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# Enhanced antibody recognition with a magneto-optic surface plasmon resonance (MO-SPR) sensor

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ABSTRACT

A comparison between sensing performance of traditional SPR (Surface Plasmon Resonance) and magneto-optic SPR (MOSPR) transducing techniques is presented in this work. MOSPR comes from an evolution of traditional SPR platform aiming at modulating Surface Plasmon wave by the application of an external magnetic field in transverse configuration. Previous work demonstrated that, when the Plasmon resonance is excited in these structures, the external magnetic field induces a modification of the coupling of the incident light with the Surface Plasmon Polaritons (SPP). Besides, these structures can lead to an enhancement in the magneto-optical (MO) activity when the SPP is excited. This phenomenon is exploited in this work to demonstrate the possibility to use the enhanced MO signal as proper transducer signal for investigating biomolecular interactions in liquid phase. To this purpose, the transducer surface was functionalized by thiol chemistry and used for recording the binding between Bovine Serum Albumin molecules immobilized onto the surface and its complementary target. Higher sensing performance in terms of sensitivity and lower limit of detection of the MOSPR biosensor with respect to traditional SPR sensors is demonstrated.



## 1. Introduction

One of the foremost technologies for labeling-free biosensing is based on the Surface Plasmon Resonance (SPR) phenomenon (Liedberg et al., 1995; Schuck, 1997; Garland, 1996). In fact, at a metal–dielectric interface, the free electrons of the metal surface can support a collective oscillation, generating an associated electromagnetic (EM) wave and a Surface Plasmon Polariton (SPP) (Raether, 1988). The field vectors of this EM wave reach their maxima at the interface and decay evanescently into both media. The evanescent field is responsible for the detection of refractive index changes at the metal/dielectric interface. Small variations in the refractive index of the medium located in contact with the metal layer are recorded by changes in the SPR optical signal (Fig.1 a, b).

The SPP oscillations are excited by an external illumination on condition that the wave-vector of the surface plasmon wave matches the photon momentum of light. If a metal film is coated directly on a prism (Kretschmann and Raether, 1968; Cullen et al. 1987–1988; Jorgenson and Yee, 1993; Homola et al., 1999) (Kretschmann geometry), such matching can be achieved by a proper choice of the angle of incidence of a monochromatic light beam onto the prism base.

Biological and chemical analyses are achieved by functionalizing the gold surface with surface bioreceptors and measuring the shift of corresponding optical signals (Homola et al., 1999).As widely reported in the literature, intensity interrogation demonstrates a higher sensitivity with respect to angular interrogation; this is why it is the most common choice for the realization of SPR sensing setup (Zacher and Wischerhoff, 2002; Ran and Lipson, 2006; Kanda et al., 2004; Giebel et al., 1999).

Numerous studies have been carried out to optimize the performance of SPR-based detection technology, owing to the fact that the detection performance of the current practical SPR biosensors is often insufficient to monitor low concentrations of small biomolecular analytes (i.e., drugs, vitamins, and antigens). The optimization of the optical metrology systems or the choice of efficient data analysis methods can lead only to slight improvement in SPR sensing performances. Better results can be obtained by modifying transducers interfaces or modulating the optical signals (Schasfoort and Tudos, 2008; Liedberg et al., 1983; Melendez et al., 1996; Zhang and Uttamchandani, 1988; Karlsson, 2004).

Transducer layers can be modified, for instance, by adding a nanostructuration on the metal sensing layer: localized SPR (LSPR) using periodic nanowires and nanoposts as well as sub wave-

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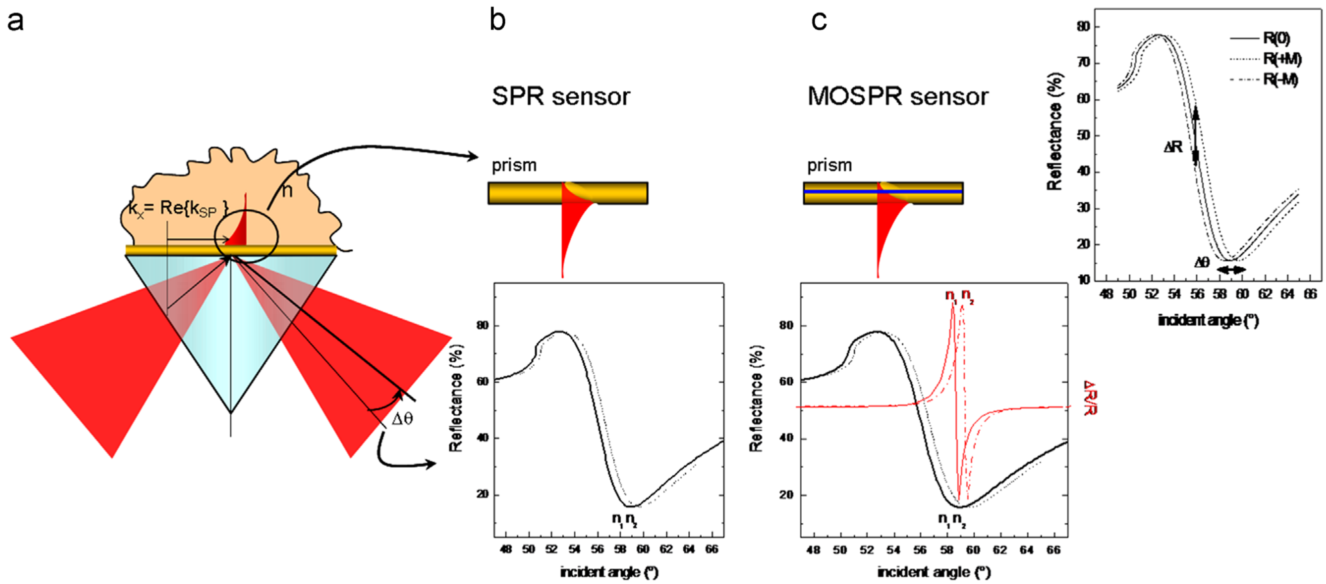


**Fig. 1.** (a) Schematic representation of the experimental setup for SPR excitation in Kretschmann configuration; (b) detail of the metal transducer/dielectric interface of a standard SPR sensor and excitation of surface plasma wave exponentially decaying into the dielectric. The changes in SPR curves upon a change in refractive indexes $n_1 < n_2$ is also shown; and (c) detail of the hybrid metal/ferromagnetic/metal trilayer transducer of a MOSPR sensor and excitation of surface plasmon wave exponentially decaying into the dielectric. The EM field is enhanced at the MO active layer, thus enhancing the magneto-optical signal. A schematic response of SPR and MOSPR signal to the same change in refractive index is reported. The graph on the right shows the effect of the reverse of magnetization on the SPR curve, namely on the angular minima shift $\Delta\theta$ and on the reflectance $\Delta R$.

length nanogratings deposited onto metal surfaces can be used (Moon et al., 2010; Kim et al., 2006; Byun et al., 2007; Malic et al., 2007). Further examples can include signal amplification using functionalized nanoparticles (He et al., 2000), or using the combination of metal nanoparticles and dielectric materials. In the latter cases sensing improvements are due to the possibility to enhance SPs capabilities and increase its ability to sense small analyte molecules. Such modifications of transducer interfaces are responsible for the enhancement of the electromagnetic field (EM) in the close vicinity of the metal transducer layer (Nenninger et al., 2001); hence, increasing the sensitivity of the biosensor when compared to traditional interfaces.

On the other hand, external modulation techniques can be used to improve the signal-to-noise (SNR) ratio of the SPR sensing measurements, thus increasing the limit of detection (LOD) with respect to traditional SPR sensors. For this purpose, the mechanical (Hooper and Sambles, 2004; Patskovsky et al., 2008) and the phase (Wu et al., 2003; Markowicz et al., 2007; Kabashin et al., 2009) modulated SPR sensors have been proposed in the literature.

In this work, the idea is to use both modification of traditional SPR transducer layer and modulation of SPR signal in order to get significant increase in sensitivity with respect to standard SPR sensors. For this purpose Au/Co/Au trilayers were used as transducer, and the magnetic modulation of the plasmon wave vector was used as the sensor signal (Fig. 1c). The modulated nature of the signal together with a proper choice of metal and ferromagnetic trilayer tailored on the nanoscale will ensure the achievement of the goal of the work.

Different papers have reported the possibility of controlling SPP excitations in metallic trilayer structures by means of an external magnetic field (González-Díaz et al., 2007; Ferreiro-Vila et al., 2009; Armelles et al., 2009). When the SPP is excited in these structures, an external magnetic field can induce a modulation in the SPP wavevector, provided that the magnetic field is applied perpendicularly to the direction of propagation of the SPP and parallel to the interface. In addition, an enhancement in the magneto-optical (MO) activity is evidenced when the SPP is excited in these structures (González-Díaz et al., 2007; Armelles et al., 2009; Armelles et al., 2013; Wallis et al., 1974; Hermann et al., 2001; Armelles et al., 2008).

The amplified MO signal induced by the excitation of the SPP is chosen as sensor signal which is able to record biomolecular interactions occurring at the metal/dielectric interface. For this purpose, a simple experimental setup is required, based on intensity interrogation provided with magnetic actuation in a transverse configuration. A small electromagnet producing a proper magnetic field intensity can be used for this purpose. These multilayered structures, showing both plasmonic and magneto-plasmonic activity, have been demonstrated to be used as proper new transducers in a MOSPR gas sensor (Manera et al., 2011; Sepúlveda et al., 2006; Regatos et al., 2010; Regatos et al., 2011; Manera et al., 2012).

In this work, by investigating a simple bioassay experiment, we demonstrate that this new strategy can be used to enhance SPR biosensor sensitivity. Biosensing measurements obtained in this work give us a complete view of functional characterizations carried out by using these novel transducers; the work extends in liquid phase our previous sensing results performed on gaseous environment.

## 2. Materials and methods

### 2.1. Materials

N-hydroxysuccinimide(NHS), N-(3-dimethylamino- propyl)-N0-ethylcarbodiimide hydrochloride (EDAC), ethanolammine and11-mercaptoundecanoicacid (11-MUA), Bovine serum albumin (BSA) and the corresponding antibody anti-BSA (a-BSA) were purchased from Sigma-Aldrich. Hybridization measurements were performed using a saline phosphate-buffer (PBS, pH 7.4). Deionized water was used for the preparation of all solutions.

### 2.2. Preparation of plasmonic and magneto-optical transducing layers

Transducer layers were composed of 15 nm Au (capping) /6 nm Co/25 nm Au/2 nm Ti deposited on SF10 glass substrates. They were deposited by dc magnetron sputtering at room temperature in an