field distribution of high magnitudes in the cutoff region to the penetration of SPP into the dielectric medium, which can be also verified since the electric fields of the cutoff region in x-z central plane are obviously higher than those in y-z central plane. Since the input source is polarized along x axis, the light in x-z central plane propagates like the p-polarized wave which is capable of exciting the SPP mode. While in y-z central plane, the light behaves similar to the s-polarized wave which is ineffective to the SPP excitation [20,24]. On the other hand, as shown in Figs. 5(c) and 5(d), the field magnitudes in the cutoff region are much weaker than the adjacent part of propagating region, and the fields at the aperture are rather weak, which leads to the poor transmission ratio. Under this situation, SPP effect is not apparent due to the ineffective excitation of SPP mode. In terms of SPP, the excitation condition is determined by Eq. (5),

$$k_{spp} = \frac{2\pi}{\lambda} n_1 \sin\alpha \tag{5}$$

where k_{spp} is the wave vector of SPP, α is the incident angle of light wave from the dielectric medium to the metal surface. When the probe shape is changed, α will be changed accordingly, hence, the excitation of SPP is determined by the probe structure and wavelength. Consequently, the fluctuations of the transmission ratio in cutoff region are attributed to the selective excitation of SPP modes.

In general, the propagating regime and SPP modes in cutoff region will both cause the fluctuations of transmission ratio, and are both affected by the probe shape and wavelength. Therefore, the fluctuations of the transmittance are attributed to the joint effect of propagating and SPP modes.

4. Conclusions

We have systematically investigated the propagation properties of parabolic nano-probes, and find that the efficiencies are fluctuated and significantly affected by the probe shape and the wavelength. This is explained by the compound effect of the propagating modes in the propagation region and the SPP modes in cutoff region. In the propagating regime, the fluctuations are derived from the resonant cavity effect of light waves, while in the SPP regime, they are attributed to the selective excitation of SPP mode. This work provides the design guidelines for optical fiber nano-probes in SNOM application, and the highest transmission efficiency can be obtained through optimal design of probe shape and appropriate selection of wavelength.

Acknowledgment

This work is financially supported by National Science Foundation of China (No. 51275195) and the National Instrument Development Specific Project of China (No. 2011YQ160002).

#195789 - $15.00 USD Received 14 Aug 2013; revised 31 Oct 2013; accepted 1 Nov 2013; published 8 Nov 2013