Evolved injection seeded THz-wave spectrometer for mail inspection

Kodo Kawase[1, 2], Ryo Yamzaki[1,3], Kazuki Imayama[1], Kosuke Murate[1]

[1] Nagoya University, Furo-cho, Chikusa, Nagoya 464-8603, Japan
[2] RIKEN, Advanced Science Institute, Aramaki-Aoba, Sendai 980-0845, Japan
[3] Nagoya Customs, Irifune, Minato, Nagoya 455-8535, Japan

***Abstract*— In 2003, we demonstrated a non-destructive terahertz spectroscopic imaging of illicit drugs hidden in envelopes using a widely tunable THz-wave parametric source [1], though its dynamic range at that time was less than four orders. Recently, we have realized ten orders of dynamic range with an evolved injection seeded THz-wave spectrometer. Now we can detect drugs under much thicker obstacles than before. In this report, we introduce related topics; 1) Enhanced tuning range up to 4.7 THz, 2) >90dB dynamic range THz detection using near infrared detector, 3) Comparison between is-TPG spectrometer and TDS, and 4) THz-wave amplifier.**

I. WIDER TUNABILITY

For years, we have worked on the development of a high-power THz-wave source, based on parametric processes in a $LiNbO_3$ crystal [2]. In 2001, we created an injection-seeded THz-wave parametric generator (is-TPG) [3] with 300mW output. Recently, the peak output power of is-TPG approached 100 kW [4] by introducing a new pump laser; a microchip YAG laser with shorter pulse width [5]. However, the tunability of is-TPG was still limited less than 3 THz due to the strong absorption loss inside the $LiNbO_3$ crystal. In order to suppress this absorption loss, we tilted the $LiNbO_3$ crystal slightly so that the THz waves were generated at the very near-surface of the crystal. The pump beam was totally reflected at the crystal surface where the THz-wave was generated. Thus we have realized much wider tunability up to 4.7 THz.

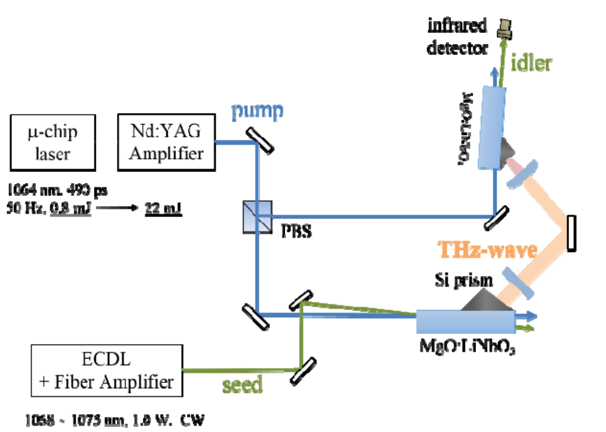

Fig.1. Experimental set up for THz spectrometer using is-TPG

II. HIGHER DYNAMIC RANGE

In the detection section of our system, THz-wave was converted back into near infrared beam by nonlinear optical wavelength conversion [6] as shown in Fig. 1. Since the detection methodologies in optical frequency region are well established and high sensitive near infrared detectors are readily available, we were able to measure the extremely small THz-wave output by measuring the power of converted near infrared beam. In order to measure the dynamic range of our system, the energy of the emitted THz-wave was varied for 10 orders of magnitude using THz wave attenuators. At the frequency of 1.5 THz, we were able to achieve the dynamic range of > 90dB using commercially available near infrared photo detector as shown in Fig. 2 [7]. This system has potential applications in non-destructive sensing and imaging of a wide variety of materials [e.g.8].

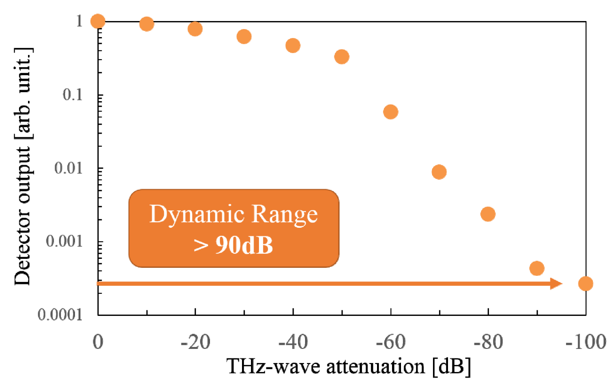

Fig.2. THz-wave attenuation VS Detector Output of idler

III. SPECTROSCOPY

An injection-seeded terahertz parametric generator (is-TPG) is monochromatic with a widely tunable THz wave source and can obtain THz spectra directly over a relatively wide detection area. Therefore, the spectra from the contents contained in covering materials that refract, diffract, or scatter THz waves can be measured using is-TPG. Recent is-TPG research has resulted in a significant increase in power output and the highly sensitive detection of THz-waves. Studies have also developed a high dynamic range spectrometer using an is-TPG. In this study, in order to evaluate the performance of is-TPG in mail inspection [1], we measured the transmission spectra of various chemicals under different covering materials using an is-TPG spectrometer, and compared the spectra with those measured by THz-TDS as shown in Fig. 3.

IV. AMPLIFICATION

We report a terahertz wave amplifier based on optical parametric processes in magnesium-oxide-doped lithium niobate ($MgO:LiNbO_3$) crystals. The amplifier operates at room temperature and has a gain of 55 dB [9]. The non-linear crystals used for the purposes of emission and amplification of the THz waves are pumped separately using a microchip laser (Fig. 4), which leads to an enhancement of the gain in comparison with existing approaches. The energy of both the input and output THz-waves were measured using a calibrated pyroelectric sensor. The energy of the input THz wave was varied in the range from 2.2 nJ/pulse to 1.7 fJ/pulse using a combination of calibrated THz attenuators. We were able to achieve a maximum gain of more than 55 dB as shown in Fig. 5, which is significantly larger than in our previous work.

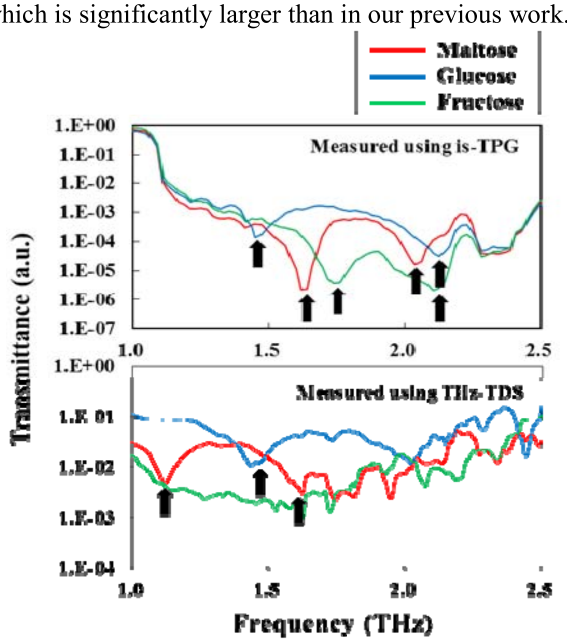

Fig. 3 Transmission spectra of powdered saccharides in standard bubble wrap envelops.

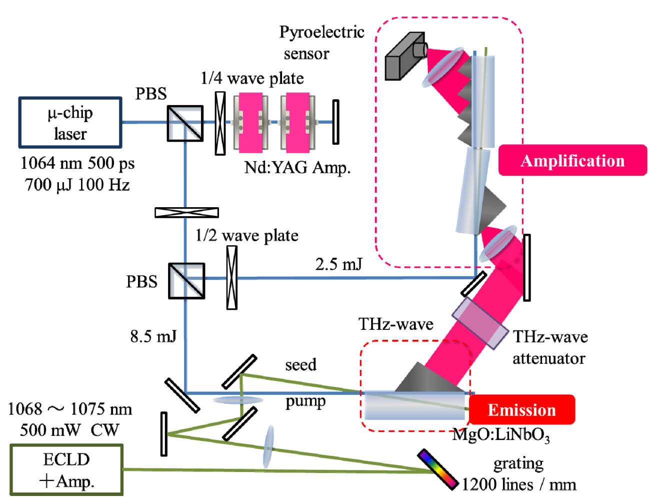

Fig. 4 Experimental setup used for THz wave amplification

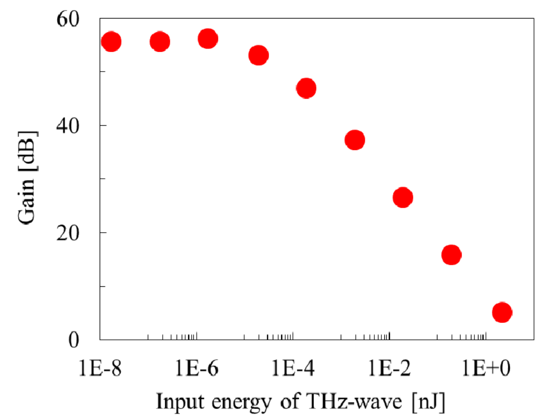

Fig. 5 The amplification gain plotted as a function of the input THz energy. The gain is calculated as $G = 10\log_{10}(E_{out}/E_{in})$, where E_{out} and E_{in} are the THz input and output energy respectively.

The authors wish to thank Dr. S. Hayashi, Dr. H. Minamide, Dr. K. Nawata of RIKEN and Prof. T. Taira of IMS for helpful discussions and advices. This work was partially supported by JSPS KAKENHI (25220606), and the Japan Science and Technology Agency (JST).

REFERENCES

[1] K. Kawase, Y. Ogawa, Y. Watanabe, H. Inoue, "Non-destructive terahertz imaging of illicit drugs using spectral fingerprints," Opt. Exp. **11** (2003) 2549.

[2] K. Kawase, M. Sato, H. Ito, "Coherent tunable THz-wave generation from $LiNbO_3$ with monolithic grating coupler," Appl. Phys. Lett. **68** (1996) 2483.

[3] K. Kawase, J. Shikata, K. Imai, H. Ito, "Transform limited, narrow linewidth, terahertz-wave parametric generator," Appl. Phys. Lett. **78** (2001) 2819.

[4] S. Hayashi, K. Nawata, T. Taira, J. Shikata, K. Kawase, H. Minamide "Ultrabright continuously tunable terahertz-wave generation at room temperature," Scientific Reports **4** (2014) 5045.

[5] H. Sakai, H. Kan, T. Taira, "> 1 MW peak power single-mode high-brightness passively Q-switched Nd:YAG microchip laser," Opt. Exp **16** (2008) 19891.

[6] H. Minamide, S. Hayashi, K. Nawata, T. Taira, J. Shikata, K. Kawase, "Kilowatt-peak Terahertz-wave generation and sub-femtojoule Terahertz-wave pulse detection based on nonlinear optical wavelength-conversion at room temperature," J. Infrared, Millim THz Waves **35** (2014) 25.

[7] K. Murate, Y. Taira, S. R. Tripathi, S. Hayashi, K. Nawata, H. Minamide, K. Kawase, "A high dynamic range and spectrally flat terahertz spectrometer based on optical parametric processes in $LiNbO_3$", IEEE THz Sci. Tech. **4** (2014) 523.

[8] M. Tonouchi, "Cutting-edge terahertz technology," Nature Photonics **1** (2007) 97.

[9] Y. Taira, S. R. Tripathi, K. Murate, S. Hayashi, K. Nawata, H. Minamide, K. Kawase, "A terahertz wave parametric amplifier with a gain of 55dB" IEEE Trans. Terahertz Sci. Tech. **4** (2014) 753.