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GaN Schottky Diode for High Power THz Generation using Multiplier Principle

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Abstract

GaN-based planar Schottky barrier diodes with potential applications in THz frequency multipliers were fabricated and characterized. GaN is a promising candidate to overcome all the physical limitations of GaAs which have been reached in the frame of high frequency power multiplier applications. Fabrication process of GaN Schottky diodes performed by e-beam is presented and DC characterizations are reported. The preliminary results showed that the behaviour in reverse bias is dominated by a leakage coming from the Schottky surface more than the periphery of the diode despite the supposed damage caused by the dry etching.

Introduction

The only technology that has proven its potentials in the THz range relies on the frequency multiplier principle. The GaAs-based frequency multiplier chains delivers state of the art performance with an output power of 18 μ W obtained at 2.58 THz and about 1 mW at 1 THz [1]. However, even if these results are impressive, a large access to these powers THz sources remains critical for mass-market applications. Despite the improvements in many technological and design aspects, all solutions cannot overcome the GaAs intrinsic electric field breakdown limitation and the limited thermal conductivity which both represent now the definitive bottlenecks.

The search of a candidate exhibiting a high breakdown electric field combined with high thermal conductivity is crucial. This candidate is the Gallium Nitride (GaN) [2]. The first bottleneck will be surpassed by its high breakdown electric field, 10 times larger than GaAs. The second bottleneck will be managed thanks to GaN and SiC substrate which present a thermal conductivity 3 and 10 times larger than GaAs, respectively. Both, high breakdown electric field and high thermal conductivity will increase the power handling capabilities of devices resulting in a high output power. Indeed, it has been shown that the power handling capability of a GaN Schottky diode is almost one order of magnitude larger than its GaAs counterpart.

Experimental

The GaN epitaxial layers used in this study were grown by MOCVD on *c*-plane sapphire substrate. A 3 μ m thick n^+ GaN ($1 \times 10^{20} \text{ cm}^{-3}$) layer was grown first to achieve low series resistance and a 650 nm n^- GaN ($5 \times 10^{16} \text{ cm}^{-3}$) acted as active layer. First of all, SiO₂ was deposited on the GaN surface in order to be used as a hard mask for the Schottky diodes. SiO₂ is then patterned first using negative AZ-nLOF defined via e-beam lithography and then followed by a SF₆ dry etching. The remaining resist is subsequently removed by O₂ plasma. Next, using Cl₂-based ICP dry etching, the diode mesa is defined up to the n^+ GaN layer. The resulting mesas were approximately 750 nm. Ohmic contacts were fabricated with typical lift-off technique: a standard bi-layer of copolymer and PMMA was exposed and developed. Before the multilayer evaporation

consisting of Ti/Al/Ni/Au, the sample was treated with a HF-based solution. Afterwards, RTA was used to anneal the contact at 850°C. Before the Schottky electrode fabrication, the SiO₂ mask was removed with a BOE solution. Then, a by-layer e-beam lithography process is used and the Pt/Au electrode was deposited by e-beam evaporation. This process allowed fabricating planar Schottky diodes of different diameters, ranging from 70 to 1400 μ m in order to study the material properties and to optimize at first order the critical technological steps. In the same time a process of submicronic Schottky diode including air-bridge was under development and presently under optimisation. The figure 1 shows an anti-parallel submicronic diode.

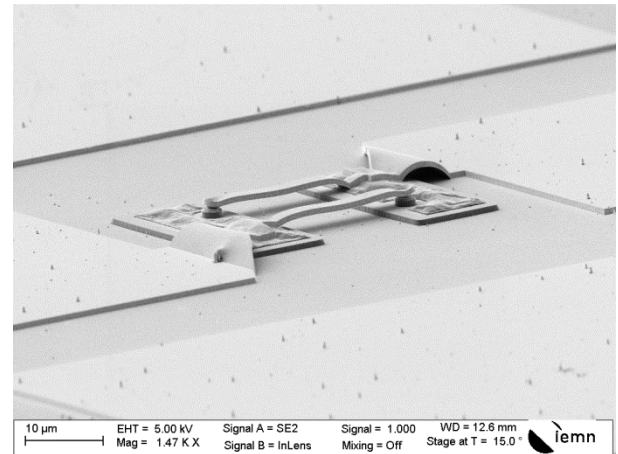


Figure 1: Micronique anti-parallel GaN Schottky diode.

Results and discussion

The main technological limitation in GaN technology comes from the epitaxy since the semiconductor lattice is not matched to the sapphire substrate. The material suffers from defects and dislocations that affect its electronic properties. This impacts the leakage currents and affects the device performances [3].

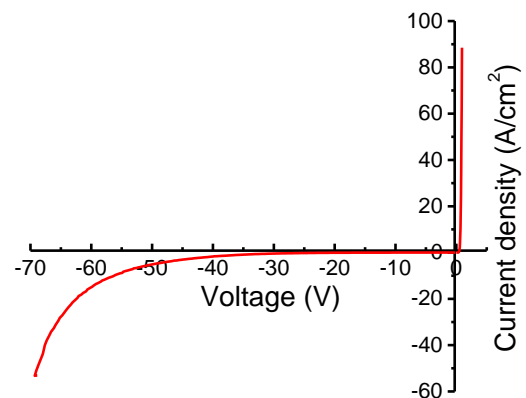


Figure 2: I-V characteristic of the GaN Schottky diode.

Figure 2 shows the I-V characteristics of one of the devices studied in this work. The breakdown voltage, at the destruction, has been measured at around -70V. Based on the thermionic standard model, the barrier height and the ideality factor have been determined at 0.56 eV and 2.2 respectively.

A study of leakage currents origin has been undertaken. Leakage currents could take place with two origins: from the interface between the Schottky metal contact and the GaN semiconductor or from the edge of the mesa diode. In order to discriminate the influence from the surface or from edge for our technology, diodes with diameters from 70 μm up to 1400 μm were fabricated. This variation allows comparing phenomena for a surface variation factor of 400 and a perimeter variation factor of 20. As it can be seen from Fig. 3.a the leakage current normalized as a function of the surface is about the same for all the surface variations, while the normalization with respect to the perimeter Fig. 3.b shows that non-ideality effects due to the edge of the diode do not contribute in a relevant way to leakage. As a result, for our technology, leakage current is dominated by surface phenomena.

Various explanations can be attributed to this behaviour, the aforementioned presence of extensive lattice defects, the presence of contamination on the surface of GaN before Schottky contact deposition and probable GaN surface damage due to plasma and/or fabrication process. In other works presented in the literature [4], these performances are associated to the presence of a Schottky barrier inhomogeneity.

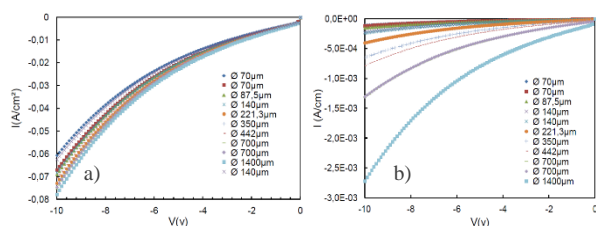


Figure 3: a) Surface-normalized current density, b) Perimeter-normalized current density.

Among the proposed solutions, of notable importance and worthy of further investigation are the choice of a suitable acid pre-treatment of the GaN surface before Schottky metallization, i.e. a wet chemical surface treatment which targets a specific contaminant in a preferential fashion (HCl for the removal of native oxides, HF for removal of carbon and/or hydrocarbon contaminants) [5, 6], and a thermal annealing for the Schottky contact which was shown to improve (in certain conditions) the quality contact [7, 9]. Future investigations will include a study of the above-mentioned surface pre-treatment, a complete study of the annealing of the Schottky contact, as well as comprehensive electrical characterization of the diodes.

Conclusions

We presented the fabrication process of GaN Schottky diodes through e-beam lithography process. Reverse leakage current characteristics normalized with respect to the surface and to the perimeter of the diodes were presented, in order to identify the main source of non-idealities. It was recognized that, for our technology, surface effects predominantly influence leakage currents. This fact motivates further investigations into the nature of these non-idealities.

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