ررسی تاثیر دما روی فرکانس برخورد و پاشندگی در حسگر دما مبتنی بر موجبر با پوسته کامپوزیت

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چکیده - در این مقاله، هدف طراحی حسگر دما با استفاده از اثرات پلاسمونیک در موجبر با پوسته کامپوزیت می باشد. ابتدا تاثیرات دما در ثابت های اپتیکی نانوذرات فلزی بررسی شده است و از مدل تئوری میانی برای بررسی خصوصیات دمایی کامپوزیت استفاده گشته است. نشان داده شده است که موجبرهای با پوسته کامپوزیت و هسته دی الکتریکی محض چگونه می توانند به عنوان حسگر دما کاربرد داشته باشند. همچنین، افزایش دما به ازای دانسیته ثابت از نانوذارت فلزی در پوسته باعث تغییر فرکانس پلاسمایی، فرکانس برخورد و پاشندگی می گردد. نتایج شبیه سازی برای موجبر با پوسته کامپوزیت نشان می دهد که موجبر کامپوزیت با دانسیته بالاتر موجب حبس بهتر مد شده و اثرات دمایی را نیز به صورت برجسته‌تری نشان می دهد.

کلید واژه- موجبر کامپوزیت، فرکانس برخورد، پاشندگی، حسگر دما، آنالیز مدال

Investigating the effects of temperature on the collision frequency and dispersion in the thermal sensors based on the waveguide with composite cladding

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Abstract- The purpose of this is article is to design the thermal sensors using Plasmon effects in the waveguide with composite crust. Therefore, the effects of temperature in optical constants of metal nano-particles were first investigated and used the Mid-range theory model to investigate the thermal features of composite. It is also shown how the waveguides with composite crust and the pure dielectric core can be utilized as the thermal sensor. Also, by the constant density of the metal nano-particles in the crust, the increase in the temperature leads to the changes in the Plasmon and collision frequencies and dispersion. The simulation results of the waveguide with composite crust reveal that the composite waveguide with higher density leads to better imprisonment of mode and shows the thermal effects extraordinarily.

Keywords: Composite waveguide, collision frequency, dispersion, thermal sensor, modal analysis

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1 Introduction

The vast amount of research is continuing for years to reach the thermal sensors which work very accurately and with high sensitivity based on the surface Plasmon. In the recent decade, a lot of studies were investigated the effects of nano-particles in the sensitivity and the ratio of signal to noise and the effect of the use of different dielectric platforms in metal-dielectric composite [1,2]. It was shown that in the multi-modal optical fiber, using the elements of gold and silver in the fiber cladding, the ratio of signal to noise for silver is more, compared to the gold. In contrast, for the sensor which uses gold, the sensitivity rate is more and is chemically more stable [3].

On the other hand, as a bridge to pass to the optical instruments in the dimensions smaller than the wavelength, the surface Plasmon represents a new perspective of using the metals. Therefore, other resources have investigated the thermal dependence of metals in multilayer structures in which the thermal dependence of angle changes of surface Plasmon stimulation, spectral width of the sensor along with spectral changes of absorption have vastly been discussed [4,5]. Also, the temperature dependence of the modal parameters of the waveguide with the clad which includes the thermo-optic dielectric platform in which the metal nano-particles are spread homogenously has not been investigated.

In this article, in order to investigate the effects of temperature on the thermal features of composite and dispersion, we intend to make use of the guiding mode formulation in the usual waveguide, radiation mode in the composite one and Effective Medium Theory [6]. Therefore, the first section, talks about the theory includes the Effective Medium Theory for the composite and formulation related to the modal analysis of the waveguide in which the relationship between the dispersion of the guiding mode and radiation mode will also be compared. In second section, the effects of the temperature on the dielectric constants and the effects of the temperature on the modal system parameters with the physical variables dependent on the temperature will also be investigated. Ultimately, it will be shown that to measure the temperature in the optical dimension, which area will be more sensitive and operates better.

2 Theory and formulation

Drude Model has been used for permittivity to talk about the frequency and thermal dependency. Plasmon frequency (ω_p) and collision frequency (γ) are strongly dependent on the temperature [4].

$$\varepsilon(\omega) = 1 - \frac{\omega_P^2}{\omega^2 + i\gamma\omega} \quad (1)$$

Plasmon frequency strongly depends on temperature and it has a declining trend by the increase of temperature.

$$\omega_P(T) = \omega_P(T_0)[1 + 3\gamma'(T - T_0)]^{-1/2} \quad (2)$$

In contrast, the collision frequency is for the metalloid electrons which are related to the microscopic mechanisms including the collision of free electrons with other electrons and the phonons and deficiencies of the network in metal surfaces which have an increasing trend by the increase of the temperature. The thermal dependence of the collision frequency to the electron-electron and electron-phonon are shown in equations (4) and (5), respectively. The values of the parameters have obtained by [4].

$$\gamma = \omega_{e-e} + \omega_{e-ph} \quad (3)$$

$$\omega_{e-e} = \frac{\pi^3 \Phi\Delta}{12\hbar E_F}[(K_B T)^2 + (\hbar\omega/2\pi)^2] \quad (4)$$

$$\omega_{e-ph} = \omega_0\left[\frac{2}{5} + \frac{4T^5}{{\theta_D}^5}\int_0^{\theta_D/T} \frac{Z^4}{e^Z - 1} dZ\right] \quad (5)$$

It is worth mentioning that if the particles get a bigger size, in the empirical experiments, the composite features for the absorption spectrum show the transfer to the bigger wavelengths and their effects are inevitable [7]. The geometry of the waveguide with composite cladding with positive and negative Goos-Hanchen shift are shown in figure1.

If we calculate the composite index in the effective medium theory based on equation (6), in this case, by lower densities, the impurity particles of the real part of the effective constant will be positive and the composite can be named as dielectric composite and if the metal features are prevalent because of the density of the metal nano-particles, it can be called metal composite which the real part of its effective constant will be negative [6].

$$\sqrt[3]{\varepsilon_{composite}} = f_p\sqrt[3]{\varepsilon_{particle}} + (1-f_p)\sqrt[3]{\varepsilon_{SiO_2}} \quad (6)$$

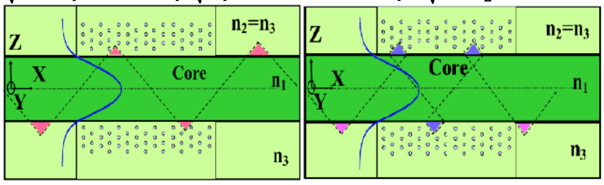

Figure 1: the analytic geometry in the shape of guiding mode with positive Goos-Hanchen shift (a) and the radiation in the cladding of the waveguide with negative Goos-Hanchen shift (b).

Now, if the real part of the refractive index of composite cladding is smaller than the effective index of the core, the electromagnetic waves under the total reflection can be propagated in the core of the waveguide as the guiding mode (figure 1a) and if the effective index of the core is smaller than the real part of the effective index of the clad, the waves in composite cladding are broken like the radiation wave and are propagated in the clad as the oscillation damping (figure 1b).

The geometry of the dielectric waveguide without losses and with the guiding mode shows the radiation mode in composite cladding and by applying the border conditions for the tangential components of the fields, the dispersion equation for the waves of TE and TM in the exponential and geometric forms will be as follows[8]:

$$\exp(2ik_1d) = \left(\frac{1+\frac{k_2\mu_1}{k_1\mu_2}}{1-\frac{k_2\mu_1}{k_1\mu_2}}\right)^2, \exp(2ik_1d) = \left(\frac{1+\frac{k_2\varepsilon_1}{k_1\varepsilon_2}}{1-\frac{k_2\varepsilon_1}{k_1\varepsilon_2}}\right)^2 \quad (7)$$

$$\begin{matrix} k_1d=(m+1)\pi-2\tan^{-1}\left(i\frac{k_1\mu_2}{k_2\mu_1}\right) \\ k_1d=(m+1)\pi-2\tan^{-1}\left(i\frac{k_1\varepsilon_2}{k_2\varepsilon_1}\right) \end{matrix}, m = 0,1,2,\ldots \quad (8)$$

3 simulation and results

As the thermal effects in the composite structures have an influence on the changes in the dispersion ratio of electron-electron and electron-phonon in collision frequency, first, we start comparing the effects of temperature in the changes of the collision frequency in different frequencies. Comparing figure 2a with figure 2b reveal that, when the energy of electromagnetic waves is in the visible and infrared range, the effect of the dispersion of the electrons on the effect of the other electron will be much less than the dispersion of electron with phonons. However, in the UV range, the effects of frequencies related to the electron-electron are comparable with electron-phonon. It should be noted that the dispersion of electron-electron for gold is always more than the one with silver. We should take into account that, the higher sensitivity of gold is because of the higher temperature dependence in the damping frequency for gold.

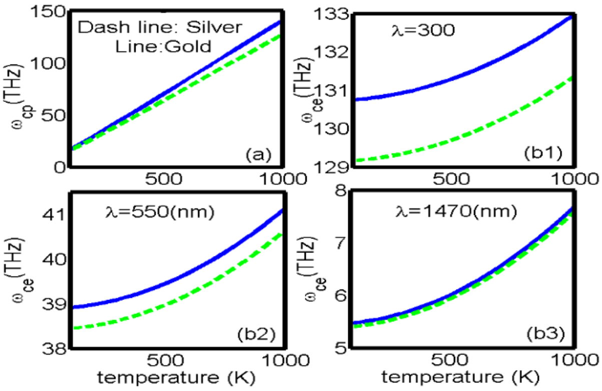

Figure 2: comparing the dispersion of electron-phonon (a) with the dispersion of electron-electron for the wavelength of UV (b1), visible (b2), and infrared (b3)

As shown in figure 3, by the increase in the temperature, the real part of the complex refractive index which shows the changes in the phase of electromagnetic wave in the element will increase and the imaginary section which shows the rate of attenuation in the electromagnetic field of the element will decrease. The changing trends by the changes in the wavelength are not the same. This effect for the wavelengths of 300 and 550 nanometer will not have the same trend compared to the wavelength of 1470 nanometer and will make the real refractive index get bigger in the infrared range which shows the increase in the time of the interaction of the electromagnetic field with the metal nano-particles. In contrast, by increase in the temperature, the imaginary section of the complex refractive index will experience a declining trend which the slope of the changes for the infrared range will be more than UV and visible range. Figure 4 shows the unequal behaviour of the complex refractive index in the wavelength of 1470 nanometer compared to the wavelengths of 300 and 550 nanometer with different densities of nano-particles in dielectric platform. With the increase in the temperature, the real part of the complex refractive index will experience an increasing trend. In contrast, the imaginary part will decline and the slope of the changes will be more for the bigger wavelengths.

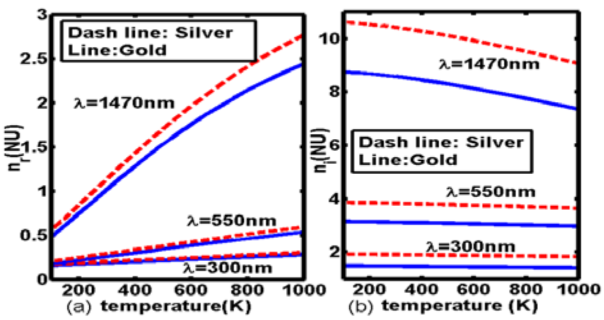

Figure 3: comparing the thermal dependency of the real and imaginary refractive index in metal nano-particles in the wavelengths of UV, visible and infrared

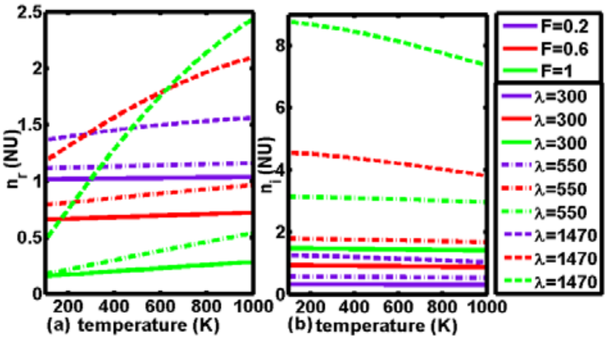

Figure 4: Comparing the thermal dependence of the real and imaginary refractive index in metal nano-particles in wavelengths of UV, visible and infrared

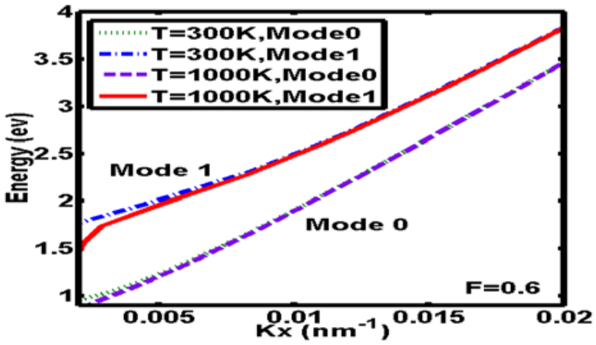

Figure 5: Dispersion curve of the Plasmonic waveguide with the possibility of stimulating the guiding modes of first and second stage

Figure 5 shows the dispersion curve of the electric width mode in 1000 Kelvin compared to 300 Kelvin temperature in basic mode and first mode in the waveguide with the core thickness of 500 nanometers and in which the density of the impurity nano-particles of the silver in the composite cladding is shown as 60%. It is clear, by the increase in the temperature, the propagation constant will also increase and the rate of the increase for the electromagnetic waves with less energy is higher. This is because in the lower energy, the metal features in the composite show a better effect of themselves. Therefore, the effective propagation constant of the waveguide is going to be under the influence of the effective index of the composite.

Conclusion

In this article, we investigated the effects of temperature in the optical constants. We also studied the temperature dependence of the collision frequency on the electron-electron and electron-phonon dispersion. Generally, by the increase in the density, the real part of the composite will decrease with the constant temperature and wavelength and the imaginary part will increase. It is also proved that when the temperature increases, propagation constant will increase. Ultimately, it is suggested that for the thermal sensors, it is better to use the infrared area because in this area, the temperature dependency to dielectric constant in the metal experiences more changes.

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