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A fiber optic concentration sensor

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Abstract : A simple fiber optic concentration sensor based on the coupling of light from one fiber to another through a solution is discussed. The operational characteristics of the sensor are illustrated by taking the solutions of potassium permanganate and fast green dye as samples. The extrinsic type sensor described here shows linearity at lower concentrations.

Keywords : Fiber optic concentration sensor, operational characteristics.

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During the past decade, there has been extensive research and developmental activities related to design and fabrication of fiber optic sensors (FOS) (Giallorenzi *et al* 1982 and Pitt *et al* 1985) for the measurements of physical and chemical variables. FOS offer several advantages over conventional sensors; the most important among them being the immunity of such sensors to electromagnetic interferences. These sensors may generally be classified into extrinsic and intrinsic types. In extrinsic type fiber sensors, light is guided to and from a location at which sensor head is positioned. In intrinsic sensors, light does not leave the sensor except at the detection end of the sensor. In this paper we describe a simple fiber optic concentration sensor working on the basis of coupling of light from one fiber to another through a solution.

Part of the light emerging from the tip of an optical fiber can be coupled to a second fiber by butt coupling. If a small axial gap is allowed between the two fibers, coupling losses will depend on the separation between the tips of fibers. The power coupled from one fiber to another can be snown to be inversely related to the square of the separation between the fibers. Assuming uniform intensity distribution for the near field pattern for the light emerging from the input fiber, the power coupled to the output fiber can be shown to be proportional to $P_i a^2/\theta^2 d^2$ where P_i is the optical power at the tip of the input fiber, sin θ is the numerical aperature of the input fiber, a is the effective core diameter of the output fiber and d is the separation between the two fibers. Therefore, for a given set of fibers, the power coupled is proportional to $1/d^2$. When the fibers are immersed in a solution, the coupling losses will also depend on the transmission characteristics of the liquid medium. Hence for a given pair of fiber and for a fixed separation between them, the power coupled from one fiber to the second will be a function of the extinction coefficient of the medium. According to Lambert-Beer law, the extinction coefficient at any wavelength within the absorption band for a solution is proportional to the concentration of solute in an absorbing medium.

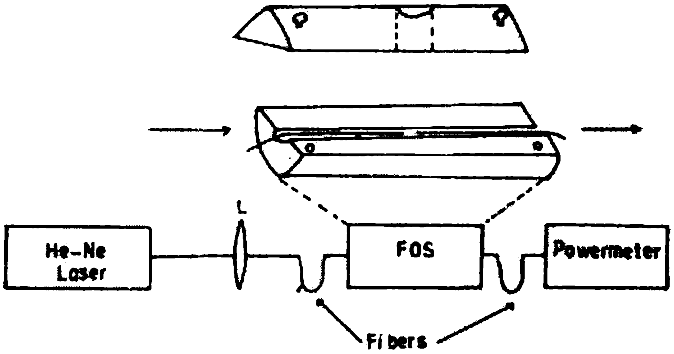

Figure 1. Fiber optic sensor and the experimental arrangement to measure concentration using the FOS.

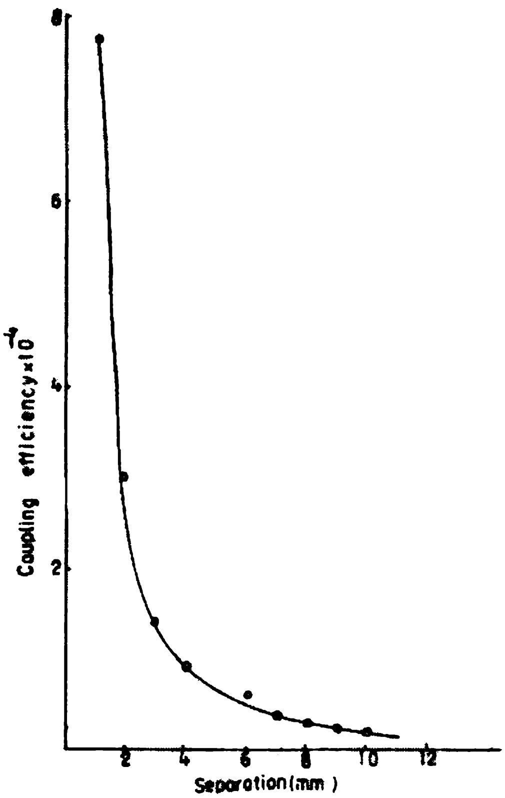

Figure 2. Separation between fiber ends vs coupling efficiency.

FOS designed here consists of a pair of multimode fibers (200/380 μm, Hafner, France) fixed axially inside a teflon cylinder with a small separation (Figure 1). The teflon cylinder is made in two halves and the lower half of the cylinder contains an axial groove of 1 mm for properly positioning the fibers. Spacing betwgen the polished ends of the two fibers inside the groove is kept at about 2 mm so as to obtain sufficient coupling efficiency (Figure 2). A hole of 4 mm diameter is drilled on the upper half of the cylinder so that the gap between the fiber ends are positioned exactly below the hole.

The two halves of the teflon cylinder are joined together with fiber pair positioned with a separation of 2 mm between their terminations. If the separation between the fiber tips is too small, the sensitivity of the sensor will be reduced since the interaction length between light and the liquid medium becomes very small. However, at high concentration range the separation can be made small. In the range of concentration studied, 2 mm separation was found to give good sensitivity for the measurements. The gap between these fiber ends is filled with the absorbing solution at a specific concentration through the hole on the upper half of the cylinder. Experimental arrangement to measure concentration using the fiber optic sensor is shown in Figure 1. A He-Ne laser beam (5 mW at 6328 A) is coupled to the input fiber using bulk optics. A microscope objective of reasonably small focal length (1 cm) is used for focussing the laser beam onto the input end of the fiber. This increases the effective numerical aperture of the sensor head. The input fiber guides the light to the sensor head containing liquid. The near field pattern obtained at the end of this fiber was uniform. The output light, which suffers attenuation after passage through the liquid is gathered by the second fiber. This in turn is guided through the output fiber and its level is

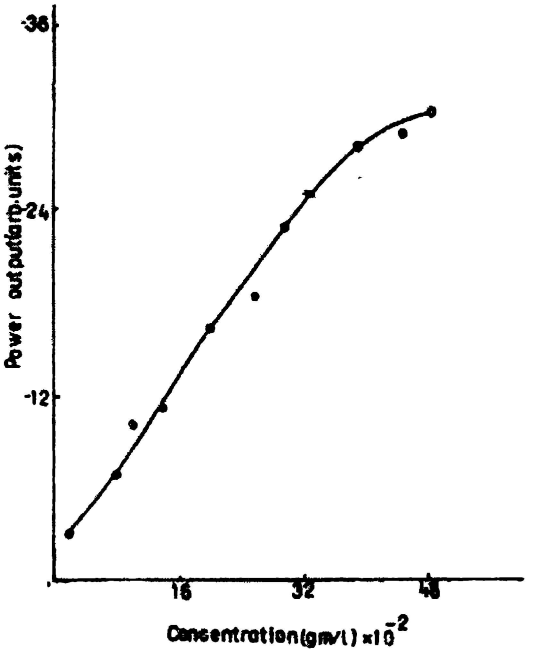

Figure 3. Power output vs concentration for the fast green dye.

monitored using a suitable optical detector. A commercial fiber optic power meter (Megger OTP 510) was used here and this can directly measure the power level of the output light.

The performance of the FOS concentration sensor is illustrated here with two different kinds of solutions, viz., potassium permanganate and fast green dye in water. The sensor was cleaned with water with the help of a syringe in between trials for different concentrations. Fast greet dye has a strong absorption band (40 nm FWHM) around 620 nm; $KMnO_4$ solution has an absorption tail at 6328 A. Measured variation of relative power output with concentration of fast green dye is shown in Figure 3. In the case of both the solutions the plot is linear upto a certain concentration level and shows saturation at higher concentrations. The saturation behaviour at higher concentrations can be attributed to formation of aggregates/ion clusters which in turn decreases the amount of light coupled to the second fiber (Penzkofer and Leupacher 1987). The FOS concentration sensor described here is compact and flexible and can perform satisfactorily in a flow system. The design and fabrication are very simple and the measurements made using the FOS are highly reproducible. One of the application of the sensor is in the monitoring of dye concentration in a commercial dye laser.

Acknowledgments

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