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Electromagnetic Modelling of Metal-Dielectric Multi-Nanolayer Structure Supporting Surface Plasmons

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Surface plasmons (SPs) suffer from high loss in metals supporting them, which results in very short propagation distances (no more than 100 μm). The reason is wavelength-scale optical field confinement in the vicinity of metal-dielectric interface, where strong enhancement of electric and magnetic field component values is observed. There are several ways to overcome this problem such as introducing an optical gain near the metal interface, adding dielectric-loaded SP waveguide with amplifying abilities and others. However, all these approaches essentially complicate the structure while providing modest propagation length enhancement. As an alternative approach, we are suggesting an artificial material – metal-dielectric multi-nanolayer (MDMNL) structure supporting SPs. We used the method of single expression to model electromagnetic properties of such structures. Kretschmann-type configuration, where thin metallic layer is substituted by MDMNL structure is analysed. An oblique incidence of TM polarised wave on a dielectric prism of permittivity $\varepsilon_1 = 3$ covered by MDMNL structure is modelled. We considered a structure consisting of silver nanolayers $d_m = 9\,nm$ thickness and SiO_2 nanolayers of $20\,nm$ thickness at $\lambda_0 = 530{,}9\,nm$. We showed that MDMNL structure is able to support SPs at the specific number of bilayers, when the sum of metallic nanolayers thickness is less than the thickness of one thin metallic layer in conventional Kretschmann structure. Excitation of SPs is determined by obtaining strong dip in angular reflection spectrum. In the considered case SPs are supported by 5 bilayers at the incidence angle $\theta_{SP} = 45.914^o$. The MDMNL structure with an outer dielectric layer reduces the loss in outer metallic nanolayer as it is located out of highest value of electric field amplitude (see Fig. 1).

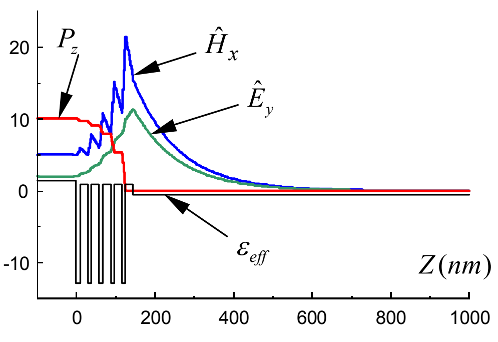

Fig. 1. Distributions of magnetic and electric field amplitude ($\hat{H}_x$ and $\hat{E}_y$), P_z - Poynting vector and profiles of effective permittivity $\varepsilon_{eff} = \varepsilon_i' - \varepsilon_1 \cdot \sin^2\theta$ (i = 1(prism), m (metal), d (dielectric), 2 (air)). Where $\tilde{\varepsilon}_m = \varepsilon_m' + j\varepsilon_m'' = -11.3 - j0.62$, $\varepsilon_d = 2.393$, $\varepsilon_2 = 1$, $\theta = \theta_{SP} = 45.914^o$. (For comparison, in conventional Kretschmann structure $d_m = 49nm$, $\theta_{SP} = 37.269^0$).

In conclusion, application of MDMNL in Kretschmann-type structure considerably decreases the losses in metallic layers and hence increases SPs propagation distance.