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Coupling of (1,0)Ag/Air Surface Plasmons in Tri-Layer Ag/SiO_2/Ag Plasmonic Thermal Emitter with Different SiO_2 Layer Thickness

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1. Introduction

The emission spectra of tri-layer Ag/SiO_2/Ag thermal plasmonic emitters with different SiO_2 thickness were demonstrated experimentally [1-2]. 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 layer. Surface plasmons (SPs) in the top and bottom Ag/SiO_2 interface couple together if the thickness of SiO_2 is not thick enough. This coupling effect makes the effective refractive index of SiO_2 increase and results in the red-shift of Ag/SiO_2 SPs mode [3]. The tri-layer Ag/SiO_2/Ag plasmonic thermal emitter with hexagonal lattice generates only one specific (1,0) Ag/SiO_2 emission peak, no surface (1,0) Ag/air plasmon polariton was observed, whereas a similar thermal emitter with squared lattice generates both (1,0) Ag/SiO_2 and (1,0) Ag/air emission peaks [4]. However, when the thickness of SiO_2 is reduced, the position of the emission peak shifts to longer wavelength substantially compared with the predicted value because of the strong coupling between surface plasmons at top and bottom Ag/SiO_2 interfaces.

2. Theory

The SPs are induced at the interface of top patterned silver film and central dielectric materials in the plasmonic thermal emitter. The emission peak wavelength can be predicted from the momentum conservation equation and the dispersion relation of surface plasmons. For a metal film perforated with a two-dimensional periodic squared hole array, at normal incidence ($k_x = 0$), SP modes appeared at wavelength λ_{sp} [5,6],

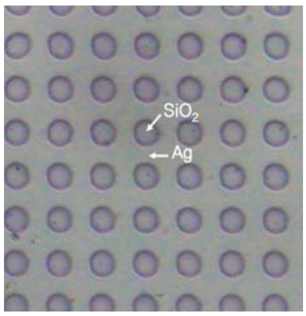
$$\lambda_{sp} = a\,(m^2 + n^2)^{-1/2} \left(\frac{\varepsilon_d \varepsilon_m}{\varepsilon_d + \varepsilon_m} \right)^{1/2} \qquad \textbf{(1)}$$

, where a is the period of the squared hole array; ε_d and ε_m are the real part of dielectric constants of the dielectric material and metal, respectively, "m", and "n" are integers that specify the order of the scattering event that couples the incident light and an eigen mode of the structure with the wave vector $\vec{k}_{sp}$.

3. Experiment and results

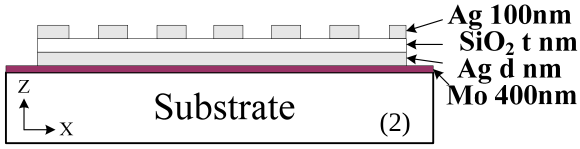
The top and side views of plasmonic thermal emitter are displayed in Fig. 1(a) and (b), respectively. The 400 nm thick Mo film was sputtered on the front of the double-polished Si substrate as heating source. The Ag film with thickness d (200 and 300 nm) were deposited on the Mo film followed by a e-beam evaporated SiO_2 layer with thickness t. Then a square hole array of 100 nm-thick Ag film was deposited and lifted-off on SiO_2 layer with the lattice constant a of 5 μm and hole diameter d of 2 μm. The devices are heated by injecting electric current through the Mo metal pad on Si substrate as shown in Fig. 1 (b). 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.

Top view



(a)

Side view



(b)

Fig. 1 (a) Top and (b) side views of the plasmonic thermal emitter.

Figures 2(a), 2(b) and 2(c) shows the thermal radiation spectra of emitters at 240^0C with SiO_2 =150, 300 and 530 nm, respectively. In Fig. 2(c), peaks at 6.56 μm are the degenerate modes composed of (±1,0) and (0,±1) Ag/SiO_2

modes. It is almost close to the theoretical value at 6.2 μm. The peak located at 4.94 μm is Ag/air mode. When the thickness of SiO_2 reduces to 150 nm, the (1,0) Ag/SiO_2 peak shifts from 6.56 to 7 μm, and the (1,0) Ag/air peak shifts from 4.94 to 5.2 μm, as shown in Figs. 2, because of the coupling between surface plasmons at the top and bottom Ag/SiO_2 interfaces. As the thickness of SiO_2 further increases to 530 nm, the emission peaks of Ag/SiO_2 and Ag/air shift to 6.56 and 4.94 μm, respectively, which is close to the theoretical value.

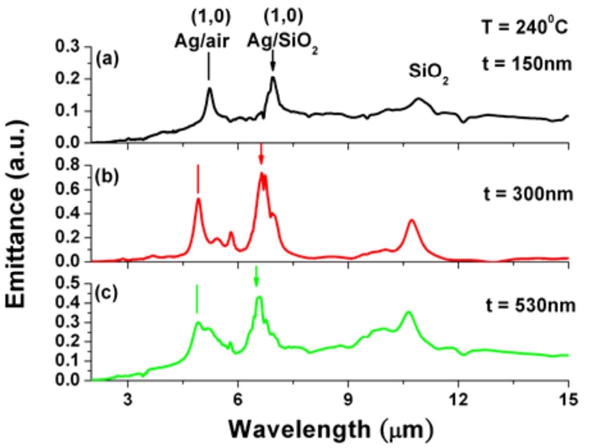
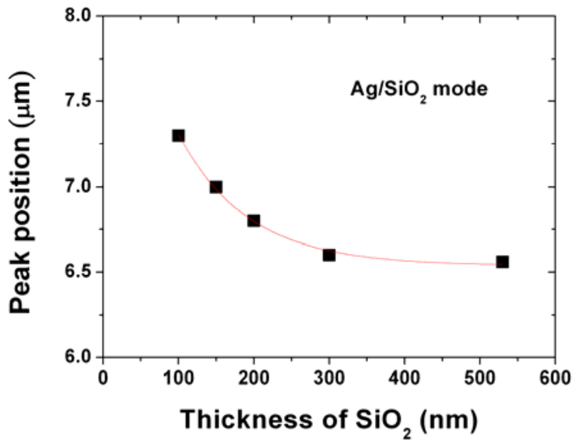


Fig. 2 Measured emission spectra of emitters with a = 5 μm, d = 2 μm, and the thickness of SiO_2 is (a) 150, (b) 300, and (c) 530 nm.

The relation between the Ag/SiO_2 and Ag/air peak positions and the SiO_2 layer thickness is shown in Figs. 3 (a) to 3 (b). Square dots are the experiment results and red line is the fitting curve. It can be seen that when the thickness of SiO_2 is less than 300 nm, the peak position red-shift substantially with the reduction of SiO_2 thickness. The influence of coupling of surface plasmons declines for thickness larger than 300 nm.



(a)

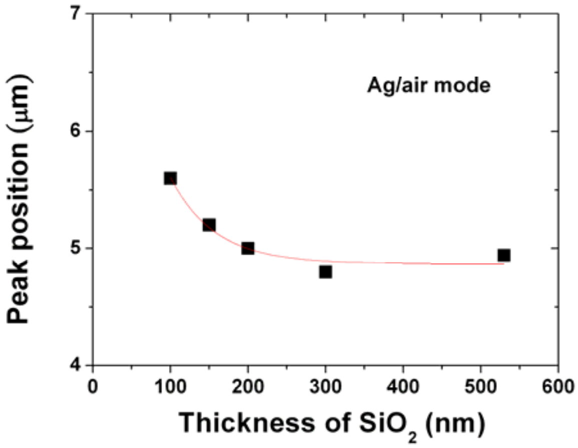


Fig. 3 The relationship between the peak wavelength of (a) (1,0) Ag/SiO_2 and (b) (1,0) Ag/air modes versus the thickness of SiO_2. Square dots are the experiment results and red line is the fitting curve.

4. Conclusions

The emission peaks of the Ag/SiO_2 and Ag/air SP modes are not only determined 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 530 nm, the position of the emission peak shifts to longer wavelength substantially compared to the theoretical value because of the strong coupling between surface plasmons in top and bottom Ag/SiO_2 interfaces.

References

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Appendix

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