

MICROBENDING LOSS AND APPLICATION IN SENSING

Aim

To study a simple intensity modulated fiber optic pressure sensor based on microbending loss in a multimode fiber.

Apparatus

Bread board, laser diode, laser diode aligner, microscope objective (20X), microscope objective holder, xyz-translational stage, photodetector with multimeter, photo-detector holder, rotation stage, microbend deformers, two fiber chucks, two post bases and 3 posts, weight box, about 2 m length of a multimode fiber, razor blade, fiber cutter, index matching liquid.

Theory

To the majority of students “fiber optics” is synonymous with optical telecommunication. Another useful dimension of fiber optics is that it has also provided a revolutionary technology base for configuring a variety of optical sensors, which offer several advantages over existing traditional sensing techniques.

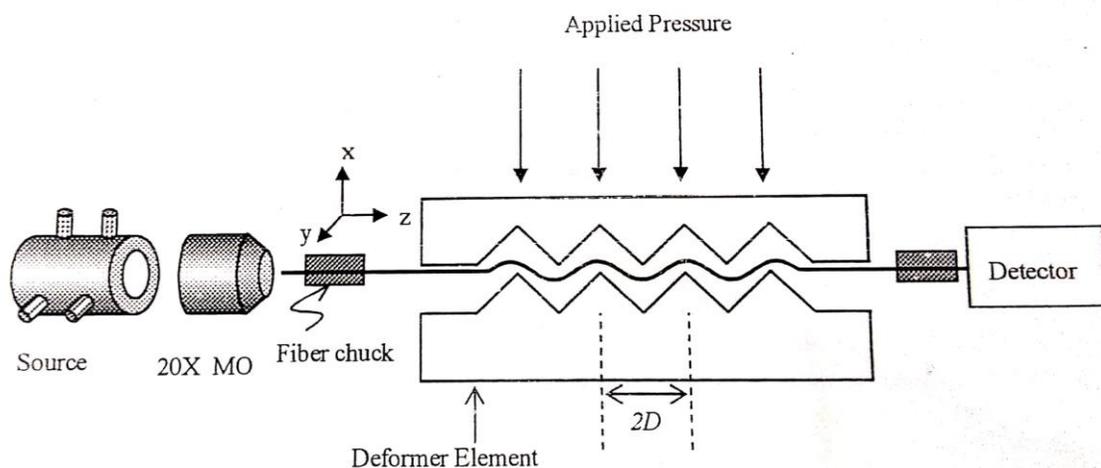


Fig. 6.1(a) Experimental set-up for a single intensity modulated fiber optic pressure sensor using a multimode fiber.

Some of the key benefits are: immunity of several signals to electromagnetic interference, intrinsic safety in explosive environments, offers remote sensing and distributed measurements, chemical inertness thereby employable in chemical process and biomedical instrumentation due to their small size and mechanical flexibility. These advantages have led to intense R & D efforts around the world and development of a variety of fiber optic sensors for the measurement of pressure, temperature, liquid level, refractive index, pH, antibodies, electric current, displacement, rotation etc. Broadly, these sensors are classified either as *intrinsic* or *extrinsic* sensors.

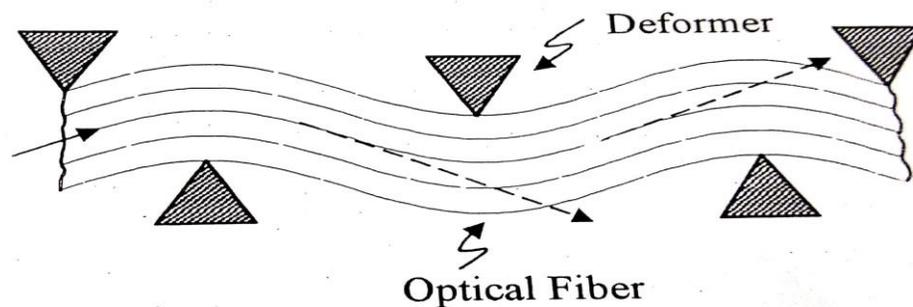


Fig. 6.1(b) Principle of microbend induced attenuation in an optical fiber.

In an intrinsic sensor, one or more of the optical properties of the guided wave, such as intensity, phase, or state of polarization, is modulated by the measurand, which is then detected at the output. In contrast to this, in an extrinsic sensor, the fiber itself serves as a conduit to carry light signal to and from the sensor head/probe to be detected by a detector.

In this experiment, we describe a simple intrinsic fiber optic sensor based on the intensity modulation of light through a fiber by inducing microbends in the fiber through a periodic deformer element. When a portion of a fiber lay is sandwiched between two deformer elements and pressure is applied to one of these deformer, the fiber undergoes periodic deformation in the form of micro-bends (see Figure. 6.1(b)). The resultant mechanical deformation of the optical fiber perpendicular to its axis causes higher-order guided modes to radiate out of the fiber's core through the core-cladding interface as shown in the figure. This results in a drop of intensity of the transmitted light through the fiber with increasing deformation.

Figure 6.2 shows the basic geometry of the microbend element about one deformation point. As the pressure is applied (from the top) on the deformer, microbending occurs along the length of the fiber, and these bending results in loss

of guided power by radiation at the bend. The loss in intensity for a bent fiber is given by [3].

$$\text{loss} = C \left(\frac{a}{R} \right)^2 \quad (6.1)$$

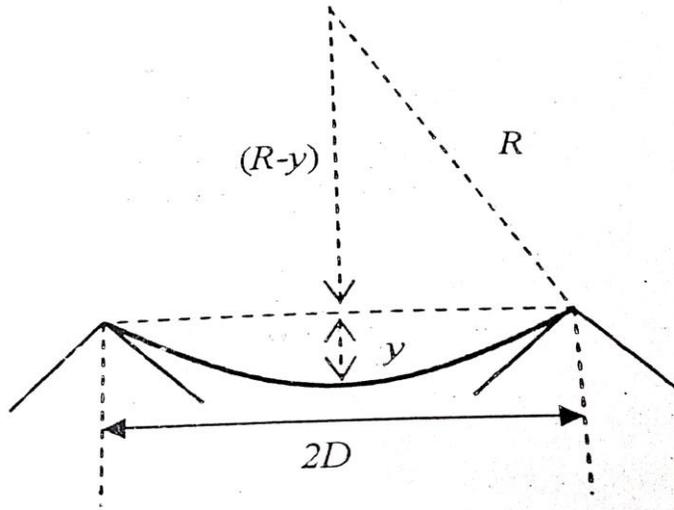


Fig. 6.2 Geometry of the microbend

where R is the radius of curvature of the bend, a represents the fiber core radius and C is a constant. Thus, for a given fiber the pressure applied can be related to the bend radius, which is given by (see Fig. 6.2)

$$R = \frac{(y^2 + D^2)}{2y} \quad (6.2)$$

Where y is the displacement of the deformer element and $2D$ is the distance between the contact points of the deformer element, which is equal to the pitch of the element. Thus, the transmittance T through the fiber is

$$\begin{aligned} T &= 1 - \text{loss} \\ &= 1 - \frac{Ca^2}{\left(\frac{y^2 + D^2}{2y} \right)^2} \\ &= 1 - C \left(\frac{q}{1+q^2} \right)^2 \end{aligned} \quad (6.3)$$

where

$$C' = \frac{4Ca^2}{D^2} \quad (6.4)$$

and

$$q = \frac{y}{D} \quad (6.5)$$

The applied force and hence the pressure is proportional to the displacement y . Therefore in terms of pressure, we have

$$q = \frac{PA}{kD} \quad (6.6)$$

Where P is the pressure, A is the surface area of the deformer and k is a constant.

Fig. 6.1 (a) *Experimental set-up for a simple intensity modulated fiber optic pressure sensor using a multimode fiber.*

Fig. 6.1 (b) *Principle of microbend induced attenuation in an optical fiber.*

Fig. 6.2 *Geometry of the microbend.*

Procedure

Figure 6.1 shows the basic configuration of a fiber-optic microbend displacement sensor. For this, following procedure have to be followed step by step.

1. Mount the laser diode on the aligner and adjust with the help of the aligning screws.
2. Fiber ends are prepared so that it has well-cleaved ends, and clamped over the fiber chucks with magnets. One end of the fiber is fixed in the xyz-translational stage and other in post bases.

3. Light is launched from the laser diode using a 20X-microscope objective into the fiber (as discussed in Experiment no.1). The output end of the fiber is coupled to the photodetector, connected to the multimeter to measure the amount of light transmitted through the fiber.
4. Microbend deformer is introduced somewhere along the length of the fiber as shown in the experimental set-up. By gently pressing on the deformer element, observe drop in the transmitted light intensity through the fiber.
5. Apply different pressure by placing suitable weights on the deformer, and each time note down the multimeter reading corresponding to the output of the detector.
6. Plot the measured relative output powers as a function of the applied weights.
7. Best fit the theoretical expression for transmittance (T) (Eq. 6.3) vs. weight to the experimentally observed data by adjusting C' as the fitting parameter.

Observations

Microbend period 1 = (mm)			Microbend period 2 = (mm)		
Mass (gm)	Detected Power (μ W)	Normalized Power	Mass (gm)	Detected Power (μ W)	Normalized Power

Results

Figure 6.3 shows a graph of the measured light transmittance through a microbend modulated fiber-optic sensor versus the applied weight. The diameter of the fiber core was $49 \mu\text{m}$ and numerical aperture was 0.19. In this figure, filled squares represent experimentally observed values and the solid curve is the least square fit to the data. As can be seen, the transmittance varies almost parabolically with the

applied pressure. Figure 6.4 shows the corresponding variation with the primary jacket of the fiber removed. As expected, the latter case is more sensitive to the applied pressure.

Comments

The microbending sensitivity of the sensing fiber must be maximized. One of the most important parameters in determining the microbending sensitivity is the periodicity of the fiber deformation. To understand this, one has to consider the mode coupling effects in fibers. From the theory of mode coupling it is well known that when a periodic microbend is induced along the fiber axis, light power is coupled between modes with longitudinal propagation constant β and β' satisfying [2.4]

$$\beta - \beta' = \pm \frac{2\mu}{\Lambda} \quad (6.7)$$

Where Λ is the mechanical wavelength of the periodic perturbation.

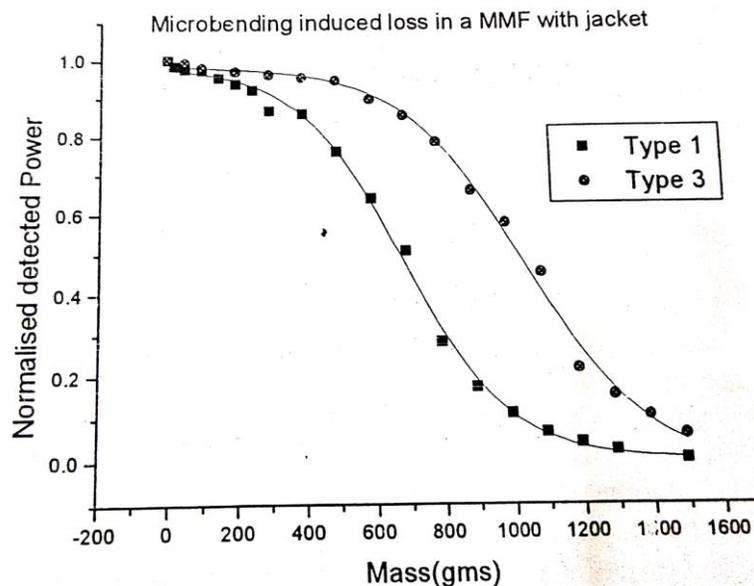


Fig. 6.3 Amount of light transmitted through a microbend-modulated fiber-optic sensor versus the applied weight., The fiber core diameter and numerical aperture were $49 \mu\text{m}$ and 0.19 , respectively, and $2D$ was equal to 1 mm . Here Type 1 corresponds to deformer 1 and Type 3 corresponds to deformer 3; the fiber was with its jacket in place.

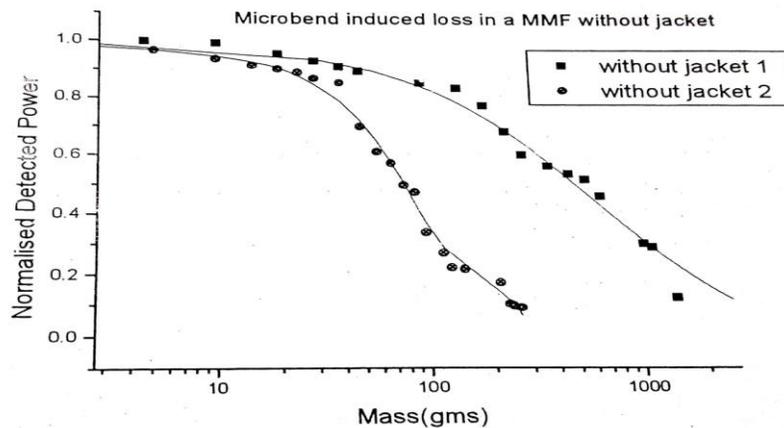


Fig. 6.4 Amount of light transmitted through a microbend-modulated fiber-optic sensor versus the applied weight., The fiber core diameter and numerical aperture were $49 \mu\text{m}$ and 0.19 , respectively, and $2D$ was equal to 1 mm , except that the fiber is without the primary jacket.

For the fiber of given refractive index profile, the detail mathematical analysis predicts [5] that higher order modes can be coupled with small periodicity Λ , whereas lower order modes are coupled with large periodicity Λ . Microbending loss is caused by the coupling between guided modes and radiation modes. For small changes in the fiber deformation where neighboring mode coupling is believed to be valid, only adjacent modes are coupled. In this case microbending loss is due to coupling of the highest order guided mode to the first radiation mode. Such coupling can be realized with periodicities predicted by Eq. (6.7) [6], which significantly enhances the microbending loss and hence the sensitivity of the sensor.

In designing the microbend sensor it is important to consider the macrobending effect, i.e., light power loss caused by fiber deformations of the order of centimeters. Even though such macrobends cannot induce mode coupling (which requires small bends), they extend the field of the propagating modes into the coating, which in turn can introduce losses. In particular, macrobending removes the preferred higher order core modes, which are responsible for the microbending sensitivity. Therefore macrobending can significantly decrease the microbending effect and must be avoided by keeping the sensing fiber straight.

In designing the sensor, the length of the sensing fiber is an important parameter, which influences the sensitivity of the sensor. It has been found that the

microbending sensitivity varies approximately linearly with the length of the sensing fiber [6].

For obtaining the best sensor response, following points must be realized, in addition, at the time of performing the experiment.

1. The fiber end faces must be of good quality.
2. Cladding-mode strippers must be used.
3. The two plates of the deformer must be accurately aligned.

The sensor response is critically dependent on the excitation. To ensure that all the guided modes are excited in the multimode fiber, an overfill launch is applied at the input end of the fiber i.e. one uses a microscope objective of NA higher than that of the fiber for launching light into the fiber.