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Circularly Polarized Localized Near-Field Radiation at the Nanoscale

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Abstract: A novel nano-antenna configuration is suggested to achieve circularly polarized optical spots beyond the diffraction limit. Intense optical spots with circular polarization are obtained using a cross-dipole nano-antenna.

Circular polarization is utilized in certain applications in radiofrequency and microwave regimes due to its advantages, such as increased efficiency in power transmission. For example, in satellite communications, using a circularly polarized transmitting antenna, rather than a linearly polarized one, ensures the polarization axis of the propagating electromagnetic wave to be minimally rotated inside the ionosphere, thus minimizing polarization mismatch on the receiving satellite antenna [1].

Diffraction-limited circularly-polarized electromagnetic radiation has been widely used in the literature for various applications. With advances in nanotechnology, circularly-polarized electromagnetic radiation beyond the diffraction limit is desired in emerging plasmonic nano-applications. One of these applications is all-optical magnetic recording [2]. Stanciu et al. demonstrated that magnetization can be reversed in a reproducible manner by using a circularly polarized optical beam without any externally applied magnetic field. The size of the magnetization reversal in that study was on the order of 20 microns due to the large optical spots that were utilized. To advance the areal density of hard disk drives beyond 1 Tbit/in.^{2}, magnetization reversal areas much smaller than 100 nm are required. To achieve sub-100 nm bits, circularly polarized optical spots beyond the diffraction limit are necessary.

In this study, a crossed-dipole nano-antenna is investigated to achieve circularly polarized near-field radiation beyond the diffraction limit. The crossed-dipole nano-antenna model is shown in Figure 1. It is composed of four gold metallic nano-rods separated by a distance G and an angle of 90º. The wavelength of incident light is $\lambda = 1100$ nm and the amplitude is 1 V/m. The dielectric constants of gold and vacuum are taken to be $\varepsilon_{gold} = - 58.8971 - j4.61164$ and $\varepsilon_{vacuum} = 1$.

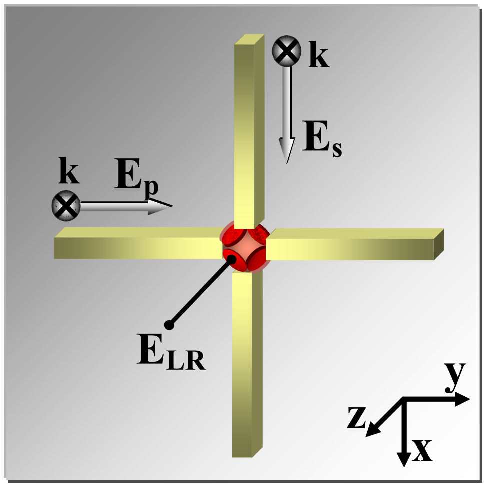

Fig. 1 Primary characteristics of the gold metallic crossed-dipole nano-antenna design: An s-polarized and p-polarized electric field is incident upon the vertical and horizontal parts of the antenna, respectively. The electric field k-vector is directed along the negative z-direction. E_{LR} corresponds to unwanted high-intensity reactive power in the vicinity of the antenna gap.

In Figure 2(a) the electric field intensity distribution 20 nm below the z = 0 cut plane is shown. This distribution indicates that an intense optical spot with dimensions beyond the diffraction limit has been obtained. Furthermore, the intensity of the optical spot is larger than the intensity due to neighboring particle interactions (designated as E_{LR} in Fig. 1). Since these interactions increase the effective size of the hot spot, their values should be minimized. The neighboring particle interaction still has to be overcome within the context of the near-field interactions of the crossed-dipole nano-antenna.

In addition to providing an intense optical spot, the cross-dipole antenna yields a circular polarization in the vicinity of its gap. Furthermore, two conditions that are required for circular polarization are satisfied: (1) The phase difference between the electric field components is π/2 and (2) the ratio of the magnitudes of the electric field components is equal to 1, in close proximity to the gap center. Figure 2(b) shows the difference between phases of the s-polarized and p-polarized electric field components. As seen around the center of the antenna gap, phase difference is equal to π/2. This indicates the sense of rotation is clockwise. Since the electric field k-vector is directed along the negative z-direction, the circularly-polarized light is right-handed.

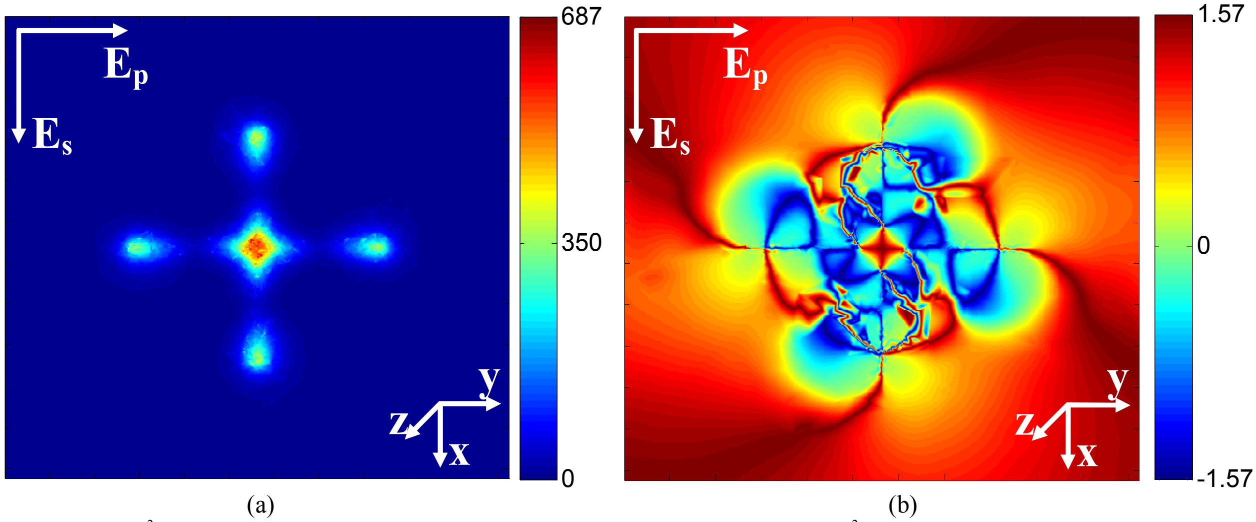

Fig. 2 (a) Total $|E|^2$ distribution on the x-y cut plane 20 nm below the gap center, $|E(x = 0, y = 0, z = - 20)|^2$. The dimensions are selected as: λ = 1100 nm, W = 10, T = 20, G = 20, (b) Phase difference on the x-y cut plane 20 nm below the gap center. The dimensions are selected as: W = 10, T = 20, G = 20.

In summary, a novel nano-antenna configuration is proposed to obtain a circularly polarized optical spot beyond the diffraction limit. The intensity plot suggests that a cross-dipole nano-antenna exhibits an intense optical spot in the gap region of the cross-dipole. The phase plot suggests that a π/2 radians phase difference is achieved at the central region of the optical spot.

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References

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[2] C.D. Stanciu, F. Hansteen, A.V. Kimel, A. Kirilyuk, A. Tsukamoto, A. Itoh and Th. Rasing, “All-Optical Magnetic Recording With Circularly Polarized Light,” Phys. Rev. Lett., 99, 047601 (2007).