Terahertz vibrational absorption resonances observed using on-chip terahertz circuits

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***Abstract* — A technique for measuring the vibrational absorption spectra of polycrystalline materials in the terahertz (THz) frequency range is demonstrated. We show that the evanescent electric field extending above lithographically-defined on-chip THz microstrip waveguides can be used to measure absorption resonances, offering higher sensitivity than typical free-space THz time-domain spectroscopy systems permit. The results indicate that on-chip THz systems could find new applications in the analysis, quality control, and identification of polycrystalline materials, such as pharmaceutical compounds.**

I. Introduction And Background

SPECTRAL analysis of absorption resonances in the terahertz frequency range is typically performed using free-space terahertz time-domain spectroscopy (THz-TDS). However, the need to purge the THz beam path (to minimize water absorption), the large overall footprint of such systems, and the restricted (diffraction-limited) spatial resolution available, can constrain the use of THz-TDS systems in potential applications. As an alternative to free-space spectroscopy, techniques using free-standing metallic waveguides (such as parallel plates [1], or suspended wires [2, 3]) that guide pulsed THz radiation in low-loss propagating modes are being developed. These waveguides have both been used to sample the THz absorption spectra of polycrystalline materials, as have more lossy stripline on-chip waveguides [4]. In this paper, we show that pulsed THz transmission through a lithographically-defined low-loss microstrip-line waveguide can detect vibrational modes in polycrystalline samples, offering enhanced sensitivity and frequency resolution compared with free-space THz-TDS.

II. Results

THz microstrip-line devices, incorporating integrated low-temperature-grown GaAs switches for THz pulse excitation and detection [5,6], were used for our spectroscopy measurements. The transmission characteristics of the microstrip were measured first with no sample in place (Fig.1). The bandwidth of the Fourier-transformed pulse propagating through the microstrip (over a distance of 4 mm) was ~1.2 THz. Lactose monohydrate samples were prepared by compression of pure powder into ~0.5-mm-thick pellets, and then cleaved to form $2\times2\times0.5$ mm^3 samples. These were brought into the evanescent field above the microstrip using a three-axis linear translation stage. The lactose samples introduced a clear absorption dip at (534 ± 2) GHz in the frequency spectrum of the transmitted pulses (Fig. 1). The frequency of this resonance agrees precisely with a free-space THz-TDS analysis of samples measured using a THz-TDS system, and with prior free-space data from other groups [7].

The volume of evanescent electric field used to sample the lactose sample is estimated (from 3D electromagnetic modeling) to be $\sim10^{-12}$ m^3. For free-space THz-TDS systems, the sampled volume is typically $\sim10^{-10}$ m^3 (assuming a diffraction-limited THz focal diameter of 1 mm^2, and a sample thickness of 0.5 mm). For suspended wire waveguides [2], typical sample volumes of $\sim10^{-9}$ m^3 can be estimated, while for parallel plate waveguides, sample volumes of $\sim10^{-10}$ m^3 have been used [1]. The enhanced sensitivity of the microstrip-line arises from the relatively tight confinement of the evanescent field extending above the signal conductor. By making long (~15 mm) parasitic microstrip-lines [8], we remove signal reflections in order to maximize the frequency resolution of our Fourier transformed frequency-domain signal; a resolution of < 2 GHz has so-far been obtained.

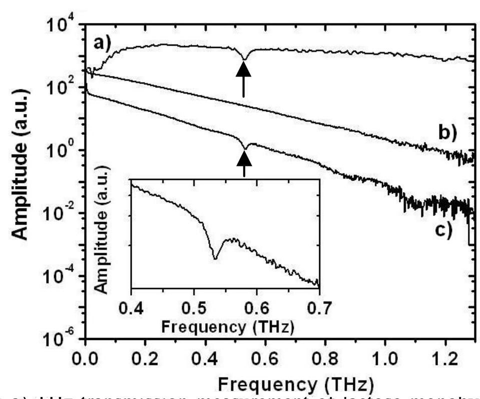

Figure 1: a) THz transmission measurement of lactose monohydrate using a free-space TDS system, with absorption resonance at 534 GHz indicated. b) THz transmission through the microstrip line with no lactose sample. c) Transmission measurement with a lactose pellet touching the microstrip. Inset: Close up view of data in c).

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