برسی تاثیر دما روی انتشار، نفوذ و میدان توزیع در حسگر دما مبتنی بر موجبر با پوسته کامپوزیت

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چکیده - **این مقاله به بررسی تاثیر دما در موجبر با پوسته کامپوزیت پرداخته است و نشان داده است که افزایش دما در پوسته کامپوزیت با هسته دی الکتریکی خالص علاوه بر ایجاد تغییرات در ثابت های اپتیکی نانوذرات فلزی، می تواند عمق نفوذ، طول انتشار، میدان توزیع و شدت نور انتشاری را تغییر دهد. نتایج شبیه سازی نشان می دهد که طول انتشار، شدت نور انتشار و عمق نفوذ به ازای افزایش دما، کاهش می یابند. همچنین میدان توزیع تغییرات قابل ملاحظه ای می کند. با آنالیز مدال موجبر با پوسته کامپوزیت نشان داده می شود که مد پایه بیشترین تاثیرات دمایی را نسبت به مدهای مرتبه اول و بالاتر در خصوصیات انتشاری نشان می دهد. شایان ذکر است شبیه سازی ها با نرم افزار متلب انجام گشته است.**

کلید واژه- موجبر کامپوزیت، عمق نفوذ، حسگر دما، آنالیز مدال، طول انتشار

Investigating the effects of temperature on propagation, penetration and distribution field in thermal sensor based on composite cladding

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Abstract- This study investigated the effect of temperature in the waveguide with composite cladding and revealed that not only the temperature increase in composite cladding with pure dielectric core can make changes in the optical constants of metal nano-particles, but also it can change the penetration depth, propagation length, distribution field and the intensity of propagated light. The results of simulation showed that the propagation length, the intensity of propagation light and penetration depth will decrease by the increase in the temperature. Also, the distribution field showed significant changes. By the modal analysis of the waveguide with composite cladding, it was proved that the fundamental mode experience the highest thermal changes compared to the first and higher order modes in the propagation features. It is noteworthy that simulation has been conducted by MATLAB software.

Keywords: Composite waveguide, penetration depth, thermal sensor, modal analysis, propagation length

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1 Introduction

So many researches were conducted to make a sensor using the characteristics of surface Plasmon with high sensitivity and accuracy in the previous years. Also, a lot of studies were done to investigate the thermal dependency of surface Plasmon. In this regard, the uses of different dielectric substrates in metal-dielectric composite, the changes in the intensity of propagation field and the operation of sensitivity and the ration of signal to noise based on the changes in the type of nanoparticles in the sensors has been under investigation[1-3]. Also, there was an investigation on the effects of temperature and pressure on the dispersion features of single-mode optical fiber [4]. In [5], the effects of the increase in the temperature with the changes in the metal characteristics in the maximum frequency transference in the absorption spectrum or optical fiber transmission were also under investigation. Also, the scientists try to make the sensors in nano-metric and more accurate dimensions by using surface Plasmon and the features of heterogeneous structures in the waveguides with the scales smaller than the wavelength [6]. Also, the modal parameters of the waveguide with the clad which entails metal nanoparticles are dependent on the temperature but no research could be found in the literature to work on the modal parameters of the system with meager dimensions. Therefore, in this article, using the theory of effective medium and using guiding mode formulation for the usual waveguide and radiation mode for the composite waveguide, thermal effects for the modal features of the waveguide with composite cladding were analyzed.

The second section includes the modal analysis of the waveguide which will compare the relationship between guiding mode dispersion and radiation mode. In the third section, using simulation, the effects of temperature on the modal parameters of the system for the physical variables dependent on the temperature will be compared. These parameters include penetration depth, propagation length and field distribution. Also, the changes in the intensity of transmitted light in the constant frequency as the measured parameter in the sensor will be studies. At last, there will be the conclusion of the study.

2 Theory and formulation

The basis of our work is the composite cladding waveguide in the guiding mode and positive Goos-Hankhen shift and radiation mode with negative Goos-Hankhen shift which is shown in figure 1. There is a presupposition that the propagation of electromagnetic wave in the waveguide is base on the general reflection principle. In figure 1a, the electromagnetic waves under general reflection will be propagated as the guiding mode in the core of the waveguide; however, in figure 1b, the waves break as the radiation mode.

In order to answer Maxwell equations for the waveguide of figure 1, we suppose that the waveguide is homogeneous and unlimited in y axis and the electromagnetic fields is timely harmonic and propagating in x axis. The dispersion equation for TE wave is gotten by applying the Continuity principle for tangential fields of E_y and H_x, in the border of $z = \pm d/2$ and by considering symmetry condition for the waveguide ($\varepsilon_2 = \varepsilon_3$).

$$\exp(2ik_1 d) = \left(\frac{1+\frac{k_2\mu_1}{k_1\mu_2}}{1-\frac{k_2\mu_1}{k_1\mu_2}}\right)^2 \quad (1)$$

$$k_1 d = (m+1)\pi - 2tan^{-1}\left(i\frac{k_1\mu_2}{k_2\mu_1}\right), m = 0,1,2,\ldots \quad (2)$$

Similarly, for the dispersion equation of TM mode, we will have:

$$\exp(2ik_1 d) = \left(\frac{1+\frac{k_2\varepsilon_1}{k_1\varepsilon_2}}{1-\frac{k_2\varepsilon_1}{k_1\varepsilon_2}}\right)^2 \quad (3)$$

$$k_1 d = (m+1)\pi - 2tan^{-1}\left(i\frac{k_1\varepsilon_2}{k_2\varepsilon_1}\right), m = 0,1,2,\ldots \quad (4)$$

It is worth mentioning that if the propagation constant in the clad for the guided damped mode equals $K_{2,3}{}^2$, then for the damped sinusoidal mode, it will be $-K_{2,3}{}^2$ [7].

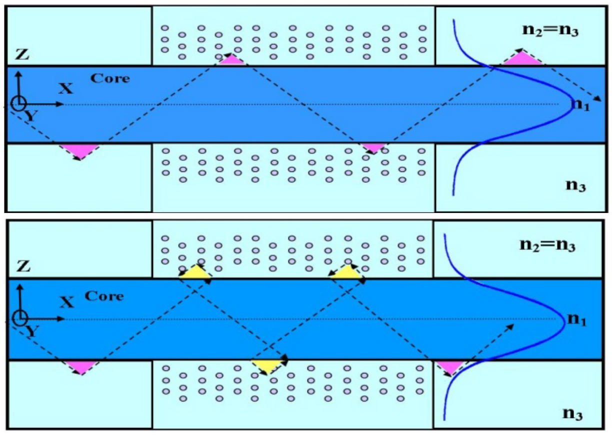

Figure 1) the analytic geometry in the shape of guiding mode with positive Goos-Hanchen shift (a) and the radiation in the cladding of the waveguide with negative Goos-Hanchen shift (b).

3 simulation and results

If we define propagation length as the decrease in the intensity of the field to 1/e times of the primary intensity in the waveguide length and if we consider the penetration depth in the clad for the guiding mode as the decrease in the domain of the field to 1/e times more than its value in the interface of core and clad, then we will have the propagation length as $L = 1/image|2K_x|$ and the penetration depth as$\delta_s = 1/image|K_x|$.

As shown in figure 2, for the electric and magnetic width mode, by the increase in the temperature, the propagation length will decrease. Generally, as the penetration of the fundamental mode in the composite cladding is lower compared to the higher order modes and the propagation length is more for it. Also, for the electric width mode, the penetration depth will increase by the increase in the wavelength. The penetration of the electric width field because of the increase in the temperature of the clad shows a declining trend which proves the increase in the confinement of the power of the mode in the core. Simultaneous decrease in the propagation and penetration for the width electric mode can be because of the dependence of the propagation on the speed of the signal and the duration of the interaction of electromagnetic waves with the losses clad. Therefore, the ratio of the propagation length of the electromagnetic waves will decrease, because of the increase in the losses in the clad which is because of the prevalence of metal effects in it.

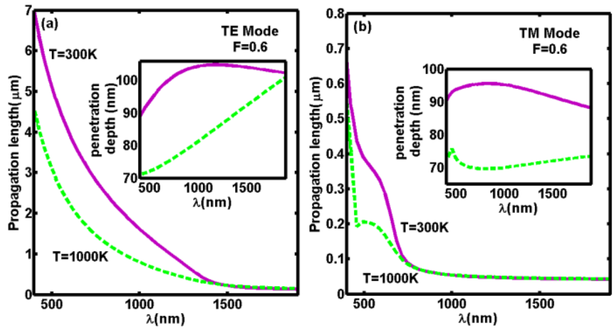

Figure 2) Thermal dependence of the propagation length and penetration depth for electric width mode (a) and magnetic width mode (b) of the silver nanoparticles

The decrease in the penetration of the clad due to the increase in the temperature can also be related to the thermal and frequency features of Goos-Hankhen shift in the clad. In [8], it will be said that if metal features prevail in the composite, in this case, Goos-Hankhen shift will have negative value and this amount will be more negative by temperature increasing. Also, as the thermal effects lead to the increase of the Brewster's Angle in the interface of core and clad, it can be expected that by the increase in the temperature, the reflection of the surfaces will decrease and the value of the negative Goos-Hankhen shift will increase and the rate of the losses in the mode of the clad have increasing trend [9].

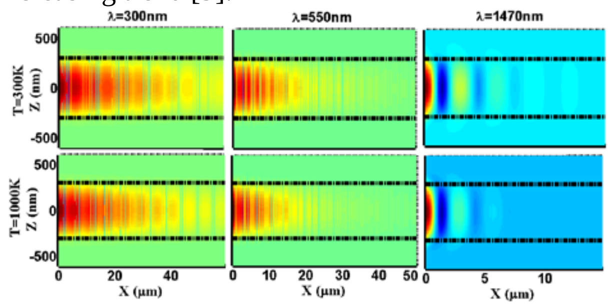

Figure 3) mode distribution profile for the composite cladding waveguide with fraction of 60% in Silver and core thickness of 500 nano-meters for 300 and 1000 Kelvin in the wavelength of 300, 550 and 1470 nm

As shown in figure 3, by the increase in the temperature in the higher wavelengths, there will be a significant decrease in the propagation of the fundamental guided mode. This issue is because of the metal effects in the clad lead to the changes in the propagation length. The similar simulation in the visible wavelengths shows that by the increase of energy in electromagnetic waves, the thermal effects of the clad on the propagation length will experience a significant decrease. It is noteworthy that the propagation of UV waves in the composite waveguide is less under the effect of thermal changes.

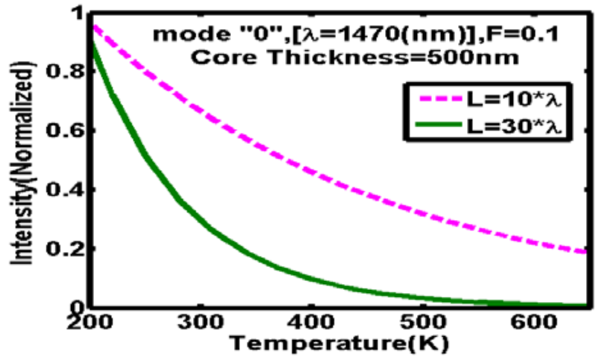

Figure 4: The changes in the intensity of the transmitted light compared to the thermal changes for fundamental mode in the waveguide with the core thickness of 500

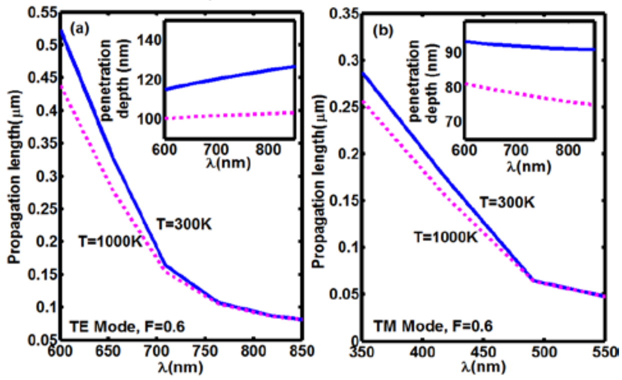

Figure 5: Thermal dependence of the propagation length and penetration depth for electric width mode (a) and magnetic width mode (b) of the gold nanoparticles

Figure 4 shows the changes in the intensity of the transmitted light from the waveguide at the end of the sensory area compared to the beginning of it. As it is shown, by the 10% impurity density of silver nanoparticles in the waveguide cladding for the wavelength of 1470 nanometers, the intensity of transmitted light will decrease by the increase in the length of the impurity area. Finally, as shown in figure 5, thermal effects lead to the decrease in the propagation and penetration of the profile mode. Also, the declining trend of the propagation and penetration depth in first order mode is less compared to the fundamental mode with thermal changes.

Conclusion

All in all, the increase in the temperature leads to the decrease in the propagation length and penetration depth for the guiding modes in the composite cladding waveguide. Declining effects of propagation and penetration depth depend on elements such as thermal dependence of Goos-Hankhen shift and increase in Brewster's Angle due to the increase in the temperature, superposition of penetrating guiding waves in the clad with Plasmonic mode deployed around metal nanoparticles and propagating Plasmonic mode in the interface of core and clad. Moreover, the increase in the confinement in the core is because of the increasing of metal features in the composite cladding. Also, fundamental mode compared to first and higher order modes, show the maximum thermal changes in propagation features. The results of simulation show that by operating in the infrared range, thermal sensor is more sensitive than UV range. Making use of thermo-optic substrate with positive thermal effects in the refractive index with metal impurity of gold nanoparticles leads to more thermal changes.

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