Tunable Surface Plasmon Resonance on an Elastomeric Grating

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Abstract— In this study, we demonstrate that periods of metallic gratings on elastomeric substrates can be tuned with external strain and hence are found to control the resonance condition of surface plasmon polaritons [1]. The periods of the gratings are increased up to 25% by the use of applied mechanical strain. The tunability of the elastomeric substrate provides the opportunity to use such gratings as efficient surface enhanced Raman spectroscopy substrates. It's been demonstrated that the Raman signal can be maximized by tuning the period of the elastomeric grating.

The surface plasmon resonance (SPR) phenomena observed on metal surfaces or nanoparticles has been a great interest in several fields of research such as nanoscale photonics and biological sensing. Continuous metallic films possessing a periodic perturbation exhibit strong extinction and scattering spectra when excited at the SPR condition. The challenge of designing effective structures to manipulate plasmonic fields and utilize them in functional devices still remains. In particular, the use of SPR in surface enhanced Raman spectroscopy (SERS) and biological sensing require an intelligent design in order to maximize the plasmonic enhancement. In this regard, the tunability of the SPR wavelength provides flexibility in many plasmonic sensing applications.

Flexible designs utilizing electronic [2], ferroelectric [3], or thermal [4] tuning mechanisms are also reported in the literature. Those methods are reversible and can be applied after the plasmonic structure is fabricated. Such a repeatable process can find wide applications in the field of Raman spectroscopy and plasmonic sensing. It was reported that by controlling the geometry of the nanoshells films, the SERS enhancements can be optimized [5]. A repeatable thermal tuning mechanism using silver nanoparticles for achieving a tunable SERS substrate was reported by Lu et al. [6].

In this study we use an elastomeric grating structure in order to excite surface plasmon polaritons (SPP) on its metallic surface. We report a way of tuning the SPR by applying mechanical strain on the elastomeric grating structure. The elongation of the elastomer effectively changes the period of the metallic grating. It can be seen that the SPR wavelength also shifts as the external strain changes the period of the elastomeric grating coated with a thin metallic layer.

We fabricated two silicone elastomers with gratings on top using two different methods. The first elastomeric grating was generated using holographic lithography with 665 nm period. The elastomeric grating is then obtained using the replication procedure. Note that the thickness of the elastomer is kept around 5 mm. To generate SPP, the PDMS grating is coated with a 55 nm of silver using thermal evaporation. For the second elastomer we used a commercially available ruled grating with 530 nm period as the master grating. The fabrication of the elastomeric grating is the same as in the first case.

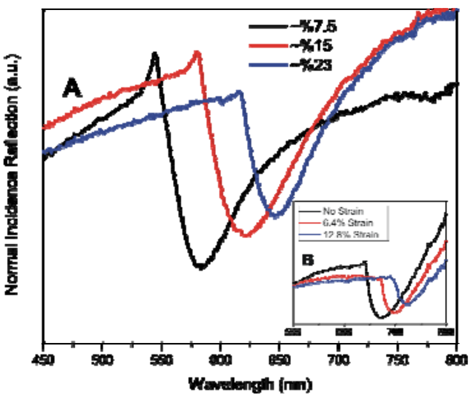

Figure 1. The normal incidence reflection spectra for three different strain values of 7.5%, 15% and 23% for grating **A** (main) and no strain, 6.4% and 12.8% for grating **B** (inset).

For demonstration of the tunable periodicity of the elastomeric grating we measured the angle of the diffracted beam when the it is excited by a 632 nm He-Ne laser for the case of 665 nm grating (A) and by a 514.5 nm Ar^+ laser for the case of 530 nm grating (B). It's been found that the periods of the gratings increase linearly up to 25% of mechanical strain. To demonstrate the tunability of the SPR condition we used both gratings, A and B. The optical normal incidence reflection spectrum of the PDMS gratings is measured using an ellipsometer (JA Woolam VASE). As seen in Fig.1, the SPR wavelengths on silver coated gratings A and B are approximately 560 nm and 670 nm, respectively, in the absence of applied strain. As the elastomeric grating is stretched, SPR wavelength red shifts due to the increased grating periodicity.

The elastomeric grating with 530 nm period is used as a SERS substrate to measure SERS signal of Rhodamine 6G (R6G) molecule. The precision mechanical strain setup is used under the objective of the spectrometer. Raman signal is maximized when the strain is 20.8\% which corresponds to a 633 nm grating period.

We have demonstrated the use of elastomeric gratings with tunable surface plasmon resonance condition. We have tuned the surface plasmon resonance wavelength by applying a mechanical strain on elastomeric gratings coated with a thin layer of metal. We have shown the use of the elastomeric grating with a SERS experiment of R6G molecule. An enhancement factor of more than 10^5 is achieved when the grating period is optimized. Note that the presented method is compatible with Raman and Micro-Raman Spectroscopy methods which utilize a fixed incident angle. We believe that the method can be used not only in SERS experiments, but also in biosensing and plasmonic enhancement applications.

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