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Dispersion relations of localized surface plasmon polaritons in a plasmonic thermal emitter

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1. Introduction

It has been well known that the periodic subwavelength perforated hole arrays in metallic films exhibit extraordinary optical emission, which results from the interaction between light and surface plasmon polaritons (SPPs). The unique properties of surface plasmons have been applied in numerous fields. One of them is in narrow-band thermal emitter, which has been demonstrated by Tsai et. al [1]. Localized surface plasmon polariton (SPP) is the charge density oscillation confined to metallic structures, such as small particles, pillars, and grooves, etc. In this letter, plasmonic thermal emitters with property of localized SPP were fabricated. Their reflection and the thermal radiation spectra were investigated in details.

2. Experiments and results

The fabrication processes of the plasmonic thermal emitter are described as follow : a 300 nm Mo layer is deposited on the back of the Si substrate as a heating source. 20 nm Ti film is deposited on the front side of the Si substrate as an adhesive layer followed by a 200 nm Ag to block the substrate radiation. Then SiO_2 layer is deposited on the top of Ag layer with electron beam evaporator. Next, another 100 nm Ag film is deposited on the SiO_2 layer and perforated with a square donut shape hole array by photolithography with the lattice constant *a* of 3 μm and line width *d* between the holes of 1.5 μm. A dc current is sent into the back metal contact and heats up the device. A Perkin Elmer 2000 Fourier transform infrared spectrometer (FTIR) system is adopted to measure the thermal radiation spectra. The reflection spectra are measured with incident angle of light from 12^o to 65^o. The structure of plasmonic emitter is shown in Fig. 1.

Figure 2(a), (b), (c), and (d) shows the reflection spectra of emitters with SiO_2 thickness of 20 nm, 40 nm, 80 nm, and 100 nm respectively. The dark region represents the less reflection of light from the surface of emitters. In Fig. 2(a), the dark horizontal line around 0.1 eV is attributed to the phonon mode of the SiO_2 layer. Moreover, the dark oblique line as indicated by black arrow is Ag/Air SPP mode, which is the surface plasmon propagating along the interface between Ag and air. None of the propagating Ag/SiO_2 SPP mode are observed in the reflection spectra, but there are five additional horizontal lines at about 0.17, 0.24, 0.35, 0.48 and 0.58 eV instead. These five horizontal lines are almost independent of the incident angle. Their group velocity, $\partial\omega/\partial k_x$, at the x-direction is zero since these five lines are horizontal. It implies that these resonant modes are localized SPP modes, and the dark horizontal line at about 0.17 eV is the first order localized SPP mode. It has been found that when the thickness of SiO_2 layer is thin enough, the induced propagating SPs at the top Ag/SiO_2 interface will couple with the SPs at the bottom Ag/SiO_2 interface. Therefore, the propagating Ag/SiO_2 modes were suppressed by the bottom Ag layer. The SPPs, which were confined at the top Ag/ SiO_2 interface, were localized. From Fig. 2(a), (b), (c), and (d), as the thickness of SiO_2 layer increases, the dispersion relation of Ag/Air mode are almost the same since the Ag/Air modes are determined by the lattice constant of periodic metallic film. However, the resonant energy of the first order localized SPP mode with different SiO_2 layer thickness is 0.17, 0.18, 0.22 and 0.24 eV, respectively. The dispersion line of the first order localized SPP mode shifts to higher energy as the thickness of SiO_2 layer increases, and so are other higher order localized SPP modes. It is because the thinner SiO_2 layer has larger effective refractive index due to stronger coupling effect. It is also clear that the LSPP modes dispersion lines get vague as the thickness of SiO_2 layer increase. This is because when the thickness of SiO_2 layer increases, the coupling effect between top and bottom Ag/SiO_2 SPPs becomes weak.

Figure 3 shows the thermal radiation spectrum of emitters at 300 ^{o}C with SiO_2 thickness of 80 nm. The spectrum includes two main emission peaks at 5.55 μm, and 10.3 μm, which correspond to the first order localized SPP mode and phonon vibration of the SiO_2 layer, respectively. The emission peaks coincide with the reflection spectra shown in Fig. 2(c).

3. Conclusion

In summary, the localized SPP dispersion relation and emission spectrum of plasmonic thermal emitter with different SiO_2 thicknesses are investigated. The top induced Ag/SiO_2 SPPs will couple with the bottom induced Ag/SiO_2 SPPs if the SiO_2 layer is thin enough. Instead of propagating along the interface between Ag and SiO_2, the SPs are localized. In addition, the dispersion lines of LSPP mode shift to higher energies as the thickness of SiO_2 layer increases. This work is supported by the National Science Council of Republic of China under Contact No. NSC 95-2120-M-002-007

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

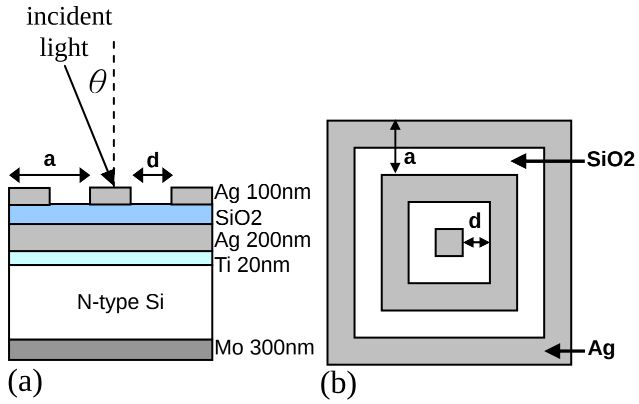

Fig. 1. Schematic diagram of the (a) side and (b) top views of the emitter. The square donut shape hole array has a lattice constant *a* of 3 μm and line width *d* between the holes of 1.5 μm.

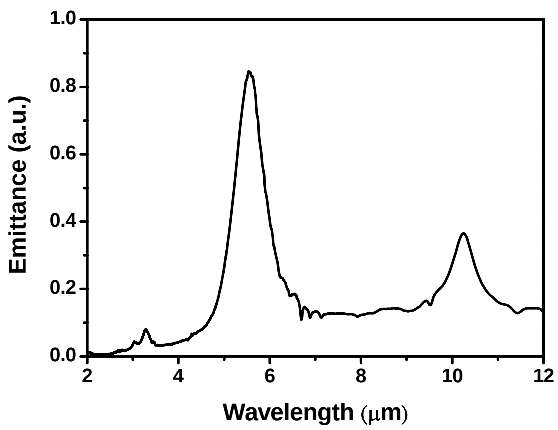

Fig. 3. Measured emission spectrum of emitter with SiO_2 thickness of 80 nm at 300 ^{o}C.

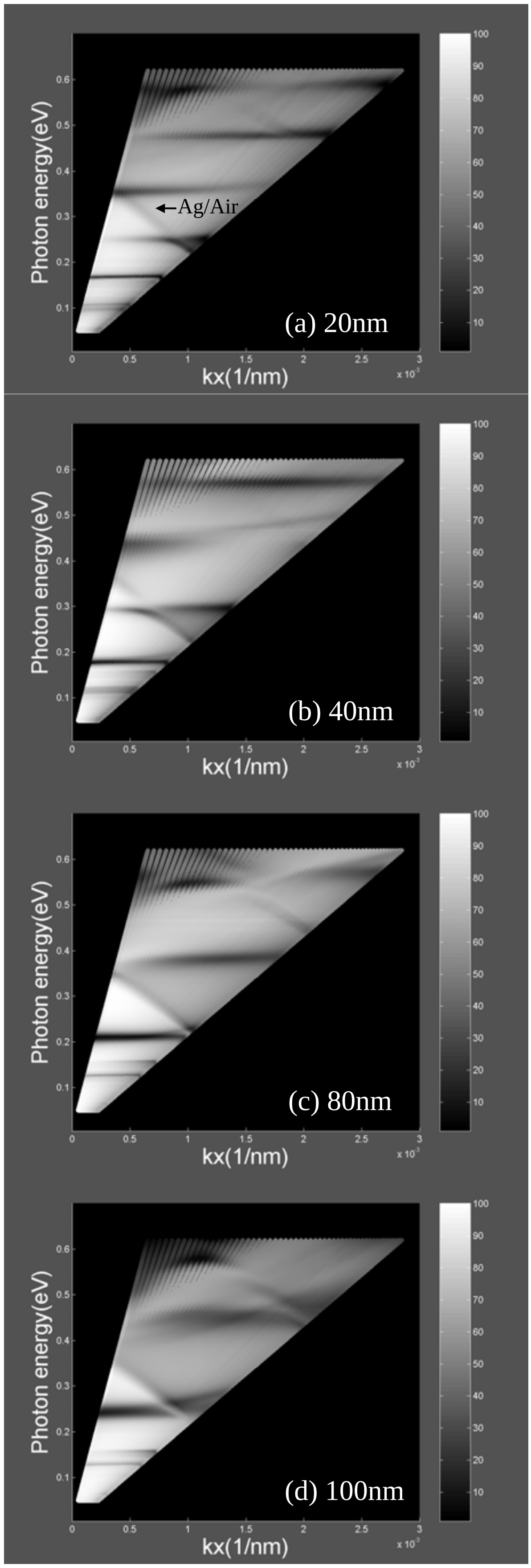

Fig. 2. Measured reflection spectra of emitters with SiO_2 thickness of (a) 20 nm, (b) 40 nm, (c) 80 nm, (d) 100 nm.