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Coupling of surface plasmons between two silver films in a plasmonic thermal emitter

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1. Introduction

Surface plasmons have been studied for years because of its potential applications in biosensor, photolithography, and light-emitting device. By using thermal radiation and the coupling of surface plasmons with light in periodic metal structure, midinfrared narrow-band plasmonic thermal emitter was demonstrated by Tsai et al[1]. Theoretically, surface plasmons are induced in the interface of top patterned silver film with neighboring dielectric materials in the plasmonic thermal emitter, thus the emission peak position can be predicted from the momentum conservation equation and the dispersion relation of surface plasmons. The peak position, however, will deviated from the theoretical value when the thickness of SiO_2 is finite. It is because that the surface plasmons induced at top and bottom silver/SiO_2 interface are coupled when the SiO_2 layer is not thick enough. In this paper, the thermal radiation spectra and reflection dispersion relation of Ag/SiO_2/Ag tri-layer plasmonic thermal emitters with different SiO_2 thickness are investigated. By analyzing the shift of peak position, the coupling length of surface plasmons between top and bottom Ag/SiO_2 interfaces is deduced.

2. Experiments

The 300 nm thick Mo film was sputtered on the back of the double-polished Si substrate as heating source. 20nm Ti and 200nm Ag metal films were deposited on the front side of the Si substrate followed by a SiO_2 layer deposited with electron beam evaporator. Then a hexagonal hole array of 100 nm-thick silver film was deposited and lifted-off on SiO_2 layer with the lattice constant a of 3 μm and diameter d of 1.5 μm. The devices are heated by injecting electric current through the back Mo metal on Si substrate. The thermal radiation generated in the SiO_2 layer resonates between the two metal films and the Ag/SiO_2 and Ag/Air surface plasmons polaritons are induced and then converted to coherent light radiation. A PERKIN ELMER 2000 Fourier Transform Infrared Spectrometer system was adopted to measure thermal radiation spectra. By measuring the reflection spectra with incident angle of light from 12^o to 65^o, dispersion relations of plasmonic thermal emitters were shown clearly. The top view and structure of emitter is shown in Fig. 1.

3. Results

Figure 2(a), (b), and (c) shows the thermal radiation spectra of emitters at 280 ^oC with SiO_2 = 500 nm, 100 nm, and 60 nm, respectively. In Fig. 2(a), peaks at 3.8 μm are the degenerate modes composed of (±1,0) Ag/SiO_2, (0, ±1) Ag/SiO_2, (-1,1) Ag/SiO_2, (1,-1) Ag/SiO_2 modes. It is almost the same as the theoretical value at 3.79 μm. The peak located at 3 μm is the cross coupling of the Ag/SiO_2 mode and Ag/Air mode. When the thickness of SiO_2 reduces to 100 nm, the emission peak shifts from 3.9 μm to 4.56 μm as shown in Fig. 2(b) because of the coupling between surface plasmons at the top and bottom Ag/SiO_2 interfaces. As the thickness of SiO_2 further reduces to 20 nm, the emission peak shifts to 5.34 μm, which is far away from the theoretical value.

Figure 3(a), (b), and (c) are the reflection dispersion relation of emitter with SiO_2 = 500 nm, 100 nm, and 60 nm, respectively. Dark lines on dispersion relation represent the dips in reflection spectra with different incident angle. Light which satisfy the momentum conservation and the dispersion of surface plasmons can couple with the surface plasmons. Therefore, less light are reflected from the emitters in the wavelength satisfied with the coupling conditions. The six degenerate modes at 3.8 μm (0.326 eV) for normal incidence light split into four dispersion lines as denoted in Fig. 3(a) when incident angle of light increases (vector $\vec{k}_x$ increases). This dispersion relation provides the evidence that main mechanism involved in the plasmonic thermal emitter is the surface plasmons. Other dark lines in higher energy region are due to the higher order modes of surface plasmons. When the thickness of SiO_2 = 100 nm, the dispersion relation is still the same but with all bands shift to lower energy slightly compared to that of emitter with SiO_2 = 500 nm. Figure 3(c) is the dispersion relation of emitter with SiO_2 = 60 nm. Now the degenerate Ag/SiO_2 modes are at 0.23 eV which is consistent with the radiation emission peak at 5.34 μm (0.23 eV) shown in Fig. 2(c). The splits which are due to the breakdown of hexagonal symmetry are all the same for three samples. If the coupling effect is enhanced, the effective dielectric constant of SiO_2 increases, surface plasmons are induced by the light with longer wavelength even though the periodic structure on top Ag film is the same.

The relation between peak position of thermal emission and SiO_2 is shown in Fig. 4. It can be seen that when the thickness of SiO_2 is less than 100 nm, the peak position redshift substantially with the reduction of SiO_2 thickness.

The influence of coupling of surface plasmons decline for thickness larger than 300 nm.

3.Conclusion

The position of thermal emission peak of a plasmonic emitter is not only decided by the periodic structure on top Ag film, but also affected by the thickness of intermediate SiO_2. When the thickness of SiO_2 is less than 100nm, the position of the emission peak shifts to longer wavelength substantially compared with the theoretical value because of the strong coupling between surface plasmons in top and bottom Ag/SiO_2 interface.

Acknowledgements

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Reference

[1] Ming-Wei Tsai, Tzu-Hung Chuang, Chao-Yu Meng, Yi-Tsung Chang, and Si-Chen Lee, Appl. Phys. Lett. **89**, 173116 (2006)

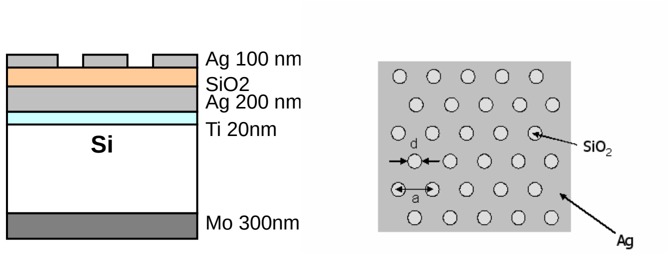

Fig. 1

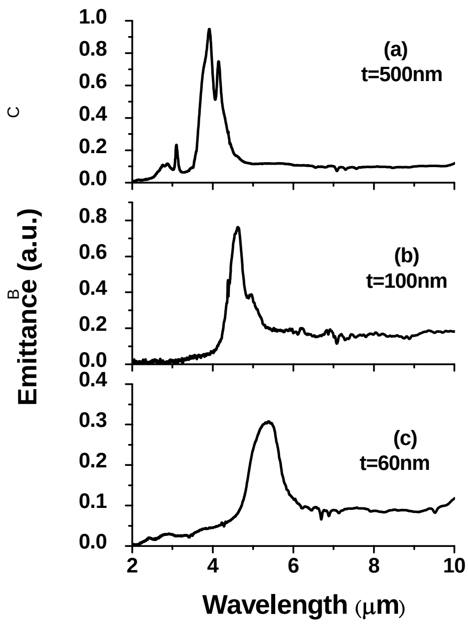

Fig. 2

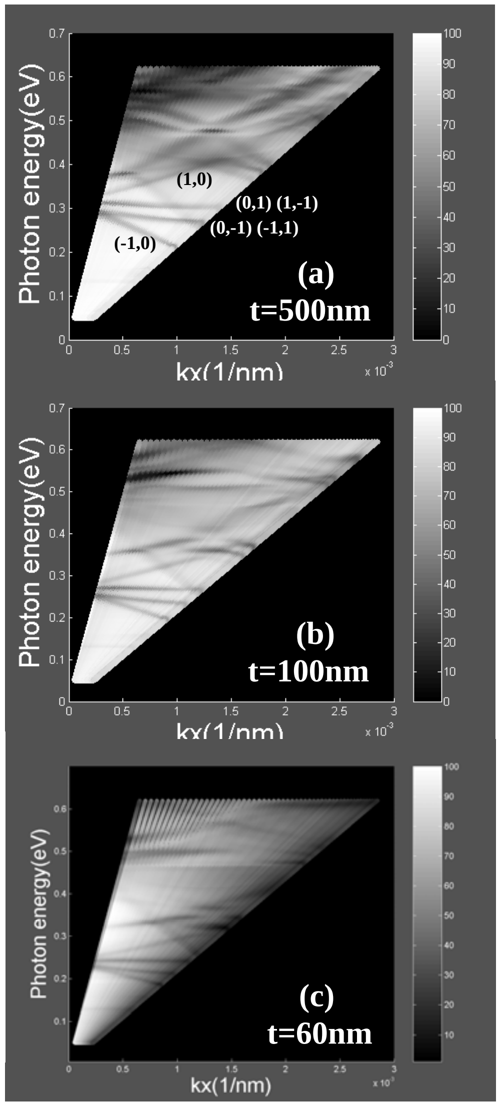

Fig. 3

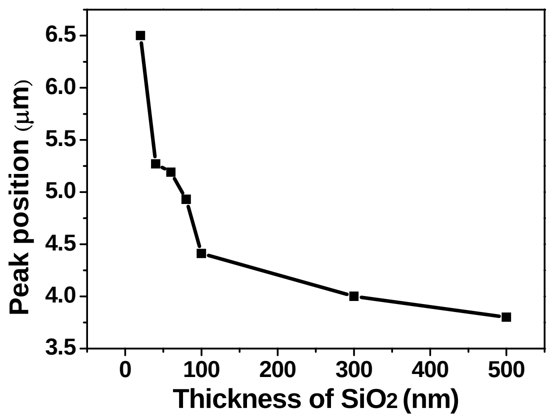

Fig. 4