DESIGN AND FABRICATION OF SINGLE MODE FIBRE OPTIC REFRACTIVE
INDEX SENSOR

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Abstract: We present a simple, compact and low–cost fibre optic refractive index sensor based on core diameter mismatch. The sensor has been made by etching out the whole cladding and some portion of the core of a SM 600 fibre. The etched out portion of the fibre makes the device sensitive to the external refractive index. We have carried out simulation and experimental study on the performance of proposed refractive index sensor. A good agreement between simulated and experimental results has been obtained.

1. INTRODUCTION

The refractive index sensors find numerous applications in industry for detecting physical and biological parameters. The fiber optic refractive index sensor is ideal for refractive index measurement of fluids in industrial, chemical and food processing industry applications. Its use allows a complete refractive index analysis in the most challenging environments. A fibre based refractive index (RI) sensor can be compact in size, lightweight and exhibit high sensitivity. Several alternatives to design RI sensors with conventional optical fibres have been reported in the literature. Metal-coated fibres using surface plasmon resonance [1, 2] and fibre Bragg grating (FBG) [3] have been used as highly sensitive RI sensing devices. Another alternative to use the optical fibre as RI sensor is the tapering of fibre and stripping of the fibre cladding [3]. Long period gratings have been also used for sensing applications [4-6]. Untapered, fully cladded fibres with thin films deposited on them have also been used as RI sensors [7-9]. Recently a highly efficient optical fibre sensor based on core diameter mismatch has been proposed by Villatoro et al. [10], where the core diameter mismatch is obtained by splicing a short section of single mode fiber to a multimode fiber [10]. In this paper we propose a simple, compact, low cost and high sensitivity RI sensor which is based on core diameter mismatch in the single-mode fibre for the first time to the best of our knowledge. To form the sensing region in the single-mode fibre, a part of the cladding is etched out in a small length of the optical fibre, however, to obtain core diameter mismatch a small portion of the core has also been etched out. Response of the sensor is investigated by the modulation of the modal field distribution and modulation of fractional power transfer with the refractive index of the external medium. We have also investigated the performance of the sensor for same core diameter in the cladded and uncladded region and also for the core diameter mismatch case. We have numerically studied the effect of etched core radius and operating wavelength on the response of the sensor. Air, water and acetone have been used as the external medium to experimentally measure the sensitivity of the sensor. The proposed sensor should be useful as a low-cost compact refractometer.

2. SENSOR STRUCTURE, WORKING
PRINCIPLE AND METHOD OF ANALYSIS

A schematic diagram of the core diameter mismatch sensor is shown in figure 1. $a$ and $s$ define the core radii in cladded and sensing regions respectively while $n_1$, $n_2$ and $n_{ex}$ are the refractive indices of the core, cladding and the external sensing medium respectively. The modal fields in the cladded and the sensing regions are represented by $\psi$ and $\psi_s$, respectively. The modal field distribution in the sensing region of the fiber, which is placed into an external medium having refractive index different from that of the cladding, is different from the modal field pattern in the cladded region. The overlap of modal fields in the cladded region and in the sensing
First of all we have studied the effect of refractive index of external medium on the fractional power transfer for same core diameter \( r = a \) and shown in figure 2. It is obvious that fractional power transfer \( T \) increases with \( n_{\text{ex}} \). For \( n_{\text{ex}} = 1 \) (air) there is strong confinement of modal field in the core of the sensing region and the overlap between \( \psi \) and \( \psi_s \) is small. As the value of \( n_{\text{ex}} \) increases the field spreads more into the sensing region and the overlap increases. As a result fractional power transfer \( T \) increases. A typical variation in \( T \) with \( n_{\text{ex}} \) is shown in figure 2. From figure it is obvious that for given parameter and \( s = a \), \( T \) varies from 85.5\% to 92.4\% when \( n_{\text{ex}} \) is increased from 1.33 (water) to \( n_2 = 1.44 \) (acetone), which shows a small sensitivity for such a large range of refractive index.

We have then calculated the fractional power transfer for the case \( s < a \) (core diameter mismatch) and results are shown in figure 4. We have seen the variation of \( T \) as a function of \( n_{\text{ex}} \) for different values of \( s \). By comparing the results of figure 3 and 4 one can see an improvement in the sensitivity of \( T \) with \( n_{\text{ex}} \). \( T \) varies from 50\% to 78\% when \( n_{\text{ex}} \) is increased from 1.33 (water) to 1.44 (acetone) for \( s = 0.7 \) \( \mu m \). In comparison the corresponding transmission in a multimode-singlemode-multimode configuration of Ref. [10] changes from 97\% to 86\%. Resolution of the sensor which is an important characteristic of the optical fibre sensor has also been calculated and found to be nearly \( 9 \times 10^{-4} \) around \( n_{\text{ex}} = 1.44 \). However for the lower values of \( n_{\text{ex}} = 1.30 \), the resolution decreases to \( 2 \times 10^{-2} \). To make this estimation, we have assumed that \( T \) is measured with an accuracy of 1\%.

### 3. EXPERIMENT

The sensor has been fabricated using a single mode SM 600 fibre to validate the principle of operation and feasibility of the sensor. In the middle portion of the fibre, the cladding and some portion of the core has been etched out by using Hydrofluoric acid with 20\% concentration to make the device sensitive to RI of the external medium. As a result, the evanescent field in the core cladding interface interacts with the external medium. Hence the total power at the output is modulated and becomes sensitive to the RI of the external medium.

To perform the experiment the sensing region of the fibre has been carefully packaged into a glass tube with an inlet to introduce and an outlet to drain out the liquid as shown in figure 4. Light at 633 nm from a He-Ne laser has been launched into the fiber through a 20X microscope objective and the output power has been measured using a photo detector and a power meter. We have launched light from a 5 mW He–Ne laser at 633 nm wavelength into the device and the output power \( P_{\text{out}} \) has been recorded when the sensing region was surrounded by air. The output
power varied on the introduction of various liquids into the sensing region and has been recorded as $P_{\text{liquid}}$. To analyze the sensitivity of the sensor we have plotted $P_{\text{liquid}}/P_{\text{air}}$ as a function of refractive index of the liquid as shown by filled circles in figure 5. We have also calculated the fractional power transfer using the mode field overlaps and have plotted numerically calculated values of $P_{\text{liquid}}/P_{\text{air}}$ as shown by continuous curve in figure 5. A good agreement between the simulated and experimental results has been obtained. The proposed sensor has wide sensing range and should be useful as a compact refractometer.

4. CONCLUSIONS

We have developed a single-mode optical fiber based refractive index sensor design. The sensor can be realized by removing the cladding and/or a part of the core from a small portion of the fiber. The performance of the sensor has been investigated with the etched core radius. It is shown that the core-diameter mismatch sensor, in which a part of the core has also been removed, is more sensitive to the same core diameter sensor. Maximum resolution of sensor is found to be $9 \times 10^{-4}$ for the acetone as an external material which is fairly good resolution for the optical fibre RI sensor. A SM-600 optical fiber sensor has been realized and its sensitivity has been tested for water and acetone. The proposed sensor can be used relatively in a wide range of the refractive index of the surrounding medium (1.33-1.44) and should be useful as a compact refractometer.

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