Dual Slot THz Antenna Array for Real Time Excised Tissue Imaging

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Introduction

The non-ionizing and penetrative nature of terahertz (THz) radiation makes it promising for detection in the commercial and defense industry [1 - 2]. Likewise, in the medical scene, particular bands in the THz regime can be identified as markers of malignant tissues. However, long image acquisition times associated with available mechanical raster scanning equipment constitutes a bottleneck. This is particularly the case for real-time viewing of excised tissue during a medical operations. Therefore, rapid THz imaging systems based on large arrays of sensitive detectors have been recently considered within the commercial and scientific communities.

Schottky diodes, monolithically integrated within a double slot antennas were previously employed as uniplanar heterodyne receivers in the THz regime. These detectors were attractive because of their high Gaussian beam coupling efficiency and diffraction limited patterns [3]. However, their large low-pass IF filter sections limit their application into tightly packed 2D focal plane imaging array. In addition, internal reflections at the lens/air boundary (as lenses are used to focus the array beam) significantly reduce coupling efficiencies of the array elements and limits their imaging properties for scan angles beyond $\pm 20^0$ [4]. To alleviate these issues, in this paper, we propose and verify for the first a dual slot antenna element integrated with a zero biased Sb-heterostructure diode for direct detection of THz radiation. We also consider a modified antenna layout to increase the number of detectors without resorting to expensive and bulky silicon lenses.

Dual Slot Antenna Element for Direct Detection of THz Radiation

Fig. 1(a) demonstrates a magnified view of the fabricated detector with the dual slot antenna and with the Sb-heterostructure [5] diode printed on it. The dual slot dipoles are designed to be 0.94mm long, 0.08mm wide, and 0.5mm apart to resonate at 100GHz. The slots are fed with a 0.1mm wide coplanar wave guide (0.06mm inner conductor width) leading to 10GHz bandwidth on silicon half-space (50Ω impedance). The diode area is adjusted to match 50Ω and a 5mm lens extension length is chosen for operation close to the diffraction limited directivity and Gaussian coupling efficiency [6]. Also, the detector is attached to a 25mm diameter silicon lens (ε_r=11.7) having a high resistivity of >10kΩ. For design, radiation into the silicon half-space is evaluated via a method of moment (MoM) solution of the magnetic field integral equation. The subsequently computed aperture currents on the lens are determined from a ray tracing technique, and integrated to calculate radiation pattern of the overall system [6].

The received radiation is rectified by the zero-biased diode and converted to a DC voltage measured through a wire bonded pigtail. A 0.1mm x 0.2mm pad with 5μm gap is formed

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adjacent to the antenna layout as depicted in Fig 1(a) for wire

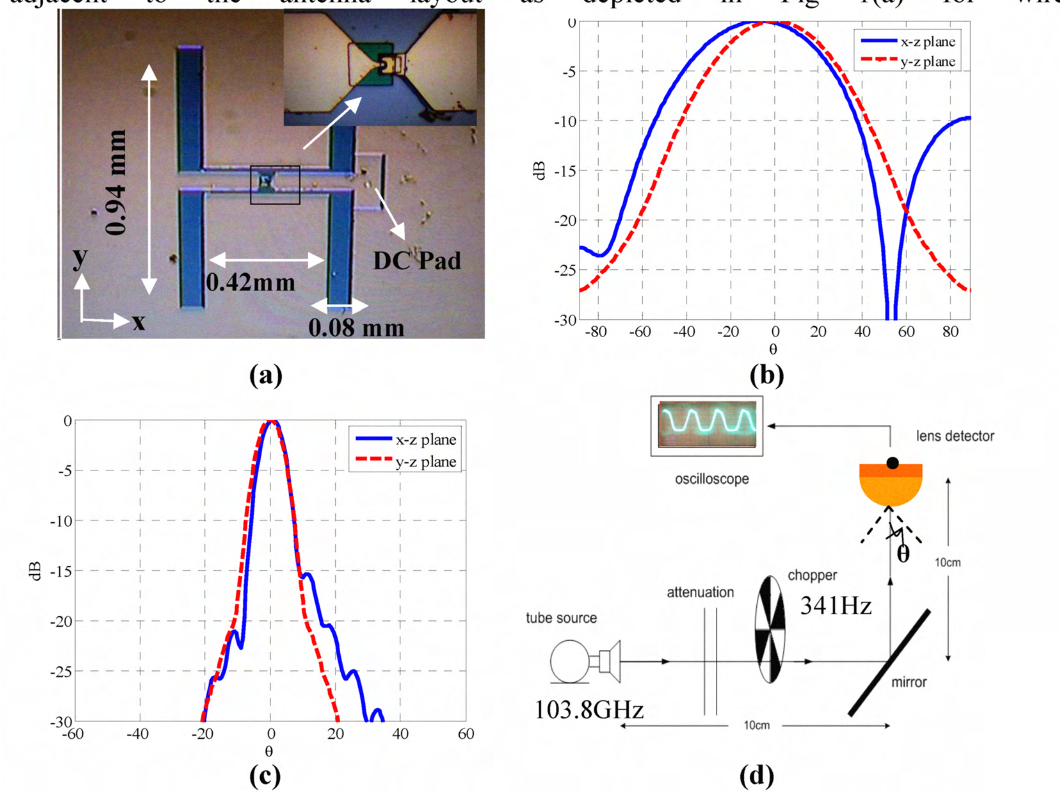

Fig. 1. (a) Fabricated dual slot antenna receiver for direct detection at 100GHz; **(b)** Calculated radiation into half-space silicon substrate; **(c)** Calculated lens radiation pattern; **(d)** Measurement setup for 100GHz detection

bonding. Although the gap is very narrow as compared to the slot widths, its presence significantly affects the *x-z* plane radiation pattern. As shown in Fig. 1(b), the *x-z* plane half power beam width (HPBW) is 8^0 wider than the *y-z* plane. Also, the *x-z* plane pattern is 8^0 tilted along -*x* and a -10dB side lobe is observed towards +*x*. This pattern broadening is expected to decrease the Gaussian coupling efficiency and associated detector responsivity in an optically coupled imaging system. On the other hand, far field patterns in Fig. 1(c) are still very close to the diffraction limited size with 21mm x 21mm effective aperture area (with only a 1^0 shift in the *x-z* plane). Figure 1(d) depicts the experimental setup for testing the direct detection and Sb-heterojunction diode responsivity. A chopper rotating with a frequency of 340Hz was mounted in front of the source horn of the backward wave oscillator radiating at 103.8GHz. Initial measurements resulted in a fairly good diode responsivity of 1000V/W. Further measurements are underway for noise and pattern characterization.

Improved Off-Axis Detection with Asymmetrically Fed Slot Antenna Arrays

The number of detectors used to form a focal plane imaging array under the extended hemispherical silicon lens are limited by the internal reflections at the lens surface [4]. To illustrate this, let us consider the off-axis radiation properties of the dual slot antenna element designed in the previous section. With the DC pad removed for simplicity, the antenna geometry, referred to as layout #1, is shown in Fig. 2(a). Since slots are positioned symmetrically around the feed in the *x* and *y* directions, the antenna radiates a pencil beam into the silicon half-space along the positive *z* ($\theta = 0^0$) axis with 10.9 dB directivity. As the detector is positioned further away from the optical axis, more of its

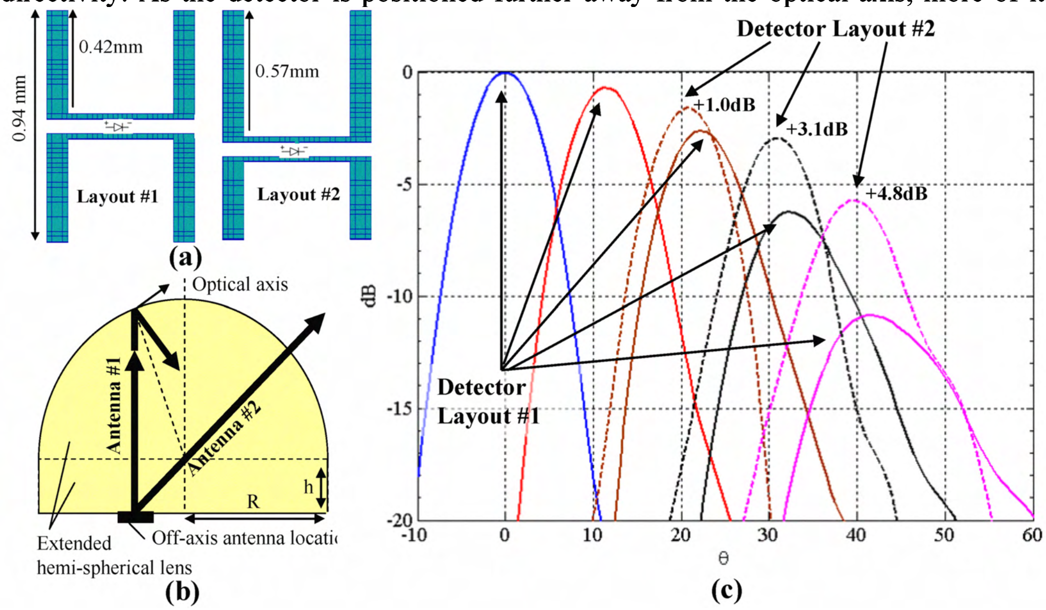

Fig. 2. (a) (Left) Dual slot detector layout; (Right) Modified layout for improved off axis detection; **(b)** Illustration of internal reflections at the lens/air surface for the antenna layouts shown in (a); **(c)** Calculated *y-z* plane lens radiation patterns when the detectors are uniformly displaced off the lens axis with 1mm intervals (along *-y* direction).

radiation is internally reflected due to the increasing angle between lens surface normal and main beam direction (see Fig. 2(b)). Solid lines in Fig 2(c) depict the computed *y-z* plane radiation patterns when the detector layout #1 is displaced off-axis along *-y* direction with 1mm intervals. These patterns are normalized with respect to the element located at the optical axis. We observe that for scan angles larger than 20^0 (off-axis distance > 2mm) a significant drop at the radiated power (<-6dB) is observed. Therefore, 25mm the silicon lens can only support 5 elements for a linear imaging array (2 along *–y*, center element, 2 along *+y*) and 13 elements (or equivalently pixels) for a rectangular 2D imaging array at 100GHz (d<=2mm, where d is the distance from the lens axis).

To alleviate this fundamental limitation and increase the number of allowable array elements for the same frequency and lens size, we propose to minimize internal reflection using antenna structures with radiating patterns tilted towards the optical axis. In the dual slot antenna configuration, such pattern tilting can be easily achieved via asymmetrical feeding or parasitic slots. For example, the half-space pattern of the layout #2 depicted in Fig. 2(a) is tilted 26^0 in the *y-z* plane towards *+y* direction (see Fig. 2(b)). This tilting is

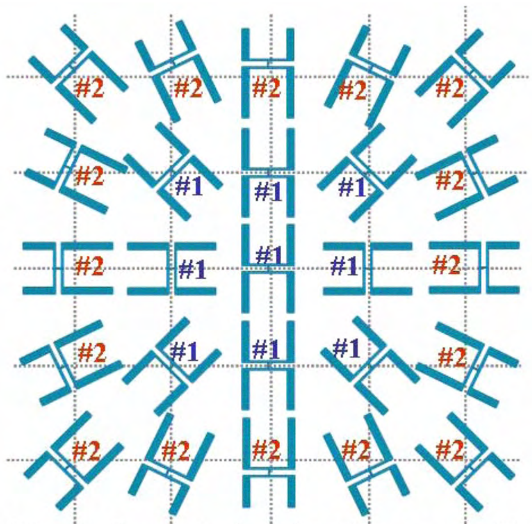

Fig. 3. Concept of an imaging array with two different detector layouts to improve number of allowed pixels

simply achieved by moving the coplanar waveguide feed line 150um along *–y* direction. The modified antenna element has a pencil beam with -7 dB side lobe level and exhibits an input impedance of 41-j60Ω. The dashed lines in Fig. 2(b) demonstrate radiation patterns (assuming that the element is impedance matched) when layout #2 is positioned at -2,-3, and -4mm off the optical axis. Due to much reduced internal reflection, the elements receive 1dB, 3.1dB, and 4.8dB more power, respectively. Hence, the 25mm silicon lens can now support 4 more elements for a linear array configuration and 36 more elements (d<=4mm) for a 2D imaging array as compared to the original double slot antenna configuration.

Fig. 3 depicts an illustration of a possible 2D array utilizing modified dual slot antenna elements. Due to different element orientations, a polarization scan is necessary for the best imaging performance. On the other hand, different types of modifications such as feed location shift along x/y or parasitic slots can be combined to tilt element patterns in an arbitrary cut without changing element.

Concluding Remarks

We presented a dual slot antenna integrated with zero bias Sb-heterostructure diode for direct detection of THz radiation. The compact layout and high responsivity of the detector makes it suitable to design 2D focal plane THz imaging arrays. Further, we proposed and demonstrated that number of detectors supported by a fixed size silicon lens can significantly be increased by proper antenna modifications such as feed location shift or parasitic slots. Implementation and measurements of such array designs are underway and will be presented at the conference.

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