Optimal Design of the Fluorescence Sensors Based on Step-index Multimode Optical Fibers

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***Abstract*— A fluorescence fiber sensor based on step-index multimode optical fibers is simulated and design by beam propagation method with Beamprop module of Rsoft-CAD software, in the requirement of the much more exciting light in fluorescent material coated on the fiber core. The normalized exciting light power in the coating layer is calculated and analyzed. According to the numerical optimal results, the refractive index n_o of fluorescent material layer is 1.49, and the optimal external diameter of coated layer should be greater than 206μm.**

Keywords—step-index multimode optical fiber; fluorescence; normalized exciting light power; beam propagation method; numerical analysis

I. INTRODUCTION

The fluorescence sensors based on step-index multimode optical fibers (SI-MMF) are manufactured by coating the fluorescent materials on the sidewall and end of the multimode optical fiber whose jacket is stripped in a certain length [1,2]. The refractive index of fiber core and coating layer is step on the cross section [3, 4, 5, and 6]. Fluorescence excited by light in the coating layer. To acquire adequate fluorescence in the sensors under the condition of steady fluorescence efficiency of the materials and steady light source power, we need that the much more exciting light power gathers in the coating layer and the exciting light should be fully interact with fluorescent materials. An effective approach to enhance the exciting light in the coated fluorescent layer is to select suitable index n_o of coated layer, external diameter D of sensing fiber with coating layer, and sensing length L. In order to obtain those optimized parameters, optimal calculation of the fiber sensor has been done.

II. MODEL FOR CALCULATION

The theoretical model of the fiber sensor is established as showed in Fig.1. The SI-MMF is set to have a core diameter of 200μm and jacket external diameter of 230μm, with a core index n_1 = 1.458 and the jacket index n_2 =1.32. The sensor constructed by a step-index multimode optical fiber pigtail and a sensing fiber covered with fluorescence material.

The plane wave fields with wavelength of 395nm are input into the SI-MMF structured sensing fiber. The parameters for initial calculation are set to be L=1cm, D=210μm, and n_o = 1.426 or 1.49. The compute step is settled to be 0.1μm in the cross section of fiber and $1\mu m$ in the propagation direction. The electric fields in the fiber sensing section are calculated by beam propagation method with Beamprop module of Rsoft-CAD software.

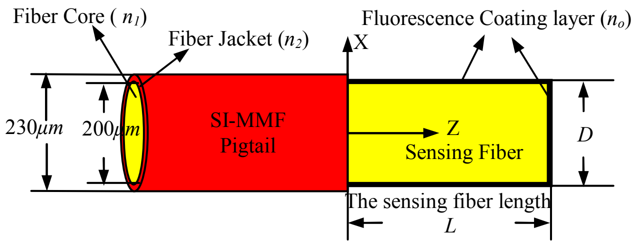


Fig. 1. The model of the fluorescence sensors based on SI-MMFs

III. NUMERICAL RESULTS

Fig.2. shows the electric field distributions in the X-Z section, where Z axis is for propagation direction and X axis for radial direction on the cross section. According to the result in Fig.2, the most electric is limited in the fiber core, while only a small amount of field is leak into the coating layer when n_o =1.426< n_1. The much more field transfer into the coating layer when n_o =1.49> n_1. So the fluorescent materials with higher index should be selected to increase the exciting light power in the coating layer.

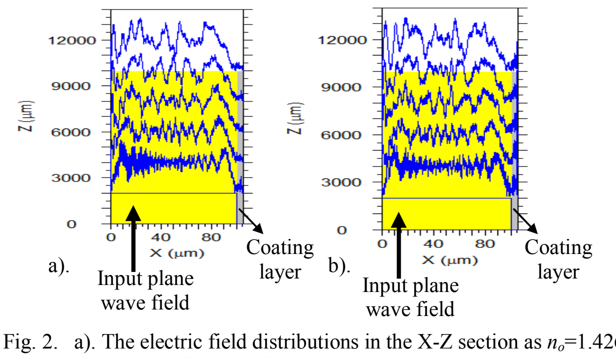
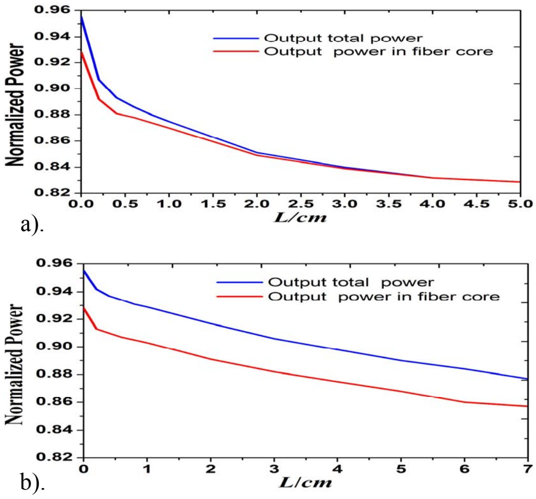


Fig. 2. a). The electric field distributions in the X-Z section as n_o=1.426; b).The electric field distributions in the X-Z section as n_o=1.49

When D=210μm, n_o=1.426 or 1.49, the normalized output light power at the end of sensing fiber with different sensing fiber length L is calculated,, as shown in Fig.3. The blue line is corresponding to the normalized total power at the output end of the sensing fiber and the red line to the normalized power in the fiber core. The difference ΔP between the normalized total power and normalized power in the fiber core can be regarded as the normalized exciting light power in the coating layer. Fig.3 shows that both of the output powers decrease while L increases. When n_o=1.426, ΔP decrease from 0.027 to 0 with a change of L from 0 to 3cm. When n_o=1.49, ΔP decrease from 0.027 at to 0.02 with a change of L from 0 to 7cm. At sensing length L=1cm in Fig.3, when n_o=1.49, ΔP= 0.02 higher than it was when n_o=1.426. It means that the normalized exciting power increase 2% by set coating layer index being a higher value 1.49 from a lower value 1.426, under the condition of steady fluorescence efficiency of the material and the steady light power.

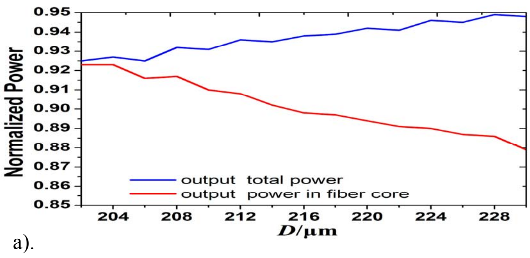


a).

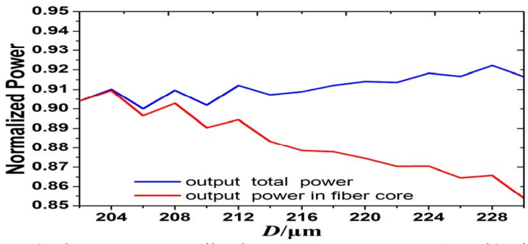
b).

Fig. 3. a).The output normalized power versus L as n_o=1.426; b).The output normalized power versus L as n_o=1.49

As n_o=1.49, L=1cm or 5cm, the normalized power of output light at the end of sensing fiber is calculated with different coating layer external diameter D. Fig.4. shows that the output normalized light power change with D from 202μm to 230μm. The numerical investigation demonstrates that the output normalized total power increase with increase of D, while the output normalized power in the fiber core decrease with increase of D. thus ΔP increase with D. When L=1cm, ΔP increase from 0.002 to 0.074 with a change of D from 202μm to 230μm. When L=5cm, ΔP increase from 0 to 0.081, ΔP increase significantly when D >206μm. Because the longer the sensing length is, the more the fluorescence arises in the coating layer, we choose the optimal sensing length to be 5cm. According to Fig.4, the external diameter D with coating layer should be greater than 206μm to increase the normalized exciting power in coating layer. To set n_o=1.49, L=5cm, D=230μm, the normalized exciting light power reach 0.08.



a).



b).

Fig. 4. a).The output normalized power versus D as L=1cm; b).The output normalized power versus D as L=5cm

IV. CONCLUSION

The theoretical model of a fluorescence fiber sensor based on SI-MMF is established and the optimal parameters, such as the refractive index of fluorescent material, external diameter and the length of sensing fiber, are simulated by beam propagation method. The normalized exciting light power in the coating layer is calculated under the condition of steady fluorescence efficiency of the materials and the steady light source power. Numerical results show that to acquire adequate fluorescence in the sensors the refractive index n_o of coating layer is selected to be a higher value 1.49, the optimal external diameter should be greater than 206μm.

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