The dispersion of surface plasmon-polaritons in the metal-nanocomposite system

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ABSTRACT

The article presents the results of computing simulation of surface plasmon-polaritons' dispersive properties at the interface between «a composite medium based on Al, Ag, Ni, Cu nanoparticles and a substrate made of the same metals» in the visible wavelength band. It is shown that the surface plasmon-polaritons' dispersive properties in these structures can be changed in a wide range by altering the nanoparticles concentration.

Keywords: surface plasmon-polariton, dispersion relation.

1. INTRODUCTION

Surface plasmon polaritons (SPP) that arise at the interface between the dielectric and conductive media are of considerable interest from both fundamental and applied standpoints. This interest is due to the properties and methods of managing surface plasmon polaritons and is explained by the opportunity to create new optical devices and sensors with high sensitivity and compact size on the basis of plasmonic structures. Also, the control of light on the nanoscales presents high practical interest, for this control the use of SPP is promising because of their high location, and, as a consequence, high intensity leading to the strengthening a number of optical, including nonlinear, effects.

The purpose of this paper is a theoretical study of the laws of surface plasmon polaritons propagation in layered structures containing media with controlled optical properties. To achieve this goal the dispersion of surface plasmon polaritons at the interface between metal nanocomposites has been investigated by means of numerical simulations. Thus, as the model media both the metals (Ag, Cu) having a plasmon resonance in the wavelength range under investigation and the metals (Al, Ni) the plasmon resonance frequency of which is out of the investigated range have been used.

2. COMPUTING SIMULATION

The most important characteristics of SPP are their thickness (of the SPP localization region) and the amplitude of the electromagnetic field in both media as well as the length of the path along the media border (the specific decay length, which is determined by the imaginary part of the wave vector Im (k)). To calculate these values it is necessary to know the dependence of each medium dielectric permeability on the wavelength.

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Figure 1 shows the spectral dependence of the real and imaginary parts of the dielectric function of heterogeneous media based on the studied metals and dielectric matrix (refractive index n = 1,53) at the filling factor f = 0,2. Calculations are performed in the approximation of the effective medium model according to the method [1].

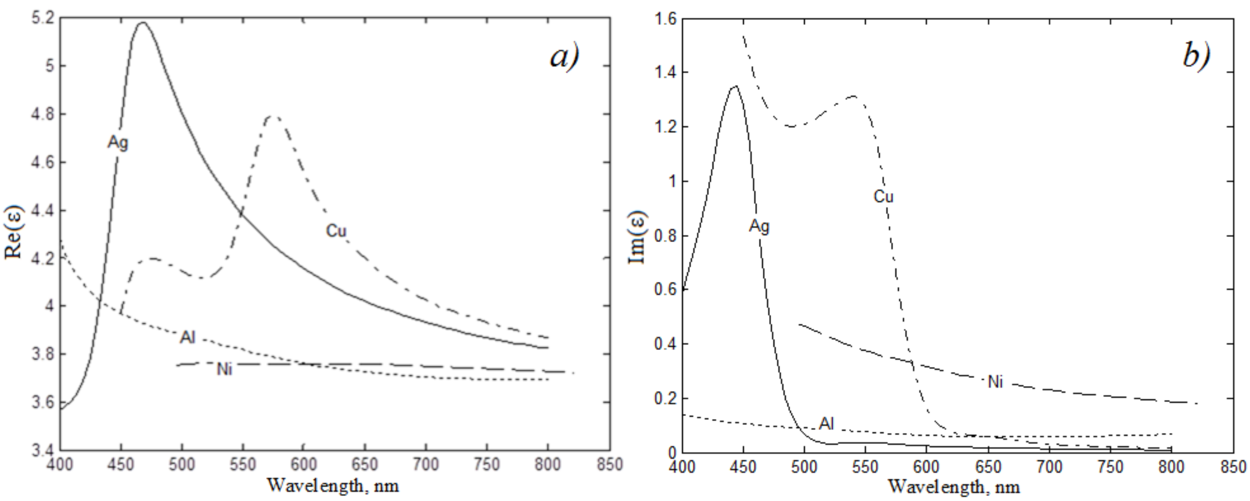

Figure 1. The dispersion dependence of the real (a) and the imaginary part (b) of the dielectric function of the composites "insulator-metal nanoparticles" on the wavelength at the filling factor f = 0,2 [2].

Numerical simulation was carried out in MATLAB for heterogeneous media based on the dielectric matrix and nanoparticles of Al, Ni, Ag, Cu in the visible and near IR ranges when changing the filling factor from 0.02 to 0.6. The impact of the material and the volume fraction of the dispersed phase on the spectral properties of the wave vector and the SPP localization region was analyzed. In the calculations the spectral dependence of the dielectric function of the studied bulk materials Ag, Ni, Al, Cu in the visible wavelength range is taken from [3, 4].

The dispersion relation for the SPP is [5]

$$k=\frac{2\pi}{\lambda}\sqrt{\frac{\varepsilon_1\varepsilon_2}{\varepsilon_1+\varepsilon_2}}\,, \qquad (1)$$

where k – a wave vector of the SPP, λ - the wavelength in free space, ε_1 and ε_2 - dielectric functions of the nanocomposite and metal.

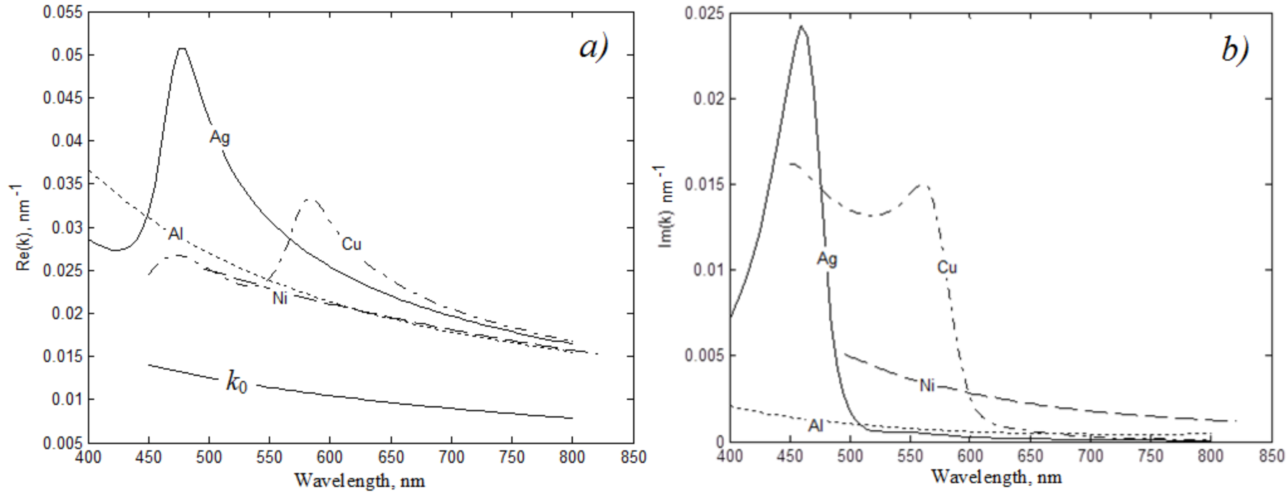

Figure 2. Dispersion dependence of the real (*a*) and (*b*) of the imaginary parts of the SPP wave vector in the "metal nanocomposite" system. The bottom graph in figure (*a*) shows the dispersion dependence of the SPP wave vector in the "metal-dielectric" system.

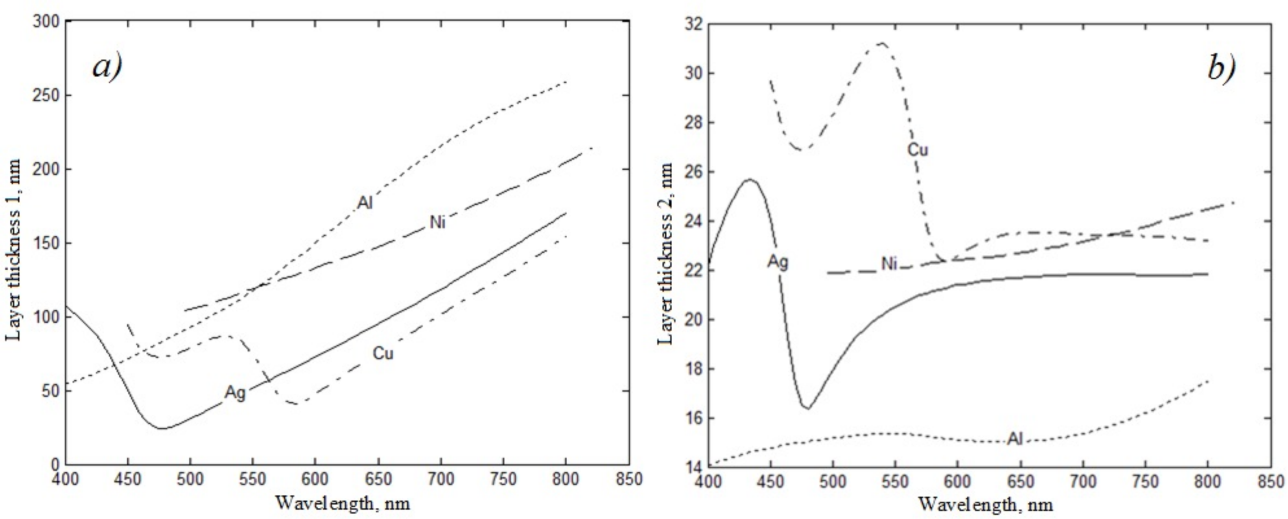

Figure 3. Dispersion dependence of the SPP localization region in the «metal-insulator» composite (*a*) and the metal (*b*).

As we can see from the above figures, the variation of the complex wave vector for metals (Ag, Cu) has a clear maximum in a plasmon resonance area. With the wavelength increasing, i.e. in the near infrared area the dispersion properties of the SPP on the studied structures differ slightly. The SPP based on aluminum and silver out of the plasmon resonance area have the maximum path length which is determined by the imaginary part of the wave vector. Also, it is necessary to note that the localization region of the SPP in aluminum is minimal in comparison with other metals. This may be used in developing waveguide structures based on the SPP to reduce energy dissipation.

3. CONCLUSION

The results of numerical simulation of the dispersion dependence of surface plasmon polaritons at the interface between "metal nanocomposite" media in the visible wavelength range have been presented. As materials the metals (Ag, Cu) which plasmon resonance frequency falls within the range under investigation as well as metals (Al, Ni) which frequency plasmon resonance does not fall within the investigated range have been taken.

It has been shown that the dispersion properties of the SPP on the basis of the researched structures can be altered within wide limits by changing the concentration of the nanoparticles. The results of this work may be useful in terms of the formation of dispersed structures with desired optical properties.

REFERENCES

[1] Oraevskiy A.N., Protsenko I.E. "Optical properties of heterogeneous media," Quantum Electronics. Papers 31 (3), 252-246 (2001).

[2] Panamarev N.S. "The interaction of low-energy laser radiation with heterogeneous media based on the solutions of organic dyes and metallic nanostructures," PhD thesis in Physics and Mathematics: 01.04.05, 01.04.21. Tomsk (2012)

[3] Johnson P.B., Christy R.W. "Optical Constants of the Noble Metals," Phys. Rev. B. Papers 6 (12), 4370 - 4379 (1972).

[4] Ordal M.A., Long L.L., Bell R.J., Bell S.E., Bell R.R., Alexander R.W., Jr., and C. Ward. "Optical properties of the metals Al, Co, Cu, Au, Fe, Pb, Ni, Pd, Pt, Ag, Ti, and W in the infrared and far infrared," Applied Optics. Papers 22, 1099-1119 (1983)

[5] Libenson M.N. "Surface electromagnetic waves of optical range," Soros Educational Journal. Papers 10, 92-98 (1996)

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