

Array of Symmetric Nanohole Dimers for STT-RAM Ultrathin Layer Sensing

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Abstract: Dimer nanohole array is designed to detect radiation effects in STT-RAM multilayer thin films, showing Fano resonance highly sensitive to dielectric layer changes. Normalized figure of merit is 13.5 times larger than single nanohole array. © 2019 The Author(s)

OCIS codes: (280.0280) Remote sensing and sensors; (050.6624) Subwavelength structures; (240.6680) Surface plasmons.

1. Introduction

In situ measurement of radiation induced defects in real time is a challenging task that requires detection of infinitesimal variations in material properties. Optical measurements have been utilized for real time measurement of variations in refractive index and absorption profile in photonic crystal fibers in the past [1]. Plasmonic structures are highly sensitive to refractive index change around them because of highly localized field enhancement of plasmonic modes at their interface. To increase the sensitivity and make the resonance sharper, creating a coupling to achieve Fano resonance has been suggested in the literature. Fano resonances have been demonstrated in arrays of metallic nanoparticles and nanoapertures. Specifically, clusters of metallic nanoparticles have been investigated [2]. However, there is much less work done on nanoaperture clusters. So far, nanohole quadrumers and heptamers have been studied [3, 4]. Plasmonic structures, because of their high field localization, can be utilized to optically detect the stability of ultrathin dielectric layer in spin transfer torque random access memory (STT-RAM) cells to gamma irradiation. Two-dimensional and three-dimensional subwavelength plasmonic structures have been suggested for such purpose [5, 6]. However, still there is a need to increase the sensitivity more.

In this paper, we suggest the simplest form of nanohole cluster, a symmetric dimer nanohole array in an Air / Au(5nm) / MgO (10nm) / Au(60nm) / Quartz multilayer, as a simplified form of STT-RAM memory cell multilayer [7]. We show that dimer nanohole array provides a highly sensitive Fano resonance without breaking symmetry in the nanohole dimer. Our simulations show that the sensitivity to a refractive index change in the ultrathin MgO layer is increased by 2.5 times compared to an array of single nanoholes. Normalizing to the area ratio of MgO per unit cell, figure of merit (FOM), defined as sensitivity divided by linewidth, for the designed dimer nanohole array is more than 13 times larger than the one for an array of single nanoholes. It's noteworthy to mention that the inter-hole spacing in the proposed structure is large enough to be fabricated using E-beam lithography, or even high-end optical lithography.

2. Dimer Nanohole Array Design

To assess the radiation effects in a multi-layer thin film metal-dielectric hybrid structure, plasmonic nanohole arrays is being investigated. The multi-layer thin film sits on a quartz substrate coated with a 60nm gold plane. STT RAM multilayer consists of Au(5nm) / MgO(10nm) / Au(60nm) / Quartz substrate. The geometry of the proposed design is shown in Fig 1a. We investigate the variations in transmitted light to detect radiation effects. We assume that incident light polarization is set to y polarization (along the nanohole dimer), illuminating the structure from the quartz side. A sharp Fano resonance takes place as a dip in transmission spectrum as shown in Fig. 1(b-d). The origin of the Fano resonance is coupling between a wideband surface plasmon polariton (SPP) mode at gold/quartz interface (bright mode), and a narrowband Wood's anomaly (WA) at the gold/air interface (dark mode). We believe that the symmetry breaking required for the coupling between the dark and the bright mode is created by the difference in the inter-hole distance for the nanoholes in a single unit cell compared to the one between the nanoholes of two adjacent unit cells. Also, the difference between the refractive index of quartz and air on the two sides of the structure contributes to the symmetry breaking.

The effect of changing the dimensions on the transmission spectrum is also shown in Fig. 1(b-d). Fano resonance wavelength is mainly dependent on the period along the nanohole dimer (P_y). This is in accordance with the fact that the transmission dip at the Fano resonance originates from the excitation of Wood's anomaly. The depth of the Fano resonance can be tuned by changing the nanohole diameter, and the inter-hole spacing.

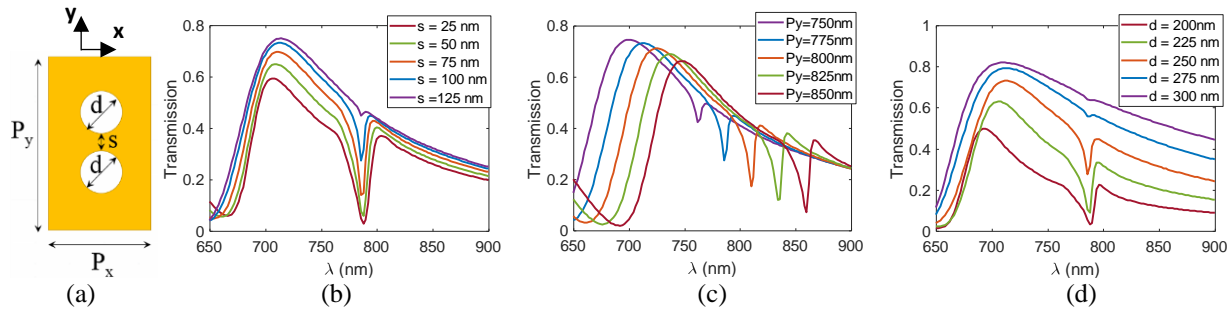


Fig. 1. (a) Top view of a unit cell of dimer nanohole array structure. (b-d) Effect of changing dimensions on transmission spectrum ($P_x=450$ nm, $P_y=775$ nm, $s=100$ nm, $d=250$ nm, $t=60$ nm)

2. Sensitivity and Figure of Merit

Setting the dimensions of the dimer nanohole array to $P_x=450$ nm, $P_y=775$ nm, $s=75$ nm, $d=250$ nm, we simulated the multilayer dimer nanohole array in Air / Au(5nm) / MgO(10nm) / Au(60nm) / Quartz substrate multilayer form. The nanoholes are assumed to be etched thoroughly in the gold layers and the MgO layer. We replaced the MgO ($n_{\text{MgO}} = 1.73$) by SiO_2 ($n_{\text{SiO}_2} = 1.45$) and estimated the sensitivity and FOM. The resonance shift is 1.8 nm, which is 2.5 larger than the resonance shift in SPP resonance of a single nanohole array. Considering the 11-nm linewidth, the FOM for sensing the nanolayer changes is 0.81. Normalizing the FOM to the area of MgO layer per unit cell in xy plane, we found that the sensitivity of the multilayer dimer nanohole array to the dielectric nanolayer changes is 13.5 times larger compared to an array of single nanoholes.

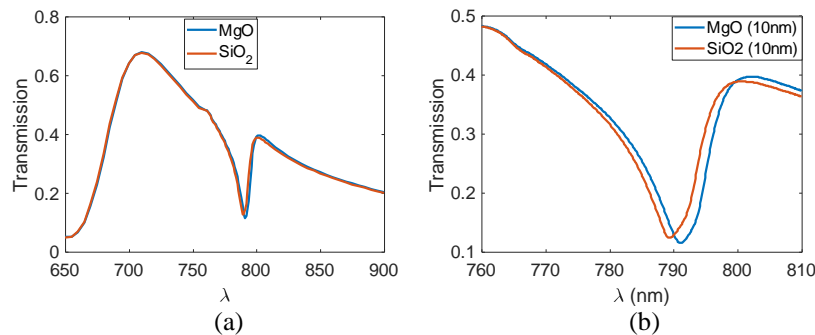


Fig. 2. (a) Transmission spectrum of the multilayer dimer nanohole array and its sensitivity to nanosized dielectric layer change ($P_x=450$ nm, $P_y=775$ nm, $s=75$ nm, $d=250$ nm) (b) Zoomed view.

4. Conclusion

We study a design of dimer nanohole array supporting Fano resonance, to increase the sensitivity to the refractive index changes in the ultrathin dielectric layer in a simplified STT-RAM multilayer. Sensitivity and FOM are increased by 2.5 times and 13 times respectively, compared to a single nanohole array. Also, our simulations show that for a dimer nanohole array of gold considering water as cover medium, a bulk sensitivity of 500 nm/RIU and FOM of 41.7 can be achieved, which are both larger than the values reported for heptamer nanohole array in [4].

5. Acknowledgment

We would like to thank Defense Threat Reduction Agency (DTRA) for funding this research project (Grant HDTRA1-16-1-0025).

6. References

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