OPTICAL PROPERTIES OF “LEFT-HANDED” MEDIA BASED ON A CUBIC LATTICE OF METALLIC NANODIMERS

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Abstract

As is well known, a “left-handed” medium is a material in which the real parts of both the dielectric permittivity and the magnetic permeability are simultaneously negative. It has been established that one type of “left-handed” medium is a composite based on a cubic lattice of metallic nanodimers. Provided that the wavelength of light is much larger than the size of the unit cell of the nanocomposite, the collective response of “left-handed” medium can approximate the response of a certain homogeneous “effective” medium. Since there is currently an active search for materials with the properties of a “left” medium, the study of the optical properties of ordered composites with metal nanodimers is a pressing task.

Figure 1, *a*

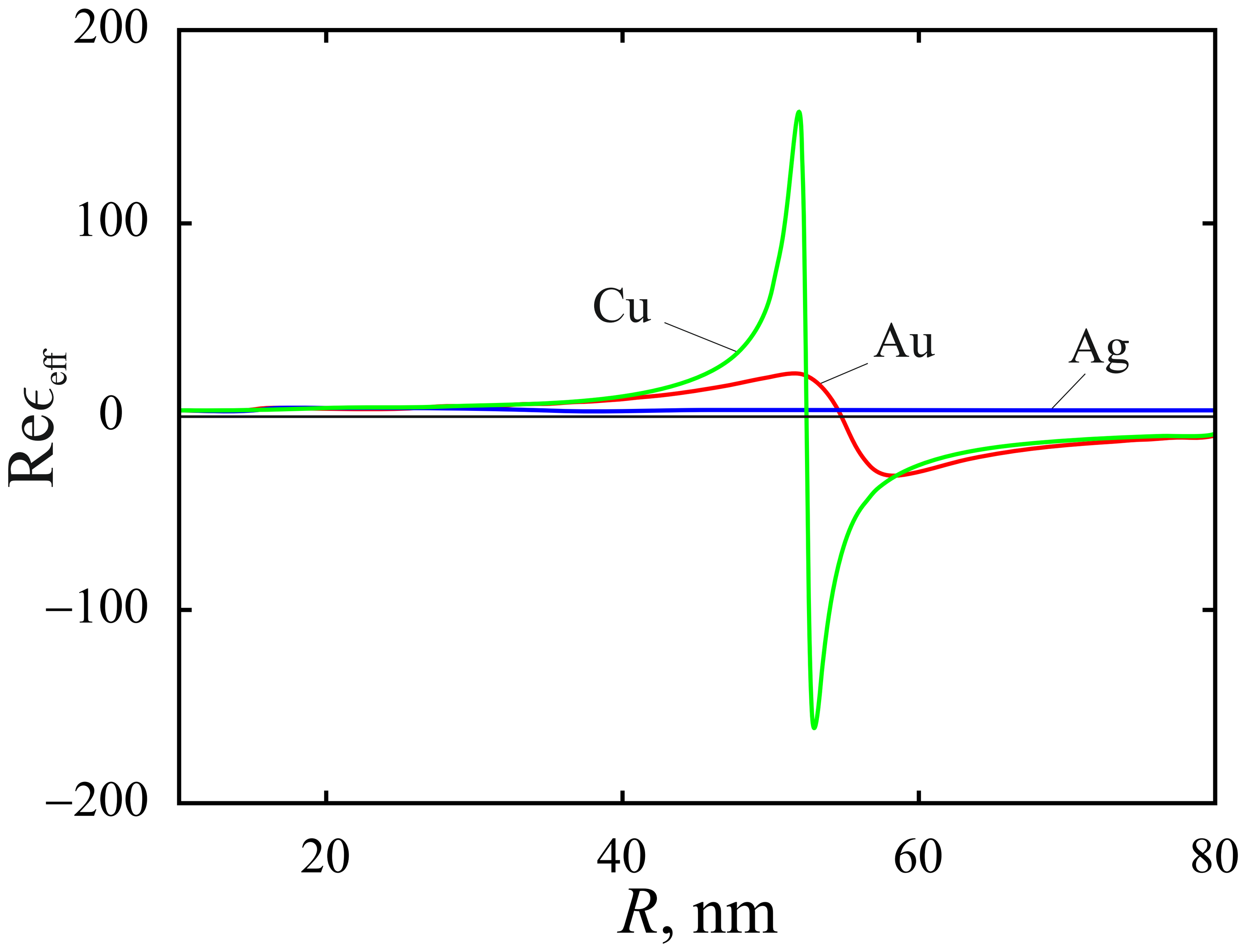
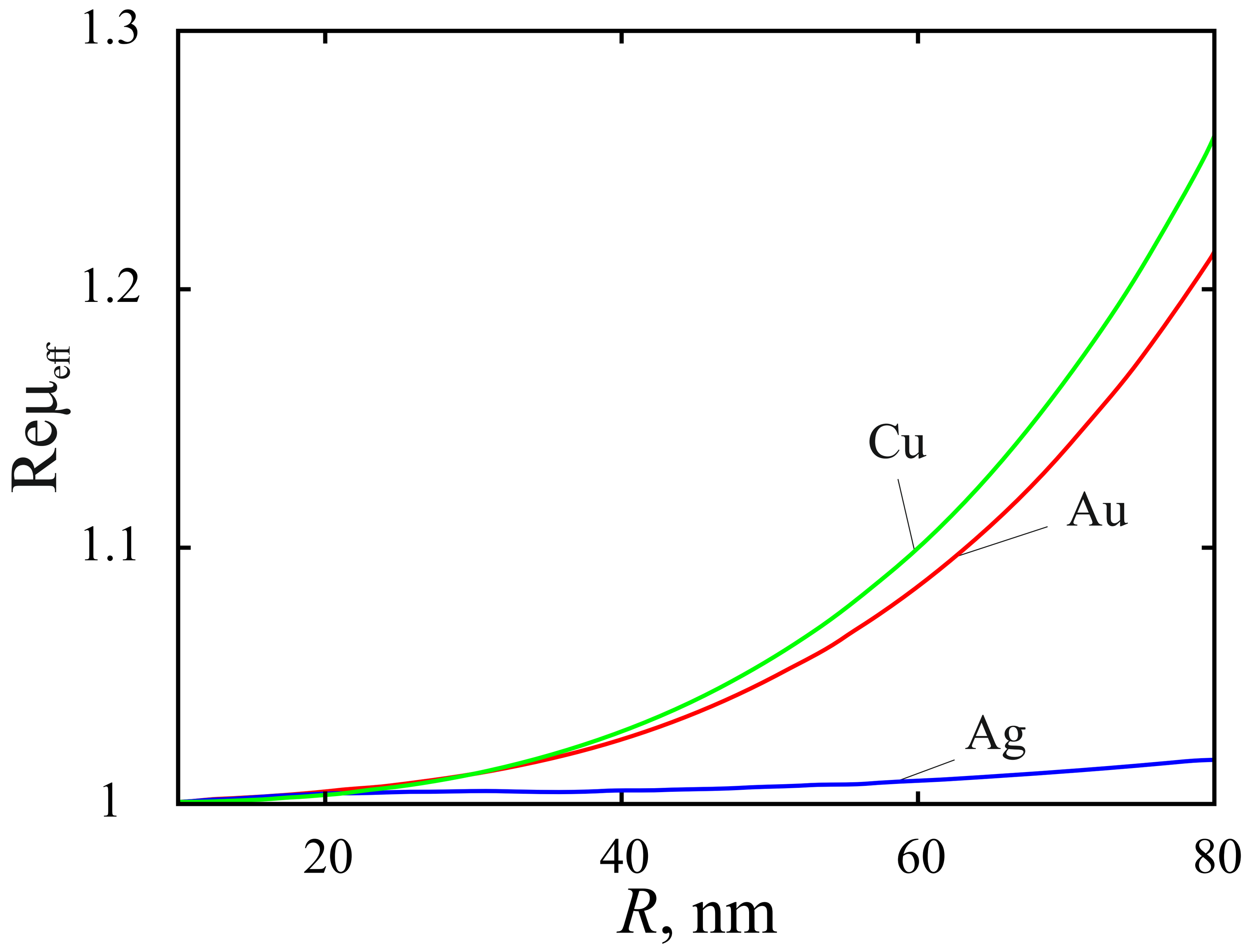


Figure 1, *b*



Dimensional dependences of the real parts of the effective permittivity (*a*) and magnetic permeability (*b*) for dimers of spherical particles of Cu, Au and Ag at $d = 100$ nm, $\hbar\omega = 1$ eV, .

Statement of the problem and results of calculations

The nanocomposite under consideration can be characterized by effective dielectric permittivity and magnetic permeability, the expressions for which take the following form

$$\epsilon_{\rm eff} = \epsilon_{\rm m}\left(1+3\beta\frac{\dfrac{R^3}{\alpha(\omega)}-\dfrac{1}{\epsilon_{\rm m}}\left(\dfrac{R}{d}\right)^3}{\left(\dfrac{R^3}{\alpha(\omega)}+\dfrac{1}{\epsilon_{\rm m}}\left(\dfrac{R}{d}\right)^3\right)\left(\dfrac{R^3}{\alpha(\omega)}-\dfrac{2}{\epsilon_{\rm m}}\left(\dfrac{R}{d}\right)^3\right)-\beta\left(\dfrac{R^3}{\alpha(\omega)}-\dfrac{1}{\epsilon_{\rm m}}\left(\dfrac{R}{d}\right)^3\right)}\right); \quad (1)$$

$$\mu_{\rm eff} = 1+\beta\left(\frac{k_0 d}{2}\right)^2\frac{1}{\dfrac{R^3}{\alpha(\omega)}-\dfrac{1}{\epsilon_{\rm m}}\left(\dfrac{R}{d}\right)^3-\dfrac{\beta}{3}\left(\dfrac{k_0 d}{2}\right)^2}, \quad (2)$$

where $\alpha(\omega)$ is polarizability of a nanoparticle in a dimer; $\epsilon_{\rm m}$ is dielectric permittivity of the matrix; $k_0=\omega/c$ is wavenumber in a vacuum, ω and c are frequency and speed of a light wave; R is the radius of a nanoparticle in a dimer; d is distance between particles in a dimer; $\beta=8\pi(R/l)^3$, l is edge length of the unit cell.

Since the polarizability of a spherical metallic nanoparticle

$$\alpha(\omega) = R^3\frac{\epsilon(\omega)-\epsilon_{\rm m}}{\epsilon(\omega)+2\epsilon_{\rm m}}, \quad (3)$$

and the dielectric function in Drude model

$$\epsilon(\omega) = \epsilon^{\infty}-\frac{\omega_p^2}{\omega(\omega+i\gamma_{\rm eff})}, \quad (4)$$

where $\gamma_{\rm eff}$ is effective electron relaxation rate in the nanoparticle, material characteristics ϵ^{∞} and ω_p are contribution of the crystal lattice to the dielectric permittivity and plasma frequency, so the width of the spectral interval, in which the considered nanocomposite is a “left-handed” medium, is determined by the relationships ${\rm Re}\,\epsilon_{\rm eff}(\mu_{\rm eff})<0$, and depends on the size and material of the particle, the geometric parameters of the dimer and the unit cell.

Calculations of the size dependences of the real parts of the effective permittivity and magnetic permeability were carried out for the case of dimers of spherical particles of Cu, Au and Ag in the near infrared region of the spectrum (fig. 1). Since in the entire range of sizes under consideration and for dimers of particles of all metals under consideration ${\rm Re}\,\mu_{\rm eff}>0$, and ${\rm Re}\,\epsilon_{\rm eff}<0$ at $R>50$ nm, then the composite under consideration in this frequency range can only be an ENG material (${\rm Re}\,\epsilon_{\rm eff}<0$) and does not have the properties of a "left" medium, since the condition ${\rm Re}\,\mu_{\rm eff}<0$ is not satisfied.

Conclusions

It has been established that ordered composites based on cubic lattices of dimers of spherical nanoparticles made of plasmonic metals cannot be “left-handed” media in the near infrared region of the spectrum, and therefore it seems appropriate to search for the corresponding spectral intervals in the optical region (at $1.56\,{\rm eV}\le\hbar\omega=3.12\,{\rm eV}$).