Development of a Terahertz Imaging System

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Introduction

This paper introduces work being conducted by the authors towards developing terahertz (THz) imaging technologies. Specifically this paper addresses two topics: the development and implementation of a THz imaging system, and design of a THz detector. The THz imaging system has been implemented to allow exploration across a broad range of applications. An overview and design of this system are presented, along with early images acquired with the system. A high temperature superconducting device capable of detection at THz frequencies is being designed. As development of this detector is at an early stage simulated detector performance results are given; however, it is expected that detector results will be presented at the conference.

Motivation for THz systems

THz frequencies (300GHz – 3000 GHz) lie above mm-wave and below infra-red frequencies in the electromagnetic spectrum. THz frequencies inherit a range of characteristics from each of these regions yielding a number of distinctive properties including:

- a strong sensitivity to polar liquids, which are highly attenuating [1],
- high transmission through a range of plastics, fabrics [2], and paper materials,
- spectroscopic responses to a range of materials [3].

These features make the THz region of the spectrum ideal for a range of new applications including imaging of skin cancers beneath the skin due to increased water content in tumour cells [4], remote detection of explosive substances through spectroscopic response of crystalline compounds in C4 [3], and non-destructive imaging of items concealed in packaging.

Despite good prospects for imaging, THz systems are not widely employed due to limitations on source power and detector sensitivities. Indeed the THz range of frequencies is often termed the 'THz gap' between electronic based and optical based systems. The paucity of high performance, cheap components have kept THz systems in the laboratory and in the area of large astronomy systems.

Terahertz imaging demonstrator design

To examine a range of applications, a THz imaging system [5] has been implemented with the following properties: wide bandwidth (500-700GHz), high source power (10mW), with the capability to plug in our own components at a later stage. The initial system layout is shown in Figure 1, and a photograph is in Figure 2. To minimize the spot size the focal length of mirror M1 was selected to maximize the illumination on the

mirror from the source, and the focal length of M2 was minimized. Mirror pairs M2, M3 and M1, M4 are identical and are conventional optical mirrors. To achieve the desired properties a backward wave oscillator (BWO) [6] has been employed with a Schottky diode detector [7].

As a demonstration of the imaging ability a leaf (Figure 3) was imaged using the transmission setup and an image taken at ~600 GHz image is shown in Figure 4. This image was taken through two sheets of cardboard and a cotton support. The leaf image demonstrates the ability of THz radiation to image through cardboard and cloth materials, along with a sensitivity to water (with higher water content leaf veins high attenuation clearly visible in the image).

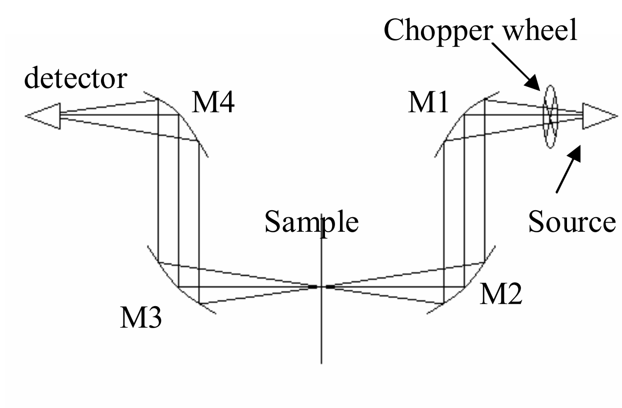

Figure 1: THz demonstrator layout in transmission imaging mode.

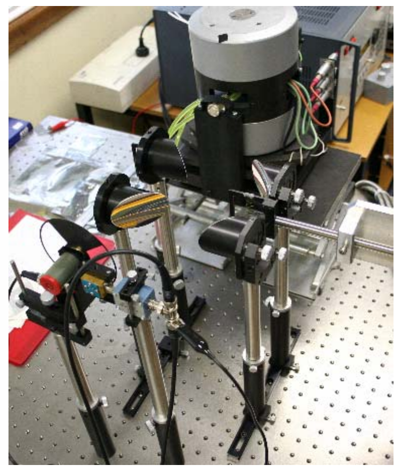

Figure 2 Photo of system on optical bench.

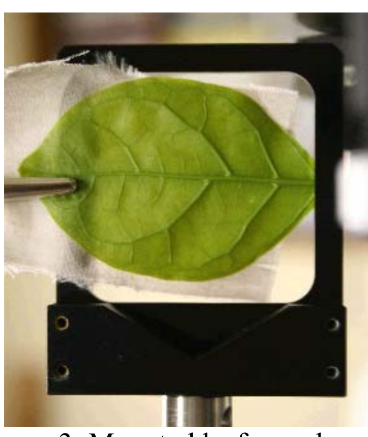

Figure 3: Mounted leaf sample.

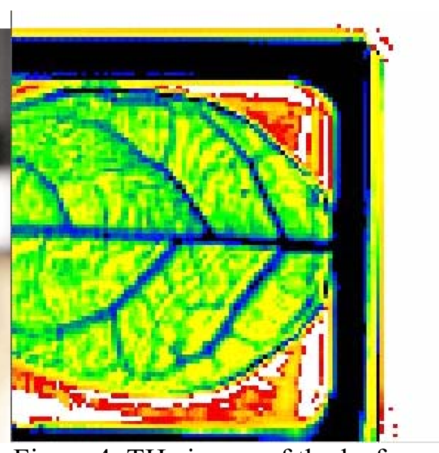

Figure 4: THz image of the leaf.

Terahertz superconducting detector

For the initial design a high resitivity silicon lens (Figure 5) directs the energy into a ring slot antenna (Figure 6 on left). The field in the antenna is coupled into a Josephson junction. The ring slot antenna [8] was selected for its simplicity, ability to be packed closely together in an array configuration, capability for dual polarization detection, and

directive radiation pattern. The design was optimised to operate at 650 GHz to correspond to the THz imaging demonstrator's frequency of operation. A range of techniques have been explored in the analysis of the structures including FDTD [9], and hybrid PO and GO. Further analysis of large arrays of detectors will require techniques such as BEM analysis [10, 11] using distributed computing methods [12].

The detector is based on 'high temperature superconductors' (HTS) which can be operated at liquid nitrogen temperatures (77K). Superconducting materials can be used for low noise detection of electromagnetic waves at frequencies higher than conventional materials. The approach involves coupling a THz signal into a Josephson junction (two Yttrium barium copper oxide (YBCO) superconductor layers are weakly linked by a barrier). Figure 6 (on right) shows an image of our step-edge grain-boundary Josephson junction. An electron wavefunction in both superconducting layers then interacts allowing quantum tunneling of electrons through the barrier. This quantum tunneling is observed in the DC current / voltage curve (measured results from our detectors are given in Figure 7). Below the critical current Ic (at which point the, the YBCO is superconducting and no voltage is measured. Above Ic the YBCO begins to transition into a normal conducting material, allowing the voltage to follow a normal IV relationship. The next step is to couple the THz field into the detector and detect the incident THz by DC biasing the detector such that the responsivity with THz illumination is maximised.

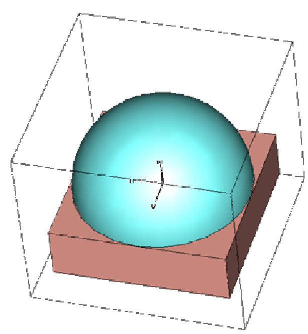

Figure 5: Lens structure to couple in THz field.

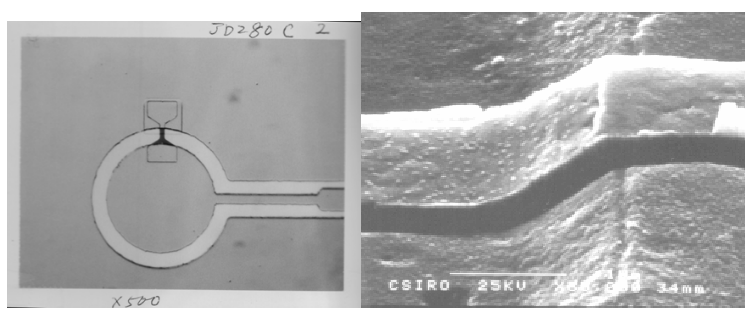

Figure 6: (left) antenna and Josephson junction detector (right): Close in view of Josephson junction structure

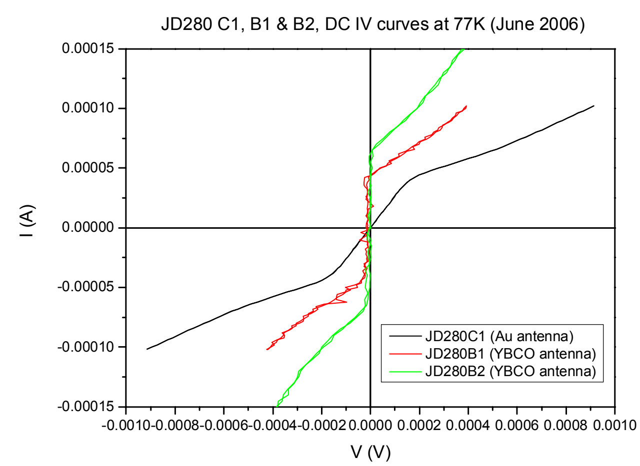

Figure 7: DC IV characteristics of gold and superconducting antennas.

Conclusions

A THz imaging system has been designed and implemented and some early images presented, the development of a superconducting detector at THz frequencies has also been discussed. Detector IV curves show that YBCO antennas give a more non-linear response than gold antennas; however, YBCO suffers from higher losses at THz frequencies. Future work will involve measuring the detector performance, characterization of the junction, optimizing the coupling into the detector, and exploiting a hybrid YBCO/Gold antenna design to minimize losses, and maximize detector responsivity.

References:

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