Applications & Early Results from THz Heterodyne Imaging at 119μm

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INTRODUCTION

The submillimeter-wave frequency bands: 300-3000 GHz (wavelengths from 1mm to 100 microns), have long been the purview of far-IR spectroscopists. Thousands of important molecular line vibrational and rotational transitions have been calculated, measured and catalogued, with the goals of a basic understanding of quantum chemistry. Equally important applications for THz measurements have dominated Earth, planetary and space science [1]. Due largely to the recent availability of ultra-fast-pulsed time domain spectrometers (TDS), there has been a growing interest in this wavelength range for biological and biomedical work [2,3,4]. TDS systems yield wide spectral coverage but have limited frequency resolution and signal-to-noise ratio (limited penetration depth in "wet" tissue). As a contrast to TDS, CW heterodyne imaging is a more traditional technique that offers the potential for extremely large dynamic range and high signal-to-noise ratio while maintaining fast data acquisition, stable magnitude and phase measurements, reasonable frequency flexibility and millimeter scale penetration in wet tissues and other biomaterials.

The authors present a description and early measurement results from a unique CW terahertz heterodyne imaging system based around two custom fabricated 2.5 THz planar Schottky diode mixers [5] and two commercially available optically pumped far IR lasers [6]. One laser is used for the signal beam and supplies as much as 70mW at 2.5 THz. The other laser acts as a local oscillator (LO) source for the two mixers. Line pairs very close to each other (CH_3OH and CH_2F_2) are chosen to provide a workable intermediate frequency output (IF) of 24 GHz. A frequency stabilization scheme has been implemented to track and calibrate the laser power (magnitude and phase) over a sample run. The system uses the second THz mixer, a low frequency (GHz) reference oscillator and a lock-in amplifier to monitor and normalize the two lasers (LO and signal). Stability of ~0.02 dB and <2 degrees of phase noise have been achieved with a dynamic range (S/N) of 110 dB. The system has been employed on both biological (mammalian and human) tissues as well as materials of interest to NASA space science applications. The instrumentation is briefly described and some representative images appear in this short paper. A more complete description of the test system can be found in [7].

THz HETERODYNE IMAGER

The recent introduction of commercial CO_2 pumped far-IR lasers [6] and high sensitivity room temperature THz planar Schottky diode downconverters [5] makes a high dynamic range THz heterodyne imaging system realizable. In order to achieve a low system noise level, $NEP_H=2kT_rB_{IF}$ the pre-detection bandwidth, B_{IF}, must be made as narrow as possible and the receiver noise temperature, T_r, must be low. However, to obtain an image of reasonable resolution (many scanned pixels) at fixed thermal sensitivity, δT, it is desirable to have minimum integration time per pixel, $\Delta t=T_r^2/(\delta T^2 \bullet B_{IF})$, i.e. large pre-detection bandwidth. In addition to these conflicting requirements, there is the added complication of the stability of the THz sources (better than 1 part in 10^9 is required, i.e. kHz). The minimum frequency drift of the commercial CO_2 pumped far IR lasers, over a 5 minute period is ~150 kHz. Bearing these limitations in mind and taking advantage of space sensor technology that we have developed for several NASA missions, a system for imaging the transmission loss and phase of thin (< 5 mm thick) biosamples at 2.522 THz has been constructed and successfully tested in our laboratory. Dynamic range as great as 110 dB has been measured to date with a 3 dB pixel size of <0.4 mm (this can be improved with faster optics at the expense of depth of field). The noise in the phase measurements is less than +/- 2 degrees. A block diagram of the imager appears in Fig. 1. The large dynamic range and amplitude stability have been obtained using a locking scheme patterned after Doane [8] wherein the two intermediate frequencies (reference and signal) are mixed with each other and filtered through a very narrow band phase-locked-loop tracking circuit. The transmission system relies on scanning the object through the fixed THz beam and building up an image pixel-by-pixel. Representative images appear in Figure 2. The system is particularly sensitive to water absorption, both an advantage (for contrast) and a hindrance (poor transmission throughput) and is therefore being used for a range of differing applications.

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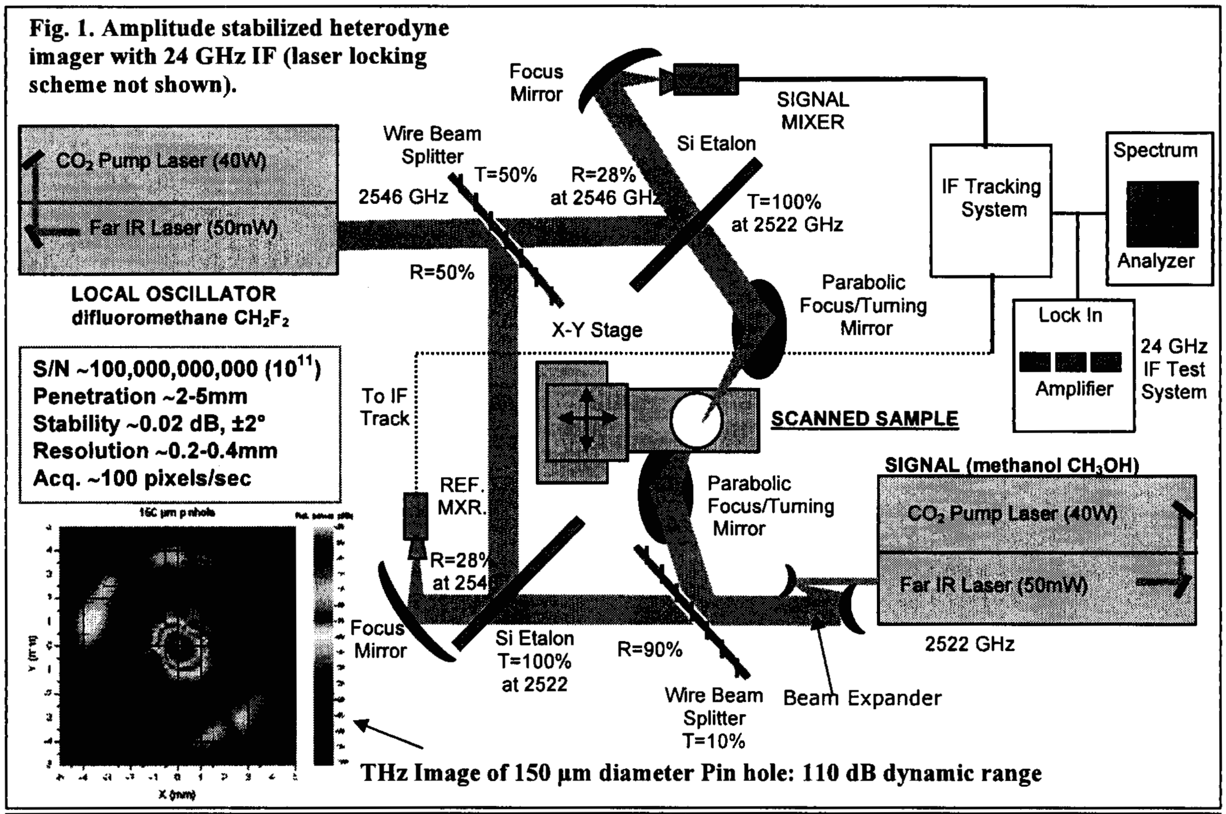

Fig. 1. Amplitude stabilized heterodyne imager with 24 GHz IF (laser locking scheme not shown).

THz Image of 150 μm diameter Pin hole: 110 dB dynamic range

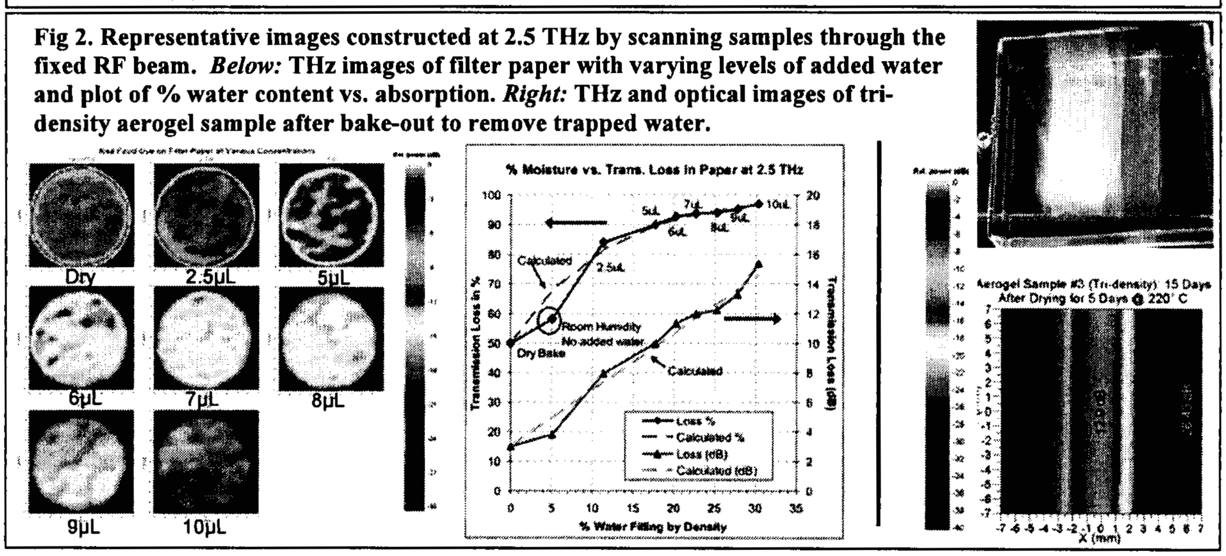

Fig 2. Representative images constructed at 2.5 THz by scanning samples through the fixed RF beam. *Below:* THz images of filter paper with varying levels of added water and plot of % water content vs. absorption. *Right:* THz and optical images of tri-density aerogel sample after bake-out to remove trapped water.

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