SURFACE WAVEGUIDE MODE RESONANCE TECHNOLOGY BASED ON OPTICAL FIBER

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Surface waveguide resonance mode is a new form of surface optical waveguide-matter interaction that has emerged in recent years, with unique manipulable properties and extremely high sensitivity, which has very great potential for surface optical field manipulation and light-matter interaction analysis. Tilted fiber Bragg grating (TFBG), due to the introduction of a small inclination angle in the fiber, allows the forward transmitted core mode to be coupled with the reverse transmitted core mode, cladding mode and radiation mode, forming a complete resonant envelope with a narrow spectral bandwidth, high sensitivity and high resolution. Surface plasmon resonance (SPR) and lossy mode resonance (LMR) are two unique physical mechanisms for the interaction of light with nanofilms of materials with different dielectric constants. Compared with SPR , lossy mode resonance (LMR) combines metal oxide and polymer films with optical fiber and has some remarkable features and advantages such as wide selection of materials, high sensitivity, and easy tuning. This project intends to coat different metal oxide films as well as polymer films on the surface of TFBG fiber based on tilted fiber grating to produce LMR phenomena on the surface of TFBG fiber as a basis for the design of various physical and chemical sensors.

Key Words: tilted fiber bragg gratings (TFBG); surface plasmon resonance (SPR); loss mode resonance (LMR); physical and chemical sensors.

INTRODUCTION

Fiber Bragg grating (FBG) has only one strong resonance λB (Bragg resonance) with the longest wavelength. The single-core guided mode has the largest effective refractive index. While TFBG cladding mode resonance is enhanced, Bragg resonance is weakened [1]. The ghost mode is composed of the superposition of several lower cladding modes, which is closest to λB and usually stronger than its adjacent cladding mode on the short wavelength side, and has many characteristics of Bragg resonance. TFBG formed cladding mode envelope fault near 1530nm and changed from guiding cladding mode to leaking cladding mode. See Figure 1. The reason is that after the grating is tilted, light can be coupled from the fiber core to a large subset of fiber cladding guide modes and cladding leakage modes[2].

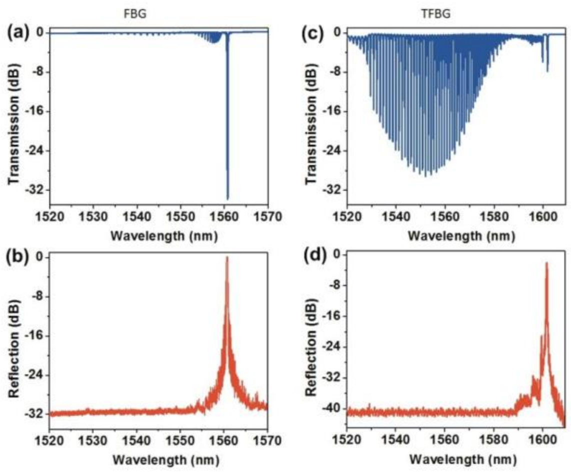

Fig. 1. Measured power transmission and reflection spectra for FBG and TFBG

(a) FBG transmission（b）TFBG transmission
（c）FBG reflection (d）TFBG reflection

For the lossy mode resonance, the loss mode is formed by destroying the total reflection of the interface through the high refractive index dielectric layer. When the propagation constant of the lossy-mode is equal to that of the waveguide mode for certain incident angles of some wavelengths, resonance will be formed, so that most of the energy enters the losse-mode and cannot be transferred to the other end, and resonance valleys will be detected on the spectrum. The propagation constant of the loss mode is related to the refractive index of the object to be measured, so the resonance valley in the spectrum will move with the change of the object to be measured.

The real part of the dielectric constant of LMR coating is positive and much larger than its imaginary part and the real part of the external environment. This requires that the dielectric constant of the coating material have a fairly large real part and a fairly small (but not zero) imaginary part [3].

Compared to traditional SPR technology, LMR has the advantages of higher sensitivity, better resolution and easier control. And the coating material of LMR is metal oxide or polymer, compared with the coating material of SPR, metal, its cost is lower, more widely used.

METHODS

2.1 Transmission matrix simulation

The transmission matrix is a method used to calculate the propagation of light in multilayer films. In this method, electromagnetic fields at different positions are linked by transmission matrix [4]. For LMR sensors, the reflectivity $R(\theta,\lambda)$ of unpolarized light can be calculated by using n-layer reflection matrix method, and then the position of resonance absorption peak can be calculated. Therefore, we can change the surrounding refractive index n, incident angle θ, incident wavelength λ, film thickness d and other parameters to find the best parameters of the experimental design of spectral determination, and prepare for the subsequent experiments. We tried to generate the LMR resonance peak at 1550 nm communication band, reduce the width of the resonance peak of LMR, improve the sensitivity of LMR, and produce a higher sensitivity optical fiber sensing equipment. The transmission matrix structure is shown in Figure 2.

2.2 Spectroscopic experiment

According to the simulation results, the optimal band of LMR is between 1510nm and 1610nm. In order to simulate different detection environments, we first configured external solutions with different concentrations and made them have different refractive indexes (1.3350-1.3650). After that, the bare optical fiber was coated with ITO film by magnetron sputtering coater, which was welded together with ordinary optical fiber and connected with laser source, polarization controller and spectrometer. Then, the ITO coated optical fiber segment was immersed in the solution successively, and the polarization controller was adjusted to observe the influence of different refractive index on the different polarization states of the LMR phenomenon. The spectrum obtained are shown in Figure 3.

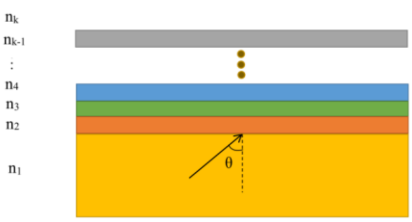

*Fig. 2.*The transmission matrix structure

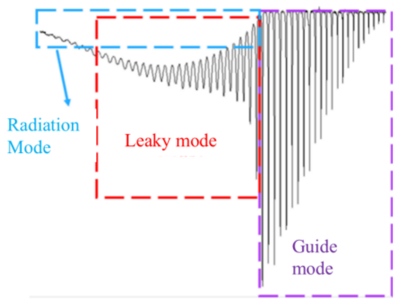

*Fig. 3.*The wave guide mode spectrum

RESULTS

3.1 Transmission matrix stimulation

For three layer transmission structure, silicon dioxide as the fiber core, ITO film as cladding, film thickness of 400 nm, is simulated in the environment of water, as shown in Figure 4, red curve for the TM waves, blue curve for TE waves, TE a TM formant deeper, resonance wavelength is bigger, the first-order (wide absorption peak, The resonance wavelength is near 1365nm, and the TE and TM modes are close.

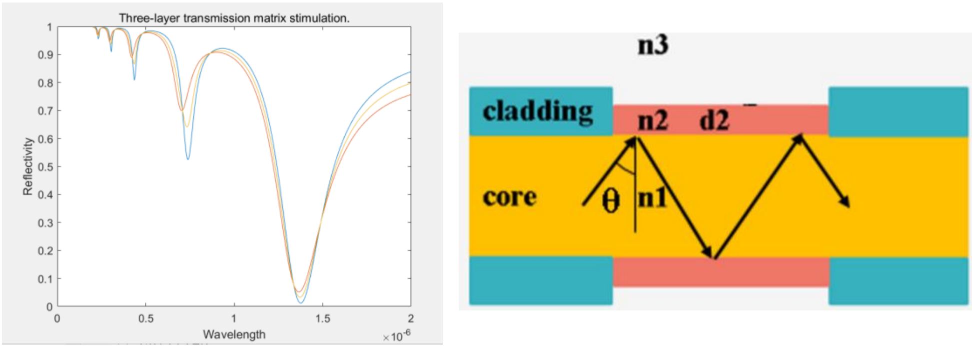

Fig. 4. The three-layer stimulation result and structure diagram

For four-layer structure, i.e. the double-film structure, we simulated the TiO_2+ITO double-film structure and exchanged coating sequence of the inner and outer film material. We found that different sequence of coating generates different lossy mode.

3.2 Spectroscopic experiment

According to the situation, we measured the LMR phenomenon of optical fibers coated with ITO films of different thickness in different external solutions, and the refractive index change was 1.335-1.365, and the refractive index change was 0.005. Figure 5 shows the spectrum variation with refractive index when ITO thickness is 120nm.

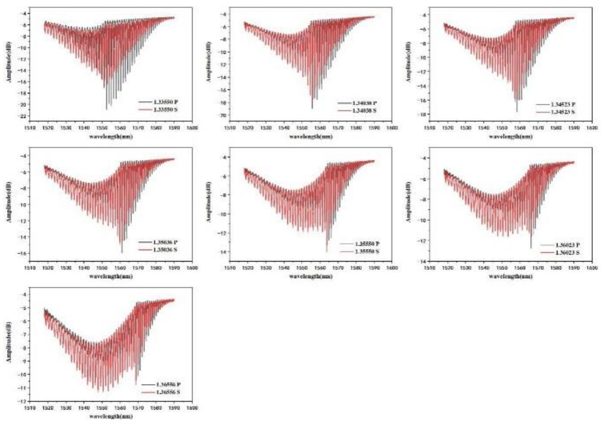

Fig. 5. Experimental spectra of refractive index variation at 120 nm thickness

According to the experimental data, as the external refractive index increases, the resonance peak gradually moves to the long wavelength direction, and the resonance spectral intensity of the guided mode part shows a compression trend. Since the corresponding solution of the radiation mode pair is a continuous solution, the concave envelope surface at the top of the spectrum is the resonance envelope formed by all the radiation modes. It can be observed that with the increase of external refractive index, the resonance peak of the radiation mode also shows a trend of gradual increase. And the resonance intensity is also different for the LMR of different polarization states. The S-state LMR is generally stronger than the P-state LMR. It is also found that with the increase of refractive index, the LMR formant of the S-polarization state is enhanced, while the formant of the P-polarization state is almost unchanged, which makes the S-polarization state have higher sensitivity.

We also repeated the above experiments for ITO with different thicknesses. LMR spectra of S polarization state under different thicknesses were obtained when refractive index was 1.365, as shown in Figure 6:

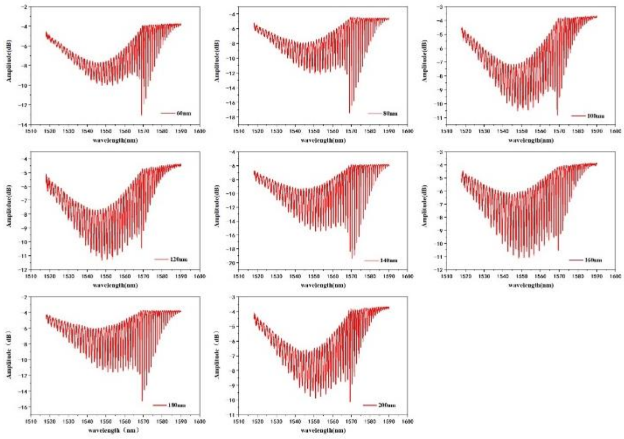

Fig. 6. Experimental spectra of ITO with different thicknesses at 1.365 refractive index

CONCLUSIONS

The TFBG-LMR optical fiber sensing system and the simulation of multilayer waveguides has been studied. Based on the transmission matrix stimulation, we simulated multilayer waveguides with different coating materials, coating thickness and incident Angle and the parameters of the fiber sensing structure are optimized to meet the experimental requirements. According to the simulation and experimental data, it can be seen that increasing the film thickness leads to multi-order LMR, while decreasing the film thickness leads to the absorption peak moving to the direction of smaller wavelength and narrowing the absorption peak. In addition, the experimental results show that the formant peak is deeper and the LMR phenomenon is better and the resolution is higher in the external solution with lower refractive index.

References

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