Fully Integrated Vertical Nanocontact Photomixer for Continuous-Wave Terahertz Generation

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***Abstract*—A new type of a fully integrated vertical nanocontact THz photomixer was fabricated on LTG-GaAs / n^+GaAs / SI-GaAs wafer with a single silver nanowire of ∅ 60 nm. The new vertical structure provides simple fabrication steps and better performance in terms of stability and antenna integration. The THz output power itself can be increased due to high photocurrent of ∼ 7.5 mA and small device capacitance of ∼ 0.6 fF.**

I. Introduction and Background

NEW device concepts and materials for the fabrication of compact THz sources are of particular interest. THz waves at sufficient power from reliable sources are key requirements for many applications in medicine, chemistry, biology, physics, materials science, public safety, and information and communications technology. Conventional lateral photomixers can partially fulfill such applications and are often used as CW THz sources. These photomixers use an interdigital configuration of electrodes on a planar high-speed photoconductive material such as LTG-GaAs, but it has limitations with respect to reliability at high photocurrents, device power, and cutoff frequency [1]. Generally, the conventional vertical photomixer shows better performance especially in the low THz spectral range (50 - 300) GHz.

In [2] the authors showed the benefits of the vertical photomixer structure over the lateral one, but with difficulties of the antenna integration. Here, in this new work these difficulties have been overcome by the full integration on a single chip.

A. The conventional vertical THz photomixer

This devise is a hierarchical structure where a photoconductive material layer is sandwiched between two electrode plates in vertical manner. The top electrode should be an electrically conducting and an optically transparent material for the used wavelengths (the optical beat signal), like a thin gold layer as shown in Fig. 1. The vertical structure improves mainly the two dimensional effects of lateral structures which have electric field spikes and a quick decrease of the electrical field as a function of the depth. Additional benefits of the vertical structure are better heat dissipation (thermal management) and improvement of radiation efficiency. The thermal management can be improved due to the fabrication of the photomixer on a high thermal conductivity material such as high resistivity silicon or diamond substrate. Overall, the vertical photomixer is superior at lower THz frequencies compared to the lateral photomixer, but there are still some disadvantages and drawbacks due to high device capacitance, complex bonding process, and antenna integration [3].

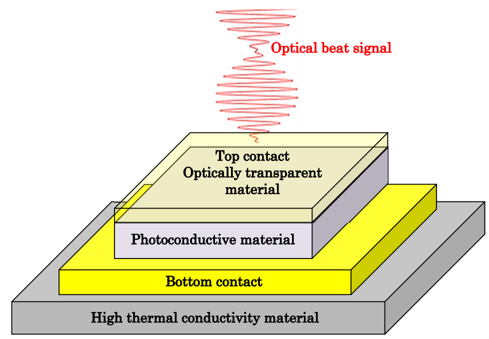

Fig. 1. Schematic diagram of the conventional vertical THz photomixer.

II. The benefits of the new vertical THz photomixer

A. Low device capacitance

The conventional vertical configuration exhibits higher device capacitance than the lateral configuration depending on the active area and the active material thickness. For example the capacitance of the 4 μm diameter photoconductor is C = 5.1 fF, considering that the photoconductor is a parallel plate capacitance, with 0.28 μm thick GaAs layer sandwiched between two disk-shaped electrodes of 4 μm diameter [4]. Or even higher device capacitance C = 13 fF for the LT-GaAs layer of thickness around W = 0.28 μm is sandwiched between two gold layers of diameter d = 6 μm [3]. Other photomixer designs were tried to reduce the device capacitance by using thicker material between the electrodes. The thicker layer leads to lower photocurrent capability compared to the thinner photoconductor. For example in [5] a vertical photomixer of 25 μm^2 area electrodes separated by a 2.2 μm thick LTG-GaAs layer the device capacitance has been calculated as C = 1.3 fF, whereas the photocurrent was reduced by around one order of magnitude to be 1.76 mA. This photocurrent value was reached by high optical power of 200 mW at 12 V bias voltage. The new configuration showed high photocurrent of ∼ 7.5 mA keeping the device capacitance small (∼ 0.6 fF). The former negative correlation between the device capacitance and the resulting photocurrent was minimized.

B. Easy integration on a single chip

The fabrication process of the vertical photomixer is improved. In [5] an epitaxial layer transfer technique was used based on wafer level AuAu thermo-compression bonding. The bonding quality must be of high quality to ensure the absence of voids. The single chip photomixer with a crystalline interface to the substrate has a good thermal conductance and high mechanical stability.

The antenna integration can be considered as essential requirement of the vertical photomixer. Where the vertical configuration required a suitable antenna to be integrated without affecting the photomixer structure during the fabrication. In [6] the transverse electromagnetic horn antenna (TEM-HA) was fabricated on a sacrificial layer by patterning 4 μm thick gold film with a triangular shape using sputtering. The fabrication complexity and mechanical stability is a critical issue for the 3D antenna structure. A lateral design with simple antenna integration steps is developed to improve the fabrication complexity, which was already available in the lateral photomixer design.

A better performance of the vertical THz photomixer is provided by avoiding these critical device and fabrication drawbacks. It was clearly shown in [7] that nanocontacts in a lateral configuration reduced the device capacitance by around one order of magnitude without reducing the photocurrent. Additionally, the optimization of the antenna integration improved the device reliability and the overall performance.

III. Results

A fully integrated vertical THz photomixer structure was fabricated on LTG-GaAs / n^+GaAs / SI-GaAs wafer with a single silver nanowire of ∅ 60 nm and THz broadband Bowtie antenna as shown in Fig. 2. The reliable measurement results showed a high photocurrent of $\sim$7.5 mA, small dark current of $\sim$5 μA, and an on/off ratio of more than three orders of magnitude as shown in Fig. 3. The initial THz power measurements for several THz will be presented at the conference.

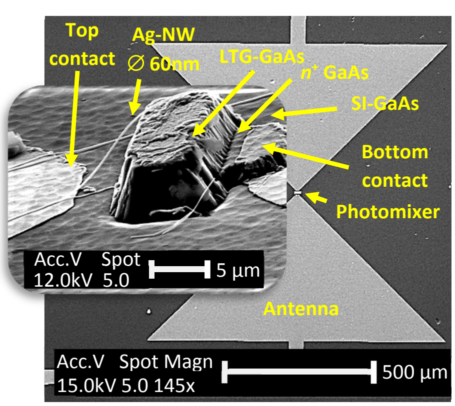

Fig. 2. SEM photo of fully integrated nanocontact vertical photomixer.

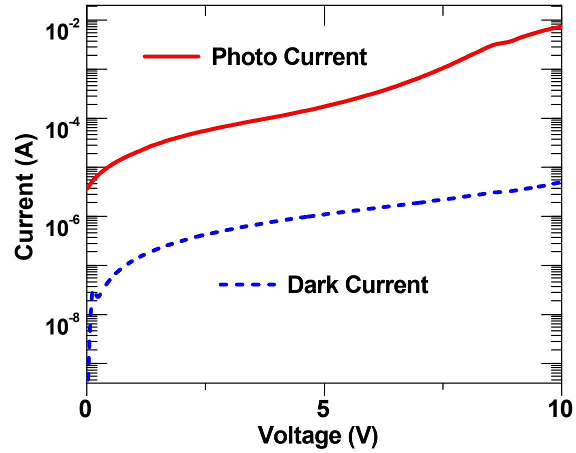

Fig. 3. DC characteristics of fully integrated nanocontact vertical photomixer.

IV. Conclusion

Overall, a clear improvement is shown for the new vertical photomixer using a single wafer with a Ag-NW of ∅ 60 nm, which has a reliable photocurrent of $\sim$7.5 mA. The combination of a very low capacitance of $\sim$0.6 fF and a high photocurrent allows the use of the upper part of the THz range ($>$5 THz) with high THz output power and high signal-to-noise ratio.

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