Design and Characterization of a Broadband Focal Plane Array for THz imaging

Kagan Topalli, Georgios C. Trichopoulos, and Kubilay Sertel

***Abstract*— A novel broadband monolithic THz antenna design that covers the 0.625 THz – 1.125 THz band is developed as the imaging pixel of THz focal plane array. Each pixel consists of heterostructure backward diodes monolithically integrated with impedance tuned THz antennas. Since THz responsivity of the pixel is optimized by conjugate matching between the antenna and the diode, it is important to characterize antenna impedance. To this end, an indirect impedance characterization method for THz antennas using coplanar probe measurements is presented.**

***Index Terms*—Focal plane arrays, Terahertz detectors, Antenna measurements.**

I. Introduction

SENSORS utilizing the terahertz (THz) waves are emerging as viable imaging tools for detection and classification of various medical anomalies, such as tumorous tissues and dental caries, as well as various security and military applications [1], [2]. This new technology has several advantages over existing imaging tools. THz waves are safe (non-ionizing), and they can provide high-resolution and high-specificity. However, state of the art THz imaging systems employ mechanical raster scans (using a single detector) to acquire two-dimensional images. This inevitably results in excessively long image acquisition times and is the main bottleneck for the widespread use of THz imaging.

An integrated focal plane array (FPA) is a key component for a real-time THz imager to have fast 2D image acquisition. There are a variety of techniques that are being researched to meet this goal including microbolometers arrays [3] and focal plane arrays composed of heterostructure backward diodes (HBDs) [4], [5] and conventional FET circuits [6]. Of these techniques, HBD FPAs offer highly sensitive low-noise, room temperature, and a cost-effective solution for a real-time THz imager [7].

In this paper, we present the FPA architecture that we developed for 0.625 THz – 1.125 THz band applications. The pixels of the FPA consists of high performance HBDs and a novel broadband antenna. The pixel responsivity is enhanced by conjugately matching the diode impedance to the antenna impedance. We also developed a methodology to characterize the antenna impedance using a set of measurements carried out with standard contact probes.

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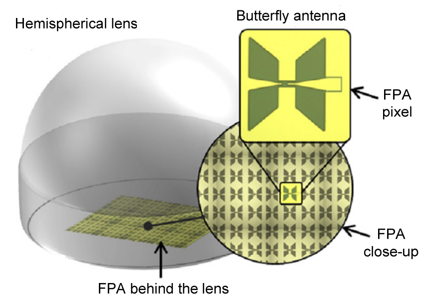

Fig. 1. The FPA behind the extended hemispherical lens. The incident radiation is coupled to the butterfly-shaped antenna through the hemispherical silicon lens. Inset, the butterfly-shaped antenna.

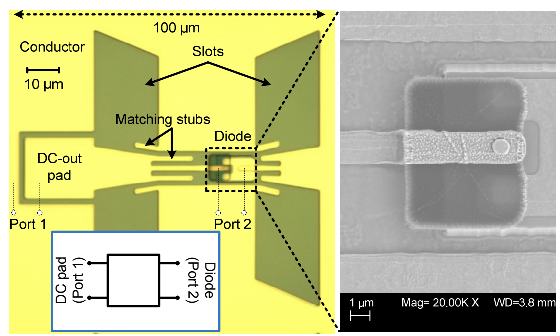

Fig. 2. Single pixel of the THz sensor array. The pixel consists of a broadband butterfly-shaped antenna and a heterostructure backward diode. SEM image of the diode on the right illustrates the details of the diode structure.

This paper starts with a summary of a broadband FPA that we developed for THz imaging applications. The next sections present the FPA structure and illustrate some design and fabrication aspects. Subsequently, the indirect impedance characterization method of the THz antennas is introduced in Section III.

II. Large Format FPA-based THz Imaging System

The proposed THz imaging system resembles the operating principles of a typical digital video camera. It consists of a THz FPA connected to a digital output. A large format (80×60) FPA, which is situated behind a hyper-hemispherical lens, is the key component for the real-time THz imaging system [7]. The incident radiation is coupled to the sensor through the hemispherical silicon lens (see Fig. 1). Each pixel of the FPA is comprised of a novel broadband butterfly-shaped antenna monolithically integrated with a high sensitivity InAs/AlSb/GaSb heterostructure backward diode (HBD).

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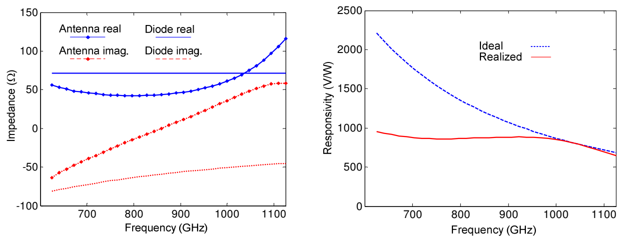


(a) (b)

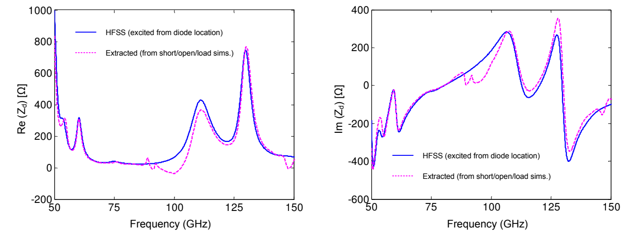
Fig. 3. (a) The antenna and diode impedances in 0.625 – 1.125 THz range and (b) The responsivity curves for ideal (perfect conjugate match) and realized cases. The pixel exhibits a responsivity of about 1000 V/W for the 0.625 – 1.125 THz band.

These diodes were recently reported to exhibit record responsivity and low-noise performance for room-temperature THz detection [4], [5]. However, in order to most efficiently couple the incident radiation onto the diode junction, a broadband impedance matched antenna must be used. The butterfly THz antenna developed here allows for broadband performance and incorporates the matching stubs into the design for optimal conjugate impedance matching to the integrated diode (see Fig. 2). Conjugate impedance match between diode and antenna ensures maximum THz power is delivered to the diode, resulting in optimal sensitivity. To this effect, Fig. 3 (a) illustrates the antenna and diode impedances in the 0.625 – 1.125 THz range. The responsivity curves for ideal (perfect conjugate match) and realized cases are also illustrated in Fig. 3 (b).

However, due to the extremely small dimensions of THz antennas, direct measurement of their port impedance at the diode location is not possible. Below, we propose an indirect method to extract the antenna impedance using a set of measurements carried out with standard contact probes.

III. Indirect Impedance Characterization of THz Antennas Using Off-Site Probe Measurements

In order to assess the THz antenna performance after manufacturing, it is essential to characterize antenna impedance accurately. Unfortunately, impedance characterization of THz components, such as antennas, is not viable using direct probe measurements due to the extremely small device details. In particular, the 0.625 – 1.125 THz butterfly antenna shown in Fig. 2 has a feed of only 1.6 μm wide. Thus, it is impossible to land contact probes for characterization since the probe pitch is much larger in size. On the other hand, DC-out pad is an easily accessible location for a standard coplanar probe contact. Thus, it may be possible to deduce the antenna port impedance using probe measurements at the DC-out pad location, rather than at the diode port. This can easily be achieved by considering the antenna as a 2-port device, as shown in Fig. 2. Port 1 is the DC-out pad where the measurements are taken, and Port 2 is the diode location whose impedance will be indirectly computed. It can be analytically shown that the reflection coefficient (impedance) at the diode location (Port 2) can be extracted with three measurements from the DC-out pad (Port 1). In order to uniquely determine Port 2 impedance, three measurements are needed, namely with Port 2 terminated by an open circuit, a short circuit, and a resistive load (e.g. 50 Ω). As seen in Fig. 4, the impedance seen at the diode location can be readily extracted analytically using numerical simulations of short/open/resistive load for 50 GHz−150 GHz band.



(a) (b)

Fig. 4. The impedance at the diode location (port 2) computed indirectly and compared with numerical simulation result of the case excited directly from diode location (port 2): (a) real and (b) imaginary.

IV. Discussion

We presented the development of a FPA for a real-time THz imaging camera. We outlined key methodologies used to enhance pixel performance and presented a new method to indirectly characterize THz antennas using standard probe station measurements. Implementation of an 80×60 THz FPA and fabrication of the test antennas for the validation of indirect impedance characterization methodology are on-going. The measurement results will be presented at the conference.

Acknowledgment

This work is supported in part by the ElectroScience Laboratory, Consortium on Electromagnetics and Radio Frequencies.

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