Active Gas Sensing with Sub-terahertz Waves Reflected from a Wall

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***Abstract*—We present active gas sensing with a sub-terahertz (THz) spectrometer. The transmitter and receiver of the system are composed of a photonic-base source and a Schottky barrier detector, respectively, and their arrangement is monostatic. From the intensity of the absorption peak of the received sub-THz signal, the density of the sample gas (N_2O) can be successfully obtained.**

I. Introduction

It is expected that various substances can be identified by making use of the characteristic feature of terahertz (THz) and sub-THz electromagnetic waves; that is, many material have their own fingerprint spectra in these frequency regions. The cw-THz spectrometer is one of the systems suitable for such material identification applications [1-5]. Another characteristic of THz and sub-THz wave is that they are less scattered by dust, soot, and smoke. By exploiting this characteristic, we can realize the system that can detect toxic gases from a distance in a disaster area and assist rescue operations and minimize disaster damage. In disaster situations, THz-waves should be transmitted over a long distance. So, a cw-THz wave source with narrow line width and high frequency accuracy is indispensable. Using the photonic technologies, we have already realized cw sub-THz-wave generators that meet these requirements [6, 7]. In this study, we developed an active sub-THz spectrometer utilizing this photonic-base sub-THz source. The system has a monostatic configuration, which is free from complex simultaneous control of beam directions of the transmitter (Tx) and receiver (Rx) and can provide simple and easy operation for remote gas sensing. The basic remote gas sensing operation of the system is presented.

II. Experimental Setup

Figure 1 schematically shows the developed system. The THz waves generated from the photonic-base sub-THz source [6] are once collimated with an off-axis parabolic mirror (OPM) and irradiated toward the wall. The THz waves reflected and returned from the wall are once bounced perpendicularly from the propagating direction by a half mirror (HM) and then focused onto a Schottky barrier diode detector by another OPM (OPM2). In this configuration, we precisely positioned the HM and OPM2 so that the beam propagation directions of the transmitted and received signals are parallel to each other. Therefore, a monostatic configuration of the Tx and Rx was realized. The intensity of the THz waves detected was measured with a lock-in amplifier. The length of the gas cell was 1 m. It was filled with N_2O diluted with N_2. Total pressure inside the cell was 1 atm. The measurements were carried out with Tx output power of about 20 μW.

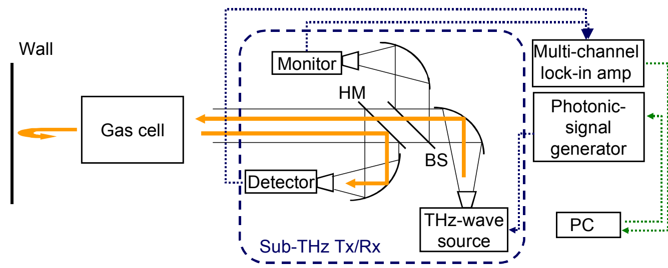

Fig. 1: Experimental setup. BS: beam splitters, HM: half mirror.

III. Results and Discussion

Red and blue circles in Fig. 2 show the measured spectra of the N_2O gases with densities of 25 and 75%, respectively. Here, we used an optical mirror as a wall that reflects the THz wave transmitted from the Tx. The reflectance of the wall for the THz wave was almost 100%. The wall was positioned 1.3 m from Tx/Rx. Two absorption peaks at 452.5 and 477.7 GHz, originating from the rotational transition of the N_2O molecules, were clearly observed for each spectrum. The solid lines are Lorentzian functions fitted to the measured spectra [7]. From these curves, we derived the N_2O density of sample gases. As shown in Fig 3, the densities derived from the spectrum curve fitting agree well with the densities of N_2O in the sample gas prepared for this measurement. These results indicate that our system can derive the N_2O gas density between 25 and 75% with the measured absorption spectra.

The results shown above were obtained in the condition where the reflectance of the THz wave at the wall was very high.

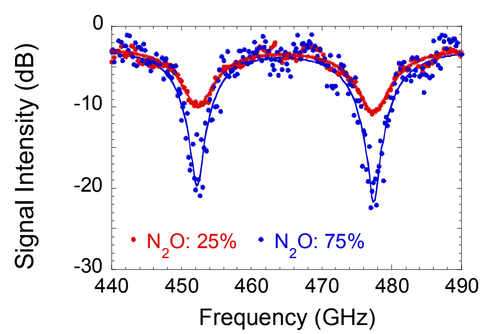

Fig.2: Spectra of N_2O gas (red and blue circles). An optical mirror placed at 1.3 m from Tx/Rx was used as a THz-wave reflector in this measurement. Solid lines are curves fitted to the measured data.

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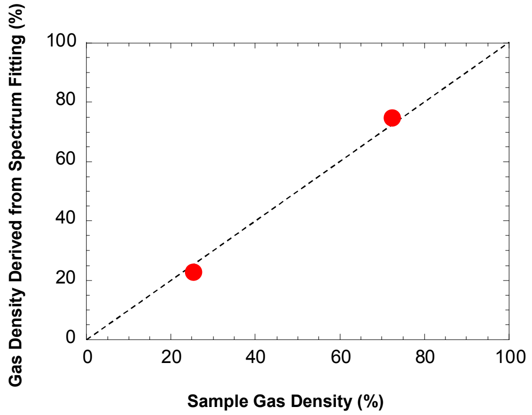

Fig.3: The N_2O gas densities measured from spectrum curve fitting.

Next, we changed a wall to one of the outer walls commonly used for Japanese houses. It was made of a metal and formed-resin base composite material. The average reflectance of the wall for THz waves with a frequency between 440 and 490 GHz was 20%. The wall was also positioned 1.3 m from the Tx/Rx, and the gas cell was placed between the Tx/Rx and the wall. Figure 4 shows the measured spectrum. When this result is compared with that shown in Fig. 2, a decrease in the signal intensity is observed at 440, 465, and 490 GHz. This is due to the low reflectance of the wall used in this measurement. Two absorption peaks of N_2O gas were observed in spite of such a low signal level. The solid line shown in the figure is the curve fitted to the experimental result. The gas density in the cell derived from this curve was 64%. This value agrees well with the N_2O gas density in the cell derived from the absorption spectrum that was measured with the wall with high reflectance (an optical mirror).

Finally, we tested this system when the gas cell and a wall were placed at a longer distance from Tx/Rx. In this measurement, an optical mirror was used as a wall. The distance between the Tx/Rx and the gas cell, and between Tx/Rx and the optical mirror were 2.5 and 3.6 m, respectively. Circles in Fig. 4 show the measured THz spectrum. A decrease in the signal intensity is also observed in this same way as observed in Fig. 4. This is due to the expansion of the THz beam diameter as a result of the longer distance propagation. However, two absorption peaks of N_2O gas were observed in this condition. The solid line in the figure is the curve fitted to the experimental result. The gas density in the cell derived from this curve is 31%, which agrees well with that derived in

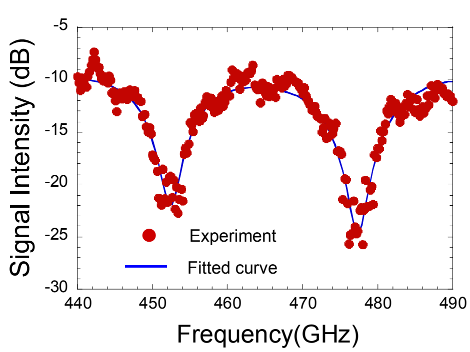

Fig. 4: Measured N_2O gas spectrum. An outer wall commonly used for Japanese houses was used as a wall that reflects transmitted THz-wave. Solid lines are curves fitted to the measured data.

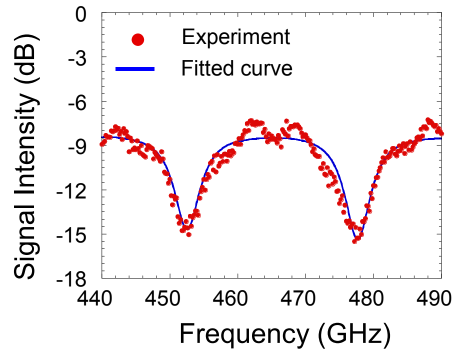

Fig. 5: Measured and calculated spectra of N_2O gas. The distance between Tx/Rx and wall was 3.6 m.

advance. These results indicate the probability of applying the developed sub-THz with the monostatic configuration for active remote gas sensing.

The maximum distance between the Tx/Rx and a wall is estimated to be less 5 m for the present system. This limitation was deduced from the beam diameter of the propagating THz wave and the noise level of the Rx. The limitation can be overcome by installing a Tx/Rx antenna with narrow radiation angle and high-sensitive receiver that fully exploit narrow linewidth and frequency accuracy of Tx.

IV. CONCLUSION

Active gas sensing with a sub-THz transmitter and receiver in a monostatic configuration has been successfully demonstrated.

ACKNOWLEDGEMENT

We thank T. Kimura for his assistance in our experiment. This work was supported in part by the National Institute of Communications Technology, Japan.

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