Surface Plasmon Polaritons in Silver-Gold Sandwich Structure

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Abstract: We propose to use silver/gold sandwich structures to combine the advantages of silver and gold – two materials of choice for nanoplasmoics and metamaterials. We report on the preparation, characterization, and theoretical modeling of the proposed system.

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Gold and silver are two materials of choice for nanoplasmonics and metamaterials applications. The permittivity of silver has larger negative real part, ε', and smaller imaginary part, ε'', than the permittivity of gold. Correspondingly, in chemical and biological sensors based on surface plasmon polariton (SPP) reflectance measurements [1], silver films have narrower dips in the angular reflectance profiles and higher sensitivity. On the other hand, the use of silver in sensors is limited since it easily oxidizes in air and can damage biological samples. Gold is a better technological material than silver and it is safer to substances to be detected. However, the disadvantage of gold is that it is more lossy than silver. We infer that layered sandwich structures consisting of a silver film topped with a very thin gold film can combine the advantages and minimize the drawbacks of the two metals. The preparation and study of such structures is discussed below.

Experimentally, Ag and Au thin layers were deposited at room temperature directly onto high index glass prisms using DC magnetron sputtering in an ultra high vacuum (UHV) system with base pressure in the low 10^{-9} Torr. Controlled and stable growth rates, typically around 1 Å/s, were used to grow the films. Thickness characterization of the grown films was carried out *ex-situ* with X-ray reflectometry (XRR) in a standard four circle diffractometer with Cu K_α radiation (λ=1.5418 Å) using the Bragg-Brentano configuration and 1/32 degree slits. Three samples were used in our studies. Sample 1 had ~58 nm silver film, sample 2 had ~54 nm Au film, and sample 3 had ~58 nm Ag film topped with ~6 nm Au film.

The studies of surface plasmon polaritons were carried out in a standard Kretschmann geometry [1] at six wavelengths ranging from 543 to 1000 nm. The angular reflectance profiles, $R(\theta)$, in the three samples studied are shown in Fig. 1a. As expected, all the experimental profiles had a characteristic dip at the angle at which the projection of the photon wave vector onto the plane of the metal-dielectric interface matched the wave vector of the SPP.

Numerically, the reflectivity of the structure was calculated using the transfer matrix method [2]. In these calculations, we assumed that the permittivities of thin Ag and Au films were well-described by their bulk values [3] and neglected possible effects of charge accumulation at the silver-gold interface. Such an approach provides an excellent qualitative description of the observed phenomena, compare Figs. 1a and 1b. Our simulations indicate that the field profile in a metallic sandwich has a maximum at the gold-air interface and, thus, resembles the profile of conventional SPP.

The experimental reflectance profiles in pure silver and pure gold films were fitted with the known formulas [1] to determine permittivities of Ag and Au at the wavelengths studied. Using these values, we calculated the reflectance profiles, which would be expected in silver and gold films of the thickness equal to the total thickness of the Ag/Au sandwich structure (~64 nm).

The full width at half maximum (FWHM) of the reflectance profile $R(\theta)$ corresponds to the total loss or to the inverse propagation length of surface plasmon polaritons [4]. By comparing the values of FWHM directly measured in the Ag/Au sandwich structure with those calculated for Ag and Au films of equivalent thickness (Fig. 1c), we were able to compare the SPP loss in the three systems studied. (Note that since the three traces in Fig. 1c correspond to the same thickness of the metallic film, the difference between the curves primarily corresponds to the difference in internal losses rather than radiative losses.) As one can see in Fig. 1c, the loss in the sandwich structure is larger than in pure silver film and smaller than in pure gold film.

Thus, we have demonstrated that the proposed Ag/Au sandwich structure can, indeed, be a good compromise between low-loss but chemically active silver and lossy but more inert and technological gold. We believe that such sandwich structures can find applications in a variety of nanoplasmonic and metamaterials systems, which include but are not limited to sensors. The detailed analysis of the optical properties of the fabricated system will be presented at the conference.

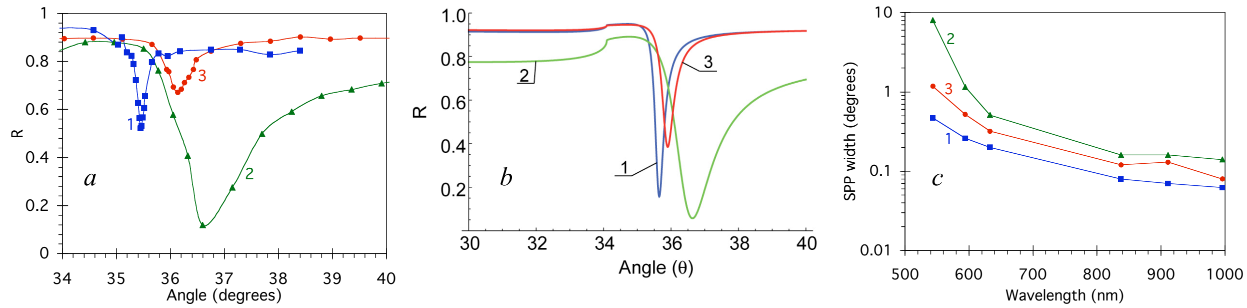

Fig 1. Reflectance profiles measured (a) and calculated (b) at λ=594.1 nm in 58 nm silver film (1), 54 nm gold film (2), and Ag(58 nm)/Au(6 nm) sandwich structure; (c) FWHM of the reflectance profiles in Ag film (1), Au film (2) and Ag/Au sandwich (3).

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