Enhancement of Optical Rectification for THz Amplification in One-Dimensional Photonic Crystals

Noriaki Tsurumachi[a], Hideto Shirai[a], Tatsuya Kokuhata[a], Hayato Miyagawa[a], Shyun Koshiba[a], Shunsuke Nakanishi[a], Hiroshi Itoh[a], and Masanori Hangyo[b]
[a]Faculty of Engineering, Kagawa University, 2217-20 Hayashi-cho, Takamatsu, Japan
[b]Institute of Laser Engineering, Osaka University, 2-6 Yamadaoka, Suita, 565-0871, Japan

***Abstract*—We fabricated cavity type THz one-dimensional photonic crystal with a nonlinear material and demonstrated the amplification of THz light using these structures.**

I. Introduction And Background

RECENT progress of ultrashort pulse laser technology leads to a convenient spectroscopy technique called as THz time-domain spectroscopy (THz-TDS). This THz technique can be utilized to many field not only spectroscopy for material science and life science, but also applications such as imaging for advanced medical technology and a security service. Although the THz-TDS system has been commercially available recently, it is not still popular since it is necessary to use an expensive femtosecond laser system as an excitation source. In order to spread the THz technology to many field, a development of lower-priced THz-TDS system with bright emitter is necessary. For this purpose, many groups have investigated several amplification techniques of THz light [1,2]. In this study, we demonstrated an enhancement of optical rectification effect in one-dimensional photonic crystal (1D-PC) for THz amplification.

The PCs are structures whose dielectric constants are periodically modulated with a period that is the same order of concerning light wavelength. We can consider various types of PC structures from one-dimensional (1D) to three-dimensional (3D) ones depending on the target. Each structure has both merit and demerit. For example, in order to control spontaneous emission or light propagation, 3D structures are suitable. On the other hand, in the case of the control of laser beams that are close to the plane wave, we do not need 3D-PC, but 1D-PC is sufficient. Moreover, for the enhancement of optical nonlinear effects, the 1D-PC is the best candidate since the incident laser light is fully coupled to the localized defect mode only in the 1D-PC. By periodically stacking of two thin dielectrics with different refractive indices, one can fabricate a 1D-PC with a wide photonic band gap. On the other hand, when a structural defect is introduced in the periodic multi-layer structure, photonic localized mode can be created in the photonic band gap. This structure is considered as microcavity structure.

Density of photon mode at localized mode or photonic band edge in the PCs is expected to become larger compared with that in vacuum or usual medium. This fact leads to the large enhancement of nonlinear optical phenomena [3-5]. In this study, we focus on optical rectification that is the one of the second order nonlinear optical effects, in order to generate the THz light. When visible or near-infrared ultrashort laser pulses which have wide spectrum, are irradiated to nonlinear material, broad-band difference frequency polarizations are generated in the material and then the THz lights with wide spectrum are emitted.

The enhancement of the optical rectification effect is expected in various types of the PCs. Since the THz and visible lights are concerned in this nonlinear process, we can consider THz region PC with an order of 10 μm periods whose mode density in THz region is increased and/or visible region PC with an order of 100 nm periods whose mode density in visible region is increased.

II. Results

In this paper, we demonstrated the amplification of THz lights using THz region 1D-PC (THz 1D-PC). We fabricated cavity type THz 1D-PC with (110) ZnTe crystal as a nonlinear material whose thickness is 1 mm by simple stacking method of thin films [4] as shown in Fig.1. As high and low index materials in mirror parts of THz 1D-PC, polypropylene thin films and air layers (spacer) are utilized. The layer sequence is $(HL)^2HXH(LH)^2$. Here, H, L and X denoted high index, low index, and nonlinear material, respectively.

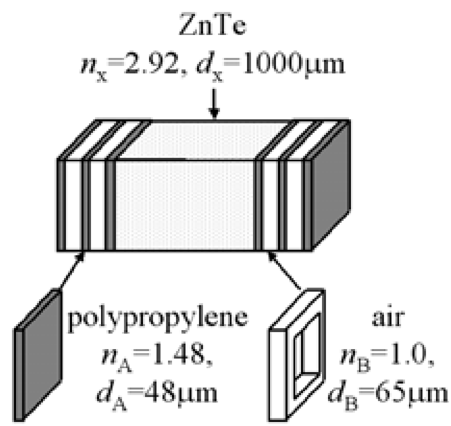

Fig.1 Schematic illustration of THz 1D-PC made of polypropylene films and air spacers with a ZnTe crystal as a defect layer.

The generated THz light spectra from the THz 1D-PC with a ZnTe crystal were measured by usual THz TDS system. The THz 1D-PC was excited by ultrashort pulses from a mode locked Ti: sapphire laser. The center wavelength, time duration and repetition were 800nm, 50fs, and 76MHz, respectively. The detection is performed by an EO sampling method using ZnTe crystal. Here, a lock-in detection of the signal was applied using intensity-modulated excitation pulse at 3 kHz.

Figure 2(a) shows generated THz spectra obtained by THz-TDS. Solid and dashed lines are THz spectra from the THz 1D-PC with a ZnTe and only the 1000 μm thick ZnTe crystal as a reference, respectively. In contract to expectation of

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amplification of THz light due to the enhancement of optical nonlinear effect, the THz intensity from the THz 1D-PC was weaker than that from a simple ZnTe crystal.

Let us consider the poor enhancement effect in this experiment. The mirror parts of THz 1D-PC were made of two kinds of material whose refractive indices were different. When the femtosecond visible pulses were irradiated to the structure, the excitation light should be reduced due to the Fresnel reflection at each interface between the polypropylene and the air layer of the THz 1D-PC before the pulses arrived at the ZnTe crystal for THz generation. This fact leads to the drastically decreasing of the generated THz light intensity. We concluded that the reason of the poor enhancement effect was attributed to the reduction of incident pulses intensity [7].

In order to avoid this problem, we put anti-reflection multi-layer coatings for visible excitation light using poly-vinyl-carbazole as a high index material and cellulose acetate as a low index material on the both surface of the polypropylene films by simple spin-coating [8]. Although we did not perfectly optimize the design of this anti-reflection coating, the transmittance at excitation wavelength (800 nm) was increased from 89 % to 94%. By this treatment, we could expect the increase of the generated THz intensity since the reduction of the excitation was partially suppressed.

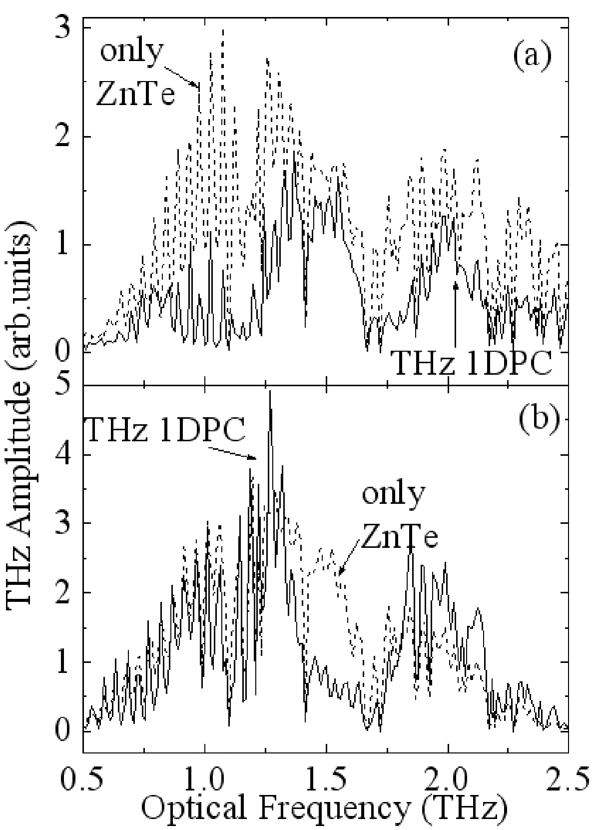

Fig.2 Generated THz light spectra from THz 1D-PC without anti-reflection coatings (a) and with anti-reflection coatings (b). Solid lines are THz 1D-PCs and dashed lines are simple ZnTe crystal as references.

The THz generation experiment was performed again using this THz 1D-PC with anti-reflection coatings. Figure 2(b) shows generated THz spectra obtained by THz-TDS. Solid and dashed lines are THz spectra from the THz 1D-PC and the 1000 μm thick ZnTe crystal as a reference, respectively. In this case, we observed 1.5 times larger THz amplitude in the THz 1D-PC compared with the ZnTe crystal at several specific frequencies around 0.6 THz, 1.3 THz and 2 THz. These frequencies where the enhancement was occurred, were corresponded to frequencies the localized peaks in the photonic band gap and other sharp peaks in the photonic band. In these frequencies, density of photon modes are expected to become larger compared with that in vacuum or usual medium. Therefore, the large enhancement effect of optical rectification was realized and generated THz light increased. On the other hand, the decreasing of THz amplitude was also observed from 1.4 THz to 1.7 THz, since THz absorption band of ZnTe crystal is existed in this region.

We successfully observed the enhancement of THz generation in THz 1D-PC compared with a ZnTe crystal at the several specific frequencies. Now we investigate the enhancement effect of THz generation in visible region 1D-PC and THz-visible doubly resonant PC. We can expect larger enhancement effect for THz generation by utilizing confinement of both THz and visible light.

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