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Controllable propagation of surface plasmon polaritons in chains of non-spherical nanoparticles on dielectric substrate

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Surface plasmon polaritons (SPPs) that can be excited in chains of metal nanoparticles (plasmonic chains) in a variety of different physical conditions is a topic of vigorous ongoing research. In the majority of previous publications, plasmonic chains as well as single nanoparticles have been studied in an isotropic medium or in free space. However, the practical use of periodic structures with certain configuration suggests their emplacement on the flat substrate. In this case, the impact of the electromagnetic interaction between plasmonic chain and substrate on the waveguiding properties of such chains is of both theoretical interest and practical importance.

In this work we study propagation of SPPs in linear chains of $N = 1001$ silver oblate spheroids located on the flat quartz substrate. We assume that the longer semi-axis of spheroids is perpendicular to the chain. The shorter semi-axis is taken to be $b = 8$nm and the center-to-center interparticle distance is $h = 24$nm. In these conditions the dipole approximation is valid:

$$\mathbf{d}_n = \alpha_n \left[\mathbf{E}_n + \sum_{m=1}^{N} \left(G_{nm}^F + G_{nm}^S \right) \mathbf{d}_m \right]. \quad (1)$$

Here $\mathbf{d}_n$ and α_n are the dipole moment and the polarizability of the nth nanoparticle; $\mathbf{E}_n$ is the external field; G_{nm}^F and G_{nm}^S are elements of the Green's tensors describing the field in a homogeneous medium and the field reflected from the substrate, correspondingly. We use the Drude model for dielectric permittivity ε_m of metal and experimental values for permittivity of the substrate: $\varepsilon_s = 2.5 + 0.01i$.

We have found that the presence of the dielectric substrate leads to conversion of SPP's polarization: linear–circular and circular–linear conversions are possible. This effect enhances at the shorter distances from the substrate.

The dielectric substrate exerts significant influence on transmission properties of the chain of metal nanoparticles. We have found that attenuation of SPP strongly depends on its polarization and the aspect ratio of nanospheroids. In most cases, the presence of substrate increases the attenuation of SPP. However, the technological substrate does not violate the nondecaying propagation of SPP that take place in chains of oblate spheroids with sufficiently small aspect ratios. In particular, for oblate spheroids with aspect ratio $b/a < 0.25$ (where a is the longer semi-axis) in the low-frequency spectral range. The absence of strong decay can be explained by high values of the depolarization factor of oblate spheroids with small aspect ratios and by increasing of quality factor of surface plasmon resonance of silver nanoparticles for low frequencies.