Focused beam effect on measuring precise optical parameters of liquid water with terahertz time domain spectroscopy

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***Abstract*— We study the refractive index and the absorption coefficient of liquid water with collimated beam and focused beam. Optical parameters with focused beam are inaccurate explained by the Gouy shift. This inaccuracy is theoretically calculated and will be compared with the experimental results with THz-TDS.**

I. Introduction And Background

Terahertz (THz) Time-Domain Spectroscopy (TDS) is a powerful tool for measuring optical properties of various materials in THz region. It simultaneously provides both real and imaginary part of the dielectric constant without using the Kramers-Kronig relations. However, there are intrinsic sources of error in THz-TDS [1].

When it comes to the samples, precise sample thickness determination is the most important factor for the accurate optical parameter extraction of the sample. And multiple reflection removal is another key factor because, in many cases, samples act like Fabry-Perot resonator in the THz time window [2].

While appropriate beam characteristic which illuminate the samples should also be considered. Tightly focused beam is frequently used as the wavelength of the THz wave is not small enough compared to the typical sample dimensions. But, plane wave approximation is typically used for the optical parameters extraction. Previous study showed that [3] focused electromagnetic pulses experience dramatic phase change which is called Gouy shift. And a recent study [4] shows that plane wave approximation leads to the overestimation of the refractive index of low absorbent materials when focused beam is used for the optical parameter extraction explained by Gouy shift. But plane wave approximation didn't lead inaccurate absorption coefficients of the samples.

Water, highly absorbent in the THz region, plays an essential role in various physical, chemical, and biological processes [5]. Especially solvation dynamics of molecules is widely studied with THz spectroscopy [6] because intermolecular vibration modes lie in the THz range. Although small absorption coefficient change of water should be precisely measured, beam characteristic dependence to the absorption coefficient has not been discussed yet.

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II. Results

Ti: sapphire laser was used for a light source. Photoconductive antenna was used for generating the THz wave. Electro-optic detection method was chosen to measure the THz signal. 4 parabolic mirrors are used for collimating and focusing the THz wave (fig.1). Beam waist location is shifted as follows when the sample is put in the focused beam. This leads to inaccurate optical parameters (eq. (1) and fig. 2).

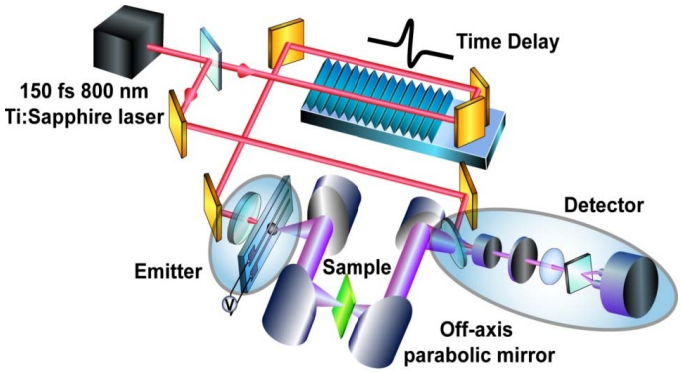

Figure1.THz-TDSexperiment setup

$$\Delta l = (d_1 + d_2 + d_3) - \left(\frac{n_0}{n_1} * d_1 + \frac{n_0}{n_2} * d_2 + \frac{n_0}{n_3} * d_3\right) \quad \text{- (1)}$$

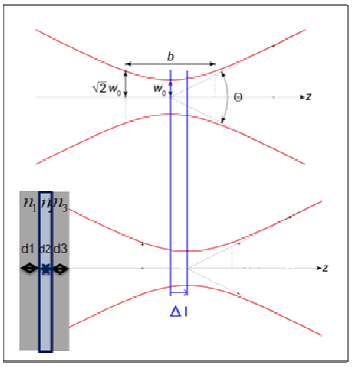

Figure2. Beam waist shift

First, we measured the optical parameters of the HRFZ-Si window. Figure2 shows the refractive index of the HRFZ-Si window (1mm-thick). Oscillations are observed throughout the frequency range due to the multiple reflections from the ZnTe crystal used for the THz detection. And the refractive index of the window measured with focused beam is overestimated which is consistent with the previous study [4].

The refractive index of HDPE window (3.5mm-thick) also showed the discrepancy when focused beam and collimated beam are used respectively (data not shown).

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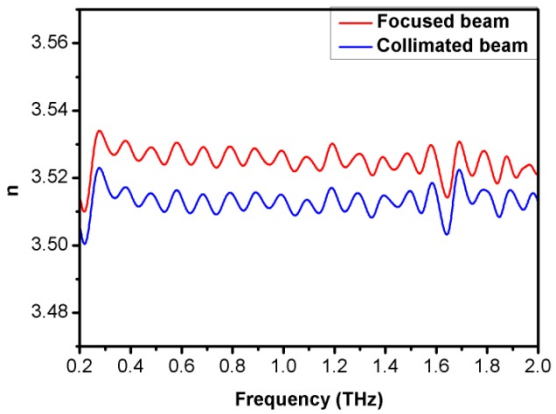

Figure3. Refractive index of the HRFZ-Si window (1mm-thick)

III. CONCLUSION

The optical parameters of HRFZ-Si, and HDPE windows were measured with collimated beam and focused beam. The refractive index measured with focused beam is inaccurate explained by the Gouy shift. This inaccuracy is theoretically calculated and is compared with the experimental results with THz-TDS.

Focused beam effect on the liquid water will be studied in the near future.

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