Quasi-near field terahertz time domain spectroscopy

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***Abstract*—We present a simple experimental set-up to generate and detect terahertz (THz) radiation with a large bandwidth of 7.5 THz. We show that by keeping the generation and detection crystals close to each other, a high signal-to-noise ratio (SNR) can be achieved without using lock-in detection and dry nitrogen flushing. Using this set-up we have measured the absorption lines in D-tartaric acid from 0.5 THz upto 7 THz**

I. Introduction

Optical rectification is a frequently used method to generate broad band THz radiation [1]. In this method, an ultra short optical pulse is focused onto a non-linear crystal where it generates a polarization in the crystal that follows the envelope of the pulse [2]. We use electro-optic sampling to detect these pulses [3]. In this method the THz pulse co-propagates with the probe pulse in an electro-optic crystal. By measuring the THz field induced polarization change of the probe pulse, the THz electric-field can be measured. For efficient generation and detection of THz radiation it is important that the phase velocity of the THz radiation is equal to the group velocity of the pump/probe pulse [4]. Generally GaP crystals of thicknesses $\leq 100\mu m$ are used to fullfill this phase matching condition

In general, terahertz time domain spectroscopy (THz-TDS) requires parabolic mirrors to collect, collimate and focus the THz radiation onto the detection crystal [5]. It is very difficult to align these parabolic mirrors accurately and the increased THz beam path requires that the set-up be flushed with dry N_2 to reduce the absorption of the THz radiation by water vapor in the atmosphere. Typically, the pump beam intensity is modulated, in conjunction with lock-in detection to improve the SNR. Here, we describe a new set-up to generate and detect THz radiation, in which the generation and detection crystals are placed close to each other. Our set-up does not require parabolic mirrors to steer the THz beam and is intrinsically easy to align and does not suffer from the problems associated with the absorption of THz light by water vapor. We demonstrate that such a quasi-near field set-up allows us to achieve a high SNR and a large detection bandwidth up-to 7.5 THz without using lock-in detection.

II. Experiments and Results

Fig.1 shows our experimental setup. The THz pulses are generated by optical rectification of the femtosecond pulses of 50fs, 800 nm and average power of 960 mW (Scientific XL Femtolasers Produktions GmbH), in a GaP (110) oriented crystal. The beam from the oscillator is split into two equal parts by a 50/50 beam splitter. One part (pump) is used to generate THz pulses and the other part (probe) is used to detect the THz radiation. The pump beam goes through an optical delay stage and is then focused onto the generation crystal. Both the generation and detection crystals have a high reflectivity (HR) coating on one surface and an anti-reflection coating (AR) on the other surface for the pump and probe wavelengths. The probe beam is focused onto the HR coated surface of the detection crystal, where the THz electric field induces a change in polarization of the probe beam. The probe beam is reflected back from the HR surface of the detection crystal. Using a beam splitter, this back reflected probe beam is sent through a conventional electro-optic detection set-up, where the ellipticity and thus THz electric field is determined. We used GaP(110) crystals with a thickness of 300 μm for both the generation and the detection.

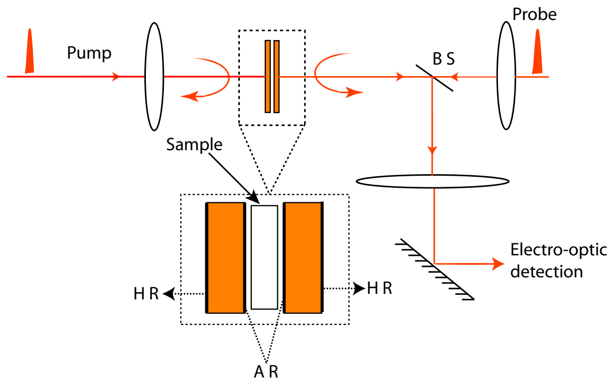

Fig. 1. Experimental set-up to generate and detect THz radiation. The detection crystal is placed very close to the generation crystal with the HR surfaces facing each other. The probe beam is reflected back from the High Reflectivity (HR) surface of the detection crystal. The beam splitter (BS) sends this to a conventional electro-optic detection set-up.

To demonstrate that our set-up is ideally suited to perform spectroscopy, we measured the absorption spectrum of D-tartaric acid [6], [7]. D-tartaric acid crystals are first ground using a mortar and pestle to reduce the particle size, so that light scattering is reduced to a minimum in the frequency range of interest. Polyethylene powder of particle size $\leq$ 30 μm (Mipelon XM-220, Mitsui Chemicals America, Inc) is mixed with the ground sample such that the the sample forms 30% of the total mass of the mixture. This is done to dilute the sample

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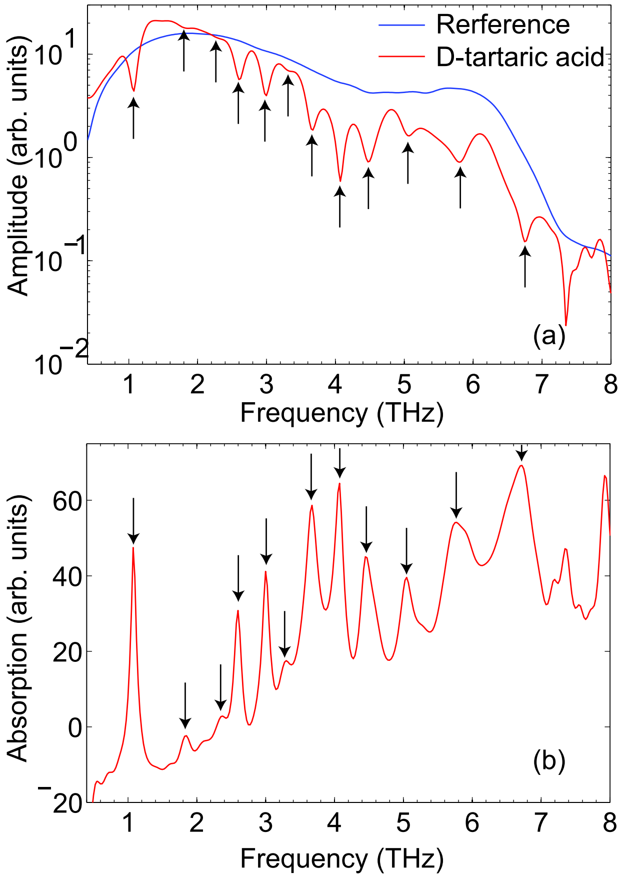

Fig. 2. (a) The spectra calculated from the temporal wave forms measured with and without pellet containing D-tartaric acid. (b) The absorption spectrum calculated from (a). The arrows indicate THz band positions

so that the absorption peaks are within the dynamic range of our system. The mixture is made into a pellet with a hydraulic press (Specac Ltd, UK). The pellets have a thicknesses of $\approx$ 0.6mm.

The D-tartaric acid pellet can be placed between the generation and detection crystals. Fig.2 (a) shows the THz spectra measured with and without a pellet containing D-tartaric acid. The absorption spectrum calculated from this is shown in Fig.2 (b). It can be seen from Fig.2 (a) that the measured bandwidth extends up-to 7.5 THz. The pump beam is slightly modulated by the movement of the speaker and this modulated pump beam reaches the detection set up, giving rise to a slow oscillation in the detected time domain signal. After calibration and fourier transformation, this slow oscillation will appear as a low frequency content in the THz spectrum as seen on Fig 2(a) below 40GHz. Reliable results are obtained from 0.5 - 7THz. The measured amplitude with the sample is higher than without the sample below $\approx$2 THz. This is due to the fact that the lower frequencies get diffracted less while being transmitted into the high refractive index sample than in to air and thus more effectively detected by the probe pulse. This gives rise to the negative values for absorption below $\approx$ 2 THz and can be considered as an artifact of our quasi-near field setup. In principle, these effects can be reduced by increasing the diameter of the pump beam and that the THz beam, which reduces the diffraction of the lower frequency components. Note that this result is obtained without using any lock-in technique and without flushing the set-up with dry nitrogen gas. We achieved a signal-to-noise ratio of $\approx$ 450 in a total measurement time of less than a minute.

III. Conclusions

We have presented a simple and efficient way to generate and detect THz radiation with a bandwidth of 7.5 THz which can be suitable for spectroscopy of solids and liquids.The Absorption spectrum of D-tartaric acid is measured in the frequency range of 0.5-7 THz

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