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Photoconductive dipole antennas for efficient terahertz receiver

Truong Khang Nguyen [a,b,*], Won Tae Kim [c], Bong Joo Kang [c], Hyeon Sang Bark [e], Kangho Kim [d], Jaejin Lee [d], Ikmo Park [d], Tae-In Jeon [e], Fabian Rotermund [c,f]

[a] Division of Computational Physics, Institute for Computational Science, Ton Duc Thang University, Ho Chi Minh City, Vietnam
[b] Faculty of Electrical & Electronics Engineering, Ton Duc Thang University, Ho Chi Minh City, Vietnam
[c] Department of Energy Systems Research & Department of Physics, Ajou University, Suwon 443-749, Korea
[d] Department of Electrical and Computer Engineering, Ajou University, Suwon 443-749, Korea
[e] Division of Electrical and Electronics Engineering, Korea Maritime University, Busan 606-791, Korea
[f] Department of Physics, Korea Advanced Institute of Science and Technology, Daejeon 34141, Korea

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ABSTRACT

We designed various photoconductive antennas applicable to efficient terahertz (THz) receivers and experimentally investigated their detection characteristics. Three different antennas based on Grischkowsky (H-), I-, and bowtie shapes were fabricated on a 1.2-μm-thick low-temperature GaAs layer that was grown on a semi-insulating GaAs substrate and subsequently attached to extended hemispherical silicon lenses. The experimental results showed different characteristics for detection responsivity and agreed well with the theoretical prediction. Measurements of the peak-to-peak amplitudes of the detected THz photocurrent were approximately 67, 42, and 59 nA for the H-shaped, I-shaped, and bowtie-shaped antennas, respectively. The I- and bowtie-shaped antennas provided higher THz detection sensitivities than the H-shaped antenna in the low-frequency region, i.e., below 0.6 THz. At a frequency of 0.2 THz, the I- and bowtie-shaped antennas offered an approximately 3.6-fold and 6-fold enhancement, respectively, in THz detection sensitivity compared to the H-shaped antenna. The bowtie-shaped antenna produced better peak amplitude and a wider spectral bandwidth than the I-shaped antenna. The observed detection peak frequencies of the I-shaped and bowtie-shaped antennas possessing very long dipole arms indicate that the lowest limit of the frequency detected in a typical THz-TDS using a GaAs photoconductive antenna as emitter/detector is around 0.2 THz.

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1. Introduction

The techniques for generating and detecting terahertz (THz) radiation using femtosecond laser pulses have been studied extensively since the pioneering work of Jayaraman and Lee [1,2], Auston et al. [3,4], and Grischkowsky et al. [5]. Fascinating characteristics of THz waves have generated much interest in many areas, including spectroscopy, pharmaceutical applications, and medical imaging [6–9]. Among the various types of THz sources and detectors, photoconductive antennas (PCAs), which are classified as photonic-based sources, are one of the most frequently used devices for THz-wave generation and detection in established THz measurement and spectroscopy setups [10–12]. Femtosecond-oscillator-based THz PCA systems can generate high signal-to-noise ratio (S/N) broadband THz waves and detect them with high sensitivity. The performance of a PCA mainly depends on the following factors: substrate material, geometry of the active area, antenna structure, and excitation laser pulse. Optimization of photoconductive materials and designing efficient THz antennas are crucial to increasing the amplitude of the THz radiation and have attracted considerable attention since the early stages of THz research [13–18]. Our recent report has numerically revealed that a stripline dipole produced better performance in comparison with the well-known Grischkowsky antenna [19,20]. In addition to the improved performance, the stripline dipole configuration demonstrates simplicity for optimization and realization.

In this paper, we investigate the detection characteristics of three photoconductive antennas, namely the I-shaped (or the stripline dipole), H-shaped (or the Grischkowsky dipole), and bowtie-shaped antenna [21]. After optimizing the antenna design, three antennas are fabricated on a 1.2-μm-thick low-temperature GaAs (LT-GaAs) layer, which is grown on a semi-insulating GaAs (SI-GaAs) substrate and then attached to extended hemispherical silicon (Si) lenses for measurement. The experimental results show that the I-shaped and bowtie-shaped antennas could detect THz

* Corresponding author at: Division of Computational Physics, Institute for Computational Science, Ton Duc Thang University, Ho Chi Minh City, Vietnam.
E-mail addresses: nguyentruongkhang@tdt.edu.vn (T.K. Nguyen), rotermund@kaist.ac.kr (F. Rotermund).

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signals at low-frequency regions below 0.6 THz with a much higher sensitivity than the H-shaped antenna. At a frequency of 0.2 THz, for instance, the I- and bowtie-shaped antennas offer approximately 3.6-fold and 6-fold enhancement, respectively, in THz detection sensitivity compared to the H-shaped antenna. The full width at half maximum of the I-shaped antenna was about 2.2 times larger than that of the bowtie-shaped and H-shaped antennas. From the observed results, the I-shaped and bowtie-shaped dipole antennas having very long arms are expected to provide a frequency-independent nature. In addition, the lowest limit of the frequency detected with typical THz time-domain spectroscopy (THz-TDS) using a GaAs photoconductive antenna is around 0.2 THz.

This paper is organized as follows: first, the geometries of the antenna designs are described; second, the theoretical analysis and simulation model are provided; third, experimental results in a comparison with the simulation results are presented and discussed; and finally, conclusions are given.

2. Antenna design

The THz antenna is very different from the conventional RF/MW antenna with respect to feeding, measurement facility, and antenna point of views [22,23]. The THz antenna is based on laser excitation through the air or through a fiber, while the conventional antenna is excited through various analogous feed lines, such as a coaxial cable, microstrip, and CPW. Another difference

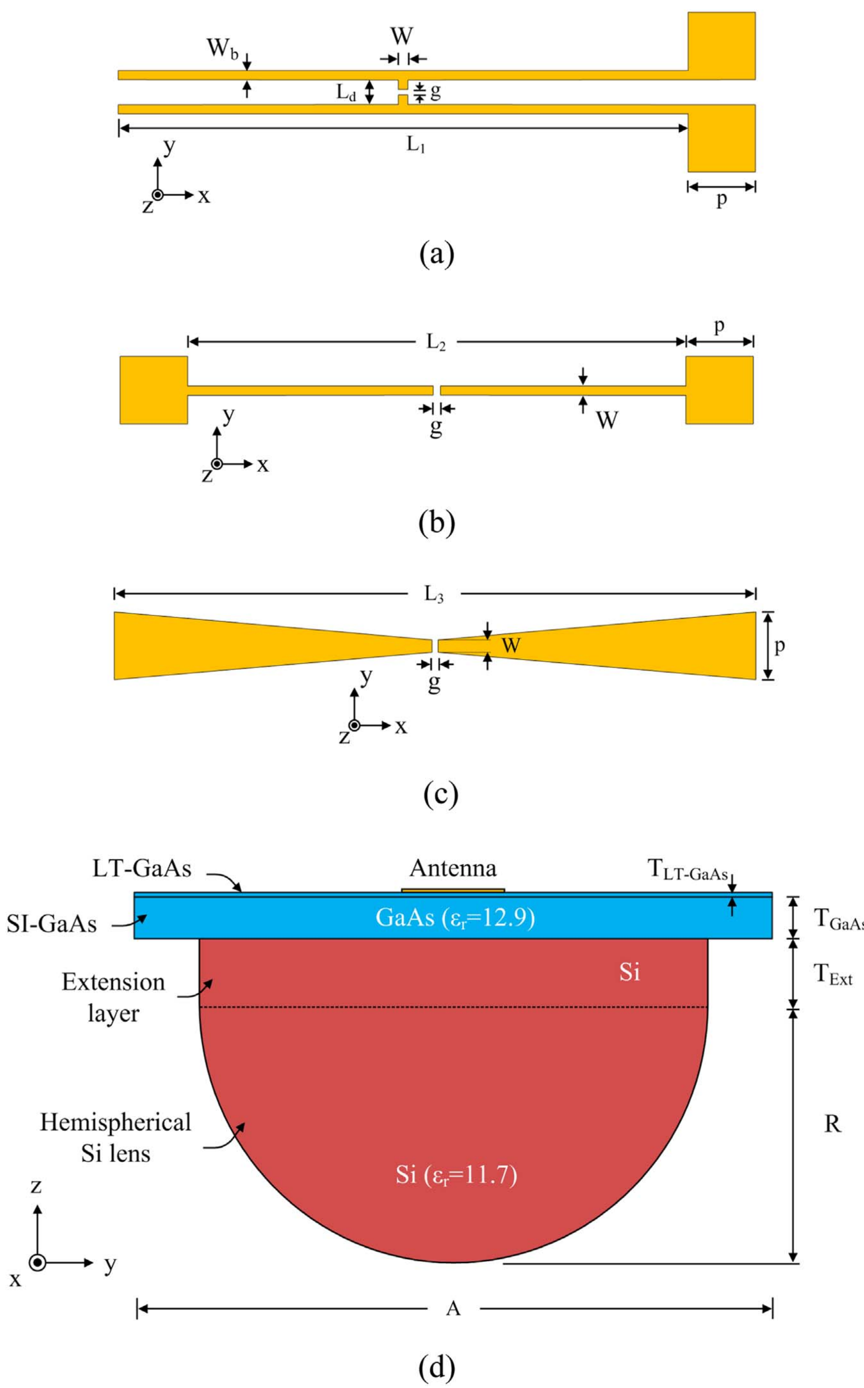

Fig. 1. Schematic pictures of the (a) Grishkowsky H-shaped, (b) I-shaped, (c) bowtie-shaped antenna and (d) extended hemispherical Si lens with LT-GaAs substrate.

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