Sub-wavelength imaging of terahertz dielectric permittivity using planar resonant circuits

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***Abstract* — A new technique for quantitative sub-wavelength mapping of terahertz dielectric permittivity is demonstrated, using on-chip resonant terahertz filters. Imaging results on etched semiconductor samples show the viability of the technique, and future applications are discussed.**

I. Introduction

Measurements of material parameters such as dielectric permittivity and absorption at terahertz frequencies are routinely performed using terahertz time-domain spectroscopy (THz-TDS). For many potential applications, however, it is desirable to measure THz permittivity over smaller, sub-wavelength, dimensions than permitted by (diffraction limited) THz-TDS. We have recently proposed a new technique to perform quantitative THz microscopy, exploiting the evanescent electric field extending above resonant band-stop THz filters attached to microstrip-lines [1]. The filters localize the electric field at specific frequencies [2, 3], and because their resonant frequencies are sensitive to the permittivity of their immediate surroundings, they act as sensitive sub-wavelength probes of their local dielectric environment.

In this paper, we present the first 2D images obtained using the technique, using two cascaded resonant filters to generate images of etched GaAs samples at two frequencies simultaneously (260 GHz and 600 GHz). Patterns etched into the GaAs sample surface create a spatial variation in the effective permittivity. By using the resonant filters to map out this variation, we demonstrate the imaging capability and potential of the technique.

II. Results

A microstrip circuit with two band-stop filters was used in this work [see Refs. 1, 3, 4 for fabrication and measurement details]. The filters had (unloaded) resonant frequencies of 260 GHz and 600 GHz. Test samples were fabricated by etching lithographically-defined 30-µm-deep patterns into cleaned single crystal GaAs wafers. The samples were scanned across the filter array, in the region of evanescent field above each filter, and the pulsed THz response recorded for each spatial position. Fourier transformation of this data enabled the frequency shift of each filter to be extracted as a function of spatial position (Fig. 1), using automated data processing. The etched pattern is clearly visible in the extracted frequency shift of each filter, and the measured dimensions of the pattern are in excellent agreement with corresponding optical images of the surface (Fig. 2). Currently, unoptimized filters show ~ 20 µm resolution [1], limited by the extent of the fringing field around the filters. The resolution is enhanced for higher frequency filters, which show better electric field localization owing to their reduced dimensions. The sample permittivity can be determined by comparing the experimentally measured frequency shift of each filter with a full 3D electromagnetic simulation of the system.

In conclusion, we have shown that on-chip terahertz circuits provide a new modality for THz imaging, with a resolution determined solely by lithographic considerations, rather than by the diffraction limit of the propagating radiation.

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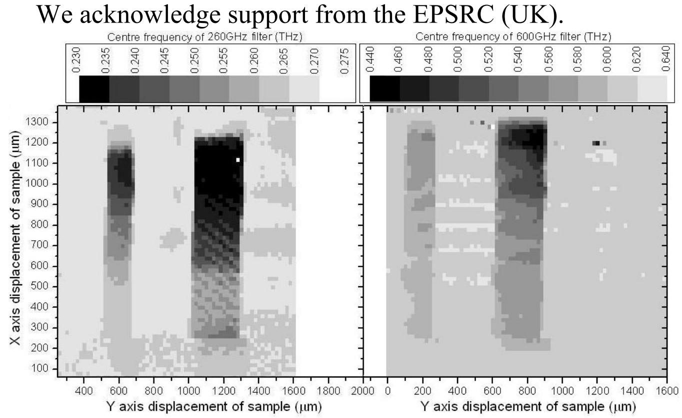

Figure 1: Images of filter resonant frequency against sample position for a) the 260 GHz filter, b) the 600 GHz filter.

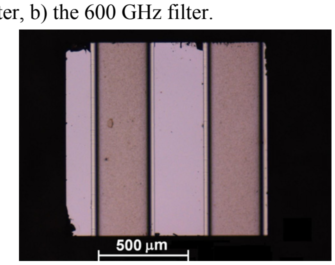

Figure 2: Optical image of the etched GaAs sample surface. Darker regions correspond to 30-µm-deep etched areas.

References

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