SPECTRAL QUALITY FACTOR OF SENSORY SENSING ELEMENTS ON SPR IN THE FORM OF METAL NANOWIRE

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Consider an optical nanosensor based on surface plasmon resonance with a sensitive element in the form of a metal nanorod of finite length (cylinder or spherocylinder). The main physical and technical characteristic of the sensitive elements of such sensors is the spectral quality factor. Due to the anisotropy of the nanorod, the spectral Q factor of such sensitive elements is a diagonal tensor of the second rank (1). Whose diagonal components are determined by the ratios (2). Where $\gamma_{\mathrm{eff}}^{(\perp)\parallel}$ is the transverse (longitudinal) component of the relaxation rate, and is the spectral sensitivity (3). Here ϵ_{m}– dielectric permeability of the surrounding medium $\omega_{sp}^{(\perp)\parallel}$ – frequencies of transverse (longitudinal) plasmon resonances. The transverse (longitudinal) effective relaxation rate for nanoscale objects is determined by the additive contribution of all relaxation mechanisms (4). Where γ_{bulk} and $\gamma_{s}^{(\perp)\parallel}$ are volume and surface relaxation rates, $\gamma_{\mathrm{rad}}^{(\perp)\parallel}$ is the rate of radiative attenuation. The expressions for the transverse (longitudinal) velocities of surface relaxation and radiative attenuation have the form (5,6).

$$\mathrm{FOM}=\begin{pmatrix}\mathrm{FOM}_{\perp} & 0 & 0\\ 0 & \mathrm{FOM}_{\perp} & 0\\ 0 & 0 & \mathrm{FOM}_{\parallel}\end{pmatrix} \quad (1)$$

$$\mathrm{FOM}_{\perp(\parallel)}=\frac{\mathcal{S}_{\omega}^{\perp(\parallel)}}{\gamma_{\mathrm{eff}}^{\perp(\parallel)}} \quad (2)$$

$$\mathcal{S}_{\omega}^{\perp(\parallel)}=2\sqrt{\epsilon_{\mathrm{m}}}\,\frac{\partial\omega_{sp}^{\perp(\parallel)}}{\partial\epsilon_{\mathrm{m}}} \quad (3)$$

$$\gamma_{\mathrm{eff}}^{\perp(\parallel)}=\gamma_{\mathrm{bulk}}+\gamma_{s}^{\perp(\parallel)}+\gamma_{\mathrm{rad}}^{\perp(\parallel)} \quad (4)$$

$$\gamma_{s}^{\perp(\parallel)}=\frac{9}{16}\frac{\mathcal{L}_{\perp(\parallel)}}{\left[\epsilon_{\mathrm{m}}+\mathcal{L}_{\perp(\parallel)}(1-\epsilon_{\mathrm{m}})\right]^{2}}\frac{v_{\mathrm{F}}}{2r}\left(\frac{\omega_{p}}{c}\right)^{2}\mathscr{F}_{\perp(\parallel)}(\varrho_{\mathrm{eff}}) \quad (5)$$

$$\gamma_{\mathrm{rad}}^{\perp(\parallel)}=\frac{V}{8\pi}\frac{\mathcal{L}_{\perp(\parallel)}}{\sqrt{\epsilon_{\mathrm{m}}\left[\epsilon^{\infty}+\left(\frac{1}{\mathcal{L}_{\perp(\parallel)}}-1\right)\epsilon_{\mathrm{m}}\right]}}\frac{v_{\mathrm{F}}}{2r}\left(\frac{\omega_{p}}{c}\right)^{3}\left(\frac{\omega_{p}}{\omega}\right)^{2}\mathscr{F}_{\perp(\parallel)}(\varrho_{\mathrm{eff}}) \quad (6)$$

Where $\mathscr{F}^{(\perp)\parallel}(\varrho_{\mathrm{eff}})$ are size-dependent functions defined by ratios

$$\mathscr{F}_{\perp}(\varrho_{\mathrm{eff}})=\left(1-\varrho_{\mathrm{eff}}^{2}\right)^{-\frac{3}{2}}\left\{\varrho_{\mathrm{eff}}\left(\frac{3}{2}-\varrho_{\mathrm{eff}}^{2}\right)\sqrt{1-\varrho_{\mathrm{eff}}^{2}}+2\left(\frac{3}{4}-\varrho_{\mathrm{eff}}^{2}\right)\left(\frac{\pi}{2}-\arcsin\varrho_{\mathrm{eff}}\right)\right\};$$

$$\mathscr{F}_{\parallel}(\varrho_{\mathrm{eff}})=\left(1-\varrho_{\mathrm{eff}}^{2}\right)^{-\frac{3}{2}}\left\{\frac{\pi}{2}-\arcsin\varrho_{\mathrm{eff}}+\varrho_{\mathrm{eff}}\left(1-2\varrho_{\mathrm{eff}}^{2}\right)\sqrt{1-\varrho_{\mathrm{eff}}^{2}}\right\},$$

and the expressions for the depolarization factors have the form

$$\mathcal{L}_{\parallel}=\frac{\varrho_{\mathrm{eff}}^{2}}{2-\left(1-\varrho_{\mathrm{eff}}^{2}\right)^{\frac{3}{2}}}\left(\ln\frac{1+\sqrt{1-\varrho_{\mathrm{eff}}^{2}}}{1-\sqrt{1-\varrho_{\mathrm{eff}}^{2}}}-2\sqrt{1-\varrho_{\mathrm{eff}}^{2}}\right);\qquad \mathcal{L}_{\perp}=\frac{1}{2}\left(1-\mathcal{L}_{\parallel}\right).$$

Here c is the speed of light; ω_{p} – plasma frequency; v_{F} – Fermi speed of electrons; V – the volume of the sensitive element; ϵ^{∞} – the contribution of the crystal lattice to the dielectric function; ϱ_{eff} is the effective aspect ratio for elongated spheroids equivalent to cylinders of finite length.

In fig. 1 shows the frequency dependence of the longitudinal component of the spectral sensitivity tensor of sensitive elements made of Au of various shapes and sizes. Note that the geometry and dimensions of the sensitive element significantly affect the value of $\mathrm{FOM}_{\parallel}$. Thus, if the sensitive element is an elongated spheroid, then the spectral sensitivity in the visible and ultraviolet frequency range will be the greatest for spheroids with the largest values of the semi-axes (Fig. 1, *a*), while for other forms of the sensitive element (cylinder and spherocylinder), the spectral sensitivity is maximum for structures with a small cross-sectional radius and a long length (Fig. 1, *b* and 1, *c*). In addition, if in the case of spheroidal and cylindrical sensitive elements they $\mathrm{FOM}_{\parallel}(\hbar\omega)$ reach saturation at certain frequencies, then in the case of spherocylinders there is an exponential increase in spectral sensitivity with increasing frequency.

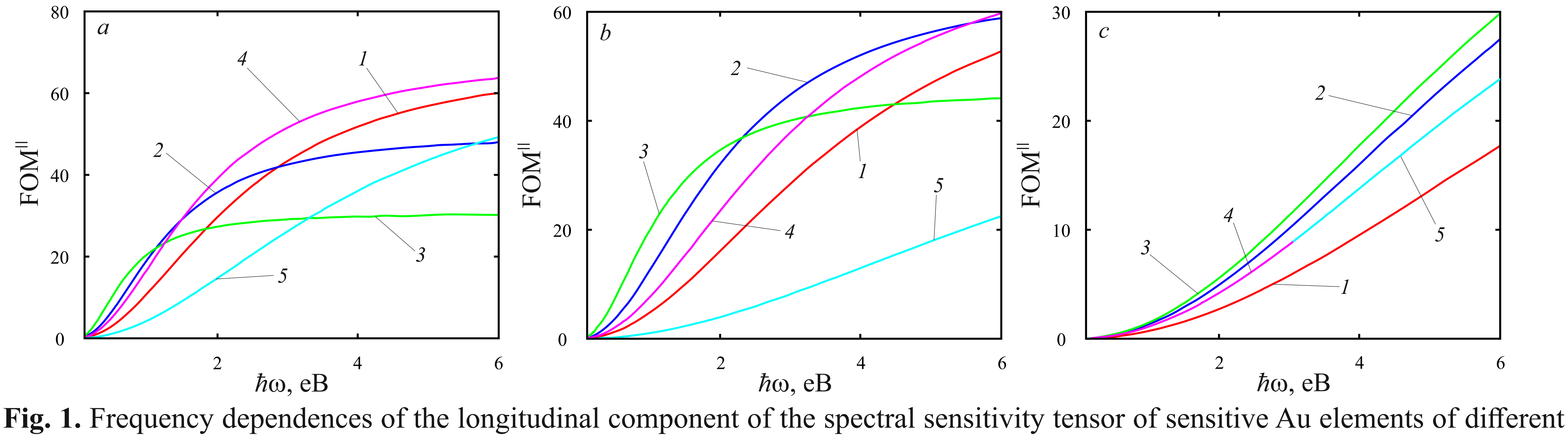

Fig. 1. Frequency dependences of the longitudinal component of the spectral sensitivity tensor of sensitive Au elements of different shapes and sizes: *a* – spheroids; *b* – cylinders; *c* – spherocylinders: *1* – $b_t = 10$ nm, $a_l = 50$ nm; *2* – $b_t = 10$ nm, $a_l = 100$ nm; *3* – $b_t = 10$ nm, $a_l = 200$ nm; *4* – $b_t = 20$ nm, $a_l = 100$ nm; *5* – $b_t = 50$ nm, $a_l = 100$ nm