Mid infrared plasmon metasurfaces for sensing applications

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1. Introduction

Plasmon perfect absorbers (PPAs) are plasmonic metasurface structures which consist of the thick metal film, insulator layer, and plasmonic nanostructures. The metasurfaces made from plasmonic perfect absorbers (PPAs) realize the perfect absorption (simultaneous zero-transmission and reflection) at a specific resonance wavelength. The simple configuration of the metal-insulator-metal(MIM) are easy to design and to make by a well-established semiconductor nanofabrication processes or self-assembly of nano particles. We focused on PPA structures as the photo-thermal light emitter and detector in mid-infrared (IR) wavelengths for constructing plasmonic non-dispersive infrared (ND-IR) gas sensors [1,2]. The Kirchhoff's law of the thermal radiation defines the absorption and emission efficiencies being equal to each other. Therefore, PPAs are expected for good performance as light emitters [3,4].

When material absorbs the light at the plasmon resonance, free electron oscillation generates heat. This heat generation can be used for the thermal bolometric detector.

In this study, we performed experiments with a wide set of parameters of MIM structures. The PPAs consist of the bottom layer (Au and Ag), insulator layer (SiO_2 with refractive index n ~ 1.4), ZnO (n ~ 2.0), or Si (n ~ 3.4), and metal nanostructures (Au, Ag, Cu and Pd), respectively. The nanodisc and metal-hole-array (NDA and MHA) of plasmonic patterns were compared. We also demonstrate thermo-optical absorption vs emission (input vs output) properties of PPAs.

2. Experiments

Sub-micrometer structure dimensions are required for the MIM structures functional at the IR wavelength range. Therefore, the reduction projection photolithography is more suitable than the electron beam lithography for the future applications, large area, and mass production of devises.

The NDA/MHA PPAs nanostructures were fabricated on a double-side polished 8-inch silicon wafer, which had a 200~nm Au film on top, using the i-line stepper (NSR205-i14E, NIKON Co.).

The positive tone (TLOR-P003 HP, Tokyo Ohka Kogyo Co.) and negative tone (TLOR-N001 PM, Tokyo Ohka Kogyo Co.) photo-resists were used for the NDA and MHA fabrication as shown in Fig. 1. Then, 10 nm of insulator and 50 nm of metal were deposited by magnetron sputtering using a 3 nm Ti adhesion layer between the insulator and metals over the developed resist pattern (AXXIS, JKLesker). After deposition, a lift-off was performed in an organic solvent to obtain final PPA structures.

3. Results and discussions

Fabricated structure has a good uniformity over the 1x1 cm^2 region. Plasmon resonance appeared from 2 to 6 μm and had a 45% reflection (a 55% absorption) at the minimum.

This was obtained with Ag (nanostructure) - Si - Au (bottom layer) system. The thickness of insulator layer was only 10 nm. Therefore, the interaction between the two metals was increasing an impedance of the system. An optimization of the insulator thickness had to be carried out to improve the absorption.

4. Conclusions

In this study, we have demonstrated the optical absorption properties of various kinds of PPAs in mid-IR wavelengths. Even in a thin insulator layer, 55¥% of absorption is realized. Using this Au PPAs, we also obtained the thermal radiation and photo-thermal generation which well agreed with the optical absorption. After optimization of the other parameters (i.e. thickness of metal and insulator), it should become possible to realize perfect absorber and efficient radiation emitter.

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