تأثیر دما، شکل و چگالی نانوذرات روی فیبر نوری با پوسته کامپوزیت

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چکیده- در این مقاله، از فیبر نوری با پوسته کامپوزیت استفاده شده است. با فرض اینکه انتشار امواج الکترومغناطیسی در موجبر طبق قاعده انعکاس کلی رخ می دهد، گوس-هانخن شیفت منفی در فیبر نوری مذکور به ازای شکلهای مختلف از نانوذرات برای دما و طول موجهای مختلف با استفاده از نرم افزار متلب شبیه سازی شده است. نتیجه اینکه، نانوذرات با شکل بیضی کشیده شده دارای کمترین عمق نفوذ هستند. بنابراین به بررسی تاثیر تغییرات دانسیته نانوذرات در گوس هانخن شیفت مثبت و منفی و همچنین بررسی تغییرات دانسیته نانوذرات به ازای طول موج پلاریزه S و P برای نمونه انتخاب شده، پرداخته شده است. در نهایت، منحنی پاشندگی و فرکانس کات آف در فیبر نوری با پوسته کامپوزیت توصیف گشته و مشخص شده است که با تغییر دانسیته نانوذرات می توان فرکانس قطع مدی را کنترل کرد.

کلید واژه- پاشندگی، شکل، گوس-هانخن شیفت، فرکانس کات آف، فیبر با پوسته کامپوزیت.

Influence of Temperature, Geometry and Density of Nanoparticles on Composite Cladding Fiber

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Abstract- In this paper, composite cladding optical fiber is used. Assuming that the emission of electromagnetic waves in the waveguide occurs by total reflection rule, negative Goos-Hanchen shift in the optical fiber for different forms of nanoparticles of different wavelengths and temperature simulated by MATLAB software. As a result, prolate ellipsoid nanoparticles are drawn with the least penetration depth. So the impact of changes in the density of nanoparticles in negative and positive Goos-Hanchen shifts as well as changes in the density of nanoparticles as a selected sample have been investigated per P and S polarized wavelengths. Finally, the dispersion curves and cut-off frequency of the composite cladding optical fiber has been described and it has been found that by changing the density of nanoparticles cut-off frequency mode can be controlled.

Keywords: Dispersion, Geometry, Goos-Hanchen Shift, Temperature, Cut-off Frequency, Composite Cladding Fiber.

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1 Introduction

Light reflection and refraction at two medium interface is one of the most basic optical processes in optical systems which is described by Snell's law and Fresnel formulas. The Goos-Hanchen shift is a displacement of S or P polarized light beam, reflected by a medium with a complex and angle dependent reflection coefficient. There are many researches in this field [1]. On the other hand, there are many models to describe composite medium [2]. Therefore, researchers are studied Goos-Hanchen shift at an interface of a composite material of metallic nanoparticles [3].

The cut-off frequency for step-index fiber is an important parameter since it is defined as the frequency at which the mode does not remain purely guided. There are investigated cut-off frequencies and propagation constant for rectangular and cylindrical waveguides [4,5]. Then, there are calculated temperature effects on dispersion for single mode optical fibers [6] and plasma waveguide [7]. In addition, there are studied about geometry of nanoparticles and investigated the influence of size and shape of nanoparticles on surface Plasmon resonances [8].

In this paper, first, the brief description for geometry of nanoparticles, temperature and Goos-Hanchen shift influence on Composite cladding optical fiber and the effect of dispersion curve and cut off frequency on optical fiber have been presented. Second, the effects of negative Goos-Hanchen shift on the composite cladding fiber for different geometry of nanoparticles, containing different wavelength and temperature have been investigated. As well, negative and positive Goos-Hanchen shift and complex reflection for P and S polarized light have been simulated for best geometry for different fraction and temperature. In addition, dispersion curves and cut-off frequency on composite cladding optical fiber have been achieved for different fraction. Finally, the result of simulation has been reported.

2 Mathematical Modeling

In this paper, as shown in figure 1, composite cladding fiber has been used.

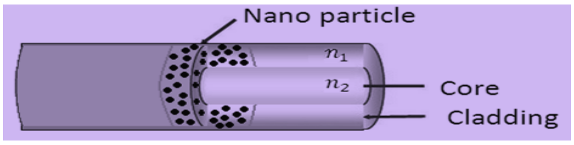

Figure 1: Optical fiber with composite cladding

The effect of nanoparticle’s shape and size has been calculated. Polarizability is the relation between uniform external field and induced dipole moment in a nanoparticle. A simple example for polarizability is a homogeneous sphere. To analyse more complex shapes, numerical efforts are needed. Polarizability equations for sphere, oblate ellipsoid, prolate ellipsoid, tetrahedron, cube, octahedron, dodecahedron and icosahedron are shown in equation 1 to 8, respectively [8,9].

$$Sphere: \alpha = 3\varepsilon_1 V \frac{\varepsilon_2 - \varepsilon_1}{\varepsilon_2 + 2\varepsilon_1} \tag{1}$$

$$Oblate\ ellipsoid: \alpha = \frac{V}{4\pi} \frac{\varepsilon_2 - \varepsilon_1}{\varepsilon_2 + L_\gamma(\varepsilon_2 - \varepsilon_1)}, \tag{2}$$

$$L_\gamma = \frac{1 - e^2}{2e^3}\left[log\frac{1+e}{1-e} - 2e\right], e = \sqrt{1 - \frac{b^2}{a^2}}$$

$$Prolate\ ellipsois: \alpha = \frac{V}{4\pi} \frac{\varepsilon_2 - \varepsilon_1}{\varepsilon_2 + L_\gamma(\varepsilon_2 - \varepsilon_1)} \tag{3}$$

$$L_\gamma = \frac{1 + e^2}{e^3}[e - tan^{-1}e], e = \sqrt{1 - \frac{b^2}{a^2}}$$

$$Tetrahedron: \tau = \frac{\varepsilon_2}{\varepsilon_1}, \alpha = \frac{\alpha'}{\varepsilon_1 V}, \alpha' = 5.0285(\tau - 1). \frac{\tau^3 + 7.65667\tau^2 + 8.50919\tau + 1.8063}{\tau^4 + 14.1983\tau^3 + 44.9182\tau^2 + 30.2668\tau + 5.0285} \tag{4}$$

$$Cube: \tau = \frac{\varepsilon_2}{\varepsilon_1}, \alpha = \frac{\alpha'}{\varepsilon_1 V}, \quad \alpha' = 3.6442(\tau - 1). \frac{\tau^3 + 4.83981\tau^2 + 5.54742\tau + 1.6383}{\tau^4 + 8.0341\tau^3 + 19.3534\tau^2 + 15.4349\tau + 3.6442} \tag{5}$$

$$Octahedron: \tau = \frac{\varepsilon_2}{\varepsilon_1}, \alpha = \frac{\alpha'}{\varepsilon_1 V}, \quad \alpha' = 3.5507(\tau - 1). \frac{\tau^3 + 5.13936\tau^2 + 5.86506\tau + 1.5871}{\tau^4 + 8.26227\tau^3 + 19.8267\tau^2 + 15.6191\tau + 3.5507} \tag{6}$$

$$Dodecahedron: \tau = \frac{\varepsilon_2}{\varepsilon_1}, \alpha = \frac{\alpha'}{\varepsilon_1 V}, \alpha' = 3.1779(\tau - 1). \frac{\tau^2 + 2.42101\tau + 1.246426}{\tau^3 + 4.72932\tau^2 + 6.53464\tau + 2.56842} \tag{7}$$

$$Icosahedron: \tau = \frac{\varepsilon_2}{\varepsilon_1}, \alpha = \frac{\alpha'}{\varepsilon_1 V}, \alpha' = 3.1779(\tau - 1). \frac{\tau^2 + 3.04968\tau + 1.990453}{\tau^3 + 5.29169\tau^2 + 8.52687\tau + 4.0896} \tag{8}$$

where V is volume of the nanoparticles shape, a and b are ellipsoid diameters and ε_1 and ε_2 are permittivity of nanoparticle in cladding and core, respectively. ε_1 and ε_2 can be obtained using Drude, Free Electron Gas, Lorentz-Drude and Brendel-Borhman models[10]. Also, effective medium theory has been used to describe composite structure in different models [10,11]. Also, TE and TM modes have been used to describe cut-off frequency and dispersion curve in the optical fiber for different fractions of nanoparticles. On the other hand, the Goos-Hanchen shift is a phenomenon of optics. It shows a light beam shift in different dielectric materials surfaces. The Goos-Hanchen shift can be expressed as

$$D = -\frac{\lambda}{2\pi}\frac{\partial\Phi}{\partial\theta} \tag{9}$$

where Φ, θ, λ and D are phase of complex reflection coefficient (r), angle of incidence, wavelength and parallel beam shift, respectively. Equation 9, Artmann formula is the simplest theory for Goos-Hanchen shift. The complex reflection for P and S polarized light are given by

$$r_P = \frac{\varepsilon\cos(\theta) - \sqrt{\varepsilon - sin^2(\theta)}}{\varepsilon\cos(\theta) + \sqrt{\varepsilon - sin^2(\theta)}} \tag{10}$$

$$r_S = \frac{\cos(\theta) - \sqrt{\varepsilon - sin^2(\theta)}}{\cos(\theta) + \sqrt{\varepsilon - sin^2(\theta)}} \tag{11}$$

Therefore, according to complex reflection, Goos-Hanchen shift for P and S polarized light can be calculated [2]. In addition, as mentioned, plasma frequency and damping constant are depended on temperature [6].

3 RESULTS

At first, negative Goos-Hanchen shift for different wavelength for different geometry of nanoparticles have been simulated. This studies are for the two wavelengths 826 and 1550 nm, which represents a wavelength in the visible and infrared ranges, is done. The study has been ignored in the ultraviolet range. It is clear, while wavelength is increased, penetration depth is decreased. Prolate ellipsoid has the lowest penetration depth. It is better For better emissions and less losses. Then, as shown in figure 3, negative Goos-Hanchen shift at $300^{\circ}K$ and $900^{\circ}K$ have been investigated. It is widely acknowledge that, penetration depth increases by increasing of temperature and prolate ellipsoidal has lowest penetration depth. As mentioned, the effect of prolate ellipsoid is better and it has the lowest penetration depth, as a result, wave passes easier and with fewer losses from core.

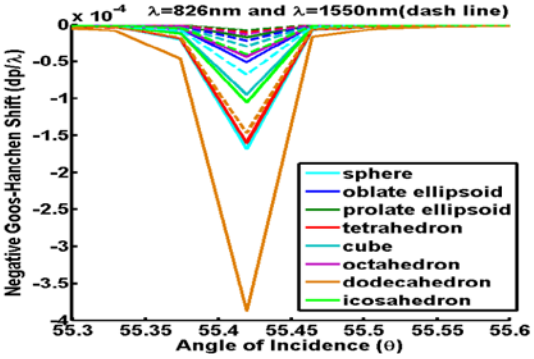

Figure 2: Negative Goos-Hanchen shift for different wavelength for different geometry of nanoparticles

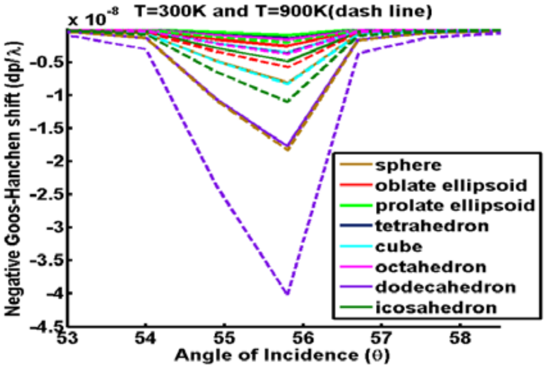

Figure 3: Negative Goos-Hanchen shift in different temperature for different geometry of nanoparticles

As shown in figure 4, penetration depth is decreased by increasing of nanoparticles fraction. The inset of figure 4 illustrated that, penetration depth for positive Goos-Hanchen shift for 1% of nanoparticles increases sharper than other fraction of nanoparticles. So can be concluded that by changing the density of nanoparticles can be improved the light propagation in the fiber core. On the other hand, Brewster's angle (also known as polarization angle) is the angle of incidence light with specific polarization that passes completely without any reflection from the surface. When non-polarized light emitted at this angle, the light reflected from the surface is completely polarized. Light in boundary between two materials have different refractive index, part of it which is usually reflected, called P polarized light. so, complex reflection for P and S polarized light has been shown in figures 5. As it is obvious, while fractions of nanoparticles are increased, reflection of P polarized light is increased and reflection of S polarized is decreased. As a result, the amount of reflected light can be increased by increasing density of nanoparticles, which reduces losses of passing wave through the core.

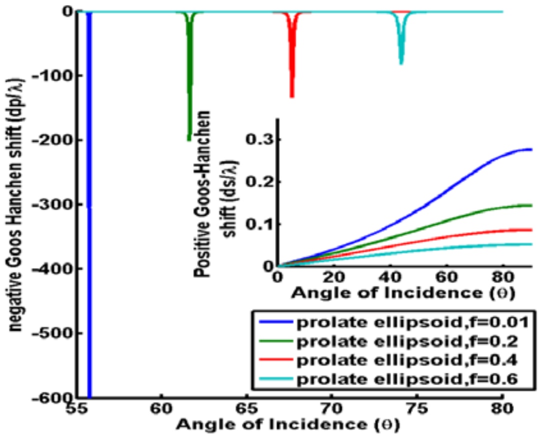

Figure 4: Negative Goos-Hanchen shift in different fraction for prolate ellipsoid. Inset of figure 4 shows positive one

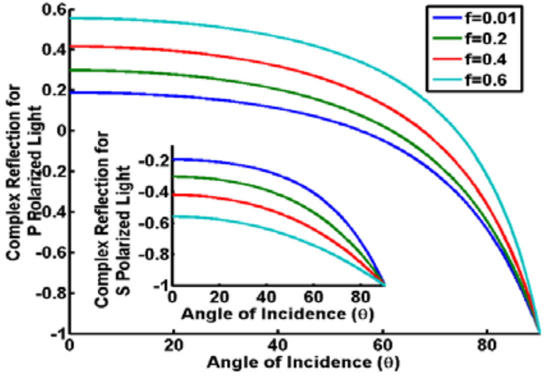

Figure 5: Complex reflection for P polarized light in different fraction for prolate ellipsoid. Inset of figure 5 shows complex reflection for S polarized light

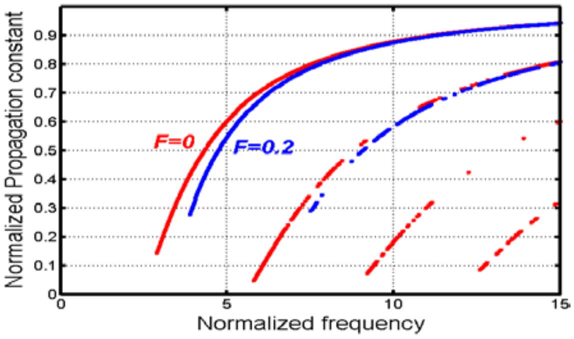

Figure 6: Dispersion curve for different fraction of nanoparticles

Finally, Cut-off frequency and dispersion curve for 0.2% of nanoparticles and without nanoparticles have been calculated. It is obvious, dispersion curve and cut off frequency have been changed by different fraction of nanoparticle. Therefore, cut off frequency and dispersion curve can be changed and controlled by different fraction of nanoparticles.

4 CONCLUSIONS

In this paper, we simulated negative Goos-Hanchen shift for different geometry of nanoparticles in composite cladding fiber containing change of temperature and wavelength. Prolate ellipsoid has the best answer. Therefore, negative and positive Goos-Hanchen shift and complex reflection for P and S polarized light simulated for different fraction on composite cladding fiber with prolate ellipsoid nanoparticles. It is clear, penetration depth increases by increasing fraction of nanoparticles and penetration depth increases by temperature increasing. Finally we investigated dispersion curves and cut-off frequency for different fractions on composite cladding fiber and we found out that we can control dispersion curves and cut-off frequency by fraction changing.

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