Polarization Aspects of Near-Field Radiation From Nanoscale Subwavelength Apertures

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Abstract: It is demonstrated that a square nanoaperture can mediate polarized diffraction-limited radiation into nanoscale optical spots with the same polarization. A rectangular nanoaperture can convert linearly-polarized diffraction-limited radiation into circularly and elliptically-polarized nanoscale optical spots.

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1. Introduction

Polarized electromagnetic radiation has led to interesting technical applications and significant advancements at both optical and microwave frequencies. With advances in nanotechnology, electromagnetic radiation beyond the diffraction limit with a particular polarization is an emerging need for plasmonic nano-applications. Among these, all-optical magnetic recording [1] requires circularly polarized optical spots. It has been demonstrated that the magnetization can be reversed in a reproducible manner using a circularly polarized optical beam without an externally applied magnetic field [1]. To advance the areal density of hard disk drives beyond 1 Tbit/in.^{2}, a sub-100 nm circularly polarized optical spot beyond the diffraction limit is required.

In this study, two techniques are investigated to obtain polarized near-field radiation from subwavelength apertures: (1) a square aperture that can mediate diffraction limited circularly or elliptically polarized radiation into an optical spot with the same polarization beyond the diffraction limit, (2) diffraction limited linear polarization that can be converted into a circularly or elliptically polarized nanoscale optical spot by creating and carefully adjusting an asymmetry in the aperture dimensions, as well as adjusting the polarization angle of the incident light [2].

2. Circularly and elliptically polarized optical spots at the nanoscale

In the first part of this study, a square aperture is investigated to obtain elliptically and circularly polarized nanoscale optical spots. Fig. 1 (a) illustrates the aperture and a circularly polarized incident beam. The edge-length of the aperture is G = 20 nm. The thickness of the thin film and the length are T = 20 nm and L = 330 nm, respectively. The operating wavelength $\lambda = 550$ nm is the resonance wavelength of the aperture. The dielectric constant of gold at $\lambda = 550$ nm is chosen as ε_{gold} = -7.1113+j1.9342. A plane wave with an amplitude of 1 V/m is utilized as the incident field intensity.

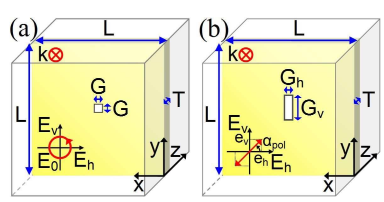

Fig. 1. (a) A square aperture illuminated with circular or elliptical polarization, (b) a rectangular aperture illuminated with linear polarization with a polarization angle of α_{pol}.

Figures 2 (a) and (d) illustrate the intensity distribution for the square aperture when it is illuminated with a diffraction limited circularly and elliptically polarized light. The intensity distribution is illustrated at z = 20 nm, which represents a typical intensity distribution on the sample plane. To obtain circular polarization within the localized optical spot, two additional requirements need to be met: a phase difference $\Delta\phi = 90°$ and a unit amplitude ratio E_y / E_x. Due to the symmetry of the geometry $\Delta\phi = 90°$ is obtained in the gap region, and a unit amplitude ratio is obtained between the horizontal and vertical field within the optical spot, as shown in Fig. 2 (b). The results in Fig. 2 (a)-(c) indicate that a circularly polarized optical spot is obtained around the aperture. To obtain elliptical polarization a nonzero phase difference is sufficient. As seen in Figure 2 (e), a non-zero phase difference is obtained around the aperture.

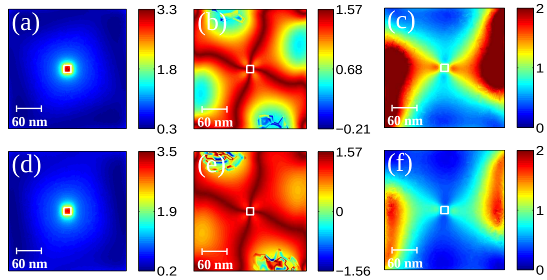

Fig. 2. First and second rows are for circularly and elliptically polarized illuminations, respectively. (a) and (d) $|\mathbf{E}|^2$, (b) and (e) $|\Delta\phi|$, (c) and (f) $|\mathbf{E_y}|$ / $|\mathbf{E_x}|$ at z = 20 nm.

In the second part, a rectangular aperture with dimensions G_h and G_v is utilized to convert diffraction-limited linear polarization into nanoscale optical spots with circular or elliptical polarization as shown in Fig. 1 (b). A key parameter in this conversion is the polarization angle α_{pol} of incident linear polarization, which is used to adjust the relative field amplitudes. The aperture is illuminated with linear polarization with $\alpha_{pol} = 45°$. As a result, a phase difference, $\Delta\phi \neq 0$, is obtained due to an asymmetry. For G_h = 20 nm and G_v = 60.5 nm we obtain $\Delta\phi$ = 1.57 radians, and E_y / E_x = 0.4 indicating an elliptically polarized optical spot. To achieve circular polarization $\Delta\phi$ = 1.57 radians is not sufficient. In addition, E_y / E_x should be unity. This is achieved by changing α_{pol} from 45° to 68°. Localized near-field radiation is achieved as shown in Fig. 3 (a). Localization of $\Delta\phi$ and E_y / E_x is shown in Figs. 3 (b) and (c). Around the optical spot, $\Delta\phi$ and E_y / E_x are 1.57 radians and 1, respectively. Therefore, a circularly polarized optical spot is obtained in Fig. 3.

Localized surface plasmons (LSP) play an important role in obtaining intense optical spots and converting a linearly polarized diffraction limited radiation into a circularly polarized nanoscale spot. The desired phase difference and amplitude ratio in Fig. 3 is a result of (i) the significantly shorter wavelength of the LSP as compared to the wavelength of the incident photons and (ii) an asymmetric aperture. By creating an asymmetry in the aperture shape, an optical path difference is created between LSP in the horizontal and vertical directions, which is tuned to obtain a 90° phase difference. The amplitude ratio is tuned using α_{pol} in Fig. 3.

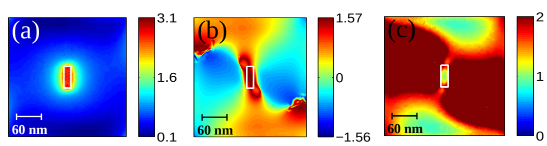

Fig. 3. (a) $|\mathbf{E}|^2$, (b) $|\Delta\phi|$ and (c) $|\mathbf{E_y}|$ / $|\mathbf{E_x}|$ for $\alpha_{pol} = 68°$ for G_h = 20 nm and G_v = 60.5 nm.

In summary, circularly and elliptically polarized nanoscale optical spots are achieved via subwavelength square and rectangular apertures. Linearly polarized diffraction limited radiation was converted into circularly or elliptically polarized nanoscale optical spots by obtaining a phase difference between field components using a rectangular aperture.

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