Terahertz Schottky barrier diodes based on homoepitaxial GaN materials

Shixiong Liang, Dong Xing, J. L. Wang, D. B. Yang, Y. L. Fang, G. D. Gu, H. Y. Guo, L. S. Zhang, X. Y. Zhao, and Zhihong Feng
The National Key Laboratory of ASIC, Hebei Semiconductor Research Institute, Shijiazhuang, 050051, China

***Abstract*—The Schottky barrier diodes based on homoepitaxial n-type GaN materials are fabricated for high-power terahertz multiplier applications. The dislocation density of the GaN homoepilayer is estimated to be about 2-3 orders lower than the typical dislocation density of hetero-epitaxial GaN, the defect density and square resistance are also reduced. So, the series resistance of the diodes is decreased. The air-bridge structure and the substrate thinning-down technique were adopted to reduce the parasitic parameters. The cut-off frequency (f_c) is improved to be above 1.2THz at zero bias by this method.**

I. INTRODUCTION

THE terahertz signal source power drops rapidly with increasing frequency, and it is still a big challenge for generating high power by solid-state devices at the millimeter-wave and terahertz region. GaAs Schottky barrier diodes (SBDs) are the most commonly used multiplier devices in all solid-state local oscillators in the millimeter-wave and terahertz region. But the performance of such devices still does not meet the requirement for practical high-frequency power electronics applications. Gallium nitride (GaN) materials offer the advantages of high power operation due to their large energy band-gap. In addition, the GaN materials exhibit good electron saturation and peak velocities, large band offsets, and good thermal conductivity. So, GaN-based SBDs are expected to have high frequency, and higher power-handling capability [1]. The capabilities of GaN homojunction SBD-based multipliers for LO power generation at Millimeter-Wave Bands have also been investigated by Siles, and for the GaAs doubler, 8 anodes are necessary for a 150 mW input power as a consequence of the lower power-handling capabilities of GaAs SBDs with respect to single anode GaN SBDs [2]. Nevertheless, even after many years' development, obtaining terahertz GaN based Schottky barrier diodes remains a major technological challenge. GaN homojunction SBDs have been fabricated by a French research group, the cut-off frequency (f_c) is around 200 GHz at zero bias, and 1.2 THz at -8 V [3]. Last year, we have also fabricated the GaN SBDs, and the f_c is around 800 GHz at zero bias [4]. Relative to the GaAs SBDs, the cut-off frequency of GaN SBDs is still much lower. If the series resistance can be reduced, and cut-off frequency will be improved, and the efficiency of GaN multipliers might be even closer to that obtained with GaAs multipliers.

In this work, we report GaN SBDs based on homoepitaxial n-type GaN materials, which was grown by metal-organic chemical vapour on a free-standing bulk GaN substrate. Compared to the hetero-epitaxial GaN, the defect density and square resistance of the materials are reduced. So, the series resistance of the diodes is decreased, and the cut-off frequency of GaN SBDs is improved.

II. EXPERIMENTS

The GaN materials used in this work were grown by a MOCVD system on a free-standing bulk GaN substrate, consist of a 1.5 μm N+GaN layer (doping concentration level was $2\times10^{18}\,cm^{-3}$) and a 200 nm N-GaN layer (doping concentration level was $2\times10^{17}\,cm^{-3}$). Another kind of GaN materials was also grown for comparison, and the N+GaN layer doping concentration level of this material was improved to 2×10^{18} cm^{-3}. The doping concentration level was improved and the epitaxial thickness was reduced for the previously reported GaN SBDs.

The air-bridge structure was adopted in our GaN SBDs. The parasitic parameters can be remarkably reduced. But the fabricated process was more difficult for GaN, and has been introduced in our former paper [4]. In this work, a 2 μm×3 μm anode was adopted. The SEM photograph of the fabricated device is shown in Fig. 1.

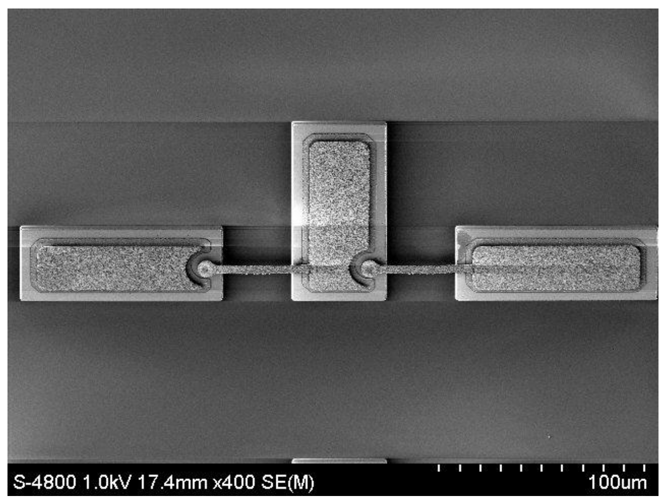

Fig. 1. SEM photograph of the fabricated GaN SBDs with an air-bridge structure.

III. RESULTS AND DISCUSSION

The I-V and C-V characteristics of the diode were measured using an Agilent B1500A Semiconductor Parameter Analyzer at room temperature. The series resistance (R_s) was extracted from the I-V data. Campared to the hetero-epitaxial GaN SBDs, the series resistance is decreased by about 30%, and the cut-off frequency (f_c) is remarkably improved to be about 1.2THz. The other DC and RF characteristics measurement is still under processing.

Compared with the GaAs SBDs, the cut-off frequency of GaN SBDs is still much lower due to the lower mobility. If the series resistance of GaN SBDs can be reduced, and cut-off frequency will be improved, the efficiency of GaN multipliers might be even closer to that obtained with GaAs multipliers. the

N+ layer doping concentration is improved to reduce the spreading resistance and ohmic contact resistance; The comparison between high and low N+ layer doping concentration materials based GaN SBDs is shown in the following figure.

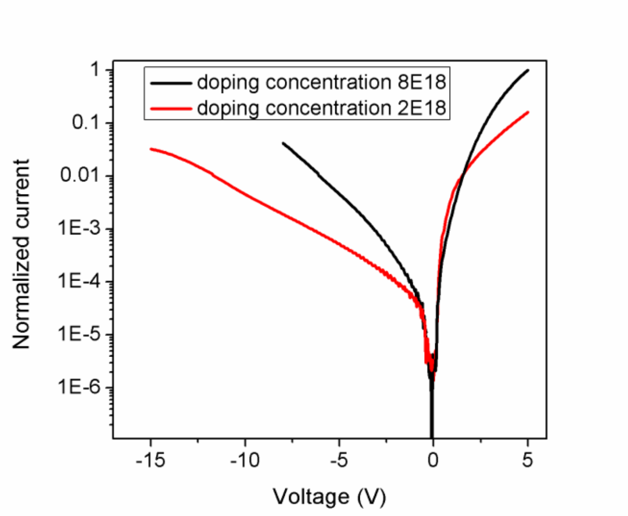

Fig. 2. The normalized current-voltage curve for high and low N+ layer doping concentration materials based GaN SBDs.

The doping concentration of the N+ layer is improved to the level above $8 \times 10^{18}\ cm^{-3}$ by homoepitaxy technology on the GaN single crystal substrate, ohmic contact resistance and the series resistance is reduced, but the breakdown voltage is reduced from -13 V @ 100 μA to -8 V @ 100 μA, so the cut-off frequency is increased by this method, and the power handle ability will be decreased.

The zero bias junction capacitance and the series resistance are calculated for different doping concentration and anode diameter.

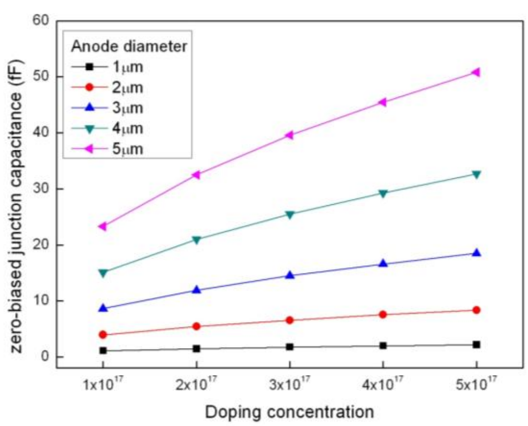

Fig. 3. The relationship of anode contact area and zero-biased junction capacitance.

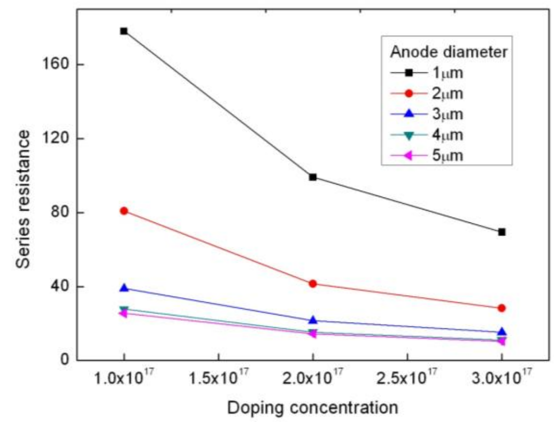

Fig. 4. The relationship of anode contact area and series resistance.

The GaN SBDs should be optimized by other methods. The anode area should be optimized to reduce the junction capacitance and the N- epitaxial resistance; meanwhile, the distance between the schottky contact and the ohmic contact should be reduced, the Quasi-Vertical structure should be adopted [5], and then the cut-off frequency will be improved remarkably. The potential capabilities of GaN SBDs are in the first stages of terahertz multiplier chains where the excellent power handling capabilities of GaN can be exploited [6].

IV. SUMMARY

The schottky barrier diodes based on homoepitaxial GaN materials are fabricated, and characterized. The I-V characteristics of high and low N+ layer doping concentration materials based GaN SBDs is discussed. The DC characteristics confirm that these devices are very promising for high-frequency applications with high power levels.

REFERENCES

[1]. Wei Lu, Lingquan Wang, Siyuan Gu, et al., “InGaN/GaN Schottky Diodes With Enhanced Voltage Handling Capability for Varactor Applications”, *IEEE Electron Device Lett.*, vol. 31, pp1119-1121, 2010.

[2]. José V. Siles and Jesús Grajal “Capabilities of GaN Schottky Multipliers for LO Power Generation at Millimeter-Wave Bands”, *19th International Symposium on Space Terahertz Technology*, pp. 504-507, Groningen, Netherlands, Apr. 28-30, 2008.

[3]. Chong Jin, et al, “E-beam Fabricated GaN Schottky Diode”, *Microwave, MTT-S International Symposium*, pp.1-4, France, 2013.

[4]. Shixiong Liang, Yulong Fang, et al, “Realization of GaN-based high frequency schottky barrier diodes through air-birdge technology”, *12th IEEE ICSICT*, pp.212-214, Guilin, China, Oct. 28-3, 2014.

[5]. Naser Alijabbari, Matthew F. Bauwens, Robert M. Weikle, “Design and Characterization of Integrated Submillimeter-Wave Quasi-Vertical Schottky Diodes”, *IEEE Transactions on Terahertz Science and Technology*, Vol. 5, No. 1, pp73-80, 2015.

[6]. José V. Siles and Jesús Grajal, “Capabilities of GaN Schottky Multipliers for LO Power Generation at Millimeter-Wave Bands,” *19th International Symposium on Space Terahertz Technology Groningen*, pp. 504-507, 2008.