Refractive index response characteristic of fiber Bragg grating in a few-mode suspended-core fiber

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Abstract: We fabricated a few-mode germanium-doped suspended-core fiber using the stack-and-draw technique. Bragg grating was successfully inscribed into this fiber and its mode properties as well as refractive index response were studied theoretically.

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1. Introduction

Microstructured optical fibers (MOFs) in which air hole channels are running along its length have been studied extensively in recent years because they exhibit a lot of novel optical properties over conventional fibers, due to the flexible design of the air hole arrangement in fiber cross section [1]. Suspended core fiber (SCF) is one kind of MOF that has a small core surrounded by one ring of large air holes in the cladding [2]. The small size of the fiber core generates strong evanescent wave, and significant portion of energy of the propagating light penetrates into the air holes, allowing strong interaction between the light and material filled in the air holes. This facilitates a lot of novel applications such as tunable filters, gas sensors, and bio-sensors [2]. The micron-size air holes of MOFs are inherent microfluidic channels that allow gas/liquids to pass through. Based on the interaction between the light and the fluids, one can achieve highly sensitive refractive index sensor [3] and chemical vapor sensor [4].

In this work, we fabricated a few-mode suspended core fiber (FM-SCF) with six large air holes surrounding the core. The fiber was designed to support several modes. The fundamental HE_{11} mode is well bound within the core and has very small evanescent field, therefore it is insensitive to the change of refractive index of liquids in the air holes. The high order HE_{12} mode has strong evanescent field, thus it is quite sensitive to the change of refractive index of liquids in the air holes. However, the two modes are sensitive to temperature variation. Therefore, it is potentially useful for simultaneous measurement of liquid refractive index and temperature or for the elimination of temperature effect in refractive-index measurements. Fiber Bragg grating (FBG) was inscribed in the FM-SCF to verify its mode properties. Theoretical analysis based on full-vector finite-element method (FEM) was performed to calculate the refractive index response of the FBG written in the FM-SCF.

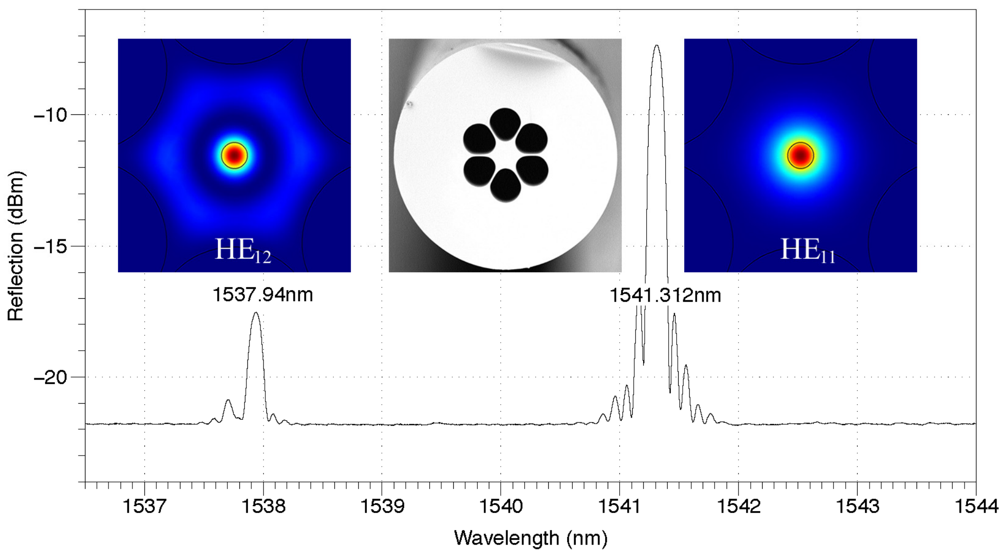

Fig. 1. Reflection spectrum of the FBG written in FM-SCF. The insets show the SEM photo of the fiber and the simulated mode fields involved (HE_{11} and HE_{12}). The second peak is due to intermodal coupling.

2. Fabrication of the FM-SCF and Bragg grating

The FM-SCF was fabricated in our laboratory using the stack-and-draw technique. Firstly, six capillaries with outer diameter (OD) of ~1.33mm and inner diameter (ID) of ~1mm (air filling ratio 0.76) were drawn from a glass tube (OD: 25mm, ID: 19mm). One rod with same size was drawn from a Silibend© Germanium-doped silica preform (OD: 22.5mm, pure silica; ID: 4mm). The stacking was conducted in a jacketing tube (OD: 12mm, ID: 4mm). The center rod is tightly surrounded by six capillaries. Finally the stacked preform was drawn into fiber with an outer diameter of 125 µm. The center inset of fig.1 shows the SEM photo of the FM-SCF cross section. As can be seen from the figure, the diameter of the center silica area is about 15.8 µm, the germanium doped area is about 2.2 µm in diameter, the air hole diameter is 20 µm, and the thickness of struts is about 1 µm.

Bragg grating was written in the fabricated FM-SCF using a phase mask and a 193-nm excimer laser. Before inscription, the fiber was put into a hydrogen chamber for around 2 days to enhance its photosensitivity. The length of the grating is 10mm and the period of phase mask used in the experiment was 1068 nm. Two peaks with a separation of ~3.4 nm were observed in the reflection spectrum as shown in figure 1. The main peak at 1541.3 nm is due to HE_{11} mode self-coupling, and the other peak at 1537.9 nm is due to HE_{11} to HE_{12} intermodal coupling.

3. Mode properties and refractive index response characteristic

The mode properties and the response to liquid refractive index of the FM-SCF were studied theoretically based on a full-vector finite-element method (FEM). Due to the high index contrast between the central silica area and the air hole region, the fiber supports several modes. The insets of fig. 1 show the mode fields of the fundamental HE_{11} mode and the high order HE_{12} mode. Their effective indices at the wavelength of 1540 nm were calculated to be 1.443756 and 1.437517, respectively, corresponding to a wavelength separation of 3.33 nm [5], which agrees quite well with the experimental result.

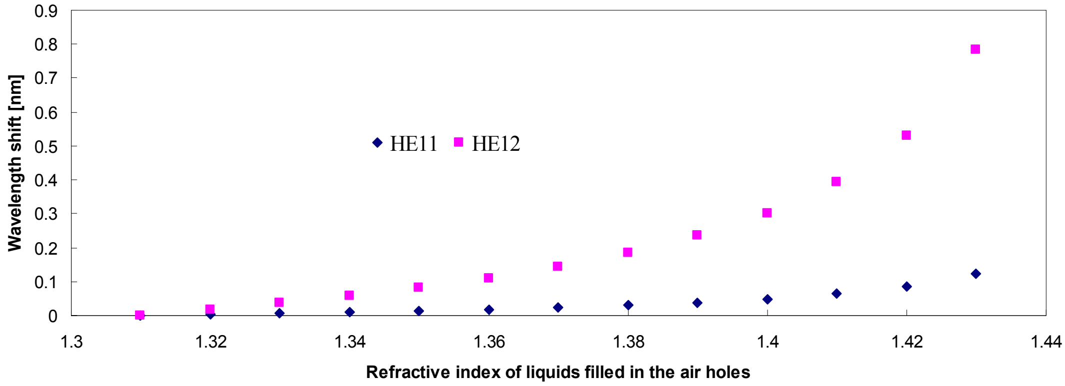

Fig. 2. Wavelength shift as a function of refractive index of the liquids filled in the air holes.

To simulate the response of the FBG to refractive index change of the liquids in the air holes, we varied the refractive index (RI) of the air hole region and calculated the effective indices of the two modes at each RI value. The obtained results are presented in fig. 2. As can be seen from it, the sensitivity of HE_{11} mode to RI is very small (less than 1 nm/RIU), while the sensitivity of HE_{12} mode much larger (about 30 nm/RIU at RI = 1.43). Considering the two modes have similar temperature response, the effect of temperature can be compensated to achieve liquid RI measurement with high sensitivity.

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