Optical Activity of Subwavelength Nanoholes

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The coupling between electromagnetic field and nanostructures is one of the fundamental and important subjects of nanoscale optics. The polarization dependent coupling mechanism of nanoparticle with electric field has been investigated [1, 2]. As the Babinet counterparts of nanoparticle, nanohole can be used as measuring local magnetic field [3, 4]. Already the research about electric field is accomplished plentifully while that about magnetic field is not. Consequently, the importance of the investigation about magnetic field is rising.

When electromagnetic field is obliquely incident on an the aperture, the incident electric and magnetic fields projected onto the reflecting plane, $\overrightarrow{E_t} = \overrightarrow{E_0} - (\hat{z} \cdot \overrightarrow{E_0})\hat{z} = E_0(-\cos\theta \sin\emptyset, \cos\emptyset, 0)$ and $\overrightarrow{H_t} = H_0(-\cos\theta \cos\emptyset, -\sin\emptyset, 0)$, respectively, are in general neither equal in strength nor orthogonal to each other. We analyze the field scattered through the hole using a polarizer (Fig. 1). Fig. 2 shows the experimental polar plot of the scattering polarization through each hole of various sizes. The hole is perforated on the gold metal film and excited by 780nm wavelength laser. The incident angle is fixed at 72° and the polarization/azimuthal angle at 45° from y axis, respectively.

We then investigate the relationship between the scattering angle and tangential fields($\overrightarrow{E_t}$,$\overrightarrow{H_t}$), as a function of the hole size. For the largest, macroscopic hole of diameter 100 μm, the polarization of the scattered light is mostly along the tangential electric field direction, consistent with the prediction of the vector Kirchhoff relation: $\overrightarrow{E_{sc}} \propto \hat{z} \times (\hat{z} \times \overrightarrow{E_0})$ [3], for the detection along the z-axis with incident wave vector $\overrightarrow{k_0}$ and polarization $\overrightarrow{E_0}$. As the hole sizes approache the wavelength or are getting smaller, the polarization rotates indicating that subwavelength holes possess intrinsic optical activity. For the subwavelength, 100 nm hole, the scattering polarization is almost 90 degrees from the tangential magnetic field, suggesting the following relation: $\overrightarrow{E_{sc}} \propto \hat{z} \times \overrightarrow{H_0}$ strongly suggesting a magnetic nature of the subwavelength aperture.

For the mid-size hole, both electric and magnetic fields contribute, so that we may write: the transition from the macroscopic, Krichhoff formalism, to the microscopic, Bethe's magnetic single hole, as the hole size becomes smaller. Our work has implication on subwavelength optics, nano photonics and near-field optics.

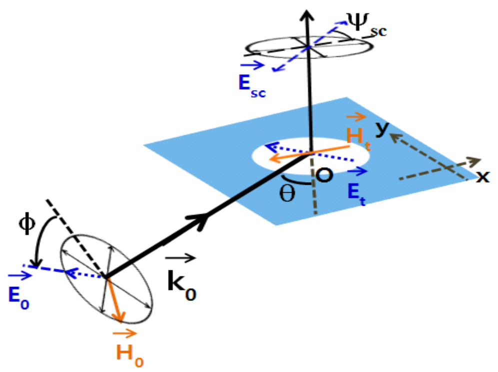

Fig. 1: Schematic of the experiment with an oblique angle θ and incident polarization Ø which measures from the axis parallel with the y axis. The field scattered through hole is analyzed using polarizer.

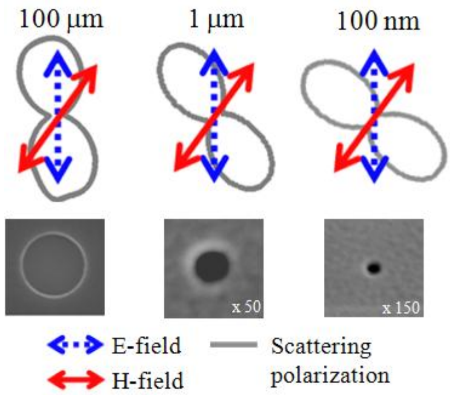

Fig. 2: The polarization analyzed scattering intensities together with $\overrightarrow{E_t}$ and $\overrightarrow{H_t}$ for d=100 μm, 1000 nm, and 100 nm (wavelength = 780 nm, incident angle = 72° polarization = 45°). The inset shows the SEM image of the hole.

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