Transient Analysis of Localized Circularly Polarized Light for All-Optical Magnetic Recording

#Hiroshi Iwamatsu [1], Tsukasa Kato [1], Shinichiro Ohnuki [1], Yoshito Ashizawa [1],
Katsuji Nakagawa [1], Weng Cho Chew [2]
[1] College of Science and Technology, Nihon University
1-8-14 Surugadai, Kanda, Chiyoda-ku, Tokyo, 101-8308, Japan
E-mail: ohnuki.shinichiro@nihon-u.ac.jp
[2] Electrical and Computer Engineering, University of Illinois
Urbana-Champaign, Urbana, IL 61801, USA

1. Introduction

For ultra-high speed recording, all-optical magnetic recording technology with circularly polarized lights has been studied [1-3]. However, it was difficult to localize circularly polarized light for realizing higher density magnetic recording because of the diffraction limit. Our proposed plasmonic cross antenna can generate the nano-sized circularly polarized light inside the recording media for high density magnetic recording [4, 5]. In this paper, we analyze the electromagnetic fields of a plasmonic cross antenna and the bit-patterned media by the ADE-FDTD method [6]. The intensity of the electric fields inside the bit-patterned media and the speed to generate the circularly polarized light are discussed for all-optical magnetic recording.

2. Computational Method and Model

We apply the finite-difference time-domain (FDTD) method with the auxiliary differential equation (ADE) method to compute the near-field light of dispersive media expressed by the Drude model [7]. In particular, we combine the Maxwell equations with the current which is described by the electron movement. The finite difference equation for the electromagnetic fields and the polarization current are expressed by,

$$\mathbf{H}^{n+\frac{1}{2}} = \mathbf{H}^{n-\frac{1}{2}} - \frac{\Delta t}{\mu_0}\left(\nabla \times \mathbf{E}^n\right), \tag{1}$$

$$\mathbf{E}^{n+1} = C_1\mathbf{E}^n + C_2\left[\nabla \times \mathbf{H}^{n+\frac{1}{2}} - \frac{1}{2}\sum_{l=0}^{K}\left\{(1+\alpha_l)\mathbf{J}_l^n - \gamma_l \mathbf{P}_l^n\right\}\right], \tag{2}$$

$$\mathbf{J}_l^{n+1} = \alpha_l \mathbf{J}_l^n + \beta_l\left(\mathbf{E}^{n+1} + \mathbf{E}^n\right) - \gamma_l \mathbf{P}_l^n, \tag{3}$$

$$\mathbf{P}_l^{n+1} = \mathbf{P}_l^n + \frac{\Delta t}{2}\left(\mathbf{J}_l^{n+1} + \mathbf{J}_l^n\right), \tag{4}$$

where

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

The computational order is $\mathbf{H}^{n+1/2}$, $\mathbf{E}^{n+1}$, $\mathbf{J}_l{}^{n+1}$, and $\mathbf{P}_l{}^{n+1}$. In this computation, the three dimensional mesh size 1.0×1.0×1.0 nm^3 and time increment 1.9×10^{-18} s are selected. The analytical region is surrounded by the convolutional PML (CPML).

Figure 1 shows the computational model of the plasmonic cross antenna with the bit-patterned media in free space. The plasmonic antenna has the width of 10 nm, the height of 40 nm, the beak size of 20 nm, and the gap of 10 nm. We choose the bit-patterned media composed of nano-sized cylinders whose diameter is 10 nm, thickness is 10 nm, and separation is 7.0 nm for realizing 2 Tbit/inch^2 recording density. The space between the media and the antenna is 5.0 nm. Materials of the antenna and the media are gold and cobalt, respectively. The incident light is a sinusoidal plane wave propagating in the negative z-direction. The amplitude of the electric field is 1.0 V/m and the wavelength is 780 nm. Here, θ is an angle formed by the x-axis and the electric field component of the incident light on the x-y plane. The observation point is at the middle of the center particle.

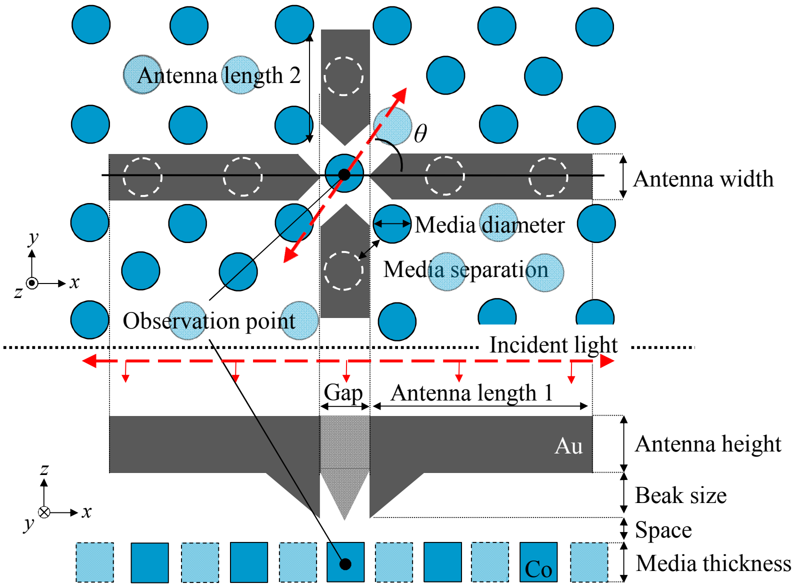


Figure 1: Computational model of the plasmonic cross antenna with the bit-patterned media.

3. Numerical Results

To determine the antenna length 1 and length 2, the plasmonic antenna with the bit-patterned media is analyzed when the angle θ is 0 deg and the antenna length 2 is 90 nm. We investigate the characteristics of this antenna to produce the phase difference between the x and y components of the electric fields.

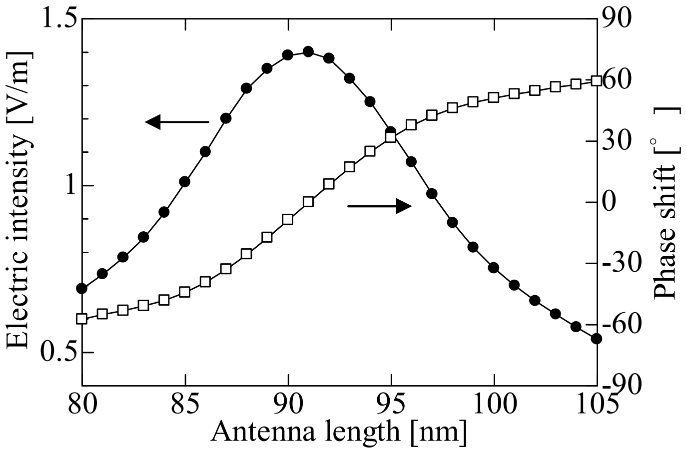
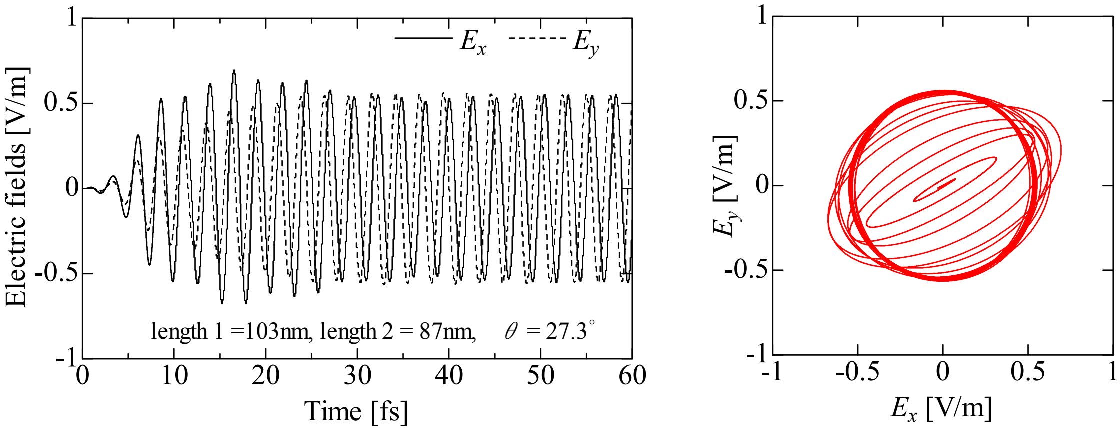


Figure 2: Characteristics of the electric intensity and the phase shift.

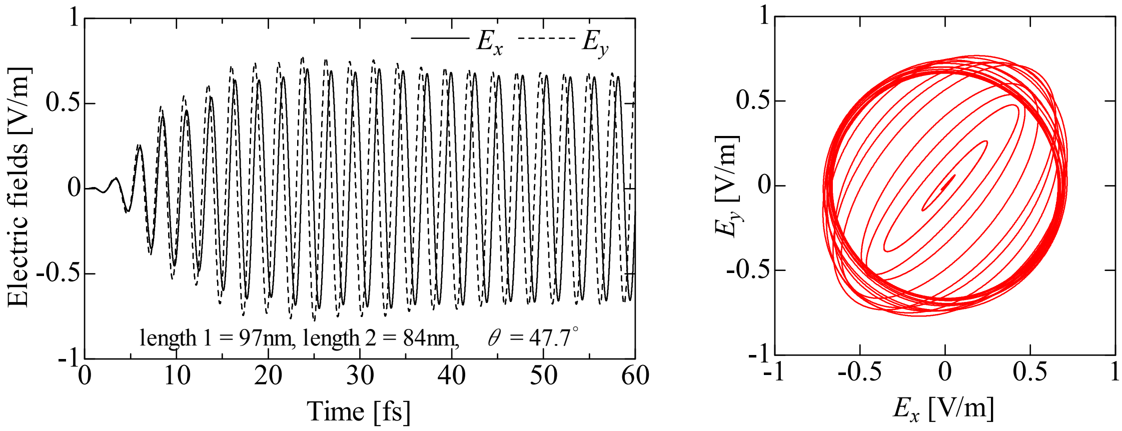
Figure 2 shows the characteristics of the intensity of the electric fields and the phase shift for the computational model at the observation point. The antenna length 1 is varied from 80 to 105 nm to observe the intensity of the electric field. The phase shift is assumed to be 0 deg for which the electric intensity becomes the maximum.

Considering the characteristics described in Fig. 2, we are able to select some combinations of the antenna length 1 and 2 for which the difference of the phase shift becomes 90 deg to generate the localized circularly polarized light from a linearly polarized light inside the bit-patterned media. For example, the antenna length 1 and 2 are selected as 103 and 87 nm, respectively, as the case 1 or the antenna length 1 and 2 are selected as 97 and 84 nm, respectively, as the case 2. The angle θ is determined as 27.3 deg to match the value of the x and y components of the electric intensity in the case 1. In a similar way, the angle θ is determined as 47.7 deg in the case 2.



(a) Time response (b) Lissajous curve

Figure 3: Temporal variations of the electric fields for the case 1.



(a) Time response (b) Lissajous curve

Figure 4: Temporal variations of the electric fields for the case 2.

Figure 3 (a) shows the time response of the electric fields E_x and E_y in the case 1. We can confirm that the x and y components of the electric fields are different in transient state. It takes about 29 fs to be in steady state. Figure 3 (b) shows the Lissajous curve of the electric fields E_x and E_y in the case 1. Clockwise circularly polarized light is generated from a linearly polarized light at the observation point.

Figure 4 (a) shows the time response of the electric fields E_x and E_y in the case 2. It takes about 51 fs to be in steady state. We verify that the x and y components of the electric fields are alike even in early time response. Figure 4 (b) shows the Lissajous curve of the electric fields E_x and E_y in the case 2. Clockwise circularly polarized light is generated from a linearly polarized light at the observation point.

The characteristic of circularly polarized light for the case 1 and the case 2 is summarized as follows: the time to generate circularly polarized light in the case 1 is faster than that in the case 2, however the electric intensity of circularly polarized light in the case 1 is lower than that in the case 2.

4. Conclusions

We analyze the electromagnetic fields of a plasmonic cross antenna and bit-patterned media by the ADE-FDTD method. Clockwise circularly polarized light is generated inside the bit-patterned media. It is clarified that the value of the electric intensity and the speed to generate the circularly polarized light are different by selecting the combinations of the antenna lengths for which the phase difference is 90 deg.

Acknowledgments

This work is partly supported by Grant-in-Aid for Scientific Research (C) (22560349), CASIO Science Promotion Foundation, and Nihon University Strategic Projects.

References

[1] 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, Vol. 99, pp. 047601-1-047601-4, 2007.

[2] K. Nakagawa, J. Kim, and A. Itoh, “Near-field optically assisted hybrid head for self-aligned Plasmon spot with magnetic field,” J. Appl. Phys., Vol. 99, pp. 08F902-1-08F902-3, 2006.

[3] K. Nakagawa, Y. Ashizawa, S. Ohnuki, A. Itoh, and A. Tsukamato, “Confined circularly polarized light generated by nano-size aperture for high density all-optical magnetic recording,” J. Appl. Phys., Vol. 109, pp. 07B735-1-07B735-3, 2011.

[4] H. Iwamatsu, T. Kato, S. Ohnuki, Y. Ashizawa, K. Nakagawa, and W. C. Chew, “Analysis of Bit-patterned Media and Plasmonic Cross Antenna for All-optical Magnetic Recording-Investigation of the electric intensity for changing the arrangement of media patterns-,” Technical Meeting on Magnetics, IEE Japan, MAG-11-110, pp. 95-100, 2011.

[5] H. Iwamatsu, T. Kato, S. Ohnuki, Y. Ashizawa, K. Nakagawa, and W. C. Chew, “Analysis of Electromagnetic fields of a Plasmonic Cross Antenna with Bit-Patterned Media, ” Proc. of IEEE AP-S/URSI, 2012.

[6] T. Yamaguchi and T. Hinata, “Optical near-field analysis of spherical metals: Application of the FDTD method combined with the ADE method,” Opt. Express, Vol. 15, pp. 11481-11491, 2007.

[7] Rakić, A. D., A. B. Djurišić, J. M. Elazar, and M. L. Majewski, “Optical Properties of Metallic Films for Vertical-Cavity Optoelectronic devices,” Appl. Opt., Vol. 37, pp. 5271-5283, 1998.