Sum-frequency-generation based terahertz detection using a periodically poled lithium niobate

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***Abstract*— Optical frequency up-conversion based on sum frequency generation is a promising technique for efficient single-photon detection because of commercially available detectors with high efficiency and low noise. We extended the frequency range of up-conversion detection based on sum frequency generation to far infrared at terahertz frequency using a periodically poled lithium niobate. Terahertz photon detection based on sum frequency generation was demonstrated. The photon conversion realizes terahertz photon detector operating at room temperature.**

I. INTRODUCTION

Optical frequency up-conversion based on sum frequency generation is a promising technique for efficient single-photon detection because of low optical noise and high quantum efficiency of commercially available detectors. Single-photon detection in the near infrared and visible range has been demonstrated [1]. In frequency translation, signal photons (at angular frequency ω_s) interact with a strong pump (ω_p) to produce converted photons (ω_c), where $\omega_c = \omega_p + \omega_s$ for up-conversion. Much noise photons caused by spontaneous Raman scattering and spontaneous parametric down-conversion due to strong pump light have the frequency less than that of the pump light. Therefore, sum frequency generation has strong advantage for low noise photon detection.

In the recent decade, terahertz (THz) technologies have demonstrated single-photon detection with ultra-low noise equivalent power (NEP) operating in cryogenically cooling temperature [2]. The THz single-photon detectors have opened up a new field such as photon-counting THz imaging [3,4] and sub wavelength high-resolution passive THz microscopy [5]. A THz single-photon detector operating at room temperature is a strong tool for assisting the above THz applications.

In this report, we demonstrated up-conversion detection based on sum frequency generation to terahertz-wave region using a periodically poled lithium niobate (PPMgLN). One of the most suitable nonlinear crystals for wavelength conversion from terahertz (THz) to near infrared (NIR) is the lithium niobate crystal thanks to its large figure of merits [6]. We have investigated sensitive THz detection based on parametric down-conversion process using a bulk and a PPMgLN crystal [7,8]. Sum frequency generation is another way for sensitive THz detection and a promising technique as a single-photon detector in THz frequency region operating at room temperature.

II. EXPERIMENTS

Figure 1 shows a schematic diagram of the experimental setup. A master oscillator power amplifier (MOPA) system consisting of a Nd:YAG microchip laser (0.5 mJ/pulse: 590 ps: 1064 nm) and a Nd:YAG diode-pumped optical amplifier was used as the pump source. The high-brightness laser with a pulse duration in sub-nanosecond region called “pulse gap” assisted wavelength conversion effectively in this experiment. The output beam of the MOPA system was relayed to the PPMgLN. The THz-wave source was an injection-seeded THz-wave parametric generator (is-TPG) that generated tunable THz waves with high peak power in a frequency range of 1-3 THz [7].

A slant-stripe-type PPMgLN with a length and thickness of 15 mm and 5 mm, respectively, was employed [9] for terahertz detection. The thick crystal allowed easy insertion for the THz-wave corresponding to the wavelength of sub-millimeter. Periodically poled structure of the crystal was slant angle, $\alpha = 20°$, and period, $\Lambda = 29.0$ µm , respectively. After passing through the PPMgLN, the up-conversion signal, which has a wavelength close to that of the pump beam, was separated from the pump beam using short-wavelength pass filters (SWPFs). After SWPFs, the up-conversion signal irradiated to a spectrometer constructed by a grating, a lens, and an avalanche photo-diode (APD; C5658-2139, Hamamatsu Corp.).

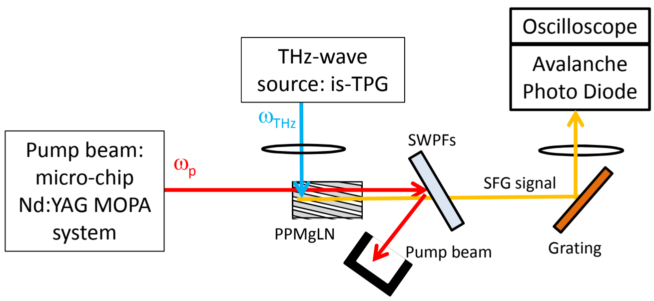

Fig. 1. Experimental setup for sum-frequency generation from THz photon to NIR photon.

III. RESULTS

Terahertz photons irradiated to side surface of the PPMgLN crystal. Strong pump beam normally input to the PPMgLN with AR coating for NIR. The configuration satisfied the law of the conservation of energy and momentum for sum-frequency mixing. The up-converted signal with higher frequency than pump photons was separated from the strong pump beam by using SWPFs to avoid optical damage for the grating. By the grating, up-conversion signal was completely separated from the pump beam in spatially. Therefore, the sensitive APD for NIR region caught just the signal light. The peak voltage from the APD was measured by an oscilloscope.

Figure 2 shows an experimental result. The signal observed at higher frequency than that of pump beam with the wavelength of 1064 nm. And the signal wavelength was measured with the frequency difference from pump frequency corresponding to irradiated THz frequency.

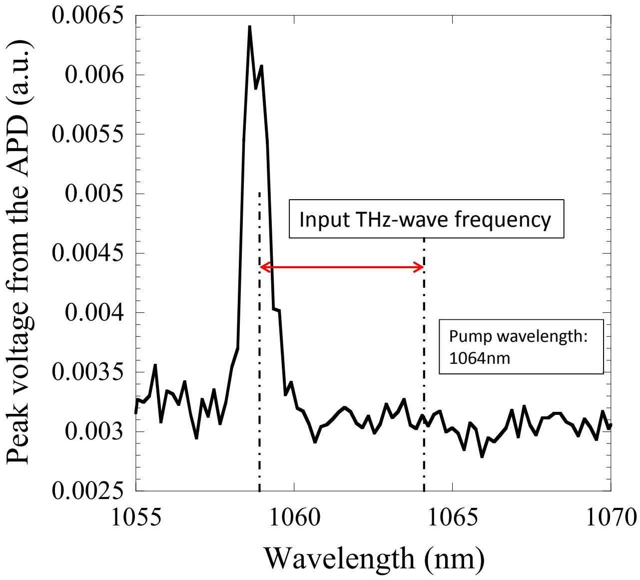

Fig. 2 Signal wavelength measurement using an APD and a grating.

IV. Summary

We demonstrated terahertz photon detection based on sum frequency generation using a periodically poled lithium niobate crystal. The signal observed at higher frequency than that of pump beam at the wavelength of 1064 nm. And the signal wavelength was measured with the frequency difference from pump frequency corresponding to irradiated THz frequency. The noise less photon conversion realizes terahertz photon detector operating at room temperature. Sum-frequency generation technique is a promising way as a single-photon detector in THz frequency region operating at room temperature.

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