IOP Conference Series: Materials Science and Engineering

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To cite this article: S Nivedha *et al* 2017 *IOP Conf. Ser.: Mater. Sci. Eng.* **263** 052031

D-shaped plasmonic sensor using a molybdenum disulfide doped photonic crystal fiber

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Abstract. We investigate a D-shaped photonic crystal fiber sensor with Molybdenum disulfide (MoS_2) as a bio-recognition layer. The proposed sensor works based on the principle of surface plasmon resonance. Here, a thin layer of gold is deposited on the side polished flat surface of the PCF over which monolayer MoS_2 is deposited in order to enhance the sensitivity of the sensor. The proposed sensor exhibits the sensitivity of 2000 nm/RIU.

1. Introduction

Over the past years, surface plasmon resonance (SPR) technique is used for sensing purpose in chemical and biological fields [1-2]. SPR is a phenomenon that involves coherent oscillation of electrons at the metal-dielectric interface. The resonance occurs when the core guided mode couples with the plasmon mode. The first SPR biosensor was demonstrated by Liedberg et al [1]. SPR sensor based on microstructure fibers has high sensitivity and has extensive applications in food safety, medicine testing and environment monitoring [3-4].

Many researchers have investigated the photonic crystal fiber (PCF) based SPR sensors. Photonic crystal fibers with a regular hexagonal array of air holes running along the fiber length have opened a new way towards the closed-form optical fiber plasmonic sensing [5]. Many new characteristics can be obtained by filling the air holes with materials like metal, liquid crystal or semiconductor [6]. Here, D-shaped fiber is a side polished fiber wherein a section of cladding is removed to get access to evanescent field and a thin layer of MoS_2 is doped to enhance the sensitivity [7, 8].

2. Geometrical structure and modelling of the D-shaped fiber

The geometrical structure of the D-shaped fiber doped with MoS_2 is shown in Figure.1. Here the pitch, Λ, is kept at 2 μm and the diameter of the air holes in the first ring (d1) and the second ring (d2) are 1.2 μm and 1.6 μm, respectively.The Sellmeier equation is used to compute the material dispersion of silica that forms the background material. The refractive index of analyte, $n_{a,}$ is varied from 1.33 to 1.36. The refractive index of gold is calculated using Drude model [9].

The thickness of MoS_2 layers = $N \times 0.65$ nm , where N is the number of MoS_2 layers [10]. Here the thickness of MoS_2 is 1.3 nm and the thickness of the gold layer is fixed as 40 nm. The complex effective mode index of the fiber is solved by finite element method (FEM) using COMSOL Multiphysics software. The real part of the effective refractive index reflects the propagation constant while the imaginary part is proportional to the confinement loss.

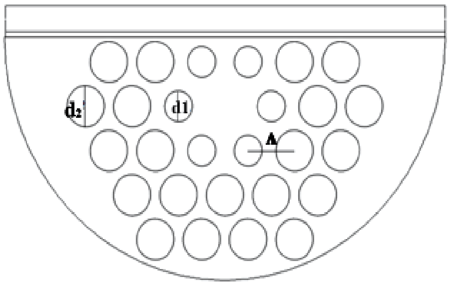

Figure 1. Geometrical structure of the D-shaped fiber doped with MoS_2.

3. Results and discussions

The mode field distribution of the D-shaped fiber is shown in Figure 2 at 750 nm wavelength. The effective refractive index of the fundamental mode and surface plasmon mode are calculated. Next we calculate the confinement loss using the following expression

$$\text{Confinement loss } L = 8.686 \times k_0 \times Im(n_{eff}), \qquad (1)$$

where $Im(n_{eff})$ represents the imaginary part of fundamental mode.

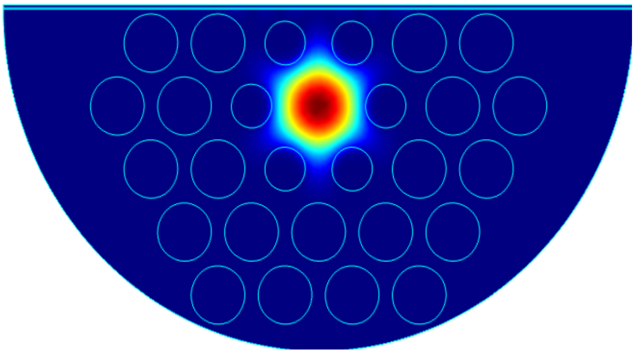

Figure 2. Mode field distribution at 750 nm wavelength.

Figure 3 shows the loss spectra of fundamental mode when the refractive index of analyte is varied from 1.33 to 1.36. From Figure 3, we observe that the loss peak is shifted towards longer wavelength as the refractive index of analyte is increased. Further, the peak loss increases with the refractive index of analyte.

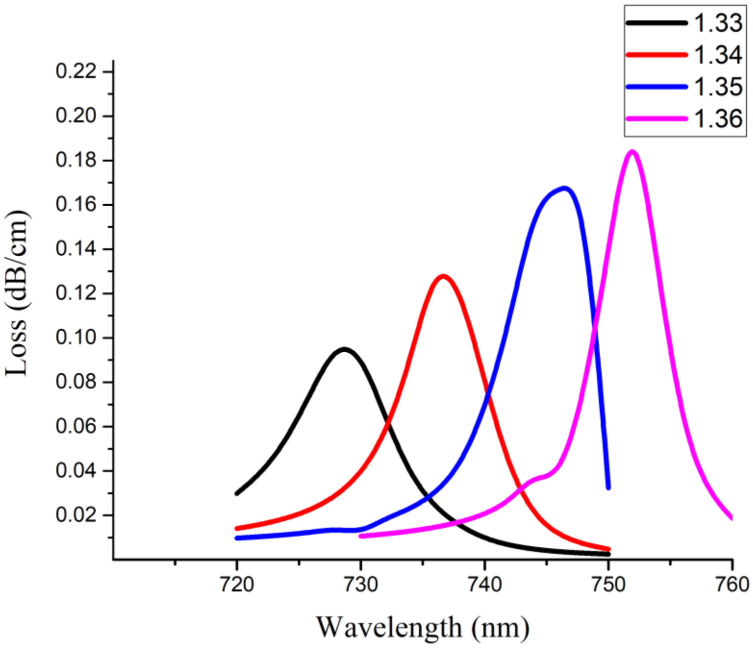

Figure 3. Loss spectra of the fundamental mode when n_a is varied from 1.33 to 1.36

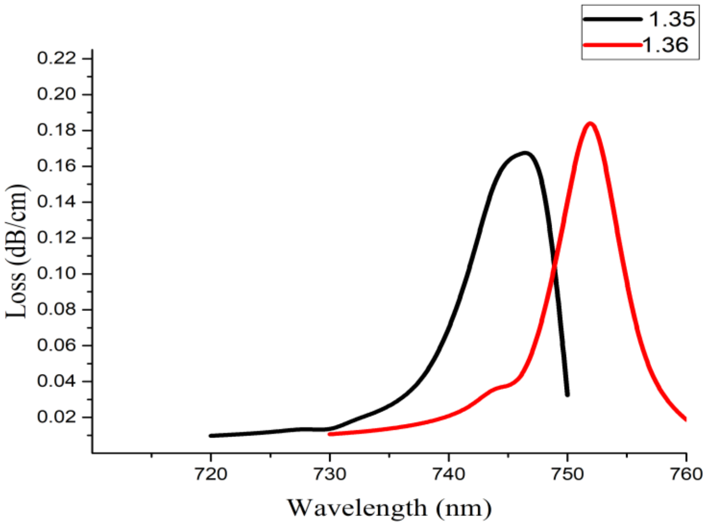

Figure 4. Loss spectra of the fundamental mode when n_a is varied from 1.35 to 1.36

Having computed the loss spectra for various values of the analytes, the next step is to investigate the sensitivity of the proposed sensor. Figure 4 shows the variation of confinement loss against wavelength to find the sensitivity.
The sensitivity is calculated using the relation

$$S(\lambda)\ (nm/RIU) = \frac{\Delta\lambda_{peak}}{\Delta n}, \tag{2}$$

where $\Delta\lambda_{peak}$ is the difference of plasmonic peak and Δn is the difference of refractive index of analyte. Here a sensitivity of 2000 nm/RIU is obtained for refractive index range 1.35 to 1.36.

4. Conclusion

In this paper a D-shaped side polished fiber is designed and a thin layer of MoS_2 is doped. The effective mode field area of the fiber is calculated. A sensitivity of 2000 nm/RIU is obtained when the refractive index of the analyte is varied from 1.33 to 1.36.

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