Chapter 1

INTRODUCTION TO FIBER OPTICS AND FIBER OPTIC SENSORS

The present chapter gives a general overview of the characteristics of optical fibers, various light sources, detectors etc and how they are used in the development of various fiber optic sensors. It also discusses the basic principles and applications of different classes of optical fiber based sensors. Emphasis is given on the physical understanding rather than on the mathematical treatment.
1.1. Introduction

The dramatic reduction in transmission loss of optical fibers coupled with equally important developments in the area of light sources and detectors have brought about a phenomenal growth of the fiber optic industry during the past two decades [1-16]. Although the major application of optical fibers has been in the area of telecommunications, optical fibers have drawn considerable attention in the field of transducing technology for fulfilling the ever-increasing need for fast, sensitive and reliable sensors. Fiber optic sensors find applications in wide range of areas like biomedicine, aviation, surgery, pollution monitoring, etc., apart from areas in basic science. However, theoretically, there exist no boundaries to the diverse areas of fiber optic sensors, where accurate measurements of different parameters are required.

1.2. Why optical fibers?

The optical fibers are widely used in all realms of industry due to its superior properties and characteristics over conventional data transmission and light transmission systems. It offers widest bandwidth till today and allows wavelength division multiplexing. Communication through optical fibers is free from electromagnetic interference and allows the simultaneous transmission of several light waves through a single fiber. It is also free from microwave and radio frequency interference. As the materials used for the fabrication of optical fibers are dielectric in nature, it is immune to electrical conductivity and hence provide higher safety. These cables have very small diameter and are lightweight in nature. It can withstand relatively higher temperature and can be used in remote sensing applications. The optical fiber confines energy into it and thus offers a high degree of security and privacy.

The unique features of the optical fiber that make them highly desirable for sensing applications include immunity to electromagnetic interference, compactness and light weight, low cost, reliability, short response time etc. With the growing environmental concern, such sensors have acquired a wide interest and acceptance for
realizing sensor systems for accurate detection and analysis of different environmental pollutants. Compared to other methods, fiber optic sensors are highly sensitive and can be used to perform accurate absorption measurements on highly absorbing or scattering media due to small effective path length.

1.3. Propagation of light within a fiber

![Diagram of light propagation in a fiber](image)

*Figure 1.1: Propagation of light through an optical fiber*

An optical radiation entering one end of a fiber at a slight angle to its axis follows a zigzag path through a series of total internal reflections (TIR) at the core cladding interface and propagates to the other end of the fiber. The following two conditions must be satisfied for the total internal reflection of light through the fiber. Firstly, the fiber core must have slightly higher index of refraction ($n_1$) than the index of refraction ($n_2$) of the material (cladding) surrounding the fiber core. Secondly, the incident angle $\theta$ (between the ray path and the normal to the fiber wall) must be greater than the critical angle $\Phi_c$, which is defined as $\sin \Phi_c = n_2 / n_1$. Any radiation incident at angles less than the critical angle undergoes refraction and these radiations penetrate the cladding and are lost. The refraction phenomena in fibers
follow the well-known Snell's law, \( n_0 \sin \theta_0 = n_1 \sin \theta_1 \), where \( \theta_0, \theta_1 \) are the incident and refraction angle and \( n_0, n_1 \) are the index of refraction of launch region and core, respectively. It is seen from the figure 1.1 that the internal incidence angle and refraction angle are related by the expression \( \theta_1 = (90 - \Phi) \), so that, Snell's law becomes \( n_0 \sin \theta_0 = n_1 \cos \Phi \). As long as the light enters the fiber at an incident angle such that the internal reflection angle \( \Phi \) is not less than the critical angle \( \Phi_c \), the light will be contained within the fiber and will propagate to the far end by a series of reflections. Thus by using the expression for critical angle, the maximum value of incidence angle for which light will propagate through the fiber is given by

\[
\theta_0 (\text{max}) = \sin^{-1}\left[\left(\frac{n_1^2 - n_2^2}{n_0^2}\right)^{1/2}/n_0\right]
\]  

(1.1)

This maximum angle is called the acceptance angle or the acceptance cone half angle. The sine of maximum acceptance angle is used as the figure of merit of the fiber and is called numerical aperture (NA)

\[
NA = \sin \theta_0 (\text{max}) = \left[\left(\frac{n_1^2 - n_2^2}{n_0^2}\right)^{1/2}/n_0\right]
\]  

(1.2)

If the light is launched from air, \( n_0=1 \), the numerical aperture NA becomes

\[
NA = \left(n_1^2 - n_2^2\right)^{1/2}
\]  

(1.3)

In terms of the normalized difference \( \Delta \) between the indices of the core and cladding and for \( n_1 \approx n_2 \), expression 1.2 becomes

\[
NA = n_1 (2\Delta)^{1/2} / n_0
\]  

(1.4)

where \( \Delta = (n_1 - n_2)/n_1 \)  

(1.5)

If the light is launched from air, the expression 1.4 becomes

\[
NA = n_1 (2\Delta)^{1/2}
\]  

(1.6)

From this equation, it is evident that, NA of a fiber is effectively dependent only on the refractive indices of the core and cladding materials and is not a function of fiber dimensions.
1.4. Modes in an optical fiber

The propagation of light in an optical fiber is characterized by a set of guided electromagnetic waves called the modes. Each guided mode is a pattern of electric or magnetic field distribution that is repeated along the fiber at equal intervals. A monochromatic electromagnetic radiation at an angular frequency $\omega$ traveling along the $z$ - direction ( i.e, along the fiber axis) is represented by the expression $e^{i(\omega t - \beta z)}$, where the factor $\beta$ is the $z$ component of the wave propagation constant $k = \frac{2\pi}{\lambda}$. For guided modes, $\beta$ can assume only certain discreet values in the limit of $n_1 \beta n_2$. A guided mode traveling along the axis of a fiber is the superposition of plane waves whose phases change at each reflection at the core-cladding interface. In planar waveguides, the solution of Maxwell's equation at the boundary yields transverse electric and transverse magnetic modes. However, in the case of cylindrical fibers, the boundary conditions lead to the coupling between electric and magnetic field components to produce hybrid modes such as HE and EH modes depending on the magnitude of electric and magnetic field. Although, the theory of light propagation is well understood, a complete description of the guided radiation modes that correspond to rays not satisfying total internal reflection condition becomes rather complex. However, a further simplification is possible by using weakly guiding approximation i.e. $(n_1 - n_2)\ll 1$, which gives linearly polarized (LP) modes.

1.5. Classification of fibers

Fibers can be classified into various classes depending on the refractive index profile of the core and the cladding medium, core diameter as well as the materials used for the core and cladding. Each of these fibers have their own advantages and disadvantages.
1.5.1. Refractive index profile

![Refractive index profile diagram]

*Figure 1.2: Refractive index profile of a step index fiber*

Based on the refractive index of the core material, optical fibers are mainly classified as step index fibers and graded index fibers. In the case of step index fibers, the core refractive index remains uniform and the core cladding interface is characterized by an abrupt change in the refractive index as shown in figure 1.2. The light propagation through the core of this type of fiber is characterized by the light rays following the zigzag path of straight line segments as depicted in figure 1.3.
However, in the case of graded index fibers, there is gradual change in refractive index within the core as shown in figure 1.4. These fibers allow light in the longer modes to travel faster than light in shorter modes and hence reduce the modal dispersion of the fiber. In this case, light rays periodically diverge and converge along the length of the fiber as shown in figure 1.5. This fiber allows somewhat larger acceptance cone than step index fiber and the rays outside the acceptance cone will escape through the cladding.

Figure 1.4: Refractive index profile of a graded index fiber

Figure 1.5: Light ray propagation in a graded index fiber
1.5.2. Core diameter

The reduction in size of the core results in the reduction of the number of modes that can propagate through the fiber. In a single mode fiber the core diameter is so small that only one mode propagates through the fiber. The typical size of the core in a single mode fiber is of the order of a few micrometers. Hence, it is very difficult to launch light into the tiny core of the fiber. As a result, the installation and operation cost increases and it outweighs the advantages for short distance fiber applications. However, for long distance applications the single mode fiber is used because of its advantages. Multimode fibers have relatively larger core diameter and allows easier operation.

1.5.3. Cladding and core materials

Based on the material used for the fabrication of core and cladding there are variety of optical fibers such as silica fibers, plastic clad silica fibers and plastic fibers. The losses in the propagation of light radiation are affected by the material used. With the introduction of proper dopants into the core material, the characteristics of optical fiber, for example Er doped fibers, can be changed. In recent years, considerable efforts have been made for the fabrication of various low cost fibers with core as polymers.

1.6. Fiber Characteristics

The research on the design and fabrication of optical fibers is focused on the development of fibers with minimal attenuation and dispersion. Decreasing the attenuation is to bring as much of the light originally launched in the fiber to the other end. Reducing the dispersion limits the amount of distortion in the signal carried by the light through the fiber.

1.6.1. Attenuation in fiber

The attenuation occurs mainly due to absorption and scattering of light that occurs within the fiber during its propagation. Depending on the wavelength used and the impurities present in the fiber, the absorption losses can be significant. The
impurities and imperfections in the fiber can cause the scattering of light and result in the scattering loss and this loss mechanism is wavelength dependent. This scattering is called Rayleigh scattering and it is inversely proportional to fourth power of wavelength used. In addition to these mechanisms, the variation in the smooth surface of the core can result in loss of light propagating through the fiber and this mechanism is called bending loss. The variation on the surface of the core or bumps, changes the angle at which light strikes the core to cladding interface and can cause the light to refract into the cladding rather than reflect into the core. Microbends can occur during the manufacturing of the fiber cable or during the handling of the fiber.

1.6.2. Dispersion in fiber

Mainly there are three mechanisms, which can cause distortion to the signals that, propagate through a fiber. They are modal dispersion which occurs in fibers having more than one mode, material or chromatic dispersion which is a wavelength based effect caused by the glass of which the fiber is made and waveguide dispersion which has a greater concern for single mode fibers. The modal dispersion occurs due to difference in path length of the different modes propagating through the fiber. As a result, some modes will travel faster than the other and consequently the pulse of light containing data gets stretched so that at the output of the fiber the data obtained is distorted. Like modal dispersion, material dispersion causes the pulses in the signal to stretch out due to the propagation of different wavelengths of light travelling at different speeds in the glass that makes up the fiber core. As the core diameter of single mode fibers is very small, some portion of the incoming radiation will travel through the cladding of the fiber. The cladding has a different index of refraction and light traveling through it will reach the end of the fiber sooner than the light traveling through the core.

1.7. Optical Sources

The selection of optical sources is extremely important in devices and sensors based on optical fibers. The parameters like spectral output, intensity, stability, ease of modulation, predicted lifetime, cost and power consumption, size etc. of optical
sources have to be considered during their selection. In general, the incandescent lamps, discharge lamps, lasers (non semiconductor) and semiconductor sources (LEDs and laser diodes) are utilized as the optical sources in fiber based systems.

1.7.1. Incandescent lamps

Incandescent filament bulbs (such as tungsten halogen lamps) emit over a broad spectral range (Vis, IR). They are relatively inexpensive and are available in compact sizes. However, they are not suited for modulation and the operational lifetime of these sources are less compared to LEDs. In addition, these sources dissipate large amount of heat and the alignment using these sources are rather difficult.

1.7.2. Discharge lamps

The UV range (200 nm - 400 nm) is an important range of electromagnetic radiation, especially for the absorption as well as for the fluorescence studies. Deuterium lamps are the best available sources in the range 200 nm - 300 nm. However, these lamps are generally bulky, consume more power and hence expensive power supplies are required for their operation. Xenon flash lamps provide a broadband output in the 200 nm - 1000 nm range, but demand a power source regulation and suffer from pulse to pulse variation in output intensity.

1.7.3. Lasers

Apart from semiconductor lasers, the 488nm and 514 nm output radiations of Argon laser, 633 nm of He-Ne laser and 325 nm of He-Cd laser are the commonly used wavelengths for the fiber based systems. The advantage of laser as source of optical radiation is that it offers monochromatic output (obviating the need for a spectral selection filter), high intensity and directionality (facilitating easy launching
into the fiber). Nevertheless, these systems are highly expensive and are fragile in nature.

1.7.4. Semiconductor sources

Semiconductor solid state sources, which include laser diodes and LEDs, are the most attractive option for fiber based systems because of their low power consumption, high stability, long lifetime, robustness and compact size. These sources are inexpensive and the laser diode provides intense collimated beam that can be easily modulated. However, unlike LEDs, laser diodes operating below 630 nm are highly expensive. The laser diodes are commonly available in the wavelength range, 630 – 670 nm, 750- 830 nm and the 'Telecom windows' (1330nm and 1550 nm). In recent years, most of the academic as well as industrial researches on this area are focused on developing blue laser diode-source based on GaN and ZnSe materials with sufficient operational time. Availability of a blue laser diode will be a major stimulus to the fluorescence based chemical sensor and biosensors and it will facilitate the development of both compact and remote systems. In addition to the advantages of semiconductor sources already given, LEDs are particularly attractive sources for optical sensing because of their low cost, ease of modulation and ease of coupling to multimode fibers. Unlike lasers, they are not sensitive to back reflection and have low coherence.

1.8. Detectors

Silicon photodiodes are the commonly used detectors with a spectral response that spans the visible range but falls sharply above 1000nm and these are relatively inexpensive. Avalanche photodiodes (APDs) are employed in systems where the gain is the prime concern. Photomultiplier tubes (PMTs) are more expensive than photodiodes, but offer greater sensitivity and can be operated even at very low light levels. In the IR range, photothermal and pyroelectric detectors find some
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applicability. However, photoconductive detectors based on PbS, PbSe, InSb and HgCdTe are commonly employed in the IR range.

1.9. Fiber optic sensors

In addition to the major role played in the modern communication systems, optical fibers find wide applicability in other realms of Photonics industry especially in the fabrication of Fiber Optic Sensors (FOS) [17-33]. The applicability of FOS is facilitated by many of the unique features of fibers. These FOS offers high sensitivity, durability and reliability and allows the direct and remote measurements. Many of the FOSs are based on monitoring the variation in one of the principal parameters that characterizes the light beam in accordance with the variation in physical or chemical parameters to be measured. The principal parameters of light utilized for the fabrication of FOS are intensity, phase, polarization and frequency. Free from electromagnetic interference and radio frequency interference and low losses gives FOS a unique place in the sensor technology. In FOSs, the light may be modulated either inside or outside the fiber and correspondingly it can be classified as intrinsic sensors and extrinsic sensors. In intrinsic sensors, the physical parameter to be sensed modulates the transmission properties of the sensing fiber. Hence, one of the physical properties of the guided light like intensity, phase, polarization etc is modulated by the measurand. In the case of extrinsic FOS, the modulation takes place outside the fiber. Based on the modulation technique employed, the FOS can be classified into different groups such as Intensity modulated FOS, Phase modulated FOS, Polarization modulated FOS, Frequency modulated FOS and Wavelength modulated FOS.

1.9.1. Intensity modulated FOS

In a simple and inexpensive intensity modulated FOS, the measurand modulates the intensity of transmitted light through the fiber and these variations in
output light is measured using a suitable detector. These FOSs offer the easiest method of implementation and compatible with multimode fiber technology. Intensity modulation can take place through light interruption due to the displacement of one fiber relative to another or misalignment of one fiber with respect to another fiber. The misalignment can take place in three different ways viz. axial (longitudinal) misalignment, transverse misalignment and angular misalignment. Among these methods, FOS based on the transverse misalignment is more sensitive. The sensitivity of FOS can be enhanced by cleaving and polishing the two ends at a slant angle and keeping the slant face of the two fibers sufficiently close as shown in figure 6. In this case, the power will get couple to the receiving fiber through the slant face due to frustrated total internal reflection.

![Diagram](image.png)

**Figure 1.6: Intensity modulated sensor based on frustrated total internal reflection**

In another class of intensity modulated FOS, the measurand modulates the light reflected from a reflecting surface. The reflective FOSs can be used to measure displacement, pressure etc and is widely used in medical field as inter-cardiac pressure transducer. A certain class of intensity modulated FOSs are working on the basis of transmission loss occurring due to microbending of the optical fiber and it is widely used for the measurement of acoustic pressure, strain, temperature, displacement and recently in chemical sensing applications which is described in detail in chapter 3.
The evanescent waves are the electromagnetic field that penetrates into the cladding of an optical fiber as the optical radiation propagates through the fiber. A class of intensity modulated FOSs utilizes these waves for sensing different physical and chemical parameters, especially for sensing different environmental pollutants. The forthcoming chapters of this thesis discuss the design and development of different forms of fiber optic evanescent wave sensors in detail.

1.9.2. Phase modulated FOS

The most sensitive fiber optic sensing methods is based on the optical phase modulation. The total phase of the light along an optical fiber depends on the properties such as physical length of the fiber, transverse geometrical dimension of the guide, refractive index and the index profile of the waveguide. If the index profile remains a constant with environmental variations, then the depth of phase modulation depends on the other remaining parameters. The total physical length of an optical fiber may be modulated by the perturbations like thermal expansion, application of hydrostatic pressure causing expansion via Poisson ratio etc. The refractive index varies with temperature, pressure and longitudinal strain via photo elastic effect. Waveguide dimensions vary with radial strain in pressure field, longitudinal strain in a pressure field and by thermal expansion. The phase change occurring in an optical fiber is detected using optical fiber interferometric techniques that convert phase modulation into intensity modulation. There are a variety of fiber optic interferometers such as Mach-Zehnder, Michelson, Sagnac and Fabry Perot as shown in figure 1.7.
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(a) Mach-Zehnder

(b) Michelson

(c) Fabry-Perot

(d) Sagnac

Figure 1.7: Optical fiber interferometric sensors
1.9.3. Polarization modulated FOS

Polarization properties of fibers are utilized for the measurement of a range of parameters. The action of any given external field on the polarization properties of an optical fiber normally modifies either the linear or the circular birefrigerence component. Thus, the measurand modulates the state of polarization in a fiber polarimetric sensor. A variety of physical phenomena such as optical activity, Faraday rotation, electro-gyration, electro-optic effect, Kerr effect, photoelastic effect etc can influence the polarization of light and can result in birefrigerence. A typical example of Polarization modulated FOS based on Faraday rotation is shown in figure 1.8.

![Diagram](image)

*Figure 1.8: Fiber optic Polarization modulation sensor based on Faraday rotation for current monitoring*

This system is highly useful for high tension lines, where current and voltage measurements using conventional techniques are both expensive and difficult to implement.

1.9.4. Frequency modulated FOS

Frequency modulation of light occurs under a limited range of physical conditions. Different effects like Doppler effect, Brillouin scattering, Raman scattering etc. are made use of in these types of FOS. A typical example of Frequency modulated FOS used for the sensitive detection of the motion of scattering bodies in a transparent medium is shown in figure 1.9. This frequency modulated FOS is based
on Doppler effect. In Doppler effect, if a radiation at a frequency $f$ is incident on a moving body with a velocity $v$, then the radiation reflected from the body appears to have frequency $f_1$, where

$$f_1 = \frac{f}{1-v/c} = (1 + v/c)f$$  \hspace{1cm} (1.7)

This fiber optic probe is readily suited to the detection of moving targets or to the detection of mobile bodies in suspension and it will detect velocities as low as one micron per second and up to meters per second or above depending on the detection electronics, corresponding to frequency offsets ranging from a few hertz to tens of megahertz.

### 1.9.5. Wavelength modulated FOS

In this type of sensors, a change in the value of the measurand is converted to a variation in wavelength of the transmitted light. There are numerous physical phenomena, which influence the variation of reflected or transmitted light intensity.

![Frequency modulated FOS based on Doppler effect](image-url)
principal areas. These are in chemical analysis using indicator solutions, in the analysis of phosphorescence and luminescence, in the analysis of black body radiation and in Fabry Perot, Lyot or similar optical filters in which transmission characteristics of the filters are made to be a function of an external physical parameter. A general block diagram of a wavelength modulated FOS is shown in figure 1.10.

![Diagram of a wavelength modulated FOS](image)

**Figure 1.10: Wavelength modulated FOS**

1.9.6. Fiber optic chemical sensors

Chemical sensors are a particular class of FOS, which is used to measure the concentration or activity of a chemical species present in the specimen. In addition to earlier mentioned qualities of optical fibers, its inertness towards chemical reaction makes it a promising candidate for the fabrication of chemical sensors. All the chemical sensors can be categorized according to their transduction mechanism; that is, the principle upon which the detection is based such as electrochemical, optical, thermal and mass transduction mechanisms. Electrochemical sensors can be based on a variety of different phenomena including amperometric, potentiometric, and conductimetric mechanisms. All of these sensors have electrodes and the nature of
the electrochemical phenomenon observed is dependent on the electrodes configuration. In some systems, an electrochemical potential is measured, whereas in others redox reaction takes place, generating a current due to the reaction of the intended species.

In temperature based sensors the uptake or release of heat caused by specific chemical reactions is measured by a thermistor. The amount of heat taken up or released is correlated with the concentration of the analyte. Mass based sensors are extremely diverse in their mechanism, but typically employ piezoelectric substrates for implementation. These sensors have a piezoelectric substrate coated with a polymeric material. Selective absorption or adsorption of the analyte alters the mass of the polymer layer coating the substrate. This mass change is detected as a change in the resonant frequency of the piezoelectric substrate. Other methods of mass detection employ chemical reactions, which generate precipitates, thereby altering the resonant frequency of the substrate on which the precipitate deposits.

The optical transduction allows a wide variety of chemical detection schemes that were previously impossible using conventional potentiometric and amperometric electrochemical devices. Fiber optic chemical sensors (FOCS) can be based on absorbance, fluorescence, polarization, Raman effect, refraction or reflection. The species or group specific chemistry can be selected from organics, inorganics, metals, enzymes, mono and polyclonal antibodies and polymers. Interaction of the analytes with the sensing reagents produces a change in one of the above mentioned spectroscopic parameters. The readout device electronically converts light flux into voltage. Modulation in the voltage reading directly correlates with the analyte concentration.

1.9.6.1. Advantages of FOCS

Chemical sensing based on optical fiber has several attractive features, which may be summarized as follows

1) No coupling optics are required in the sensing region because the interrogating light remains guided
2) The low attenuation of optical fibers enables remote *in situ* monitoring of species in difficult or hazardous locations.

3) No reference electrode is required.

4) Enhanced sensitivity.

5) Considerable miniaturization is possible.

6) Significant cost reduction.

7) Since the reagent phase need not be in physical contact with the optical fiber, it is easy to change the reagent phase.

8) No electrical interference.

9) Can be used for accurate absorption measurements.

10) Distributed sensing is possible.

11) It can exploit the high quality components like fibers, sources, detectors, connectors, etc. developed for the more mature fiber optic telecommunication technology.

1.9.6.2. Classification of FOCS

FOCS can be classified conventionally into two categories namely direct spectroscopic sensors and reagent mediated sensors.

1.9.6.2.1. Direct spectroscopic sensors

![Diagram of Direct Spectroscopic Sensor](image)

*Figure 1.11: Direct spectroscopic sensor*

In direct spectroscopic sensors, the fiber acts as a simple light guide, which separates the sensing location from the monitoring instrumentation as shown in
figure 1.11. In an alternate design, the evanescent wave of the transmitted light directly interacts with the targeted analyte via the optical fiber. Both sensor schemes identify optical modulation by changes in absorption or fluorescence properties, which correspond to the analyte concentration.

1.9.6.2.2. Reagent mediated sensors

In the case of reagent-mediated FOCS, analyte-sensitive material is attached to the tip of the fiber or its side as shown in figure 1.12(a & b). This material is often an indicator fixed to a polymeric substrate, which reacts reversibly with a component of the solution. Light sent down to the fiber interacts with this indicating layer and modifies the light. The modified light collected by the detector correlates the change in concentration of the species being measured. Optical mechanisms include absorbance, fluorescence, polarization and luminescent lifetime changes with the indicating species.

1.9.6.2.3. Porous glass sensor

Another class of FOCS makes use of porous glass fiber as the sensing element. Since the porous fiber is an integral part of the waveguide, an intrinsic sensor is developed by coating or impregnating a porous section with an appropriate
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indicator. As a result of the porosity, the analyte penetrates the fiber and reacts with the indicator, providing an in-line absorption or luminescence monitoring. The high surface area of the porous fiber enhances the sensitivity of the device since the light interaction is markedly increased. Depending upon the demands of the sensor, the depth of the porous layer may be varied from tens of micrometers to hundred s of micrometers and the depth of porosity influences sensing properties such as sensitivity, response time and dynamic range. Moreover, porous substrate have been combined with sol-gel immobilization for making a variety of chemical sensors including pH sensing, gas sensing, etc. Chapter 5 of this thesis explains this technique in detail for the detection of ammonia gas sensing.

1.9.7. Distributed Optical Fiber Sensors (DOFS)

Distributed Optical Fiber Sensors (DOFS) utilize the very special properties of the optical fiber to make simultaneous measurement of both the spatial and temporal behavior of the measurand field. This technique provides a new level of understanding, especially in the case of large structures and leads to a finer monitoring of the behavior of measurand. Using DOFS, we can measure the spatial distribution with resolution of 0.1-1 m over a distance of 100 m and to an accuracy of 1%. With the aid of these sensors, it becomes possible to determine the value of a desired measurand continuously as a function of position, along the length of a suitably configured fiber having arbitrary large spatial resolution. The temporal nature is determined simultaneously from the time dependence of the signal. Thus, this technique offers many attractive possibilities for industrial and research applications. It is very important and necessary to get accurate information of the spatial/temporal behavior of strain and temperature from the point of view of both safety monitoring and improved understanding of the behavior under anomalous conditions in dams, bridges, multi-storied buildings, air crafts, space crafts, boilers, chemical pressure vessels, electrical generators etc. The flexibility of the fiber makes it relatively easy to install over the chosen measurement path and thus allows
retrospective fitting unlike other sensor systems. Distributed sensing has also potential application in the field of chemical sensing for detecting a number of chemical species simultaneously.

1.9.8. Biosensors

In recent times, considerable efforts have been going for the development of an important class of FOS namely biosensors. Biosensors employ a biological recognition element to impart selectivity. An important application of the biosensors is for the detection of glucose, in which, an oxygen sensor is employed in conjunction with an enzyme. The sensing element is comprised of an immobilized enzyme attached or trapped within a polymer layer. When glucose encounters the enzyme, glucose oxidizes in the presence of oxygen, oxidation of the glucose to gluconic acid occurs and hydrogen peroxide is released as a byproduct. The uptake of oxygen is monitored with an oxygen sensor such as oxygen-sensitive electrode or optical sensor. In this way, the degree of oxygen depletion can be correlated directly to the concentration of glucose. However, there are several disadvantages with enzyme biosensors. First, the enzyme activity changes with time because of enzyme denaturation. Second, the concentration of co-reactant, in this case oxygen, must be kept in excess or must be measured independently. A second type of biosensor employs antibody molecules as the recognition element. These sensors are complex because they need to couple the signal to the binding event and the antibodies, unlike enzymes, do not transform the analyte. Consequently, complicated schemes for ascertaining the degree of binding must be employed. The selectivity of antibodies for their antigen-binding partners is extremely high, making antibodies attractive recognition elements for sensors. A major disadvantage of antibodies is their extremely high affinity for antigen, which results in binding such a way that it is irreversible. Sensors, based on antibodies, therefore, are only useful for extremely limited periods of time, as antibody binding sites become saturated and cannot be recovered except by exposure to rather harsh conditions. FOS used in biomedical
applications are mostly of the intensity modulated type, which employs optical spectroscopy as the basic tool.

The following chapters describe the design and fabrication of some fiber optic sensors for the trace detection of some pollutants in air and water using techniques such as evanescent waves, microbending and long period grating.
REFERENCES

31. F. Ansari, Cement and Concrete Composites, 19, 3 (1997)