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Vertical split-ring resonator based nanoplasmonic sensor

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1. Introduction

The optical properties of the plasmonic metamaterials are often times intrinsically connected to the localized surface plasmon (SP) resonances (LSPR) arising from the collective oscillations of free electrons which induce strong electromagnetic fields adjacent to the artificial sub-wavelength metallic elements in the metamaterials. The resonance wavelengths are determined by feature geometries of metamaterial elements and their surrounding environment, and thus can be tuned by either changing the element dimensions or the surrounding dielectric. Such a property can be explored for a variety of applications, one of which is sensing based on the following general design principle. The motivation of exploring metamaterials for the sensing application is the potential for achieving high sensitivity. To this end, metamaterials require to possess strong plasmon resonance features that are sensitive to environment change. The split-ring resonator (SRR) is such a metal structure that is typically used as a building block for metamaterials because of its strong magnetic resonance accompanied with strong field enhancement within the SRR gap [1]. One important measure of a metamaterial sensor is its sensitivity characterized as the ratio of LSPR shift to the change in refractive index of its nearby sensing medium ($\delta\lambda/\delta n$). Unfortunately, a majority of the metamaterials reported so far have planar SRRs that lay flat on substrates, resulting in a rather appreciable fraction of the plasmon energy distributed in the dielectric substrate below which limits the effective sensing volume as well as the sensing performance [2]. In this work, we report the fabrication of vertical SRRs (VSRRs) capable of lifting essentially all of the localized fields above the supporting substrate they stand on as illustrated in Fig. 1(a). Using Fourier transform infrared spectroscopy measurement and numerical simulation software, we demonstrate that plasmonic refractive index sensors constructed of VSRRs deliver significantly improved sensitivity over their planar counterparts reported in the literature.

2. Results and Discussion

Figure 1(a) shows the schematic concept of our designed VSRR structure standing up vertically on a fused silica substrate under normal illumination. This upright configuration strongly confines an electromagnetic field within the gap as the magnetic plasmon is excited, suspending the enhanced field entirely in the free space away from the dielectric substrate and thus increasing the sensing volume. To demonstrate and examine the sensing performance of the VSRR structure, we have performed the sensitivity analysis by experiment and simulation. According to the linear fitting, the simulation has predicted a sensitivity of about $\delta\lambda/\delta n$ = 797 nm/RIU, while our measurement has produced a less value of 603 nm/RIU, as shown in Fig. 1(b). It is interesting to point out that our transmittance measurement has yielded spectral resonance shift between the two different liquids greater than what was predicted by the simulation.

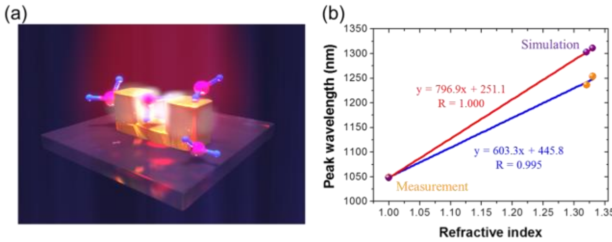

Figure 1. (a) Illustration of the field distribution in the VSRR gap and its advantage for increasing sensing volume. The resonance wavelength associated with magnetic resonance of experimental (orange dots) and simulation (purple dots) results as a function of the surrounding refractive index.

3. Conclusions

Our recently developed alignment technique has allowed us to fabricate VSRR structures capable of lifting localized plasmon fields off of the substrates. Such a feature is desirable for developing refractive index sensors based on plasmonic structures that respond to environment change with LSPR shift. By reducing the fraction of the plasmon field diffused into substrates, we effectively increase the sensing volume and therefore the sensitivity. We have experimentally demonstrated the sensitivity of 603.3 nm/RIU while our simulation predicts about 800 nm/RIU from this simple VSRR based sensor. Further improvement is achievable with optimized VSRRs or coupled structures. The employment of VSRR structures in refractive index sensors for biosensing applications is a promising method for achieving ultrahigh sensitivity and label-free properties at low cost.

References

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