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A microbent fiber optic pH sensor

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Abstract

Optical fiber sensors developed for measuring pH values usually employ an unclad and unstrained section of the fiber. In this paper, we describe the design and fabrication of a microbent fiber optic sensor that can be used for pH sensing. In order to obtain the desired performance, a permanently microbent portion of a plastic optic fiber is coated with a thin film of dye impregnated sol–gel material. The measurements are simultaneously carried out in two independent detection schemes viz., the bright field detection configuration for detecting the core modes and dark field detection configuration, for detecting the cladding modes. The results of measurements of core mode-power and cladding mode-power variation with change in pH of a solution surrounding the coated portion of the fiber is presented. This paper thus demonstrates how a bare plastic fiber can be modified for pH sensing in a simple and cost effective manner.

Keywords: Microbend; Microbent; pH sensor; Evanescent wave; Fiber optic; Dye doped

Fiber optic pH sensors form one of the major classes of fiber optic chemical sensors. They are extensively used in in-vivo and in-vitro applications, especially in ground water analysis and in blood pH measurements [1,2]. All of them make use of the reagent mediated spectroscopic technique in which a pH sensitive dye is coated on a portion of the optical fiber. Different coating techniques include, electrostatic binding, polymeric support and sol–gel technique, of which the sol–gel route is found to be the most versatile, because of the tough, inert and intrinsic binding nature of the membrane thus prepared [3,4]. Usually, evanescent wave fiber optic sensors (EWFS) are used for pH sensing, where a pH sensitive dye is immobilized on the uncladded portion of an optical fiber [5–8]. However, in this paper we demonstrate the feasibility of using a microbent fiber for pH sensing. Microbend loss has been exploited for the past 20 years for fabricating a variety of sensors, especially physical sensors for measuring temperature, pressure, displacement etc. Usually, a pair of corrugated plates is used to produce microbends on to the fiber and the amount of bending will be proportional to the

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pressure applied over the plates [9–12]. While, the bends thus produced usually remain temporary in most of the cases, we have recently shown how a permanently microbent optical fiber can effectively replace a conventional uncladded optical fiber in evanescent field sensing applications [13].

When light passes through the microbent portion of an optical fiber, power propagating will be coupled between mth and nth order mode if the spatial frequency of the perturbation is

$$\lambda = \frac{2\pi}{\beta_m - \beta_n},$$

where β_m and β_n are the propagation constants of mth and nth order modes, respectively. Thus the light propagating up to the bent portion of the fiber as guided (core) modes only, gets coupled between higher order unguided modes which comprises of the cladding and the radiation modes. The evanescent wave of the cladding modes extend into the absorbing region of the dye doped sol–gel coating and hence the power in the cladding modes gets attenuated which in turn decreases the power in the core modes since the mode coupling is a bi-directional phenomenon. But after the bent portion there is little power coupling between the core and cladding modes and they continue to propagate without much coupling. This power in the cladding modes is measured by placing an index matching liquid over the cladding of the fiber, just beyond the bent portion. Such a detection scheme may be considered as the dark field detection scheme where as core mode intensity measurement is the bright field detection scheme.

The optical fiber used is an unjacketed multimode plastic fiber of length 35 cm. The middle portion of the fiber is pressed in between a pair of corrugated plates, which produces permanent microbends. The pitch of the corrugation is 1 mm and the total number of corrugations is 60. To prepare the sol, tetra ethyl ortho silicate (TEOS) is used as the precursor. As a single dye is capable of responding only over a restricted range of pH values, we have used a mixture of bromocresol purple (BCP), bromocresol green (BCG) and cresol red (CR) dyes so as to provide a larger dynamic range for pH measurements. This mixture has a broad absorption band with peak at 589 nm. Eventhough the operating wavelength in the present case, 633 nm, does not correspond to the peak absorption, it is observed that there is considerable amount of absorption even at this wavelength. TEOS, anhydrous ethanol, water and indicator dyes are mixed in the molar ratio 1:4:1:0.02 at room temperature using a magnetic stirrer. The porous silica is made to adhere on to the bent portion of the fiber using dip coating technique, where the dipped fiber is pulled upwards at an optimized rate of 100-mm/min using a stepper motor controlled device. These fibers are then kept for 15 days for the dye to get stabilized in the gel matrix. It is then washed in water to remove the excess and unbound dye. The coated region is again dried at 50 °C.

The experimental setup used to calibrate the present sensor is shown in Fig. 1. The laser emission at 633 nm from a diode laser is coupled to the optical fiber. An index matching liquid (liquid crystal BL-35, Merck UK) is applied just before the sensing region, so that the cladding modes get eliminated. Similarly the same index matching liquid applied just after the sensing region enables

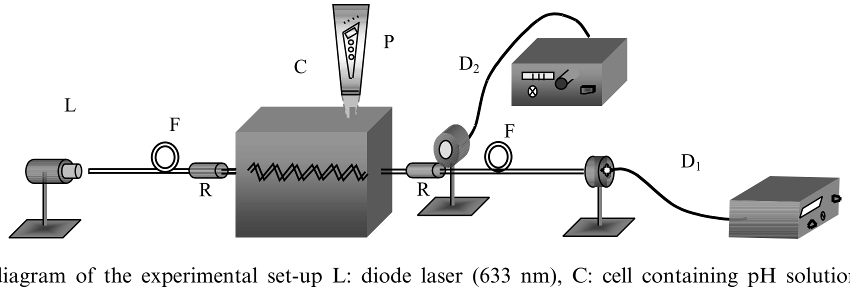

Fig. 1. Schematic diagram of the experimental set-up L: diode laser (633 nm), C: cell containing pH solution, P: pH electrode, F: optical fiber, R: index matching liquid D_1: detector 1 (Metrologic 45–545), D_2: detector 2 (Newport 1815-C).

the measurement of optical power of the modes coupled into the cladding region by the microbends. Two detectors D_1 (Metrologic 45–545) and D_2 (Newport – 1815 C) are used simultaneously to measure the optical power contained in the core modes and that in the cladding modes, respectively. The pH of the solution is varied by adding either HCl or NaOH and monitored by a pH electrode (pH Scan 2, MERCK), which has a sensitivity of 0.1 pH units.

Figs. 2 and 3 show the variation of the optical power corresponding to the core modes and cladding modes, respectively, with respect to different values for pH of the solution surrounding the sensing region of the fiber. It can be seen that the core mode-power variation and the cladding-mode power variation are similar to that obtained with a conventional uncladded EWFS [3–8]. However, it may be noted that the sensitivity in the bright-filed detection scheme is greater than that in the dark field detection scheme. In an earlier work [13] it was observed that the sensitivity of the dark field detection is higher compared with that of the bright field detection scheme. This apparent contradiction in the case of sensitivity against that described in [13] is a result of the effect of the microbending amplitude, which has lesser effect on the optical power in the cladding mode. The dynamic range of the present sensor system is fairly large and it covers 3–11 pH units. It should also be noted that the present sensor uses a double detection scheme which is certainly an advantage over conventional sensors. This aspect provides a double check and thus greater reliability for the measurements. It is also observed that the graphs obtained are independent of the direction of the change in pH value of the solution, i.e. a low to high pH variation gives the same curve as a high to low pH variation.

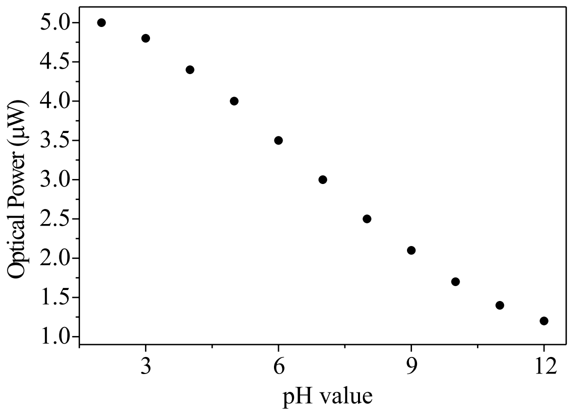

Fig. 2.

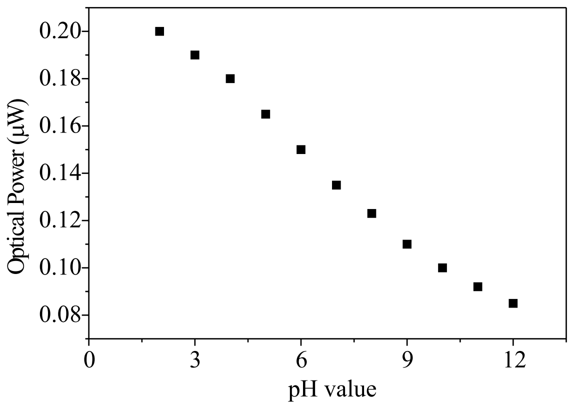

Fig. 3.

In summary, we have demonstrated a fiber optic pH sensor based on a microbent optical fiber. The present sensor is superior to the conventional fiber optic sensor because of the following advantages. The fabrication of microbends on an optical fiber is easier and convenient than uncladding the fiber as in EWFS where it requires mechanical as well as chemical etching of the optical fiber. We have in the present case used plastic fibers that are usually inexpensive and can be easily and effectively manipulated. This can definitely add to the cost effective nature and simplicity of the sensor. Moreover, the technique described here employs a double detection scheme thereby increasing the reliability, unlike the conventional schemes where single detection alone is possible. Hence the accuracy and reliability of measurement using the present fiber sensor is much higher than conventional sensors.

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