Maskless exposure system toward fabrication of THz metamaterials

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Introduction

Recently many applications of terahertz (THz) wave have been proposed with improvement of laser technology. Part of the reasons why THz wave is getting attentions is that many materials have eigen-oscillation modes called "finger print spectra" in THz frequency region. However this is synonymous with the absence of materials useful to optics in wide band THz region. Thus artificial structures, such as a wire-grid polarizer [1], have been used historically for experiment in THz region.

The relative ease to fabricate sub-wavelength artificial structures for terahertz (THz) wave promotes metamaterial researches in this region. The maskless exposure technique which is one of rapid prototyping techniques is useful in processes of trial-and-error and optimization of structural parameters in fabrication of artificial structures owing to its flexibility for design. In this paper we applied the photo-lithography based on maskless exposure technique toward fabrication of THz-band metamaterials. These have potential to design useful optics in wide band THz region.

Maskless exposure

We converted a commercial PC projector into a patterning device for photo-lithography process. One can easily get a projector as a good patterning device with decreasing the price of projector recently. We selected a DMD (Digital Micro-mirror Device) -type projector (BenQ, MP515) rather than liquid crystal (LC) type [2] because absorption of UV-light for exposure may damage the latter. We removed lenses originally equipped for image expansion from the projector and alternately integrated it with a lens array for reduced projection to pattern micron size structures. The light source was also exchanged for a UV-light (USHIO, SP-9) for UV curing. In our experiments the size of one pixel was set to ~ 8 μm.

Sample fabrication

As a first example for our maskless exposure, we have fabricated a grating structure. SU-8 which

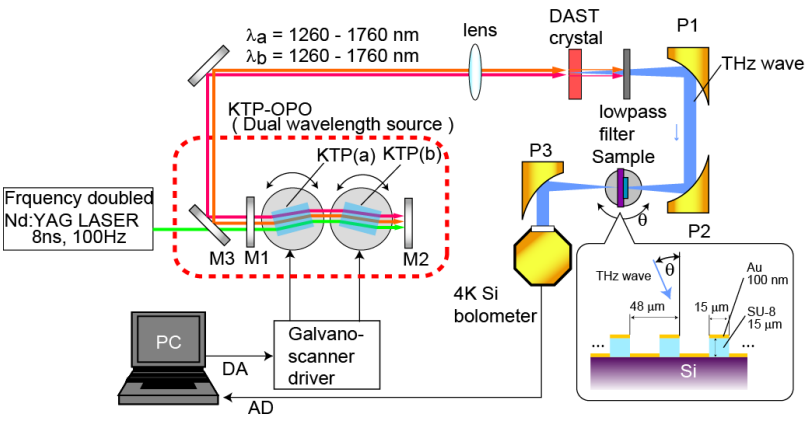

Fig. 1 Experimental setup to measure angle resolved transmission measurement in THz-region. The inset shows a sample structure. M1, M2 and M3 denote mirrors containing OPO cavity. P1, P2, and P3 denote off axis parabolic mirrors to collimate and focus the THz beam from a DAST crystal.

is well known negative photoresist to produce thick structure was spin-coated in thickness of 15 μm on a high resistive Si substrate. A grating pattern was exposed on a resist layer by using the maskless exposure we developed. Period, linewidth and height of the structure were 48, 15, and 15 μm, respectively, as shown in the inset in Fig. 1. After the photolithography process of SU-8, 100nm-thick Au was evaporated on the grating structure, which would be enough to reflect THz-wave totally if it was on a plane substrate.

Experiment and results

The sample was characterized by angle resolved transmission spectra. The experimental setup is shown in figure 1. We used a difference frequency generation (DFG) type monochromatic THz-wave source [3] with DAST as a nonlinear crystal, which allowed us to measure the spectra in wide THz range by controlling the wavelengths of infrared light for sources. THz wave is introduced to a sample mounted on a rotational stage. By changing a configuration of rotational stage, we measured the polarization dependence of transmission spectra for s- and p-polarized light. We used a 4K Si bolometer to measure the intensity of the THz wave transmitting a sample.

Measured transmission spectra for several incident angles are shown in figure 2. Spectra for normal incidence are drawn as blue curves. Remarkable features are seen for both polarizations. For p-polarization the frequency of dips shifts with the angle, which suggests some propagating modes in interfaces of constituent materials. For s-polarization there are two types of band-pass features: one is observed only at near normal incidence, while the other shifts with the incident angle. The former is ascribed to the half-wavelength resonance in SU-8, according to our calculation based on the scattering matrix method.

The maskless exposure system will be useful as a cost-effective technology for artificial structures that show characteristic responses in THz region.

Acknowledgements

Authors would like to thank Prof. Hiromasa Ito, Dr. Ming Tang, Dr. Koji Nawata, and Dr. Takashi Notake for fruitful discussions about THz wave sources, Yuko Kamata for FTIR measurements, Mikiko Saito for preparation of DAST crystals, and Makoto Saito for assembling of the maskless exposure.

References

1. Auton J P, Applied Optics **6**, 1023 (1967)
2. K. Itoga, M. Yamato, J. Kobayashi, A. Kikuchi, and T. Okano, Biomaterials **25**, 2047 (2004)
3. H. Ito, K. Suizu, T. Yamashita, A. Nawahara, and T. Sato JJAP **46**, 7321 (2007)

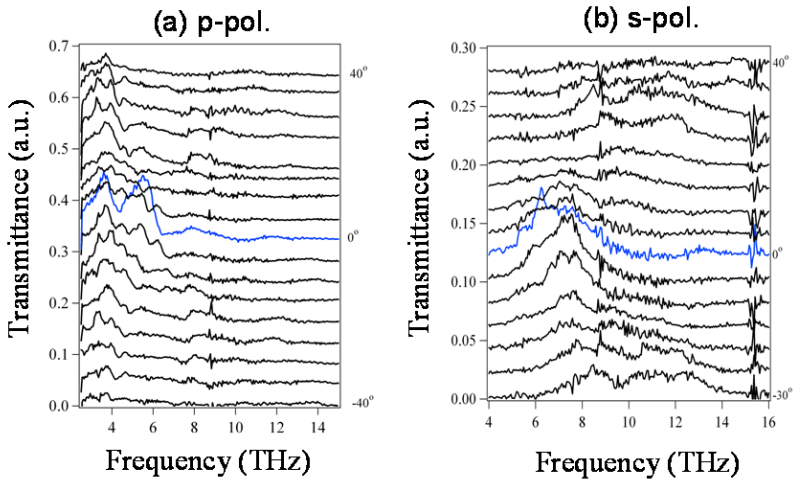

Fig. 2 Angle resolved transmission spectra in the grating structure for p- and s-polarized THz wave.