Control of random fluctuations in terahertz time-domain spectrometer

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***Abstract*—Beam pointing fluctuations originating from air turbulence and thermal drifts are the major sources of random error in terahertz time-domain measurements. We have reduced these pointing fluctuations from 5.4 mrad to 1.8 mrad with proper control of air turbulence and temperature thus increasing the reproducibility of the measurements.**

I. INTRODUCTION

TERAHERTZ time domain spectroscopy is a phase-sensitive technique to measure optical and dielectric parameters of different materials in THz range. It has been used to investigate numerous materials including polymers, semiconductors, liquids, crystals, organic materials, and thin films etc. This technique is advantageous over other techniques, such as Fourier transform infrared (FTIR) spectroscopy, due to its coherent detection and high signal-to-noise ratio. Inspite of that, its measurements have certain uncertainties, major arising from laser-source instability, optical & electronic noise, water vapors fluctuations, and reflections from sample surfaces [1]. Effects of these instabilities on the measured parameters of the samples under investigation have been previously addressed analytically and the propagation of this error to the final results has also been explained in Ref. [2-5]. However, to the best of our knowledge, the effects of laser-beam pointing on THz emitting and detecting photo-conductive antennas have not been studied. Air fluctuations and temperature drifts disturb laser beam pointing on THz antennas which results in the change in the photo-resistance of the antenna thereby affecting the amplitude of emitted THz signal and extracted parameters. This effect reduces the reproducibility and reliability of the measurements. Our previous experience of THz-TDS [6] reveals that these measurements are quite sensitive to the beam pointing fluctuations. Particularly, for the case of discrimination of similar species, where minor difference of parameters is expected, such errors have to be minimized. Otherwise, the results might be intermixed in the error bars. In this work, we have performed studies of such fluctuations and have provided a solution to reduce them to an acceptable level.

II. EXPERIMENTAL DETAILS

To investigate the effect of laser beam pointing on THz signal amplitude, we have used the standard THz-TDS system from EKSPLA, shown in Figure (1). It consists of photoconductive antenna based THz emitter and detector which are pumped by a femtosecond fiber laser (TOPTICA) of pulse duration 100 fs, repetition rate 82 MHz, and average power 150 mW. The laser beam has been divided into two parts with beam splitter (BS1). One part has been used to generate THz while other part is used to optically gate the THz pulse. The delay between THz emitting and detecting pulse has been controlled with delay line. THz emitter is DC biased with 40 V modulated at 70 KHz. The data is recorded with the lock-in technique. The components of THz-TDS setup are mounted on an Aluminum base plate.

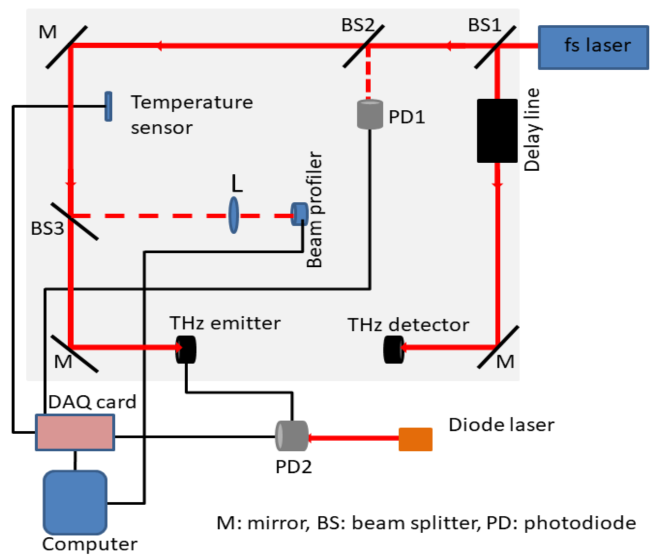

Figure 1: The schematic of standard THz-TDS setup along with additional elements for the measurement of beam pointing effects on THz signal. The solid line shows the path of laser for standard system and dashed line represents the parts of laser used for systematic measurement of laser power using photodiode (PD1) and pointing fluctuations with beam profiler (WinCamD-UCD12, DataRay Inc.), while the temperature sensor measure the base plate temperature.

To control the laser pointing fluctuations, the standard THz-TDS system has been upgraded. The air fluctuations have been reduced with covering the system with enclosure. Whereas, the laser pointing fluctuations due to thermal build up, have been reduced by controlling the temperature of the base plate of THZ-TDS setup. For this purpose, a temperature controlled cooling plate has been attached with base plate. The design of temperature controlled cooling plate is shown in Figure (2). Its lower part is an acrylic sheet and the upper part consists of copper (Cu) tubing in which water flows at particular temperature. Water temperature has been controlled with chiller. For the better thermal conductivity between the cooling plate and base plate of THz-TDS setup, thermal paste has been applied. However, the acrylic sheet prevents the thermal conduction between the upper part of cooling plate and optical table.

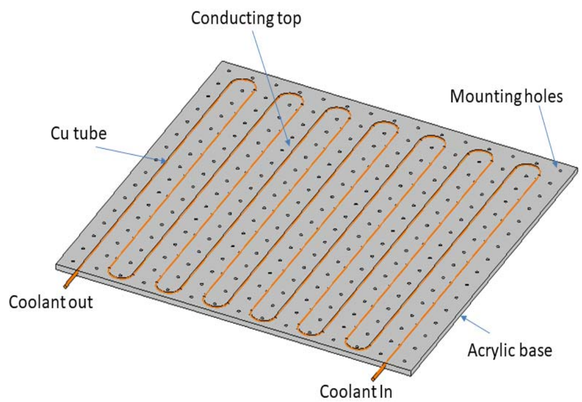

Figure 2: The design of temperature controlled plate which has been used to reduce the beam pointing fluctuations due to thermal build up. Its acrylic base acts as a thermal shield between base plate and optical table and copper tubing controls the temperature (±0.2 ^{O}C) with water flowing through them.

The measurements have been performed by imaging the THz antenna on the CDD of the beam profiler (WinCamD, DataRay Inc.). A part of laser from beam splitter (BS3) has been used for this purpose. The effect of laser beam pointing on THz signal amplitude has been measured sensitively by measuring the photo-resistance of PCA. For this purpose, the photo-resistance has been used as a load resistance of large aperture photo-diode illuminated with a constant power of diode laser. A part of laser from beam splitter BS2 has been used to monitor the laser power. The temperature of base plate, optical table and laboratory has been measured with LM35 temperature sensor.

III. Results

For the systematic measurements, all the variables, such as THz signal, photo-resistance of antennae, laser power, base-plate temperature, optical-table temperature, and the room temperature have been monitored in-parallel using different probes. Firstly, the measurements were performed under uncontrolled conditions, i.e., without the enclosure and temperature control, in order to study the cumulative effect of air-fluctuations and temperature drifts. Later on, the system performance was checked in the controlled conditions in two steps, i.e., with i) enclosure, and ii) with temperature-controlled base plate.

Figure (3a) shows the base plate temperature, THz signal, laser power and beam pointing (inset of figure 3a) in uncontrolled conditions. Here the temperature of base plate has shown a slow drift of 1.5 ºC in 3 hours. Laser beam position at the beam profiler was fluctuated upto 5.4 mrad, reducing the THz signal by 40%. The laser power remained nearly constant during the measurements as shown in Figure (3a), indicating that the measured THz instabilities could be correlated with the beam pointing fluctuations due to air-turbulence and temperature drifts.

For the second case, when the same measurements were repeated with the enclosure, the beam pointing fluctuations reduced from 5.4 mrad to 4.1 mrad. The THz signal instability was measured to be 32%. Finally, under the temperature-controlled environment the fluctuations were further reduced to less than 1.8 mrad, and the THz signal instability to <5%. This improvement will be helpful to enhance the reliability and preciseness of the optical parameters such as refractive indices and absorption coefficients.

IV. Summary

In summary, the laser beam pointing fluctuations due to air turbulence and thermal drifts have been reduced with control on these parameters. The fine control has reduced the THz amplitude instability to an acceptable value. This improvement results in more precise and reproducible measurements of optical parameters, including absorption coefficient and refractive index of low absorbing samples and thin samples.

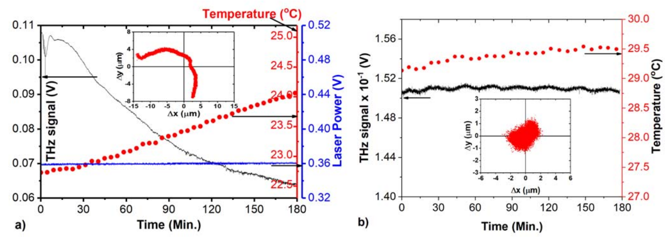

Figure 3: a) The variation of THz signal, laser power, and temperature with time for uncontrolled conditions whereas, inset depicts the beam pointing fluctuation during measurements. b) Represents the temperature and THz signal in controlled conditions and inset shows the beam pointing.

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