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Evanescent wave sensor to monitor the etching rate of an optical fibre

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The design and development of an evanescent wave sensor to determine the etching rate of the core of an optical fibre is discussed in this paper. The working of the device is based on the principle of propagation and loss of the evanescent wave in the cladding region of the fibre. The fraction of light intensity creeping out of the core of an uncladded fibre is a function of the core radius. As this radius decreases, the evanescent wave coupling to the medium surrounding the core enhances. This results in a decrease of the transmitted light intensity through the fibre. This technique is useful to design and fabricate optical fibres with different core geometries.

1 Introduction

During the past few years, the fibre optic sensor (FOS) technology has achieved tremendous progress and this sensor technology is taking advantage of the mainstream developments in electronics and telecommunications. The extensive progress of research activities in this area is related to design and fabrication of fibre optic sensors for the measurements of physical and chemical variables[1]. The advent of fibre optics technology has revived the interest in the well known evanescent wave absorption spectroscopy[2,3]. Evanescent field absorption occurs when a medium occupying the uncladded region of the waveguide absorbs light at the wavelength being transmitted[4]. Study of variation in the core radius of an optical fibre has applications in the design and fabrication of certain types of optical fibre sensors in which various types of core geometries are used. For example, the tapering of the fibre end can be made by slowly pulling the fibre through an etchant. The tapering angle depends on the rate of etching of the fibre core. The use of fibre with tapered core will enhance the sensitivity of optical fibre sensors. In this paper we discuss the evaluation of the etching rate of the material of the fibre core using evanescent wave coupling.

2 Principle

In the case of FOS based on the evanescent wave coupling, the light is transmitted via a series of total internal reflections[5]. In each reflection most of the electromagnetic field is trapped inside the waveguide, but a fraction of it appears as an evanescent wave in the uncladded region of the fibre. The fraction of the optical power outside the core is given by[2]:

$$\gamma \cong 4(2)^{1/2} \frac{\lambda}{6\pi p(NA)} \qquad \ldots (1)$$

where λ is the wavelength of light transmitted, p the core radius and NA is the numerical aperture of the fibre. When the uncladded region of fibre is immersed in a liquid, the evanescent field penetrates into the liquid and interacts with it. As the core diameter decreases with the etching, intensity of evanescent light increases and hence the light transmitted through the fibre is attenuated.

3 Experimental Set-Up

Fig. 1 shows the schematic diagram of the FOS. The FOS arrangement employed in the present investigation consists of a multimode plastic clad silica fibre (200/380 μm) of numerical aperture 0.2 with its cladding removed from the central region over a finite length. The uncladded region of the fibre acts as the sensor element. A rectangular reaction cell (3 cm in length, 1.5 cm in depth and 1 cm in breadth) acts as the container for the etchant hydrofluoric acid (40per cent HF). Two holes are drilled on the end faces of the cell so that they are along the same line. The fibre is introduced through these holes so that the sensing

Fig. 1—Experimental set-up of fibre optic sensor

region is well immersed in the HF acid. Further, the ends of the fibre are well polished so as to get optimum coupling. Light from a 5 mW He-Ne laser with stabilized output is launched into one end of the input fibre using a short focal length lens and the transmitted power is detected using an optical fibre powermeter (Megger OTP 510). As the beam propagates, it results in the coupling of the evanescent wave to the medium surrounding the core. Since the fraction of light creeping out of the core of an uncladded fibre is inversely related to core radius, evanescent wave coupling enhances with time due to the action of HF on the glass core of the optical fibre. This results in a decrease of the transmitted light intensity through the fibre as time progresses. The amount of light intensity transmitted is noted for every 30 s. The investigations are carried out for various uncladded lengths l = 3, 2.6, 2 and 1.5 cm. Variation of the transmitted power with time gives the etching rate in terms of the output power.

The etching rate as a function of radius is then determined using a travelling microscope. A fresh sample of the same fibre with its cladding removed from a length 3 cm is introduced into the reaction cell containing HF. The travelling microscope is focussed on the uncladded portion of the fibre. Using the miscroscope the radius is measured for every 30 s.

4 Results and Discussion

Fig. 2 gives a typical plot of the power output and radius versus time for l = 3 cm. The plots for different lengths of the sensing region show a nonlinear behaviour indicating that as time progresses, the material of the core takes more time to etch; that is the etching rate decreases. This is attributed to the decrease in the effective concentration of HF.

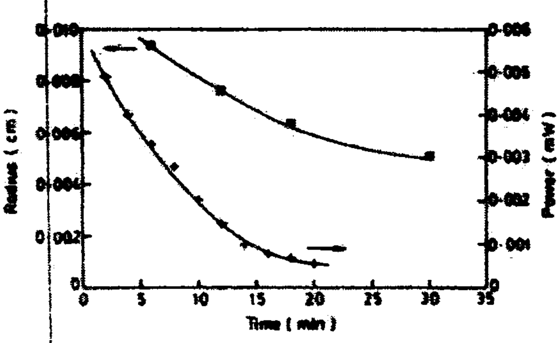

Fig. 2—Variation of power output and radius with time

Table 1—Sensitivity of evanescent wave sensor

Length l (cm)	Sensitivity dp/dr $\mu W/\mu m$
3.0	3.5×10^{-2}
2.6	1.7×10^{-2}
2.0	1.4×10^{-2}
1.5	0.7×10^{-2}

Assuming the etching rate to be proportional to the decrease in the transmitted power as an approximation, for the initial period;

$$\frac{dp}{dt} = K \frac{dr}{dt} \qquad \ldots (2)$$

From Fig. 2, dp/dt evaluated from the linear part of the plot is 5.2×10^{-6} mW/s and dr/dt evaluated from the linear part of the plot is 0.055 μm/s. Therefore, the etching rate or rate of decrease of radius;

$$\frac{dr}{dt} = 10 \frac{dp}{dt} \text{ m/s} \qquad \ldots (3)$$

This enables us to directly read out the etching rate from the observed power variation. Assuming the value of dr/dt determined using the microscope to be a constant for various uncladded lengths of the fibre, the etching rate of the core of the fibre can be evaluated for various uncladded lengths. It is observed that the sensor becomes more sensitive as the length of the uncladded portion of the optical fibre is increased (Table 1).

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