Large area array of split ring resonators for sensing applications

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Abstract

Split Ring Resonators (SRR) are one of the most common elements used to fabricate metamaterials. In this paper we present design, fabrication and characterization of golden SRR; the aim is to obtain large area samples for sensing purposes. The fabrication process we exploit is X-ray lithograpy, in order to obtain large area sampless in a fast parallel process. We propose to use the rich resonant response of an array of SRR, and in particular the features in the visible, to detect bio-chemical quantities.

1. Introduction

In the last few years the interest in nanostructures for sensing application has grown increasingly [1], [2], [3], leading to the development of new designs based on the surface plasmon resonance of metallic structures. Tuning the geometry of the structures it is possible to adjust resonance frequencies, sensitivity, electric field enhancement. Bearing in mind the importance of the control of the geometric parameters, we decided to approach the structure fabrication using top-down lithographic techniques, in particular X-Ray Lithography (XRL). Moreover, this choice is justified by the request of large area samples for sensing purposes: the advantage of XRL, compared to other lithographic techniques such as Electron Beam Lithography (EBL), is the possibility to obtain large active areas in a single rapid exposure.
The structure we focused our research on is the Split Ring Resonators (SRR), one of the most popular and studied geometries for metamaterials. As metamaterial building block, the SRR exhibits characteristic plasmonic resonances and a tunable frequency magnetic resonance [4]. Besides, the SRR shows a strong polarization dependance and a strong mechanical stability.
In this paper we will focus only on the plasmonic modes of the SRR.

2. Design and Simulation

The software COMSOL Multiphysics, implementing the finite elements method, has been used in order to study the optical response of the SRR array structure. The unit cell consists of a gold SRR upon a layer of Indium Tin Oxide (ITO) and a substrate of glass. Solving the full three dimensional electromagnetic problem, we obtained the transmittance and the reflectance of the structure in the case of normally impinging plane with electric field polarized parallel to the gap, focusing our attention on plasmonic response of the structure. In this configuration a considerable enhancement of the field is obtained, which is strongly localized in the gap area. The parameters used in the calculation are the following: period $a = 360$nm, side $l = 360$nm, width $w = 90$nm, gap $d = 90$nm and height $h = 400$nm (Fig. 1).

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In Fig. 4 we report the transmittance spectrum over 400nm-1100nm wavelength range. The dips in the spectra correspond to various longitudinal plasmonic modes in the gap region. An increasing of the height of the structure creates larger number of plasmonic resonances excitable within the NIR-VIS spectrum.

3. Fabrication

The fabrication process we are presenting is based on XRL. In this lithographic technique a high energy x-radiation is used to transfer a pattern from a mask to a photoresist covered surface. The X-ray mask has been produced by EBL on silicon nitride mask and subsequent electrochemical gold growth (Fig. 2).

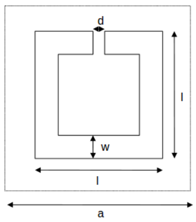

Fig. 1: SRR geometry

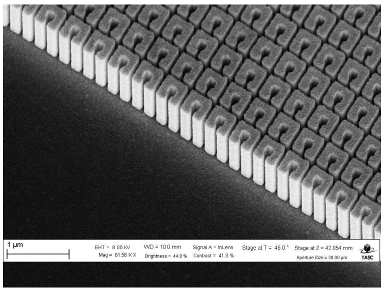

Fig. 2: SEM image of the XRL mask produced by EBL

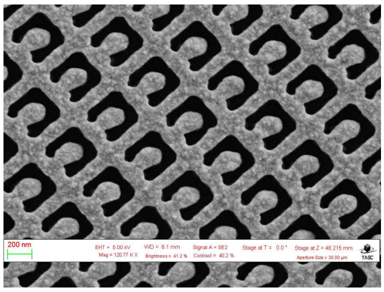

Fig. 3: SEM image of the mask replica produced using XRL

EBL has been performed on 500nm thick layer of polymethylmethacrylate (PMMA) in HR mode using a 100keV acceleration voltage and a beam current of 100pA. The area of the SRR array chip is 1×1mm^2. XRL is performed at ELETTRA synchrotron in Trieste on LILit beamline in soft X-ray regime (beam energy 1-2 keV). The SRR array is lithographed on three different substrate: chromium and gold baseplating covered silicon nitride for mask replica, chromium and gold baseplating covered silicon and ITO covered glass for samples, to achieve reflectance and transmittance measurement. In order to have good contrast we are using positive PMMA. This choice leads to two separated X-ray lithographic steps in order to obtain the correct tone, the first of which consists on the replica of the mask (Fig. 3). We use few nanometers of SAL as adhesion promoter for PMMA, that we remove after the development of the exposed PMMA using O_2/CF_4 reactive ion etching (RIE). After the XRL, the resist mold is filled by an electrochemical gold growth.

3. Characterization

We performed a preliminary characterization of SRR array fabricated using EBL on ITO covered glass (Fig. 7). Transmission analysis has been performed using the monochromatized 75W Xe lamp of a VASE (J.A. Woollam) Spectroscopic Ellipsometer with a wavelength resolution of 0.3nm. Transmission spectra (Fig. 5) were acquired in the range $400 - 1100$nm, step 5nm, at normal incidence and TE polarization values.

Though measured transmittance amplitude is lower than the simulated one, the measurement shows the same central resonance of the simulated case. Probable causes of deviation from the simulated pattern may be surface roughness and differences in the SRR shape due to the fabrication step. We functionalize the sample using a self-assembled monolayer of dodecanethiol ($C_{12}H_{25}SH$, hereafter C_{12}), deposited on the gold surface at room temperature and performed the measurement in the same conditions: in Fig. 6 we show the 15nm red shift of the resonace peak due to the presence of C_{12}.

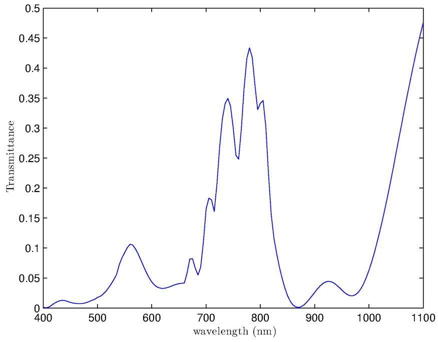

Fig. 4: Simulated transmittance spectrum

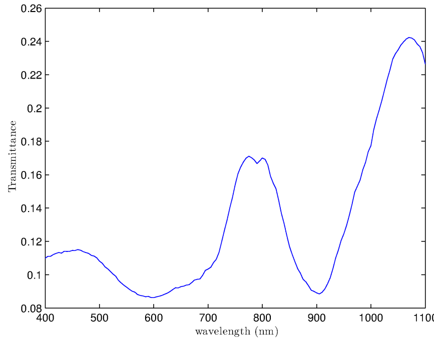

Fig. 5: Measured transmittance spectrum

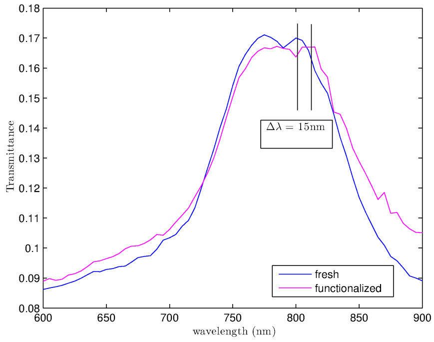

Fig. 6: Measured transmittance before (blue) and after (red) functionalization

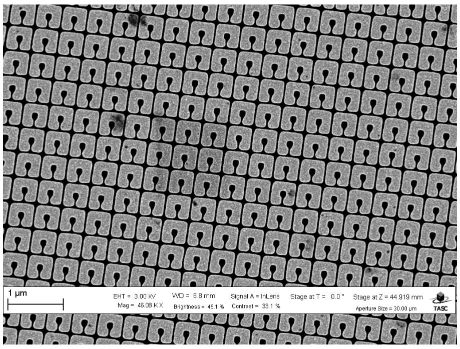

Fig. 7: SEM image of the measured SRR array

4. Conclusion

We are investigating the plasmonic response of SRR in the visible range. The fabrication technique we are proposing, XRL, offers the possibility to obtain large area samples with good lithographic quality in a faster process compared to other techniques. A preliminary characterization of the SRR array showed the detection potential of this geometry. Geometric tunability, sharp resonances in the NIR-VIS spectrum and mechanical stability make SRR a good candidate for futher improvement of sensing applications.

References

[1] I.M. Pryce, Y.A. Kelaita, K. Aydin and H.A. Atwater, Compliant metamaterials for resonantrly enhanced infrared absorption spectroscopy and refractive index sensing, *ACS Nano*, vol. 5 (10), pp. 8167-8174, 2011

[2] E. Cubukcu, S. Zhang, Y.S. Park, G. Bartal and X. Zhang, Split ring resonator sensors for infrared detection of single molecular monolayers, *Applied Physics Letters*, vol. 95, p. 043113, 2009

[3] B. Päivänranta, H. Merbold, R. Giannini, L. Büchi, S. Gorelick, C. David, J.F. Löffler, T. Feurer and Y. Ekinci, High aspect ratio plasmonic nanostructures for sensing applications, *ACS Nano*, vol. 5 (8), p. 6374-6382, 2011

[4] Z. Jakšić, O Jakšić, Z. Djurić and C. Kment, A consideration of the use of metamaterials for sensing applications: field fluctuations and ultimate performance, *Journal of Optics A: Pure and Applied Optics*, vol. 9, pp. S377-S384, 2007

