An aperture NSOM probe based on a magnetic field polarizer

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Recent advances in optical technologies such as plasmonics [1], negative index metamaterials [2], artificial structures with large magnetic dipole moments [3], and subwavelength optics [4,5] have revived the idea that the magnetic field of light is an equally important component of the *light vector*. For optical in the quasi-static limit involving evanescent wavevector components, electric and magnetic fields are neither perpendicular nor equal in strength to each other and a *magnetic* polarizer as a separate entity from an *electric* polarizer is required for the complete description of the optical field. Here, we show that an aperture NSOM probe with subwavelength circular nano-scale aperture is a magnetic Mie scatterer with a negligible electric dipole moment, allowing the magnetic field direction to be determined independently from the electric field direction.

In this work, we experimentally verify that a subwavelength aperture-NSOM probe scatters tangential magnetic field component dominantly. We excite the tip aperture by using an oblique angle incidence (Fig 1 (a)). The incident fields projected onto the hole, $\mathbf{E}_t$ and $\mathbf{H}_t$ are in general neither orthogonal nor are equal in strength (in Gaussian units). This allows us to rotate $\mathbf{H}_t$ relatively with $\mathbf{E}_t$ by adjusting and can confirm whether $\mathbf{E}_{sc}$ follows the rotation of $\mathbf{H}_t$ or not, if any.

Fig. 2 (a) plots scattering polarization (ψ_{sc}, angle between $\mathbf{E}_{sc}$ and $\mathbf{x}$) of the two NSOM tips as a function of the incident polarization (ϕ). The incident angle θ is fixed at 72°. The striking difference between these two tips merits our full attention.

To see the effect of the $\mathbf{H}_t$ rotation, we plot the relative scattering angle $\psi_{sc,E}$ (Fig 1. (b)) as a function of the relative angle ψ. (Fig. 1 (b)). ψ can be expressed as

$$\cos\psi = \frac{-\frac{1}{2}\sin 2\phi \sin^2\theta}{\sqrt{1-\sin^2\theta+\frac{1}{4}\sin^2 2\phi\sin^4\theta}}$$

The plot of ψ_{sc} vs ψ in Fig. 2 (b) shows that the polarization of $\mathbf{E}_{sc}$ from the tip with a ~ $\lambda/2$ flat bottom (triangle) follows the rotation of $\mathbf{H}_t$ with a 90 degree offset, while the polarization of $\mathbf{E}_{sc}$ from the tip without flat bottom (rectangle) is fixed along $\mathbf{E}_t$. Therefore, the tip with metal flat bottom scatters tangential magnetic field, and the one without it scatters tangential electric field. Finally, it should be mentioned that the magnetic tip can transform itself into an electric tip simply by focused ion beam machining.

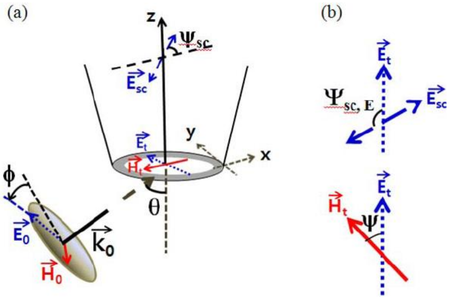

Fig. 1: (a) Schematic of the experiment with an oblique angle θ and incident polarization ϕ. (b) $\psi_{sc, E}$ and ψ are defined graphically.

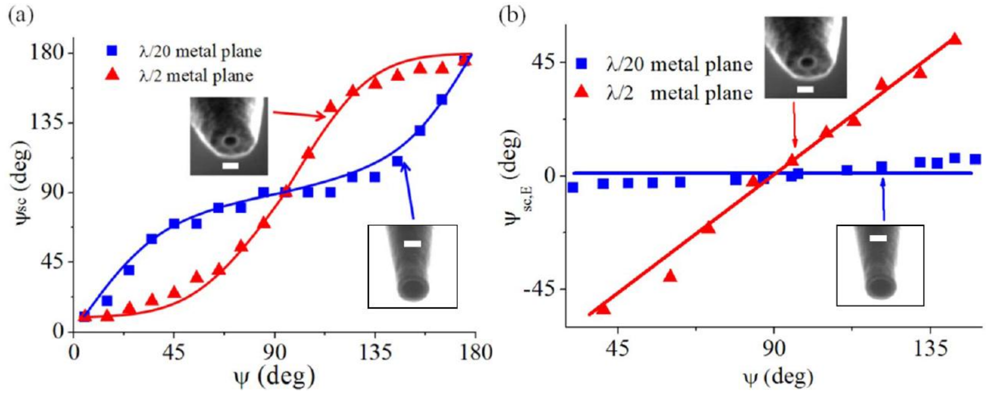

Fig. 2: (inset) SEM images of the two contrasting tips, with a scale bar of 200 nm (a) Experimentally measured scattering polarization (ψ_{sc}) of the tip with ~ λ/2 flat bottom (triangle) and without flat bottom (rectangle). (b) Scattering polarization measured from the tangential electric field, $\psi_{sc, E}$ is plotted as a function of ψ. Red and blue lines are linear curves with slope of one and zero, respectively.

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