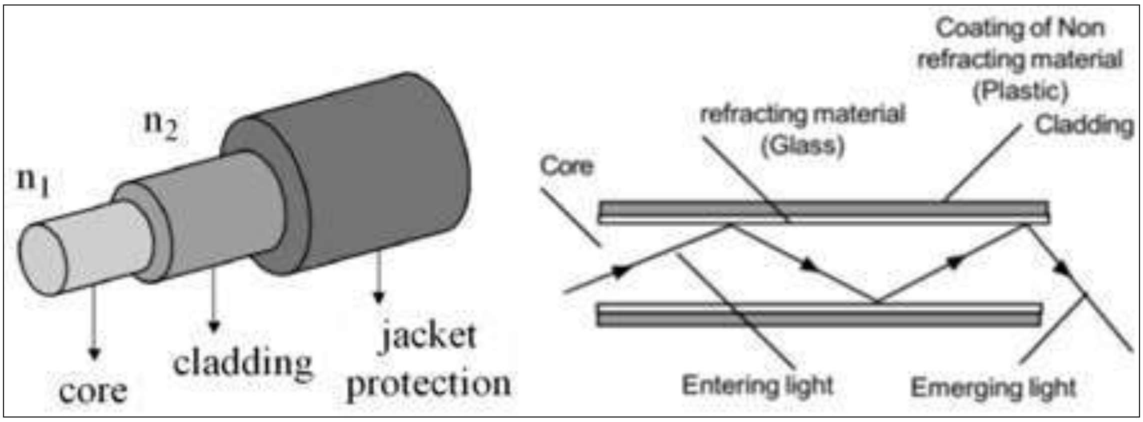

Fig 2: (a) Components of an optical fiber (b) propagation of light wave in optical fibers

Classification of optical sensor based on its application [5]

Based on the application, an optical fiber sensor can be classified as follows:

- **Physical sensors:** Used to measure physical properties like temperature, stress, hazardous gas 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.

Use of Surface plasmon resonance in fiber optic sensor

In general, the cladding from a certain small portion (middle portion for most of the cases) of the fiber core is removed and is coated with a metal layer, which is further surrounded by a dielectric sensing layer. The light from a polychromatic source, if wavelength interrogation method is used, is launched into one of the ends of the optical fiber. The TIR takes place for the rays propagating with an angle in the range varying from the critical angle (depending upon the numerical aperture of the fiber and the light wavelength) to approximately 90 Deg. Consequently, the evanescent field is generated, which excites the surface plasmons at the fiber core-metal layer interface. This coupling of the evanescent field with surface plasmons strongly depends upon light wavelength, fiber parameters, fiber geometry, and metal layer properties. For instance, coupling mechanism will be different for single-mode and multimoded optical fibers due to having different mode transmission properties depending upon the number of modes a fiber will support. fiber-optic sensor supports wavelength interrogation method because all the guided modes are launched in the fiber so it's different from prism coupling method where angle interrogation is most suitable technique. Strength of light coupling with surface plasmons depends on an important fiber parameter known as numerical aperture. The spectrum of the light transmitted after passing through the SPR sensing region is detected at the other end. The sensing is accomplished by observing the wavelength corresponding to the dip in the spectrum. This wavelength is called as the resonance wavelength. A plot of resonance wavelength with the refractive index of the sensing layer gives the calibration curve of the fiber-optic SPR sensor [6].

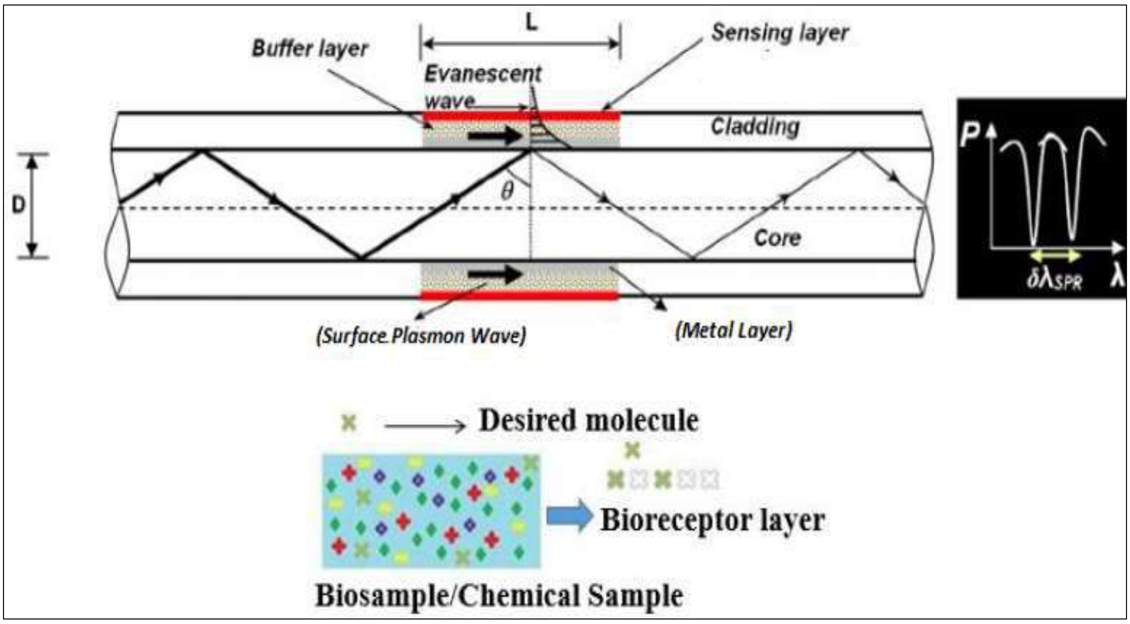

Fig 3: (a) fiber-optic SPR sensor probe setup for the detection of bio samples or chemical samples SPPs at metal/dielectric interface excited by p-polarized laser beam at incident angles greater than the critical angle for total internal reflection. (b) bonding of antigen-antibody on bio-recognition layer

Excitation of free electrons takes when excite with P polarized (or TM polarized) incident light under total internal reflection (TIR) condition. This phenomenon gives rise to evanescent wave which is the strongest at metal dielectric interface. The resonance of free electrons (Plasmon) realized in terms of minimum reflectance where SPR angle reaches to its lowest value of reflection intensity. The mathematical expression of surface Plasmon resonance generation is given [7] in Eq.1.

$$k_o n_{fiber} sin\theta_{spr} = Re\{k_o \sqrt{\varepsilon_m \varepsilon_s/(\varepsilon_m + \varepsilon_s)} \quad (1)$$

Where

ε_m *and* ε_s the dielectric constants of the metal and

the sensing are layer respectively, and $k_o = {2\pi}/{\lambda_o}$ is the wavenumber of the incident light in free space, n_{fiber} is refractive index of dielectric material (core of fiber). Sensitivity, figure of merit, detection accuracy and dynamic range these are various kinds of parameters of a optical sensor and they can modify by using various types of nano-materials like graphene, MoS_2, Heterostructure of 2D/TMD materials etc.

Phase modulated optical sensor [8]

Let there are two waves having amplitude of E_1 *and* E_2. If they are in phase then after superposition of them their amplitude will enhance and net amplitude will be $|E_1 + E_2|$ similarly in out of phase condition of two waves net amplitude will $|E_1 - E_2|$. Net intensity of signal in former case will be-

$$I = |E_1 + E_2|^2$$

$$I = |E_1|^2 + |E_2|^2 + 2E_1.E_2$$

If δ is phase term then resultant intensity will be –

$$I = |E_1|^2 + |E_2|^2 + 2E_1.E_2 \ cos\delta$$

Or $I = I_1 + I_2 + 2\sqrt{I_1.I_2}cos\delta$

This additional term $2\sqrt{I_1.I_2}cos\delta$ is interference term.

If $I_1 = I_2 = I_0$

I=2$I_0(1 + cos\delta)$

By applying cos property

$$I = 4I_0 Cos^2\frac{\delta}{2}$$

If $\delta = 2m\pi, m = 0,1,2,3 \ldots\ldots$ constructive interference

And if

$\delta = 2(m + 1)\pi, m = 0,1,2,3$ Distructive interference

If d_1 and d_2 are distance between mirror M_1 andM_2 respectively in any Michelson interferometer then net path difference will be 2(d_1 -d_2).

From the relation formula of path difference and phase difference we have

Phase difference=$4I_0 Cos^2[\frac{2\pi}{\lambda} 2(d_1 - d_2)]$

By using this property one can make phase modulated optical sensor. Since optical phase cannot be detected directly by the optical detectors. So interferometric techniques are required to convert phase change into intensity change. The most commonly used interferometers are Mach-Zehnder, Michelson, Fabry Perot, Sagnac polarimetric and grating interferometers. Here, in an interferometer light is spitted into two beams where one beam is exposed to the sensing environment and undergoes a phase shift and other one is used as a reference because it is isolated from the sensing environment. Once these two separated beams recombine they interfere with each other (refer to Fig. 4 (a, b)) [9].

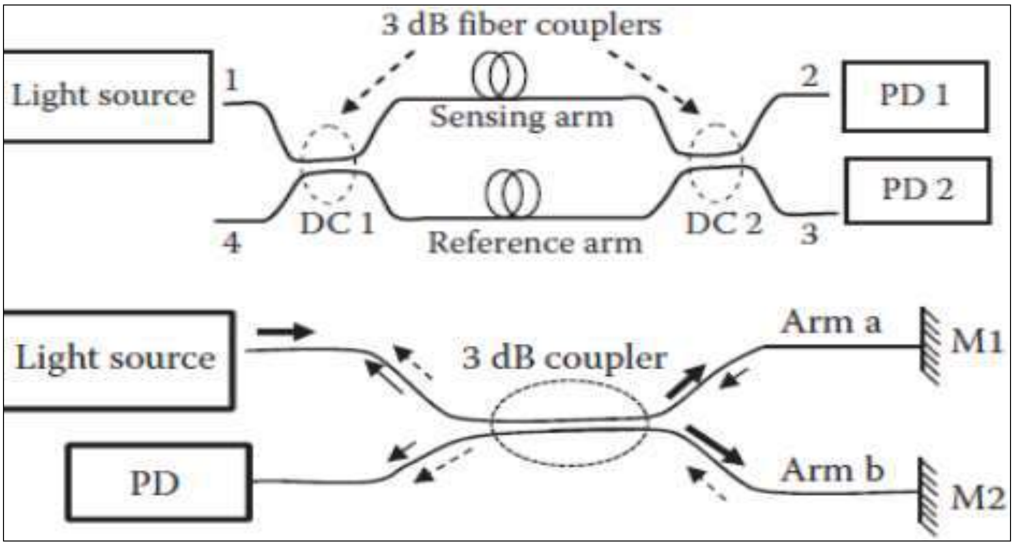

Fig 4: (a) A fiber-optic Mach–Zehnder interferometer, in which two 3dB fiber couplers (b) A fiber-optic Michelson interferometer-based sensor

Conclusion

In this paper author have shown basic concept of optical sensor and use of optical fibers in sensing application. Optical fibers based sensor have various application and advantages over already existing sensors, they are useful in medical use chemical sensing gas sensing and remote sensing application. Surface plasmon resonance based optical sensor shows sensing ability by detecting change in refractive index of sample under consideration and they show real time sensing, high accurate and real time monitoring so widely acceptable technique. Phase modulated optical sensor is also shown in the manuscript which done sensing by using interference-based device like MZM modulator and Michelson interferometer.

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