Real-time measurement system using multi-wavelength THz-wave parametric generation and detection

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Abstract

In this study, we achieved real-time identification of reagents using combination of machine learning and simultaneous generation and detection of multiwavelength terahertz (THz) waves by injection seeded terahertz wave parametric generator (is-TPG).

1. Introduction

We have spent many years developing an injection-seeded terahertz (THz) wave parametric generator (is-TPG) as a high-power THz-wave source with a $LiNbO_3$ crystal. Recently, we achieved a peak power of 50 kW and frequency tunability of 0.4–5 THz[1], [2]. is-TPG is a narrow linewidth and high brightness THz wave source; therefore, it can generate one wavelength per pulse, and the wavelength was tuned for each spectroscopy. On the other hand, in this study, we aimed at simultaneous generation of multiwavelength THz waves from is-TPG. In multiwavelength generation, the wavelength does not need to be changed, which would shorten the measurement time. Averaging would also not be required because spectroscopy is done by one pulse. Moreover, we introduced machine learning for identification of samples. This would enable real-time identification system with a repetition rate equal to that of the excitation laser.

2. Principle of multi-wavelength generation and detection using is-TPG

When a high-power pump beam and seed beam are input to a $LiNbO_3$ crystal, narrow line width and high brightness THz wave is generated by parametric wavelength conversion. At that time, wide tunability of THz wave can be achieved by controlling the wavelength of the seed beam and its angle to satisfy the non-collinear phase-matching condition of the $LiNbO_3$ crystal. We call this THz wave source is-TPG[1], [2]. On the other hand, when the multi-wavelength seed beams are injected to the crystal, the energy was distributed to each wavelength and multi-wavelength THz wave is generated[3]. Although the principle of multi-wavelength generation is simple, multi-wavelength seed beam source (i.e. multiwavelength continuous-wave laser) was not easily accessible. Therefore, we prepared it by combination of multiple external cavity laser diode (ECLD).

The detection of THz wave is also possible using same principle of is-TPG[1], [2]. It is the reverse of generation; in other words, a THz wave is used as the seed beam, and a near-infrared detection beam is generated. In this method, the generation angle of the near-infrared detection beam changes based on the wavelength of the input THz wave, according to the non-collinear phase-matching condition. Therefore, one-pulse spectroscopy is achieved by inputting multi-wavelength THz waves and converting the generation angles of the resulting multi-wavelength near-infrared detection beam to THz-wave frequencies.

3. Experiment and results

A schematic diagram of the experimental system is shown in fig. 1. A pump beam emitted by a micro-chip Nd:YAG laser and a five-wavelength seed beams emitted by five ECLDs irradiate a $LiNbO_3$ crystal under non-collinear phase matching conditions, resulting in the emission of five wavelength THz waves. The emitted THz waves are focused

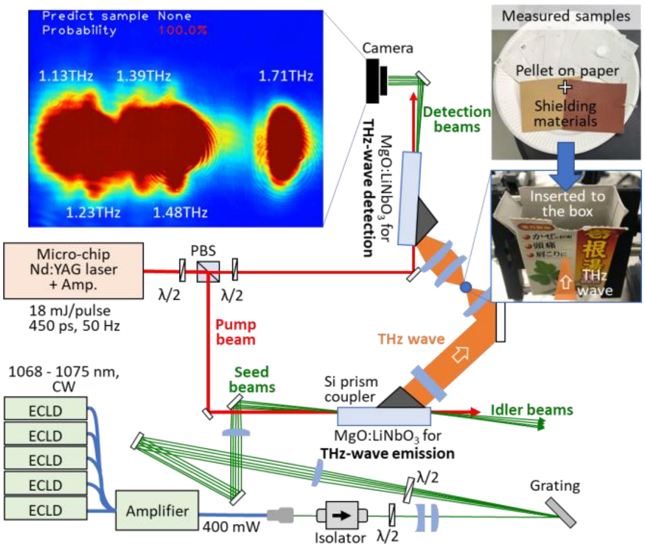

Figure 1: Real-time measurement system with combination of deep learning and multi-wavelength THz-wave parametric generation and detection. Right upper side inset shows the measured samples.

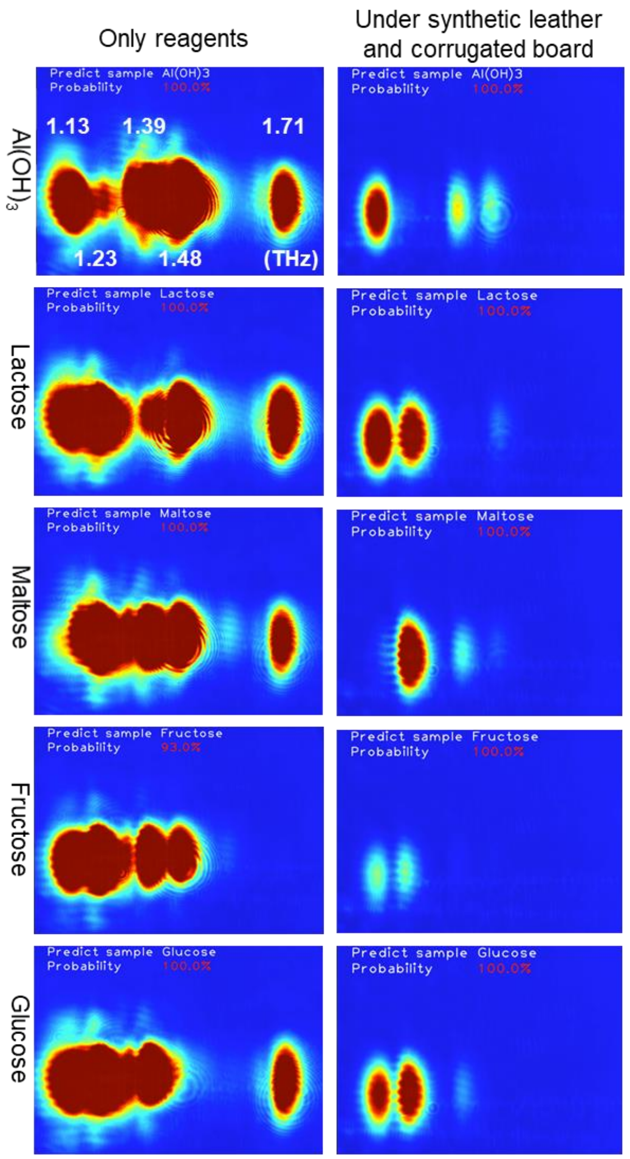

Figure 2: Screenshots of detection beams measured with camera when each sample was inserted to the THz path. The "predict sample" and "probability" shown in the upper part of each screenshot shows the identified result at that time via the CNN.

onto the sample and then it is up-converted to a near-infrared (NIR) detection beams at another crystal. Here we used camera to detect the multiple detection beams.

We measured five pellet samples of Aluminium hydroxide, Lactose, Maltose, Fructose and Glucose on the paper. Those samples were placed under some shielding materials which were and combination of those two shielding materials. The emitted THz frequencies were chosen as 1.13, 1.23, 1.39, 1.48 and 1.71 THz that matched to the absorption peak of samples.

The real-time identification was performed on images of the detection beams obtained with the camera. We input those data for the convolutional neural network (CNN)[4], [5], which is one of the deep neural network specialized for image data, and classified seven classes which were five reagents, Shielding (includes three kinds of shielding materials), and None. As training data for CNN, we used 30 images of each class, for a total of 270 images.

Upper left side inset of fig. 1 shows an image of the detection beams without any sample (i.e. None class). At that time, intensities of detection beams were saturated because it was optimized when samples with shielding materials were inserted to the THz path and attenuated THz wave. Fig. 2 shows the results of real-time measurement. We took screenshots, showing the timing when each sample was inserted to the THz path. An absorption profile corresponding to the transmitted spectrum of each sample was obtained using the multi-wavelength is-TPG in real-time. The "predict sample" shown in the upper part of each screenshot shows the sample name predicted in that instant via the CNN; "probability" corresponds to the sample prediction probability. By applying the CNN to the images of the detection beams, all samples were identified with almost 100% accuracy. This shows that, by combining multi-wavelength is-TPG with a CNN, samples can be identified through shielding material in real-time.

4. Conclusions

In this work, we achieved real-time measurement of reagents using multi-wavelength is-TPG. Sample was identified in real-time with almost 100 % prediction rate using CNN. The results of this study are expected to advance THz nondestructive testing technology.

Acknowledgements

Authors appreciate with Dr. S. Hayashi of NICT; Dr. H. Minamide, Dr. K. Nawata, and Dr. Y. Takida of Riken; and Prof. T. Taira of IMS for the fruitful discussions and Mr. R. Mitsuhashi, Ms. R. Kawaguchi and Mr. Y. Torii from Nagoya University for assistance in the experiments.
This work was partially supported by Japan Society for the Promotion of Science KAKENHI (18H03887, 19H02627); and Research Foundation for Opto-Science and Technology.

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