New insights into fiber-optic mode transition

P1.41

Xianxin Yang(杨现鑫), Zhihong Li(李志红)

College of Electrical and Electronic Engineering, Wenzhou University, Wenzhou 325035, Zhejiang ,China

Introduction

The deposition of thin film with high refractive index onto optical fibers has become one of the most effective approaches to improve sensing performance of fiber-optic sensors . The mechanism is based on the phenomenon of mode transition induced by the thin film.

Analysis and discussion

The film guided modes, if exist in this configuration, will zigzag in the thin film [Fig. 1]. The light is totally internally reflected at both interfaces of thin film. The reflection gives rise to phase shift that is related to the reflection coefficient $r_{f,j}$:

$$r_{f,j} = \frac{k_{r,f}/n_f^{2\gamma} - k_{r,j}/n_j^{2\gamma}}{k_{r,f}/n_f^{2\gamma} + k_{r,j}/n_j^{2\gamma}} \quad (1)$$

where $k_{r,f} = \sqrt{(k_0 n_f)^2 - \beta^2}$ and $k_{r,j} = \sqrt{\beta^2 - (k_0 n_j)^2}$ with $k_0 = 2\pi/\lambda$ and $\beta = k_0 n_{eff}$ with n_{eff} being effective refractive index (ERI), $\gamma = 0$ for S-polarized modes and $\gamma = 1$ for P-polarized modes. The phase shift $\phi_{f,j}$ can be then obtained as:

$$\phi_{f,j} = arctan\left(i\frac{1-r_{f,j}}{1+r_{f,j}}\right) = arctan\left(\frac{n_f^{2\gamma}}{n_j^{2\gamma}}\frac{k_{r,j}}{k_{r,f}}\right) \quad (2)$$

The total phase shift between two adjacent reflection points at the same interface should be:

$$2k_{r,f}d - 2\phi_{f,cl} - 2\phi_{f,s} = 2v\pi \quad (3)$$

Depending on the film thickness, this planar thin film waveguide supports three kinds of modes including film guiled modes, film cladding modes and leaky modes. As the film thickness is increased, the planar waveguide firstly supports the leaky modes, then the film cladding modes, and finally the film guided modes [Fig. 2].

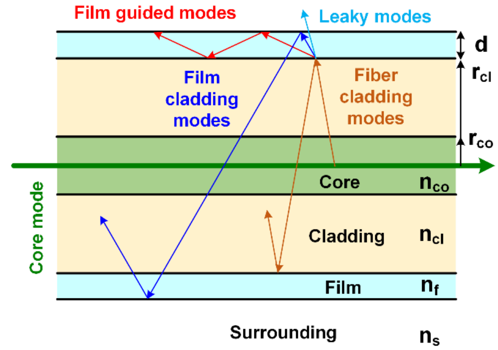

Fig.1.Configuration of thin film coated single mode fiber.

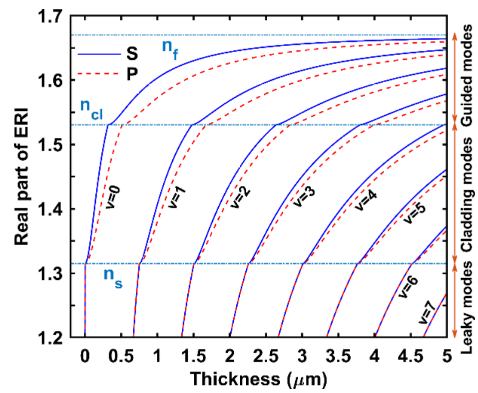

Fig. 2. Modes supported by thin film waveguide

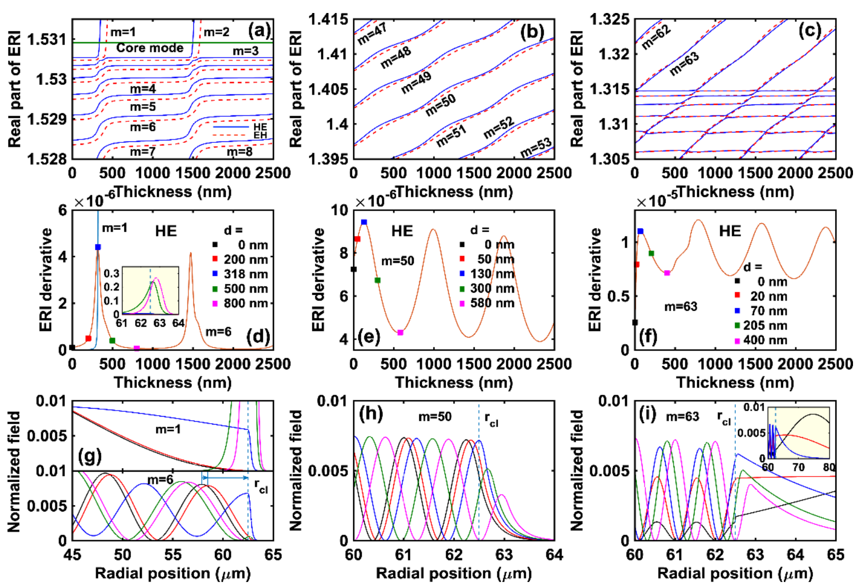

Fig.3. Evolution of full-vector HE/EH$_{1,m}$ modes tuned by thin film: (a)~(c) ERI, (d)~(f) ∂ERI/∂d, and (g)~(i) mode field. Inlet in (d) gives the field profile of film guided mode in Fig. 3(g, top panel). Inlet in (i) shows the field of a leaky mode.

The ERI of low-order modes varies almost concurrently with the film thickness[Fig.3(a)]. High-order modes begin to increase the ERI at a much smaller film thickness than that of low-order modes[Fig.3(b)~(c)]. The mode transition does occur before a fiber cladding mode becomes guided in the thin film[Fig.3(d)~(f)]. A whole mode transition actually corresponds to the generation of film waveguide mode, which includes two processes: a high-order fiber cladding mode → a phase-matched film cladding mode → an adjacent low-order fiber cladding mode[Fig.3(g)~(i)].

Conclusion and outlook

The mode transition occurs from the last cladding mode as the thin film thickness is increased. The transition process actually corresponds to the generation of film waveguide modes including film guided modes and film cladding modes. The results obtained in this work provide new perspectives in the field of fiber-optic devices tuned by thin film.

Acknowledgement

National Natural Science Foundation of China (61905180);
Basic Research Project of Wenzhou (G20190005).

Corresponding author: Zhihong Li (李志红), PhD, Associate Professor, Email: zhihong@wzu.edu.cn, Phone: +86-18758715179