

Electrical Detection of Surface Plasmons for Sensing Applications

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Abstract: Photoinduced voltages in metal films with rectangular profile modulation demonstrate sharp polarity switching at plasmon resonance conditions. We explore this effect for applications for compact plasmonic sensors with electrical detection. © 2019 The Author(s)

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Plasmon-based biomedical sensing [1] commonly uses relatively broad localized plasmon resonances and also requires bulk optical setup for the detection of changes in local environment. We explore a new approach which (i) can significantly enhance the sensor sensitivity based on the use of sharp features in optical and electric behavior of some plasmonic nanostructured systems, and (ii) provide compact electric monitoring of modifications in local environment via the plasmon drag effect, which is strong enhancement of the photoinduced electric effects at plasmon resonance conditions [2]. In flat metal films and gratings with small profile modulation height, the photoinduced voltage polarity commonly corresponds to the electron drag along with propagating plasmon polariton [3]. In strongly modulated grating structures, the angular dependence of the voltage has a Fano resonance-like shape and demonstrates sharp switching of polarity [4] around the surface plasmon polariton (SPP) resonance conditions.

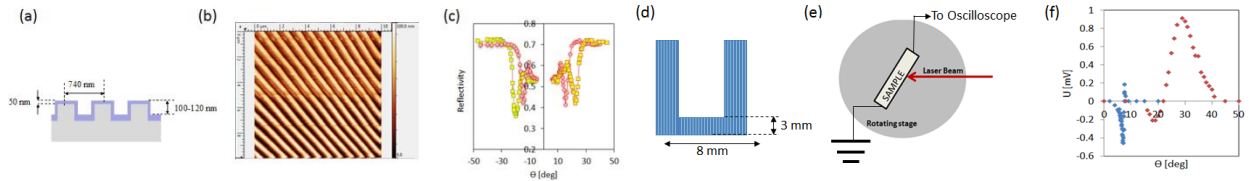


Fig. 1. (a) Schematics of the sample profile; (b) AFM image; (c) Angular dependence of reflectivity featuring SPP-related dip at 623 nm (red) and 585 nm (yellow); Schematic of the (d) experimental sample and (e) setup; (f) Typical angular dependences of the photoinduced voltage at 650 nm (blue) and 585 nm (red) (taken in air).

In this work, we explore the sensitivity of such a sharp switching to small changes in the dielectric environment. Our structure is obtained using commercially available DVD substrates [5] and subsequent thermal deposition of metal film (gold, silver) with 50 nm thickness. Disassembled polycarbonate DVD substrates have rectangular grooves of ~ 100 nm height with the periodicity $d = 740$ nm, see Figs. 1(a) and (b). According to optical characterization, Fig. 1 (c), the SPP conditions will follow the condition for SPP excitation in periodic surfaces, $k_{SPP} = k_0 \sin \theta + 2\pi/d$.

Here k_0 is the optical k-vector, $k_{SPP} = k_0 \sqrt{\frac{\epsilon_m \epsilon_d}{\epsilon_m + \epsilon_d}}$ is the SPP k-vector, and ϵ_m and ϵ_d are the permittivity of the metal and dielectric respectively.

The experimental sample is cut in the U-shape; see Fig. 1 (d), with the width of 3 mm and vertical orientation of the grooves. Two electrical contacts are attached at opposite ends of the sample. The sample is placed on goniometer stage and illuminated in air with pulsed laser light with pulse duration of 5 ns and energy of ~ 0.3 mJ per pulse at 630 nm. The photoinduced electric voltage is recorded with the Tektronix 3 GHz oscilloscope (with 50 Ω internal resistance) as the function of the angle of incidence Fig. 1 (e). The voltage shows switching around the SPP conditions, following typical observations in the systems with strong profile modulation, Fig. 1 (f), demonstrating

the polarity switching from the electron drag in the direction of the projection of the optical k-vector on the film plane to that in the opposite direction.

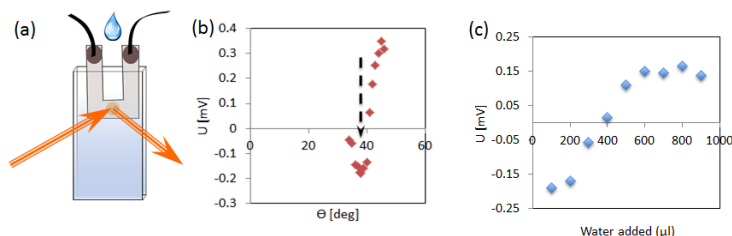


Figure 2: (a) Schematics of the experiment with water/ethanol solution; (b) Angular dependence of the electric signal in ethanol. The arrow indicates the orientation of the sample in the water addition experiment; (c) Photoinduced voltage as the function of added water.

In order to test the sensitivity of the photoinduced voltage to the environment, the sample is placed into the cuvette containing 1.8 mL of ethanol, Fig 1(a), and illuminated with the laser light at 630 nm. The angular dependence shows the switching of the polarity around the angle of incidence of $\sim 40^\circ$ deg, Fig.2 (b), which is different from what is observed in air ($\sim 11^\circ$ deg), which is well expected due to the change in the dielectric constant of the environment (from 1 to 1.8). Then, the stage is fixed at the position of polarity switching of photoinduced voltage. Water is added with amount of 100 μL per step. As one can see, small addition of water results in the switching of polarity of photoinduced voltage, which can be explained with the shift of the switching point toward lower angle, since the dielectric constant of water (1.77) [6], is lower than that of the ethanol.

In conclusion, the angular dependence of the photoinduced voltage in plasmonic gratings with high amplitude modulation demonstrates a highly asymmetric Fano shape behavior and polarity switching with the position very sensitive to the dielectric environment. This can provide opportunity to use compact electric monitoring in plasmonic sensors instead of bulk optical setup.

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