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Extended Abstracts of the 2009 International Conference on Solid State Devices and Materials, Sendai, 2009, pp549-550

The influence of the hole size on the peak emission wavelength of a plasmonic thermal emitter

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Abstract-The influence of the hole size of the top metal film on the peak emission wavelength of a plasmonic thermal emitter was investigated. With the same periodic structure, the emitting wavelength related to Ag/SiO$_2$ surface plasmon (SP) red-shifts with decreasing hole size. The SP coupling between top and bottom Ag/SiO$_2$ interfaces was demonstrated to become weak by increasing the thickness of the central silicon dioxide layer.

1. Introduction

Surface plasmons (SPs) are longitudinal waves that propagate along the surface between dielectric and conductor [1]. SP has attracted much attention due to its unique properties and wide applications in extraordinary optical transmission(EOT), mid-infrared thermal emitter [2], light emitted device and biosensor. In the previous study, it was found that when the hole size increased, the transmission peak slightly red-shifted [3], and the dielectric layer thickness between two silver films affect the emitted wavelength [4]. In this paper, the influence of the hole size of the top silver film on the peak emission wavelength are investigated. By increasing the thickness of the dielectric layer, the effect of the SP coupling between top and bottom Ag/SiO$_2$ interfaces was reduced.

2. Experiments and results

For structure A, 300nm silicon dioxide was directly deposited on a double polished wafer by PECVD. The perforated silver film with thickness of 100nm was fabricated by photolithography and thermal evaporation process. A Bruker IFS 66v/s system was adopted to measure the transmission spectra. The light was incident to the structure A in normal direction and the wavenumber resolution of the measurement is 8cm^{-1}. The beam size of incident infrared light is 3mm. For structure B, a 20nm titanium film was deposited on the single polished wafer followed by 200nm silver film and SiO$_2$. The thicknesses of SiO$_2$ layer were 100, 300, 500 and 1000nm, respectively. Patterned silver film was obtained by photolithography and thermal evaporation process. Mo was deposited on the back of structure B by DC sputtering. The hexagonal lattice with circular shape holes was developed on the wafer. The lattice constant was fixed at 5μm and the hole diameter was varied from 1.5 to 3μm for both structures. DC current was applied through the Mo film which heated up the structure B. A PERKIN ELMER 2000 Fourier Transform Infrared Spectrometer (FTIR) system was adopted to measure the thermal radiation spectra.

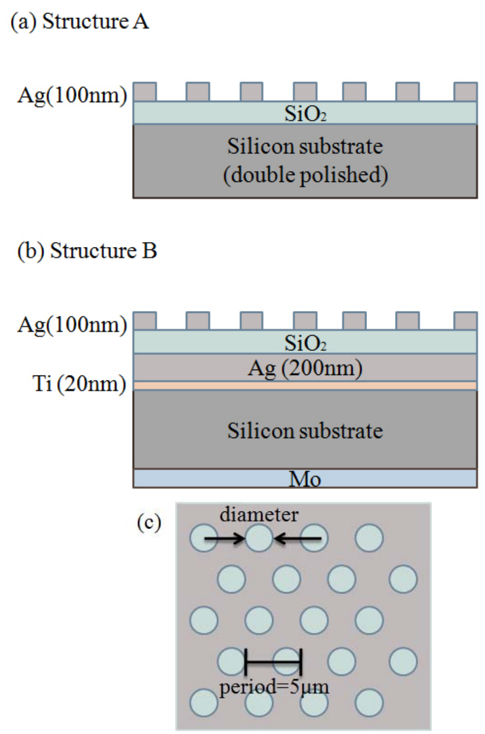

Fig.1 (a) Side views of structure A for transmission experiment. (b) Side views of structure B for thermal emission experiment. (c)Plane view of the perforated silver film with hexagonal lattice on both structures.

SP resonance peak wavelength can be predicted from the following equation:

$$\lambda = a[\frac{4}{3}(i^2 + 2ij + j^2)^{-\frac{1}{2}}][\frac{\varepsilon_m \times \varepsilon_d}{\varepsilon_m + \varepsilon_d}]^{\frac{1}{2}} \qquad (1)$$

, where a is the lattice constant of the periodic structure; ε_d and ε_m are the real part of dielectric constants of the dielectric and metal, respectively. i and j are the integers. Fig. 2 shows the transmission spectra of structure A with different hole diameter. It is clearly that the transmission peak positions of (1,0) Ag/Air and (1,0) Ag/SiO_2 were not shifted as the hole diameter increased. Fig. 3 shows the emittance spectra of a plasmonic thermal emitter with 300nm thick SiO_2 layer heated to 200℃. Peaks around 6μm are due to the degenerate modes composed of (±1,0) Ag/SiO_2, (0, ±1) Ag/SiO_2, (-1,1) Ag/SiO_2 and (1,-1) Ag/SiO_2 modes, designated as (1,0) Ag/SiO_2 degenerated mode [1]. Obviously that the peak position was red-shifted with the decreasing hole diameter. Fig. 4 shows the peak position as a function of hole diameters with SiO_2 layer thickness i.e., 100, 300, 500, and 1000nm, as an independent variable. Peak position red-shifts for thin SiO_2 layer due to the SP coupling between two Ag/SiO_2 interfaces which effectively increases the refractive index of SiO_2 as demonstrated by Chen et al [4]. The thermal emitter can be considered as two parts, one is $Air/SiO_2/Ag$ structure and the other is $Ag/SiO_2/Ag$ structure. Silver covered area due to the SP coupling result in the higher refractive index [4]. The covered area increases with the decreasing hole diameter, the increasing effective refractive index results in the red-shift of the peak position to longer wavelength as shown in Fig. 4. As the thickness of SiO_2 layer increases to 1000nm, the peak position does not shift any more with the different hole diameters due to the weak SP coupling effect. The emitted wavelength approach the wavelength of 6μm with different hole diameter was observed.

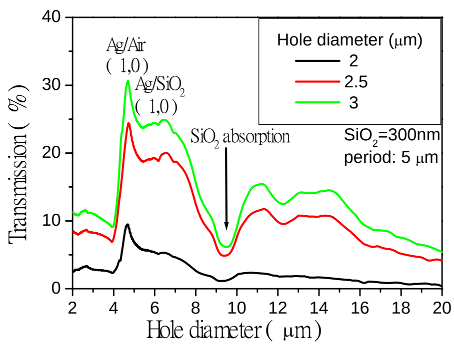

Fig. 2 Transmission spectra of sample A with the hole diameter of 2, 2.5 and 3μm respectively.

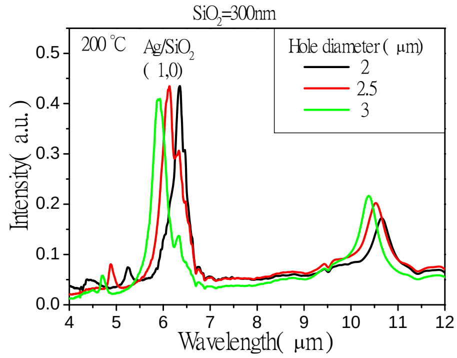

Fig. 3 Thermal emission spectra of sample B with the hole diameter 2, 2.5 and 3μm respectively.

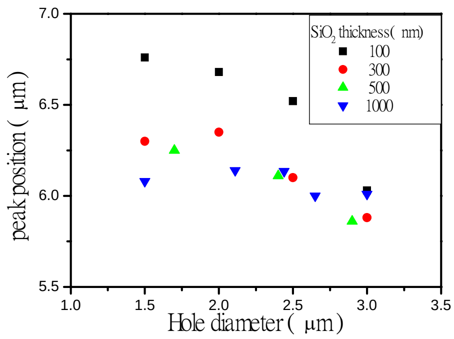

Fig. 4 The peak position as function of hole diameter with different SiO_2 thickness.

3. Conclusions

In conclusion, the effect of the hole diameter on the peak emission wavelength of a plasmonic thermal emitter has been demonstrated. The emitted wavelength is not only affected by the thickness of SiO_2 but also by the hole size on the top silver film. The red-shift of the peak wavelength is attributed to the SP coupling between two Ag/SiO_2 interfaces with different covered area. As the thickness of SiO_2 is increased to 1000nm, the emitted peak wavelength approaches the theoretical value of 6μm irrespective of the hole diameter.

References

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