Confocal THz Imaging Using a Gas Laser

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***Abstract*—We report a clear improvement on the quality of terahertz (THz) images obtained with an optically pumped gas laser which emits at a wavelength of 119 µm. The improvement is achieved by employing the principle of optical confocal microscopy.**

I. Introduction And Background

There has been intensive research during the last few years in the field of terahertz technology. Since THz waves are able to penetrate most non-metallic objects, early detection of possible terrorist attacks, mail inspection, quality control and molecular spectroscopy are among the foreseen potential applications for terahertz technology [1,2]. Imaging techniques play a central role among these sensing applications. A common THz source is the optoelectronic generation and detection using photoconductive dipole antennas excited with femtosecond laser pulses [1,3]. Other schemes use a coherent THz-wave parametric oscillator, a Gunn diode or a quantum cascade laser. Here, we employ a far- infrared (FIR) gas laser as the source and a Golay cell as the detector. Our approach extents the early work of Hartwick et al. [4] in which a similar THz radiation source was used to obtain the first reported THz images of hidden metallic objects, and the recent work of Siegel and coworkers who used a THz gas laser in combination with a heterodyne detection scheme to investigate biomedical samples [5].

II. Experimental Setup and results

We use a far-infrared (FIR) laser with methanol (CH_3OH) as active medium in the THz resonator. Methanol is a molecular gas which has spectroscopic resonances that cover the spectral range from 0.3 - 10 THz. It is optically pumped by a CO_2 laser with an average power of 10 Watts, at a wavelength of 9.6 µm (31 THz). As a result methanol emits continuous wave THz radiation with a power of up to 50 mW at a wavelength of about 119 µm (2.52 THz).

The experimental setup of the confocal THz laser microscope is depicted in figure 1. A confocal imaging setup is an optical system that has three foci along the optical path [6] in which a very tight focus guarantees a high resolution and point to point imaging of the confocal part of the sample. To increase the contrast and to improve the resolution of images we employ the principle of confocal microscopy. We use pinholes at the first and the last focus serving as spatial filters to eliminate any unwanted scattering or out-of-focus radiation.

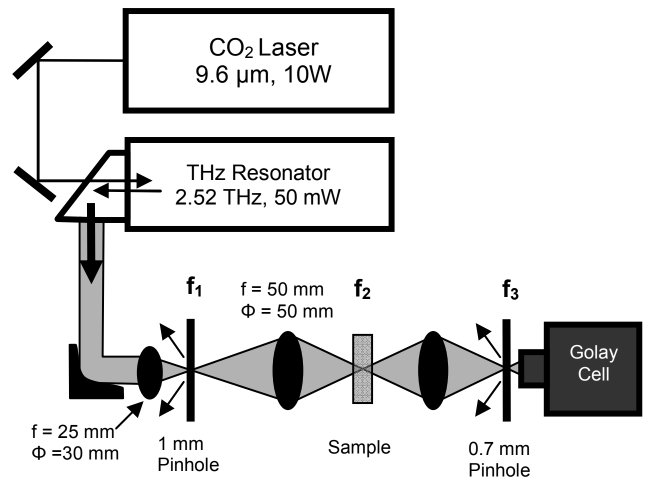

Fig. 1: Schematic of the confocal THz laser microscope.

The sample is scanned in a raster pattern using an x-y translation stage placed in the middle focus. Any rays scattering from the imaged sample are blocked by the confocal hole before the detector.

To illustrate the high resolution of the imaging system, we show in figure 2 a photograph of a fresh plant leaf and a THz image of the leaf taken with our confocal THz laser microscope. The dark areas in the THz image represent regions of low transmission. These areas correspond to the veins in the leaf. As they are thicker they contain more water and hence lead to higher absorption. The THz image reveals minute details of the leaf with a submillimeter resolution that cannot be observed in the photograph.

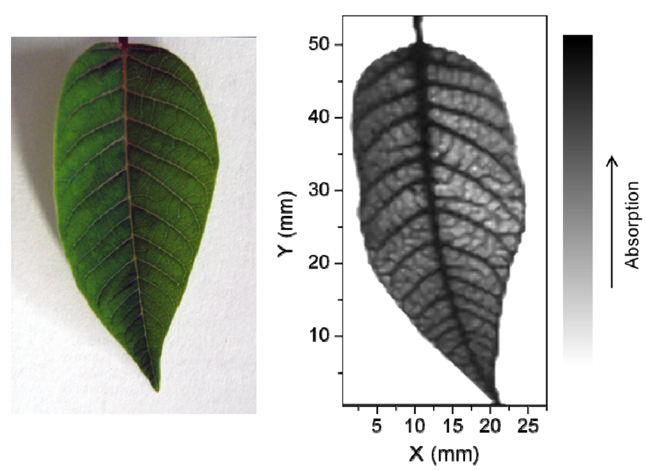

Fig. 2: Photograph of the fresh leaf (left) and confocal THz image (right).

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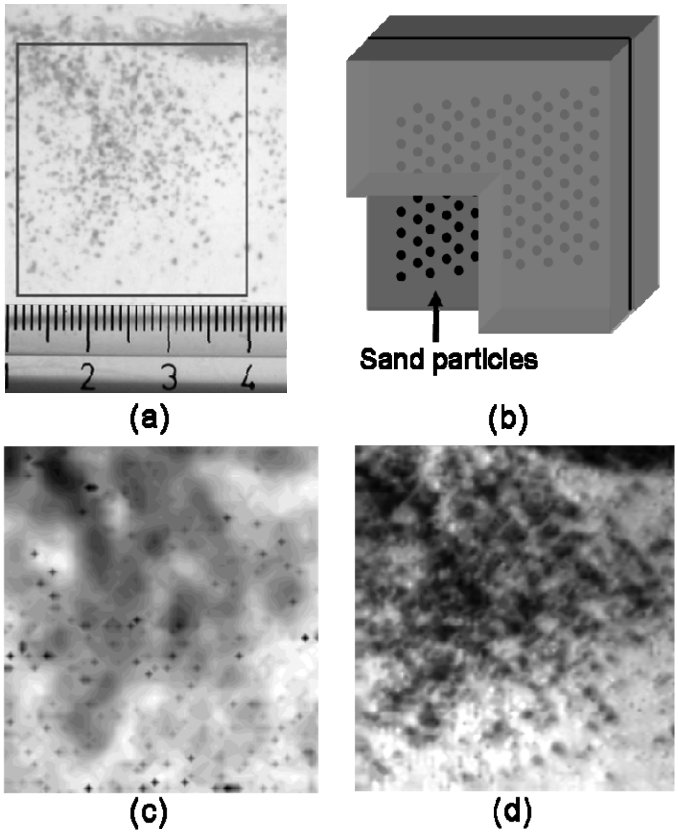

Fig. 3: Photograph (a) and schematic (b) of the sample. THz image obtained with a THz TDS system (c) and with the confocal THz laser microscope at a frequency of 2.52 THz.

Recently, Wietzke et al. have demonstrated that THz time-domain spectroscopy (TDS) is well suited to identify contaminations like metal or small sand particles in plastic weld joints [7]. Yet, the spectral intensity of a THz TDS system typically peaks below 0.5 THz. Hence, images obtained with a THz gas laser at 2.52 THz can have a superior spectral resolution due to the smaller wavelength employed. This is illustrated by the example shown in figure 3. Part (a) shows a photograph of a back-lighted sample consisting of two plastic pieces each of which is three millimeters thick, welded on a lab joint and contaminated with sand particles in between. In order to obtain a visual verification of the THz data a high-density polyethylene (HDPE) from Simona AG, Kirn, Germany, is chosen. This material is translucent in the visible and has a refractive index of n = 1.54 in the THz frequency range.

Part (b) depicts a three dimensional illustration of the sample. In (c) we see a THz image taken with a conventional terahertz TDS system using the frequency window from 0.3 to 0.4 THz. Part (d) shows a THz image obtained with the demonstrated confocal microscope. Comparing the last two images, the quality difference between them is obvious, with the confocal system bringing out the individual sand particles very clearly.

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