Polarization analyzer for the magnetic vector of light

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Abstract
We here report about subwavelength metallic aperture on infinite plane acting as polarization analyzers for magnetic field following Bethe's circular aperture diffraction, analogous to conventional polarizers determining the electric field direction.

1. Introduction

Sensing [1], confinement [2] and enhancement [3] of magnetic field of light have attracted immense attention with the advancement in the field of plasmonics. Magnetic light-matter interaction can modify the resonance frequency of photonic crystal nanocavity and has been used to determine the mangnetic polarizability of near field apertures. [4]. There are ongoing efforts to tune the magnetic response using nanostructured metamaterials [5] for possible realization of perfect lenses [6] and optical clocking [7]. In this work, through measurement of scattering of light of wavelength 780 nm, we have established the use of λ/10 Bethe-hole as polarization analyzers for magnetic vector of light.

2. Results

For comparison, the scattering from an 80 nm diameter circular aperture in an 80 nm thick gold film deposited on a sapphire substrate and an 80 nm metal nanoparticles was measured. Using light at oblique incidence angles, the effect of incident electric and magnetic field components projected onto the reflecting plane ($\vec{E}_t$ and $\vec{H}_t$) on scattering polarization was monitored to access the magnetic activity of the hole, schematically shown in Fig. 1(a). The angle between $\vec{E}_t$ and $\vec{H}_t$ is represented by ψ . Fig. 1(b) shows the polarization analysis of the scattered light on the surface normal direction (z axis), for three different angles ψ . Interestingly, the scattering polarization is perpendicular to $\vec{H}_t$ instead of being along $\vec{E}_t$. For comparison, the scattering polarization from an 80 nm gold particle is shown in Fig. 1(c). Fig. 1(d) shows the change in the scattering polarization measured from the incident tangential electric field direction versus ψ for 80 nm diameter aperture (filled circles) and for the 80 nm particle (open triangles). A single hole combined with far-field polarization analysis acts as a polarization analyzer for optical magnetic vector field, as was confirmed by changing ψ (by changing incidence angles θ and ϕ) and analyzing the scattered polarization. The measured scattering polarization from nanohole (filled circles) follows $\vec{H}_t$, while the nanoparticles (open triangles), shows a zero slope indicating its response as an electric field analyzer. Measured scattering polarization (ψ_{sc}) of 80 nm diameter nanoparticle (open blue square) and 80 nm hole punctured in an 80-nm thick gold film (open red circle) follows electric and magnetic dipole radiation pattern respectively, as shown by linear fits in Fig. 1(e). The scattering profile of the metallic circular aperture has been found to follow Bethe's theoretical analysis on diffraction by a circular aperture, providing a method of detection of the magnetic field direction independent of the electric field direction [8].

Fig. 1(f) shows angle of polarization ($\psi_{sc,E}$) for the collection signal from a flat-bottomed near-field optical scanning microscopy (NSOM) probe plotted against ψ . Analogous to the subwavelength

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hole at the end of a metal coated tapered optical fiber functions as nanoscale polarization analyzer for the magnetic vector of light. In contrast to metallic hole and flat bottom metal coated optical probe, the scattering from a gold nanoparticle of 80 nm diameter follows only $\vec{E}_t$. Further, the nanomagnetic field polarization functionality was ascertained by testing the ability of flat bottom NSOM probes to discern two unusual electromagnetic field configurations. First, when electric and magnetic fields are aligned parallel schematically as shown in Fig 1(g) and second a combination of linearly polarized electric field and a circularly polarized magnetic field. Our FDTD calculation of surface currents on the scattering side of the structure indicates its induced nature, with symmetric axis determined by the incident magnetic field. Also the far field polarization was found to be invariant with respect to changes in incident electric field direction due to negligible tangential electric field on the metal surface. In agreement with experiments, calculation shows magnetic vector sensitivity of subwavelength aperture. Our work establishes the Bethe-hole as an optical device for study of magnetic metamaterials at optical frequency and other high permittivity materials.

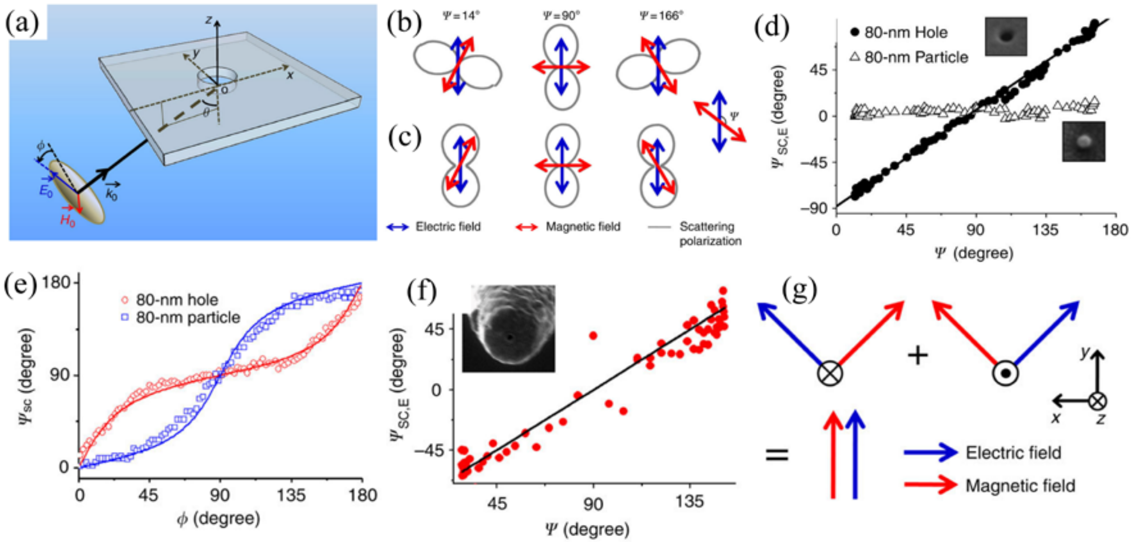

Fig. 1 (a) Schematic of the setup with an oblique incidence ($\theta \neq 0°$) $\vec{k}_0$ in the xz plane, with the polarization angle ϕ. (b) Polar plot (grey) of the scattering polarization for the aperture, and (c) for the nanoparticles with the chosen relative angles (ψ =14°, 90°, 166°) of the tangential magnetic field $\vec{H}_t$ (red) direction measured from the tangential electric field $\vec{E}_t$ (blue). (d) Scattering polarization ($\psi_{sc,\,E}$) for aperture (filled circles) and for an 80-nm diameter gold nanoparticle (open triangles) measured from the incident tangential electric field direction (ψ). (e) Measured scattering polarization (ψ_{sc}) of 80 nm diameter nanoparticle (open blue square) and 80 nm hole punctured in an 80-nm thick gold film (open red circle) follows electric and magnetic dipole radiation pattern respectively, as shown by the fits. (f) The angle of polarization ($\psi_{sc,E}$) for the collection signal from a flat-bottomed near-field optical scanning microscopy (NSOM) probe plotted against ψ shows it acts as a magnetic field analyzer. (g) Schematic for the generation of parallel electromagnetic fields using two counter-propagating orthogonally polarized light. Measurements using λ=780 nm of parallel electric and magnetic field polarizations shows magnetic field orientation as an independent entity.

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