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Power Handling of GaN Schottky Diodes on Semi-Insulating Ammonothermal GaN Substrate at 94 GHz

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Abstract

In this paper, we report electrical results and handling power results of different Schottky diodes based on 620 nm of n-Gallium Nitride (GaN) fabricated on ammonothermal GaN substrate. The breakdown voltage obtained is 115 V/ μm . Diodes held 29.6 dBm at zero bias and we detected an output voltage of 16.5 V at 94 GHz.

Introduction

One of the most promising technologies and the only one that has proven its potential up to the THz range is based on frequency multiplication. The established Gallium Arsenide (GaAs) technology enables state-of-the-art output power levels (near 1 mW of power at 1.6 THz and 50 μW at 2.5 THz) have been obtained with classic frequency multiplier [1-2]. Unfortunately, even if these results are impressive, access to these sources remains critical for specialized applications or mass markets. In addition, despite significant improvements in physics and technology, these solutions cannot overcome the intrinsic limit of the GaAs breakdown electric field and its thermal limit which represent fundamental barriers. In this context, novel technologies based on wide bandgap semiconductors such as GaN are emerging as highly promising materials to pave the way for high power applications in the millimeter wavelengths [3]. In this work, initial electrical characterization and handling power results of GaN Schottky diodes on ammonothermal GaN substrate are presented.

Experimental

The process has been developed and applied on an epitaxy obtained by Metalorganic Chemical Vapor Deposition (MOCVD) on a semi-insulating (SI) GaN substrate, which comes from our partners of the Institute of High Pressure Physics of the Polish Academy of Sciences in Poland [4]. The epitaxial layer has the following structure: from the top, it consists of 620 nm of GaN with low doping level to define the core of the Schottky diode, a GaN 425 nm layer is used as a contact layer with high doping level to get low contact resistance for the ohmic contact and finally a 426 nm buffer of GaN layer (undoped) with high resistivity which will allow the isolation of the diode.

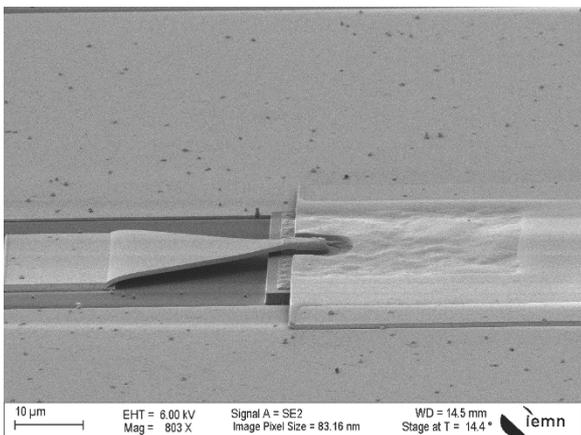


Fig. 1 SEM image of schottky diode with an area of $5\mu\text{m}^2$ with air-

bridge.

The GaN Schottky diodes were fabricated using the following steps process. A SiO_2 hard mask was used in order to define the mesa of the Schottky diode. Subsequently, using Cl_2 -based ICP dry etching, the diode mesa is defined down to the GaN n+ layer. After that, the diodes are isolated by using the same Cl_2 -based ICP dry etching. Then, the ohmic contacts were fabricated by the standard lift-off technique: a standard bi-layer of copolymer and PMMA was exposed and developed and ohmic contacts were deposited by evaporation of Ti/Al/Ni/Au on the n+ GaN layer. Then, rapid thermal annealing (RTA) at 850°C for 30s in an N_2 ambient is used. Finally, for the Schottky contacts itself, a Pt/Au bilayer that was deposited by electron beam evaporation and then annealed. The air bridges between the substrate and the contacts of the anode and cathode were defined and metallized by e-beam evaporation with Ti/Au (Fig. 1).

Results and Discussion

Using the Transfer Length Method (TLM), the ohmic contact are firstly evaluated and then leakage current was measured. The electrical resistivity and contact resistance determined by this method are respectively $5.10^{-7} \Omega\cdot\text{cm}^2$ and $0.1 \Omega\cdot\text{mm}$. We measured a leakage current of 1.2 nA at 70 V. These values indicate on one side that the SI-GaN ammonothermal substrate is extremely resistive and on the other side the quality of the ohmic contacts.

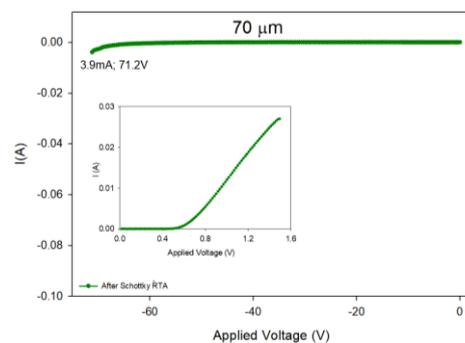


Fig. 2 I-V characteristic of the GaN Schottky diode on GaN ammonothermal substrate with diameter of $70\mu\text{m}$.

Figure 2 shows the I-V characteristics of one of the devices studied in this work with $70\mu\text{m}$ diameter. Results of this diode with this diameter are representative (several measurements of diodes with the same diameter have been made). The breakdown voltage, at the destruction, has been measured at around -71V with a leakage current of 3.9 mA. The leakage currents can have an origin of defects and/or the presence of contaminants at the edge of the mesa of diode. These results show the interest to optimize the mesa etching step in order to minimize the defects and the presence of contaminants on the edges of our mesas and to have a proper interface between the metallised contacts and the semiconductor [5].

Using Cheung's method [6], the barrier height and the ideality factor have been determined at 0.75 eV and 1.24 respectively, which confirms that the main electrical conduction mechanism is thermionic emission.

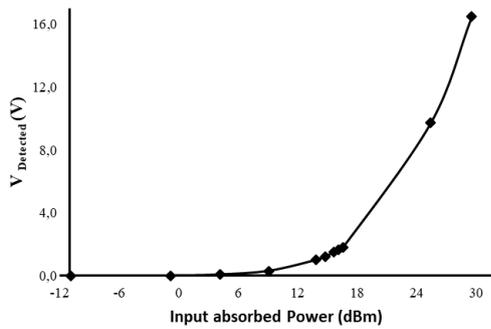


Fig. 3 Detected Voltage as function of input absorbed power at 94 GHz of the GaN Schottky diode on GaN ammonothermal substrate with an area of $5\mu\text{m}^2$.

The figure 3 illustrates the output voltage of GaN Schottky diode with an area of $5\mu\text{m}^2$ in detection configuration under sweeping input power at 94 GHz. It indicates that the output voltage increases almost exponentially with the input power. The output voltage is 16.5 V with 29.6 dBm input absorbed power. We stressed the diode for 5 hours and got the same results. These results show the superior power handling of the GaN diodes.

Conclusions

We presented the fabrication process of GaN Schottky diodes through e-beam lithography process. Electrical measurements results show us the interest to optimize the fabrication technique in order to limit the leakage current. Power measurements results show the interest to work on a homoepitaxy in order to avoid crystalline defects, which affect the diodes electrical performances. This result is confirmed after a stress of several hours and to have a better thermal dissipation compared to the GaN Schottky structure on sapphire substrate.

Acknowledgments

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