Terahertz Time Domain Spectroscopy of Petroleum Products and Organic Solvents

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***Abstract*—We demonstrate the application of terahertz time domain spectroscopy (THz-TDS) for analysis of petroleum products and organic solvents. Refractive index, absorption coefficient, and dielectric constant of gasoline, diesel, kerosene, and organic solvents such as xylene, toluene, and benzene were analyzed in the spectral range of 0.2 – 2 THz. Variation of physical properties for the mixture of gasoline and organic solvent was also investigated.**

I. Introduction And Background

PULSE terahertz time domain spectroscopy (THz-TDS) is a coherent technique, in which both the amplitude and the phase of a THz pulse are measured. THz-TDS provides a non destructive and contactless method for studying various kinds of liquid sample[1-3)]. The discrimination among various kinds of petroleum products and organic solvents is important for the product identification and screening applications. The goal of this study is to investigate the feasibility of THz-TDS for a quantitative analysis of petroleum products and organic solvents. Physical properties of six kinds of petroleum products and organic solvents were obtained. And the change in the physical properties for the mixture of gasoline and organic solvents was also measured.

II. Experimental

We carried out the THz-TDS with a standard transmission type system using photoconductive antennas as emitter and detector of THz radiation. A commercial mode-locked Ti:Sapphire laser (Spectra Physics Mai Tai) producing 100 fs pulses at 800 nm pumped the antennas for generating and detecting THz pulses. In order to prevent absorption by atmospheric water vapor, we enclose the THz generation and detection components in an acryl box supplied with dry air. The output signal from the detector antenna is monitored with a lock-in amplifier and a computer. At each scan 1024 data points, separated by 0.04 ps, were collected with a time constant of 100 ms.

The cell for containing liquid samples is fabricated and installed in the path of the THz wave. The cell structure for containing liquid samples is illustrated in Fig.1. The cell diameter is 20 mm with a thickness of 5 mm, and is covered by 2 mm thick poly-tetrafluorethylene (PTFE; teflon) windows at both sides. The time-domain THz pulses were obtained by first measuring a THz reference pulse transmitted through the empty cell and then measuring the sample pulse transmitted through the same cell filled with the liquid under investigation. The optical constants are next obtained by comparing the Fourier transforms of the sample and reference pulse.

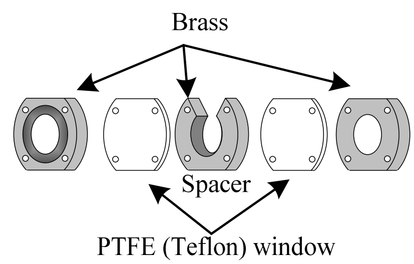

Fig. 1 Structure of liquid sample holder

III. Results

In the present study, three kinds of petroleum products (gasoline, diesel, and kerosene) and three kinds of organic solvents (benzene, toluene, and xylene) were used as liquid samples. Fig. 2 shows the measurement results of refractive indices of liquid sample. Refractive indices of petroleum products are distributed from 1.405 to 1.455 at 1 THz, and can be distinguished each other by their absolute value. On the whole, the refractive indices of the organic solvents have higher values than those of the petroleum products by more than 0.04. The difference of 0.04 in refractive index is large enough to be detected by the THz-TDS system.

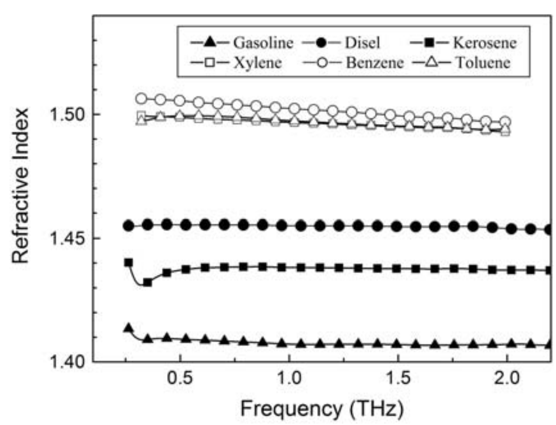

Fig. 2 Refractive indices of petroleum products and organic solvents

Fig. 3 shows comparison of absorption coefficients of petroleum products and organic solvents. Absorption coefficient of gasoline is higher than diesel or kerosene by five times. Organic solvents show higher absorption than petroleum products at high frequency region. Clear difference in refractive index and absorption coefficient imply that it is

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possible to identify the several kinds of petroleum products and organic solvents by THz-TDS.

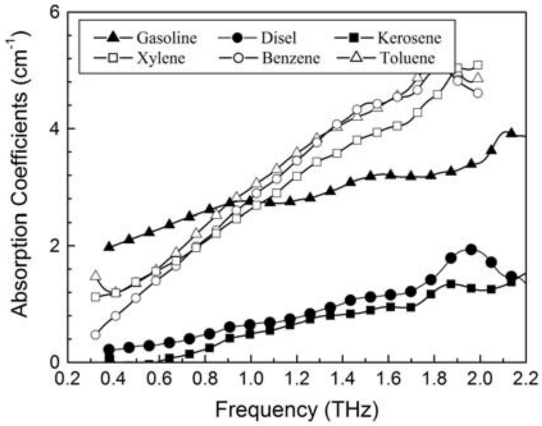

Fig. 3 Comparison of absorption coefficients of petroleum products and organic solvents

Using the individual properties of the petroleum products and the organic solvents, we made quantitative analysis on the mixture of them. Gasoline and toluene were mixed with different mixing ratio. Fig. 4 shows the variation of refractive index when the toluene content was changed from 0 to 100 % of total volume. We can see that the refractive index of the mixture increase linearly with volume fraction of toluene. Especially, when the mixture ratio is 50:50, the refractive index of mixtures was almost equal to an average of the refractive index of the component liquids ($n_{Gas.+Tol.}$ = 1.452, $(n_{Gas.} + n_{Tol.})/2$ = 1.452, @ 1THz). However the absorption coefficient of the mixture does not show a systematic variation, as shown in Fig. 5.

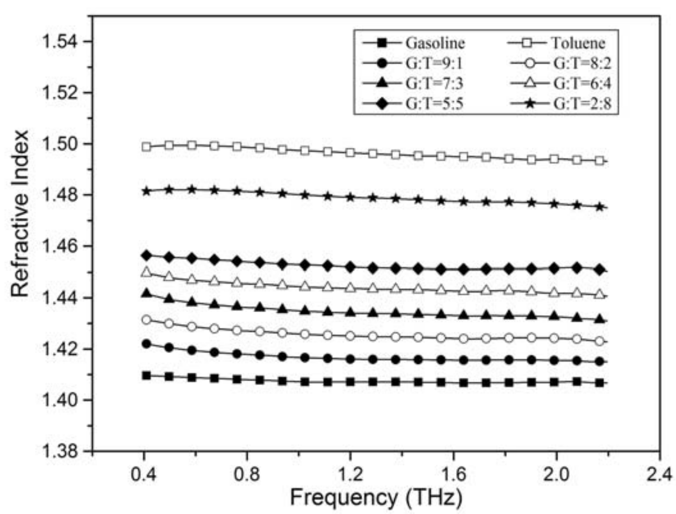

Fig. 4 Refractive index variation of the mixture of gasoline and toluene. The toluene content was changed from 0 to 100 % of total volume

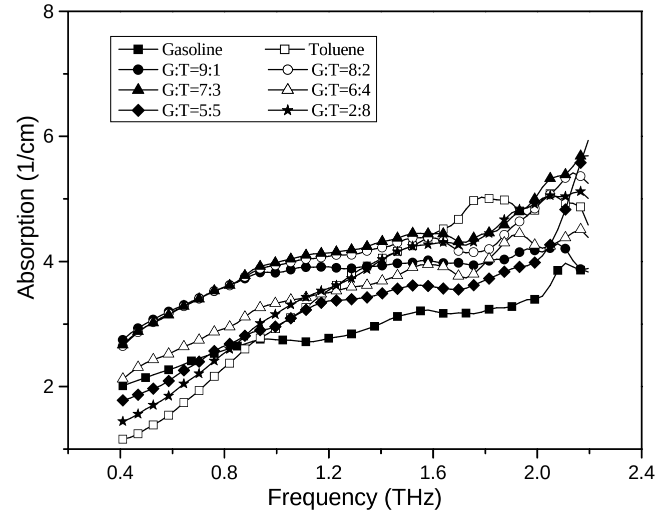

Fig. 5 Absorption coefficient of the mixture of gasoline and toluene. The toluene content was changed from 0 to 100 % of total volume

IV. Conclusion

Physical properties of three kinds of petroleum products and three kinds of organic solvents were investigated by the transmission THz-TDS method. Measurement of refractive indices and absorption coefficient in the THz range revealed that we can identify the species of pure petroleum product and organic solvents by THz-TDS.

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