Mode Coupling and Sensing in Plasmonic Layered Structures

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Abstract. Optical sensors based on a plasmonic multilayer stack, such as metal-insulator-metal (MIM), have attracted considerable attention over the past decades owing to their high resolution and high performance compared to conventional surface plasmon resonance (CSPR) sensors for bulk sensing (BS) applications. In this paper we show that CSPR is better than MIM sensors for thin film sensing, i.e. when a dielectric sensing layer (SL) is deposited on the outermost metal layer of the structure. We demonstrate that the deposition of a thin film SL on the top of the outermost-layer of an optimized multilayer structure, i.e. MIM, strongly decreases the evanescent electric field and the field enhancement at metal-SL interface and decreases the sensor's sensitivity for MIM versus CSPR. By considering the theoretical and experimental results we demontrated that CSPR is more suitable than MIM for thin films sensing applications.

1 Introduction

Plasmonics is a research field, that witnessed an exponentially increasing interest during the past decade, and which deals with different aspects of surface plasmon resonance (SPR) related sciences and technology[1–4]. SPR is a quantum electromagnetic (EM) surface wave stemming from the interaction of light with free electrons at a metal-dielectric interface accompanied by electromagnetic oscillations. Since the waves are tightly bound to metal–dielectric interface and the external medium, e.g. air or water, these oscillations are very sensitive to any change of this boundary, such as the adsorption of molecules to the conducting surface[3,5–7]. This peculiar characteristic of surface plasmon (SP) is a constituent for making use in plasmonic, and a feature that suggests the possibility of using SPR for a wide range application; e.g. in integrated optical circuits[8,9], optical waveguides and optical sensors[10–12]. Due to the high sensitivity detection optical sensors have found extensive use in the areas of food inspection[13,14],medical diagnostics, drug screening and data storage by observing and controlling the photoswitching phenomenon of photochromic molecular via refractive index change[16,15]. In recent years, molecular photoswitches have been studied extensively owing to interest in both fundamental and applications aspects . The azobenzene derivatives are one of photochromic molecules family[12,17]. When external boosts are applied this molecule permit to achieve mechanical movements, leading up to configuration changes of the switch, e.g., under the optical pumping azo-dye molecules sustain the *trans-cis* transformation due to the absorption of visible light, and they transform into each other by reversible photoisomerization. Azo-dye molecules containing materials, e.g. DR1-doped PMMA are broadly studied and used in dye chemistry over the past two decades[16]. Thin films comprising DR1-doped PMMA serve as transducers that can convert incident light to molecular motion, leading to a numerous applications[15,16]. For example, the optical pumping of DR1-doped PMMA films induces intense changes in their optical properties due to the photoisomerization process; in our previous study, light-tunable Fano resonances in a multilayer stack has been demonstrated by doping azo-dye molecules into the outermost dielectric layer of a metal-dielectric-dielectric three layer structures result in controlling the resonance position by pump light irradiation[15]. In the same context, the performance of a long range structure consisting of PVA/Ag/DR1/PMMA for use in an all-optical dye-doped polymer switch is demonstrated by doping the azo-dye into the outermost layer of the plasmonic system. In this paper, we report on the study of the photoinduced changes in the refractive index of the outermost dielectric layer of DR1-doped PMMA film using two plasmonic systems, e.g., a metal-dielectric-metal (MIM) structure; Ag/PMMA/Ag and a conventional SPR(CSPR) structure based on silver film. Our approach is to exploit the potential of the photo functional DR1 molecules in realizing the active modulation of resonances of both plasmonic systems using blue light, as a result, to achieve a comparison study of the sensitivity of MIM structure and CSPR structure in case of thin film sensing. Since SPR and MIM structures are sensitive to the change of the surrounding medium, and when DR1 doped PMMA is used as thin SL and pumped with blue light, the change in the refractive index of the thin sensing layer generate a photosensitive shift of the resonance dip of CSPR and MIM sensors. Based on the theoretical and experimental results. We clearly demonstrate that the deposition of a thin film on the top of the outermost-layer of an optimized multilayer structure, e.g., metal-insulator-metal, disturbs the

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coupling between hybrid plasmonic polaritons at the two I/M interfaces of this structure thereby, reduce the electric field and as a result, decrease its sensitivity compared to conventional surface plasmon resonance sensor based on silver film. This makes CSPR structure a promising plasmonic sensor that can provide a route for application based on thin film sensing.

2 MIM and CSPR Sensors

To measure the angle-scan ATR spectra in a Kretschmann configuration for MIM and CSPR structures, a custom made setup was prepared for this reason illustrated in Figure 1. To do so, the prepared sample was pasted first on the bottom surface of a 90°-BK7-prism and then was mounted on a rotating stage. The prism-sample system was illuminated by P-polarized, e.g., Transverse Magnetic (TM)-polarized, light from a Helium-Neon (He-Ne) laser with a wavelength of 632.8 nm as probe beam. The reflected light was measured by using a Si photodiode connected to a lock-in-amplifier as a function of the angle of incidence. The precision of the incidence angle is around 0.018°. To perform in-situ photoisomerization experiments during reflectivity scans of the present sample, a pump beam with the wavelength of 488 nm and the power at the SL could be adjusted using a neutral density filter The pump beam, ~ 6 mm in diameter and centered over the probe beam.

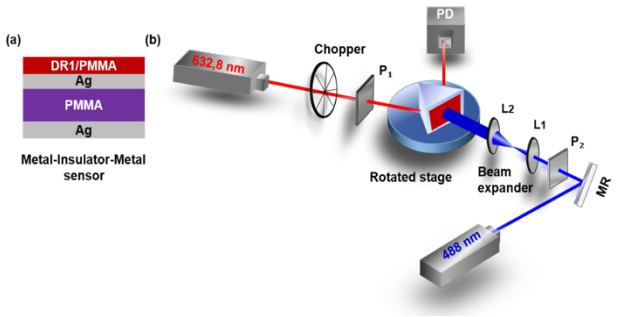

Figure 1: Schematic of MIM structure configuration with the experimental setup; (a). Schematic configuration of MIM structure with the SL of DR1/PMMA, (b). The experimental setup of ATR measurement in Kretschmann configuration and the photoisomerization irradiation scheme.

3 Results

Experimental Results, together with theoretical fits, are shown in Figure 2. The sharp resonance dip of MIM is located at low incidence angle than that of CSPR mode, and The full width at half maximum (FWHM) for MIM is about 0.23° which is smaller than that of CSPR[7,25–27]. The experimental results of ATR spectra of MIM and CSPR are in good agreement with the theoretical fits. Figure 5b shows the θ-scan ATR spectrum measured for CSPR with and without the SL. The resonance dip of CSPR is located at 42.96°, after adsorbate layer of 58 nm of DR1/PMMA, the resonance shifts toward the higher incidence angle of 59.66 °. For a comparison purpose a 58 nm of DR1/PMMA with a concentration of 12 % w/w is deposited on the top of the outer layer of MIM structure as presented in Figure 5c, based on the reflectivity measurements the sharp resonance dip of MIM structure shifts also toward higher incidence angle. The refractive index value of DR1/PMMA 1.565 is extracted from the fitted data is the same for both stacks. In addition, the broad mode of MIM structure is shifted similarly toward higher incidence angle, but it cannot be recorded experimentally.

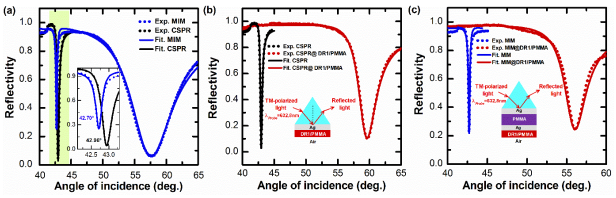

Figure 2: Angle-scan ATR spectra in a Kretschmann configuration for MIM and CSPR; (a). Angle-scan of CSPR (Ag/ Air) and MIM (Ag/ PMMA/ Ag/ Air) structures, (b). CSPR without and with the SL at 12 % w/w, (c). MIM without and SL at 12% w/w. The dots are experimental data, and the solid line are the fitted data.

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