

Characteristics of Nano-sized Circularly Polarized Light in Medium Generated by a Plasmonic Asymmetric Cross Antenna

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Abstract

All-optical magnetic recording with circularly polarized light has been studied for developing high speed recording. In this paper, we discuss that a high degree of circularity with a small spot in a medium was generated from a linearly polarized incident light by applying a new designed plasmonic cross antenna with a recording medium.

Keywords : [Near-Field Light](#) [Nanoscale Antenna](#) [FDTD Method](#)

1. Introduction

All-optical magnetic recording with circularly polarized light has attracted attention for high speed and high density recording [1] [2]. To generate a localized circular polarized light from a linearly polarized incident light in a free space, an asymmetric cross antenna was reported in reference [3]. By considering a recording medium, resonance condition changes from that of the case of free space [4]. Thus, it is very important to consider a medium when the nanoscale antennas for recording are designed. In this paper, an asymmetric cross antenna is proposed to generate localized circularly polarization in the medium from linearly polarized incident light.

2. Computational Method

Finite difference time domain (FDTD) method combined with the auxiliary differential equation (ADE) method [5] is used to compute electromagnetic fields in a dispersive medium. The finite difference equation for the electromagnetic field, the current and the polarization are expressed by,

$$H^{n+\frac{1}{2}} = H^{n-\frac{1}{2}} - \frac{\Delta t}{\mu_0} (\nabla \times E^n) \quad (1)$$

$$E^{n+1} = C_1 E^n + C_2 \left[\nabla \times H^{n+\frac{1}{2}} - \frac{1}{2} \sum_{l=0}^K \{ (1 + \alpha_l) J_l^n - \gamma_l P_l^n \} \right] \quad (2)$$

$$J_l^{n+1} = \alpha_l J_l^{n+1} + \beta_l (E^{n+1} + E^n) - \gamma_l P_l^n \quad (3)$$

$$P_l^{n+1} = P_l^n + \frac{\Delta t}{2} (J_l^{n+1} + J_l^n) \quad (4)$$

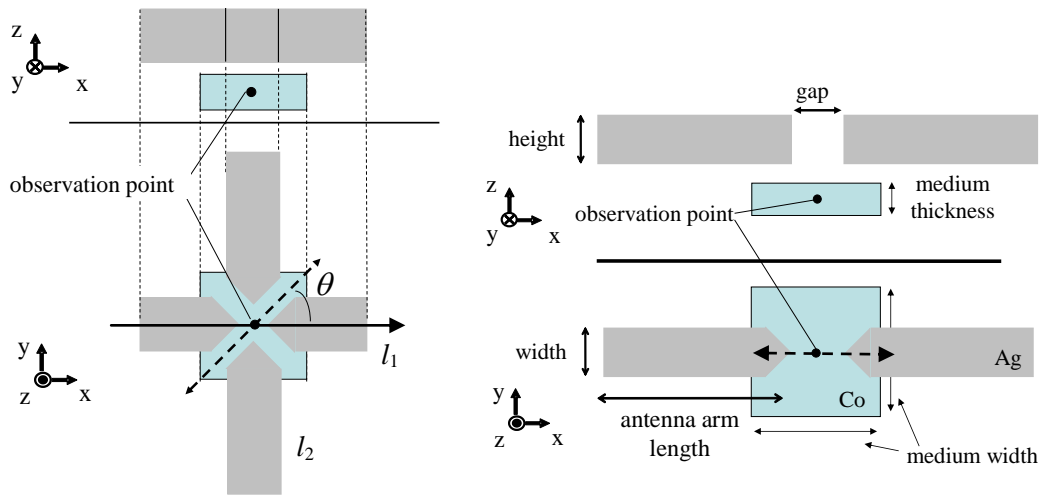
where,

$$\left\{ \begin{array}{l} C_1 = \frac{2\varepsilon_0 - \Delta t \sum_{l=0}^K \beta_l}{2\varepsilon_0 + \Delta t \sum_{l=0}^K \beta_l}, C_2 = \frac{2\Delta t}{2\varepsilon_0 + \Delta t \sum_{l=0}^K \beta_l}, \alpha_l = \frac{1}{\xi_l} \left\{ 1 - \frac{\Delta t}{4} (2\nu_l + \omega_l^2 \Delta t) \right\}, \\ \beta_l = \frac{\varepsilon_0 A_l \omega_l^2 \Delta t}{2\xi_l}, \gamma_l = \frac{\omega_l^2 \Delta t}{\xi_l}, \xi_l = 1 - \frac{\Delta t}{4} (2\nu_l + \omega_l^2 \Delta t) \end{array} \right.$$

Analytical region is surrounded by the convolutional PML (CPML).

3. Computational Model and Numerical Results

Fig.1(a) shows the geometry of the asymmetric cross antenna constituted by two perpendicular dipole antennas with different arm length located above the recording medium. To determine the antennas arm length, characteristic of a linear dipole antenna has to be clarified. Therefore, a linear dipole antenna shown in Fig.1(b) is considered. Material of the antenna and the recording medium are silver and cobalt, respectively, which are characterized by the Drude model and they are located in free space. The gap between the medium and antenna is 5.0 nm. Incident light is assumed to be a sinusoidal plane wave with the amplitude of $E = 1.0$ V/m in the wavelength of 780 nm and linearly polarized along to the antenna arm. The antenna arms have a squared cross section of 30×30 nm² and gap size of 30 nm. A three dimensional mesh size $1.0 \times 1.0 \times 1.0$ nm³ and time increment $\Delta t = 1.9 \times 10^{-18}$ s are used. To observe the resonance, the antenna arm length is varied from 90 to 190 nm. Here, we will consider about medium size $30 \times 30 \times 20$ nm³, which is relatively smaller than the antenna size.



(a) Asymmetric cross antenna model.

(b) Linear dipole model.

Figure 1: Asymmetric cross antenna and linear dipole models with the recording medium. The dashed arrow indicates the direction of incident polarization.

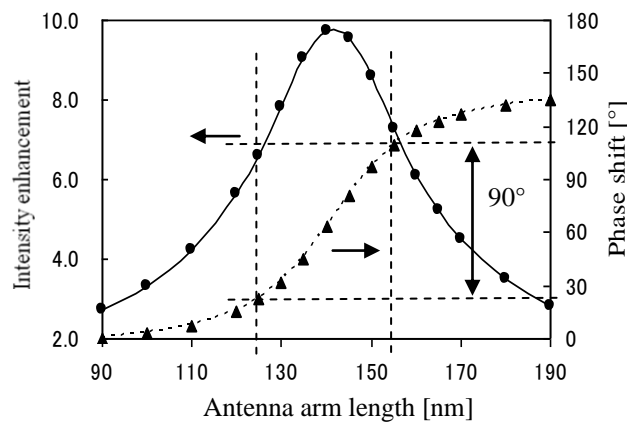


Figure 2: Intensity and phase characteristics of linear dipole antenna at the center of the medium whose size is $30 \times 30 \times 20$ nm³.

Fig. 2 shows the intensity enhancement and phase shift characteristics compared with no antenna case at the center of the medium. Considering the characteristics described in Fig. 2, two antenna arm lengths l_1 and l_2 are selected as 125 nm and 155 nm, respectively, because difference of

phase shift for these lengths is about 90° . Here, the incident direction θ is assumed to be 46.8° or 133.2° to match the value of intensity enhancement. Fig. 3 shows the time response of the electric fields of the cross antenna for the incident direction 46.8° and 133.2° at the center of the medium. For both case, it takes about 20 fs to be in steady state, where the amplitude is matched and the difference of phase shift becomes 90° . Fig. 4 shows the polarization characteristic of the cross antenna at the center of medium. By varying the incident direction, left-handed and right-handed circularly polarizations are generated at the center of medium. The transient behavior in which linearly polarized light is transformed into localized circularly polarized light is clarified. Figs. 5 and 6 show the field distribution of the total intensity enhancement I and the degree of circular polarization C' of this asymmetric cross antenna for incident direction $\theta=133.2^\circ$, where C' is the ratio between the fourth Stokes parameter and the total intensity enhancement,

$$I = \langle E_x^2(t) \rangle + \langle E_y^2(t) \rangle + \langle E_z^2(t) \rangle, \quad (5)$$

$$C' = \frac{S_3}{I} = 2 \frac{\langle E_x(t)E_y(t) \sin(\delta_x - \delta_y) \rangle}{\langle E_x^2(t) \rangle + \langle E_y^2(t) \rangle + \langle E_z^2(t) \rangle}, \quad (6)$$

where $\langle \bullet \rangle$ denotes time average, $E_x(t)$ and $E_y(t)$ are the electric field amplitudes, and $(\delta_x - \delta_y)$ is their phase difference [6]. To estimate the usage of this antenna for all-optical magnetic recording, the intensity and circularity in the medium are discussed. From Figs. 5 and 6, it could be shown that right-handed circularly polarized light is covering the most of the part of the medium when the incident direction $\theta=133.2^\circ$.

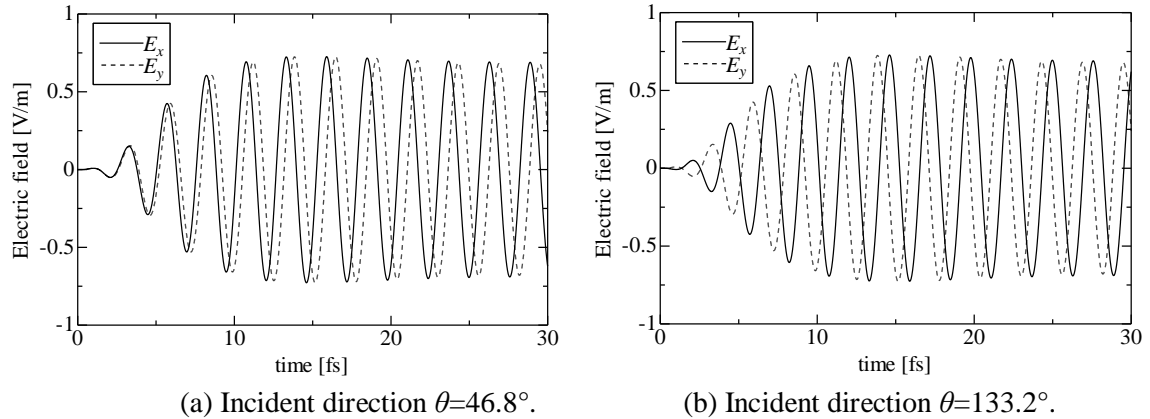


Figure 3: Time response of electric field at the center of the medium with the incident direction $\theta=46.8^\circ$ and 133.2° .

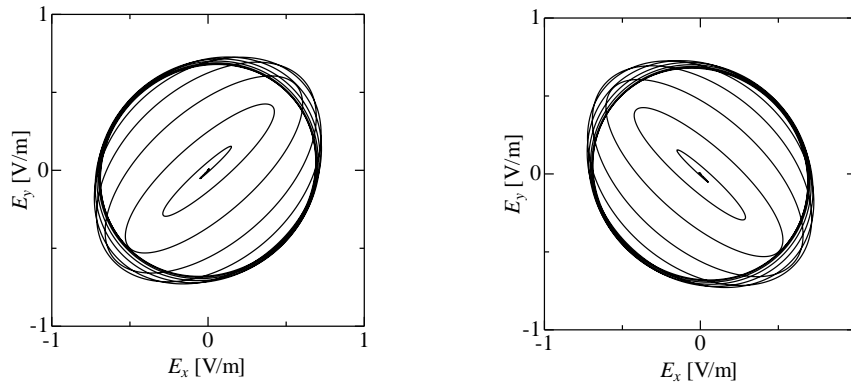


Figure 4: Polarization characteristic at the center of the medium with the incident direction $\theta=46.8^\circ$ and 133.2° .

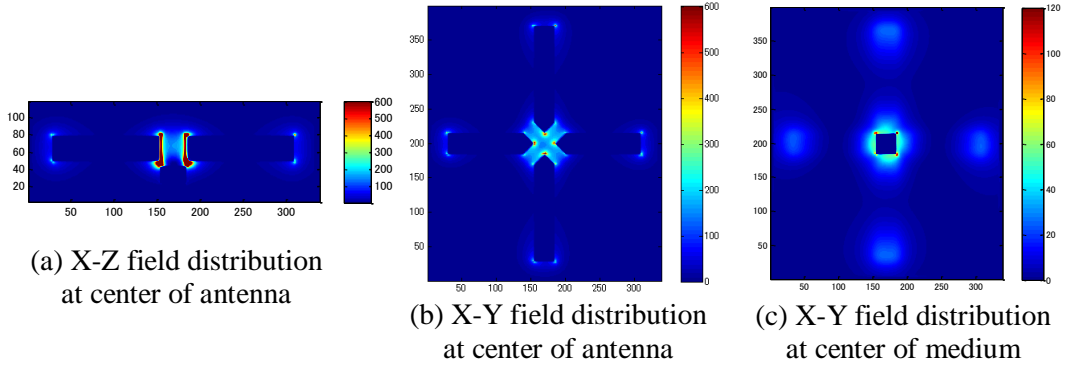


Figure 5:Field distribution of the total intensity enhancement I with the incident direction $\theta=133.2^\circ$.

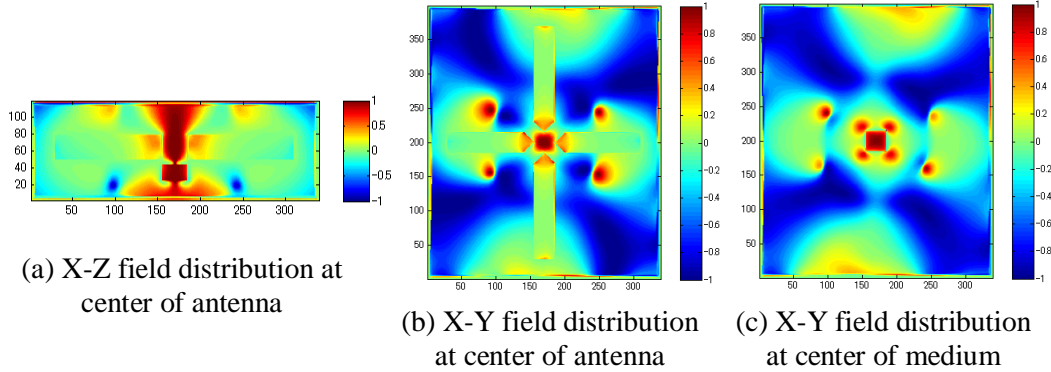


Figure 6:Field distribution of the degree of circular polarization C' with the incident direction $\theta=133.2^\circ$.

4. Conclusions

The asymmetric cross antenna with the recording medium is investigated for the all-optical magnetic recording with circularly polarized light. Transient behavior of generation of circularly polarized light and field distribution of the Stokes parameter is discussed. We verified that the circularly polarized light can be produced in the medium by designing the antenna in consideration of the recording medium.

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Acknowledgments

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