Enhancement of Terahertz Magnetic Near-field by Tapered Metallic Waveguide

Hongsong Qiu[1], Hirofumi Harada[1], Kosaku Kato[1], Takayuki Kurihara[1], Keisuke Takano[1], Tohru Suemoto[2], Masahiko Tani[3], Nobuhiko Sarukura[1], Masashi Yoshimura[1] and Makoto Nakajima[1]

[1] Institute of Laser Engineering, Osaka University, [2] Toyota Physical and Chemical Research Institute,
[3] Research Center for Development of Far-Infrared Region, University of Fukui
E-mail: qiu-hongsong@ile.osaka-u.ac.jp

1. Introduction

The usage of magnetic field of terahertz (THz) wave provides novel means to control spin dynamics in ultrafast time scales [1, 2]. While previous studies revealed coherent spin dynamics in linear or small perturbation regime, much more drastic change of the permanent magnetic order is expected under stronger excitation fluence [3, 4]. For this purpose, tight focusing effect of THz waves in plasmonic waveguide is quite useful for enhancing the available magnetic fields [5]. In this paper, we report on the direct enhancement of terahertz magnetic near-field amplitude in a tapered waveguide, observed by the magneto-optic sampling in a double split-ring resonator (D-SRR) coupled $Tb_3Ga_5O_{12}$ (TGG) crystal.

2. Experiment

A D-SRR made of gold was fabricated on TGG crystal (Fig. 1(a)). The incident THz wave, with the peak electric field of ~200 kV/cm, was concentrated by a tapered waveguide and was used to excite magnetic-mode resonance of D-SRR structure (Fig. 1(b)). This induces clockwise and anti-clockwise oscillating currents $\boldsymbol{I(t)}$ (red arrows) in the two arms of the D-SRR, which in turn produces the out-of-plane magnetic near-field $\boldsymbol{H}_z$ inside the TGG crystal (Fig. 1(a)). Owing to the high Verdet constant of TGG in THz region, such magnetic near-field can be directly visualized through the Faraday rotation of the time-delayed NIR probe pulse. In order to extract only the magnetic nearfield signals from the background bulk response, we subtracted the Faraday waveform measured at two symmetric positions of D-SRR separated by the central wire.

The solid curve in Fig. 2 shows the transient Faraday waveform measured with a waveguide. The oscillation

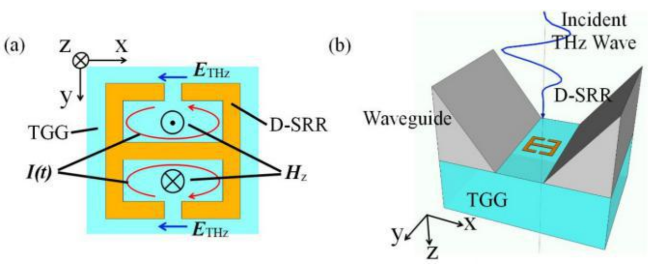

Fig. 1. Schematic of the experimental configuration. (a) Structure of D-SRR. (b) Waveguide and sample arrangement.

corresponds to the out-of-plane magnetic near-field induced by the circular current in D-SRR. The dotted curve in Fig. 2 shows the signal measured without waveguide as a reference. The peak-to-peak amplitude of the signal measured with the waveguide is about 2.2 times larger than that without the waveguide. The spectrally integrated intensity is enhanced by around 5 times. It is in quantitative agreement with the electromagnetic simulation.

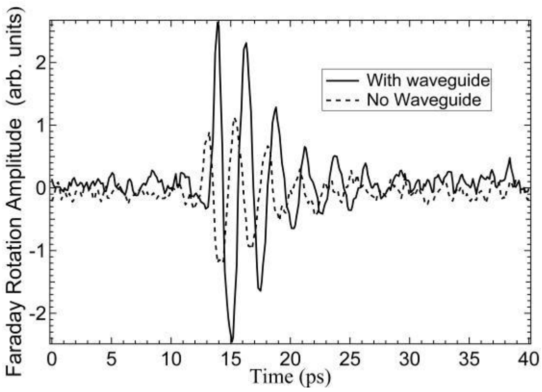

Fig. 2. Temporal evolution of the THz magnetic near-field measured by magneto-optic sampling. Solid and dotted curves show the signal measured with the waveguide and that without the waveguide, respectively.

3. Conclusions

As a summary, we demonstrated the enhancement of the terahertz magnetic near-field by a tapered waveguide, and probed the enhanced magnetic field directly by the magneto-optic sampling method utilizing a D-SRR coupled TGG crystal. The intensity enhancement of ~5 times was successfully obtained with the help of superfocusing waveguide. Further magnetic field enhancement is anticipated through optimization of the waveguide structure, which ultimately leads to a nonlinear control of spin dynamics by THz magnetic fields in wide range of materials.

References

[1] K. Yamaguchi et al., Phys. Rev. Lett. **105** (2010) 237201.
[2] M. Nakajima et al., Opt. Express **18** (2010) 18260.
[3] T. Kurihara et al., Phys. Rev. B **90** (2014) 144408.
[4] N. Kumar et al., Opt. Exp. **20** (2012) 11277.
[5] S. Tsuzuki et al., Appl. Phys. Express **7** (2014) 112401.