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Double wavelength infrared emission by plasmonic thermal emitter

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Abstract

Double wavelength infrared emission by plasmonic thermal emitter using stacked Au/SiO_2/Au structure was proposed. Two different localized surface plasmon modes were excited with the same metal width which was attributed to the different effective refractive index of SiO_2 layers in top and bottom Au / SiO_2 / Au tri-layer structures.

1. Introduction

In this decade, surface plasmon has attracted much attention due to its unique optical properties for variety of applications such as biosensing [1], thin film solar cell [2] and light emitting device [3-7]. The localized surface plasmon (LSP) mode is the most frequently utilized mode among them. LSP resonance is attributed to the spatially confined electron oscillation which is a Fabry-Perot resonance in the engineered nano (micro) metal structure. In the previous studies, the plasmonic thermal emitter with an Ag/SiO_2/Ag tri-layer structure had been studied as one-dimensional (1D) metal strip [6, 7] or metal disk [4] on the top which generated single wavelength localized surface plasmon. This was because the resonant wavelength of LSP was determined by the metal width. Two wavelengths emission was also achieved by a rectangle metal patch with different length and width [5]. The emitted wavelength and the wavelength difference between two wavelengths were determined by the metal geometry. To change the emitting wavelengths and the wavelength difference between two wavelengths, a new pattern (mask) must be used. In this study, two wavelengths localized surface plasmonic thermal emitter was realized with the same metal width. The reflection spectra of the LSP and thermal radiation spectra were measured.

2. Experiments and results

The device structure of sample A was shown in Fig. 1(a). A 150 nm gold (Au) film was deposited on the silicon (Si) wafer. Then the SiO_2 layer with thicknesses of 20 nm (A1), 60 nm (A2) and 100 nm (A3) were deposited by plasma enhanced chemical vapor deposition (PECVD) system. A periodic gold 1D strip with a thickness of 50 nm was formed on the SiO_2 layer. The period (p) and the metal width (w) of the Au strip were 3 and 1.5 μm, respectively. Next, another SiO_2 (100 nm) and Au (50 nm) layers were deposited on the strip (samples A1, A2 and A3) and denoted to be samples B1, B2 and B3 as shown in Fig. 1(b). A Bruker IFS 66 v/s system was used to measure the reflection spectra. The sample was measured at θ = 12°, where θ is the incident angles of light to the normal of the metal surface (z-axis). A Perkin–Elmer 2000 Fourier transform infrared spectrometer (FTIR) system was adopted to measure the resulting thermal radiation spectra at the normal direction (θ = 0°).

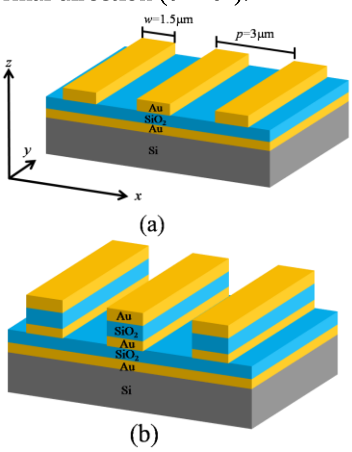

Fig.1 Tilt views of (a) sample A (Au/SiO_2/Au) and (b) sample B (Au/SiO_2/Au/SiO_2/Au).

Figure 2 shows the reflection spectra of sample A with the thicknesses of SiO_2 20 nm

(A1), 60 nm (A2) and 100 nm (A3), respectively. As described in the Ref. [4-7], the main reflection dip in Fig. 2 is the resonance of localized surface plasmon dominated by the width of metal strip and the refractive index of SiO_2 layer. The resonance wavelength can be roughly predicted by $m\lambda=2wn_{eff}$, where m is integer, w is the metal width and n_{eff} is the effective refractive index of SiO_2. The resonance wavelength shift due to the coupling between top and bottom Au layers [6]. Figure 3(a) shows the reflection spectrum of sample B1 with the top SiO_2 = 100 nm and the bottom SiO_2 = 20 nm. Two reflection dips were observed in the spectrum which were attributed to the top and bottom Au/SiO_2/Au structures, respectively. The wavelengths of sample B1 as shown in Fig. 3(a) are consistent with the individual Au/SiO_2/Au structures as shown in Fig. 2. Fig. 3(b) shows the thermal radiation spectra of sample B1 with and without a polarizer installed between the device and FTIR system. The device was heated by sending a direct current through the bottom Au layer. When the device was heated, the blackbody radiation generated from SiO_2 layer coupled to the LSP modes. The emission (E) spectrum satisfied Kirchhoff's law, which states that emissivity E can be expressed as E=1-R, where R is the reflectance of the object. Due to the charge distribution of the metal strip, the net dipole moment of secondary (m=2) LSP mode is zero at the normal direction (θ = 0°) [8]. Hence, the secondary (m=2) LSP of bottom Au/SiO_2/Au structure can not be observed in the thermal radiation spectrum (Fig. 3(b)). But the dipole moment can be induced at oblique angle [8] that is why a dip was observed at λ=3.75 μm in the reflection spectrum (Fig. 3(a)). Also, the secondary (m=2) LSP mode of top Au/SiO_2/Au structure would exist around λ=2.5 μm. Furthermore, the emission exhibited a x-polarized characteristic, which is another evidence that the emitted spectra were attributed to the localized surface plasmon resonance of the 1D metal strip [7].

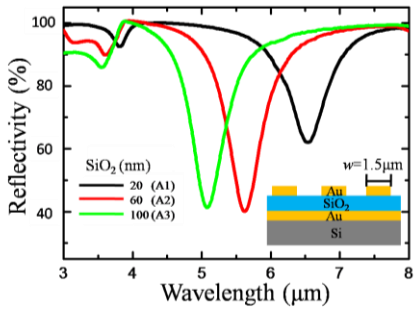

Fig. 2 The reflection spectra of the samples A1, A2 and A3 with the SiO_2 thicknesses of 20, 60 and 100nm, respectively.

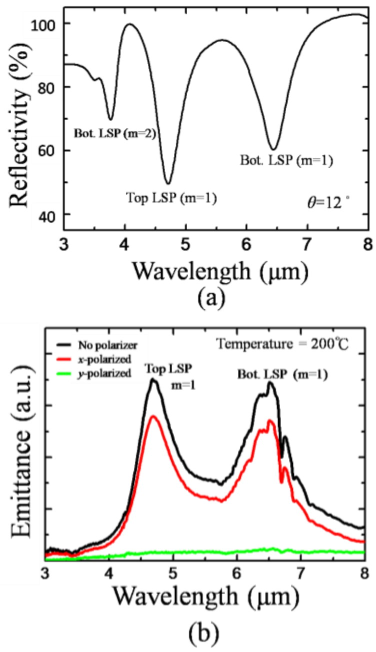

Fig. 3 (a) The reflection spectrum of sample B1. (b) The thermal radiation spectra of sample B1 with and without a polarizer installed between the device and FTIR system.

3. Conclusions

Two wavelengths infrared emission was realized in an Au/SiO_2/Au/SiO_2/Au structure. Different LSP resonance wavelengths with the same metal width were achieved by the different effective refractive index of SiO_2 layers in top and bottom Au/SiO_2/Au structures, respectively. Each resonance wavelength can be easily controlled by the SiO_2 layer thickness between two Au layers.

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