3-D THz Tomography with an InP HBT Signal Source and a SiGe HBT Imaging Receiver Operating near 300 GHz

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***Abstract*—In this work, 3-D THz tomography was demonstrated with an InP HBT signal source and a SiGe HBT imaging receiver. The signal source employs a common-base differential pair for an LC cross-coupled topology. It shows an output power of 5.3 dBm at 305.8 GHz. The receiver, which serves as an imaging detector in this work, is composed of a fundamental mixer, a local oscillator, an IF detector, and an on-chip antenna. It exhibits a responsivity of 322 kV/W and NEP of 3.9 pW/Hz$^{1/2}$ at 300 GHz. A set of sinograms was acquired with an imaging setup employing the fabricated source and detector, and 3-D tomographic images were reconstructed based on the inverse filtered backprojection algorithm from the acquired sinograms.**

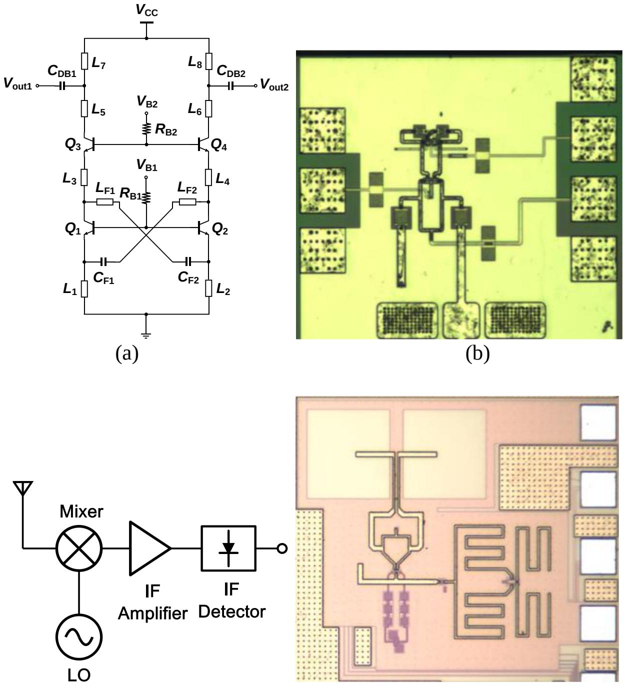
I. INTRODUCTION

RECENTLY, interests towards THz bands have been growing for various applications, imaging being one of the major parts. The traditional THz imaging systems have been based on the optical approach, which is rather bulky and power-consuming. On the other hand, efforts to implement THz imaging systems based on solid-state electronic sources and detectors, accelerated by the recent improvement in transistor operation speed, are attracting great interests due to its expected compact, low-cost, and low-power implementation. There have been THz images recently reported based on transistor-based sources and/or detectors [1] [2], but they have been limited to 2-D images so far. 3-D THz tomography is expected to have advantages in various applications such as bio-medical, security, and food inspection because it shows the internal cross-sections of the target objects without destruction. In this work, we demonstrated 3-D THz tomography with the source and the detector both implemented in transistor technologies.

II. 300 GHZ SOURCE AND RECEIVER

The signal source developed for this study is based on 0.25-μm Teledyne InP HBT technology with f_T/f_{max} of 392/859 GHz. It adopts LC cross-coupled topology for oscillator core, followed by a stacked buffer. The core is based on the common-base (CB) to improve oscillation frequency. Fig. 1(a) and (b) show the schematic and chip photo of the fabricated signal source, respectively. The output power of the signal source was measured as 5.3 dBm at 305.8 GHz, while consuming DC power of 88 mW. The chip area of the fabricated signal source is 530 × 460 um^2. The detailed description of the signal source can be found in [3].

The receiver, which serves as an imaging detector in this work, was implemented in 0.13-μm IHP SiGe HBT technology with f_T/f_{max} of 350/500 GHz. It adopts the heterodyne topology to increase the sensitivity, consisting of a mixer, a local oscillator, an IF amplifier, an IF detector, and an on-chip antenna. The block level diagram of the receiver is illustrated in Fig. 1(c) and the chip photo of the fabricated circuit is shown in Fig. 1(d). The receiver employs a fundamental-mode mixer to increase the mixing efficiency for improved imaging sensitivity. The local oscillator, driving the mixer in the fundamental-mode, is based on the push-push topology as it is challenging to achieve fundamental-mode oscillation around 300 GHz. The IF amplifier was inserted to suppress the noise from the IF detector as well as to improve the conversion gain of the receiver [4]. The on-chip dipole antenna is designed to work with the chip backside-mounted on a silicon hyper-spherical lens to avoid unwanted substrate mode in the silicon substrate. The silicon lens is also expected to increase the directivity of the antenna. The responsivity and NEP of the imaging receiver were measured as 322 kV/W and 3.9 pW/Hz$^{1/2}$ at 300 GHz, respectively. The chip area is 610 × 610 μm^2 and consumes 21 mW DC power. The details of the receiver will be reported elsewhere [5].



(a) (b)

(c) (d)

Fig. 1. (a) Schematic and (b) chip photo of the THz signal source. (c) Block diagram and (d) chip photo of the THz imaging receiver.

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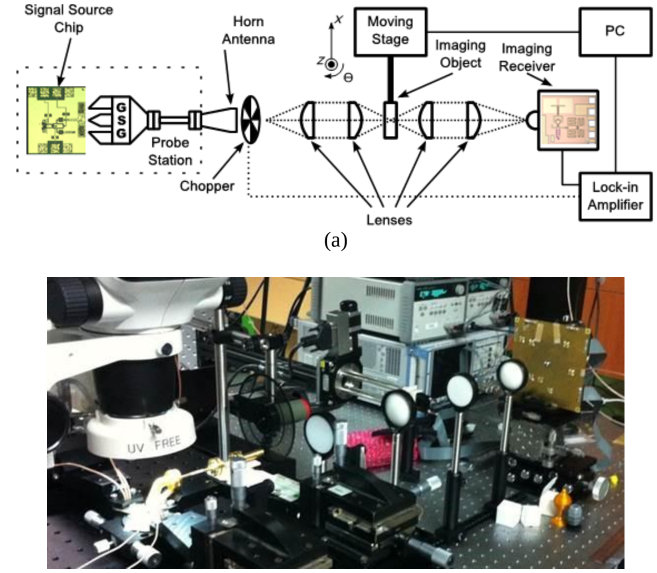

(a)

(b)

Fig. 2. (a) Block diagram and (b) Photo of the 3-D THz tomography acquisition setup employed in this work.

III. 3-D TOMOGRAPHY

Fig. 2(a) and (b) show the block diagram and the photo of the 3-D THz tomographic image acquisition setup. The signal source was on-wafer probed and the THz beam was radiated through an H-band horn antenna. A chopper was inserted after the horn antenna to amplitude-modulate the radiated beam above the flicker noise corner frequency of the imaging receiver. The imaging receiver, mounted on a hyper-spherical silicon lens, was wire-bonded to a PCB for biasing and image signal extraction purpose. The output signal from the imaging receiver was captured with a lock-in amplifier. Four lenses were applied to control the THz beam path over the signal source, imaging receiver, and imaging target object. The object was placed on a motorized rotation stage with 3 degrees of freedom (x, z, and θ) as briefly shown in Fig. 2(a). A computer was used to collect the coordinates of the motorized stage and the amplitude of the output signal from the lock-in amplifier.

The sinogram, a collection of the projection data of the object at location (x, θ) obtained by rotating the object from $\theta = 0$ to 180 degree and scanning it along with x-axis, was acquired for multiple z-axis points with the setup described above. From each of the obtained sinogram, a 2-D image was reconstructed based on the inverse filtered backprojection algorithm. Fig. 3 is the photo of the original target object. Fig. 4 shows selected examples of sinograms obtained at different z points and corresponding 2-D cross-sectional slice images reconstructed. With a series of 2-D images generated at multiple z-axis points, the 3-D tomography of the object was obtained. Fig. 5 shows the 3-D tomographic images shown from three different viewing angles. To the best of the authors' knowledge, this work demonstrates the first 3-D THz tomography with source and detector both implemented in transistor technologies.

IV. CONCLUSION

Fig. 3. Photo of the target object..

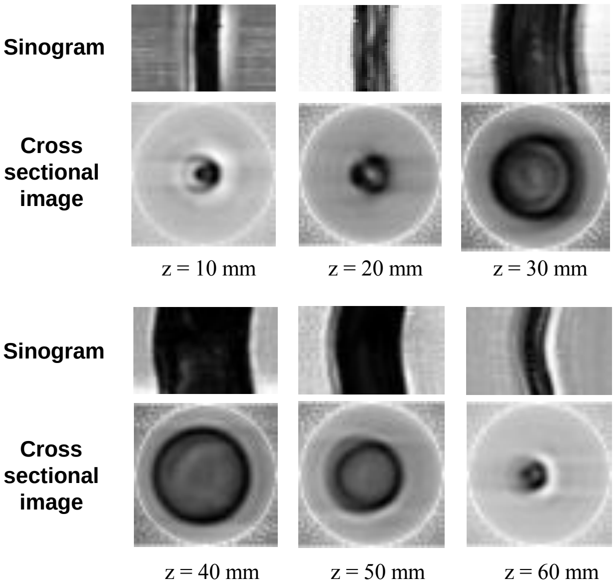

Fig. 4. Selected examples of sinograms and reconstructed images

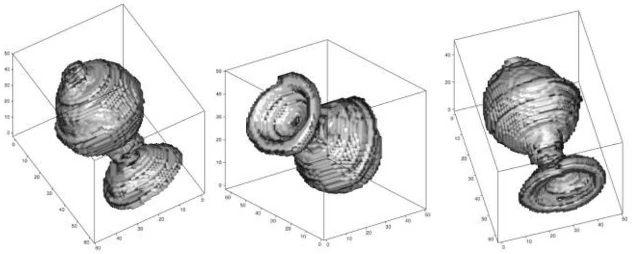

Fig. 5. Acquired 3-D tomographic images at three different viewing angles.

A signal source and a heterodyne imaging receiver operating at 300 GHz were developed and applied for a 3-D THz imaging system. Based on sinograms acquired along z-axis points, 3-D tomographic images were successfully generated. This work demonstrates the possibility of compact 3-D tomography systems based on transistor technologies.

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