GaN schottky diode on silicon substrate for high power THz multiplier

Giuseppe Di Gioia, M Samnouni, H Bouillaud, P Mondal, J Treuttel, Yvon Cordier, Malek Zegaoui, Guillaume Ducournau, Yannick Roelens, Mohammed Zaknoune

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G. Di Gioia[1]*, M. Samnouni[1], H. Bouillaud[1], P. Mondal[2], J. Treutell[2], Y. Cordier[3], M. Zegaoui[1], G. Ducournau[1], Y. Roelens[1], M. Zaknoune[1]

[1] University of Lille, CNRS, Centrale Lille, Univ. Polytechnique Hauts-de-France, UMR 8520 - IEMN Institut d'Electronique de Microélectronique et de Nanotechnologie, Lille, France
[2] LERMA, Laboratoire d'Études du Rayonnement et de la Matière en Astrophysique et Atmosphères
[3] CRHEA, Centre de Recherche sur l'Hétéro-Epitaxie et ses Applications
* giuseppe.digioia.etu@univ-lille.fr

Abstract

GaN-based planar Schottky barrier diodes with potential applications in THz frequency multipliers were fabricated on silicon substrate 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. Preliminary results on silicon showed a low breakdown voltage.

Introduction

Among the technologies that have proven great potential and use in THz generation, frequency multipliers have carved a special place due to their availability and cost-effectiveness. The GaAs-based frequency multiplier chains deliver state of the art performance with an output power of 18 µW 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 now both represent 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]. Its higher breakdown electric field and higher 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 [3]

Experimental

The GaN epitaxial layers used in this study were grown by MOCVD on silicon substrate, the epilayer included a 500 nm thick n+ GaN ($7\times10^{18}.cm^{-3}$) layer to achieve low series resistance and a 500 nm n- GaN ($1\times10^{17}.cm^{-3}$) as active layer. First, SiO_2 was deposited on the GaN surface in order to be used as a hard mask for the Schottky diodes. SiO_2 was then patterned using negative resist defined via e-beam lithography and then followed by a SF_6 dry etching. The remaining resist was subsequently removed by O_2 plasma. Next, using Cl_2-based ICP dry etching, the diode mesa was defined up to the n+ GaN layer. 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 SiO_2 mask was removed with a BOE solution. Then, a by-layer e-beam lithography process was 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 µm in order to study the material properties and to optimize at first order the critical technological steps. At the same time, submicronic quasi-vertical Schottky diodes with air-bridge were fabricated with the same masks, with diameters ranging from 40 to 0.6 µm (Fig. 1).

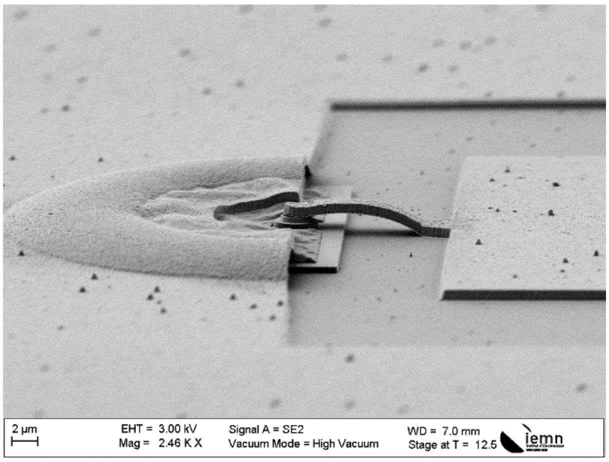

Figure 1. 2-µm diameter quasi-vertical Schottky diode with air-bridge.

Results and discussion

A typical characteristic for a 70µm diode can be seen in Fig. 2. The barrier height and ideality factor were determined through thermionic emission model from the forward characteristic: 0.48eV and 1.3, respectively. This high ideality factor is indicative of the fact that, other than thermionic emission current, there are other current mechanisms that contribute in a significant way to the diode characteristic, notably tunnelling current, generation recombination current and leakage current [4]. The reverse breakdown voltage has been measured to be around -20V, as opposed to a breakdown voltage of circa -80V obtained with our previous work on GaN on sapphire [5]. This premature breakdown can be attributed to the high leakage current affecting the reverse characteristic. The main technological limitation in GaN technology comes from the epitaxy since the semiconductor lattice is not matched to the substrate. Therefore, the material suffers from defects and dislocations that degrade its electronic properties which in turn impacts leakage currents and affects the device performances [6].

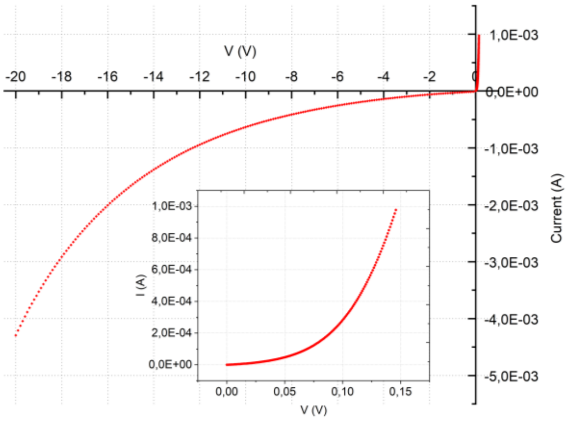

Figure 2. I-V characteristic of a 70µm diode (inset: forward characteristic)

The large mismatch between silicon substrate and GaN could explain the lower breakdown voltage due to the high presence of dislocation defects.

By performing a normalization of the current versus surface and perimeter, the nature of this leakage current can be better understood.

As can be seen respectively in Fig. 3 and Fig. 4, the leakage current normalized versus surface is about the same for all the diode (surface variation factor of about 400, i.e. variation of current density by a factor ~4) while the normalization with respect to the perimeter (variation factor of about 20, i.e. variation of current density by a factor ~10^2) shows that nonidealities which could stem from the edge of the diode do not contribute in a relevant way to the reverse current.

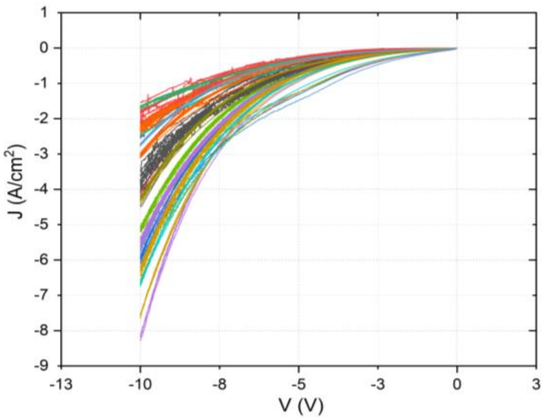

Figure 3. Surface normalization of reverse current (23 diodes with diameters ranging from 40 to 2 µm)

The presence of contamination prior to Schottky contact metallization and/or a semiconductor-metal interface that is not at the thermodynamical equilibrium may contribute also to a lower barrier height and a higher reverse leakage current. Indeed, a stabilization of the contact could improve the overall characteristics of the diode [7].

A study of an annealing temperature for the Schottky contact is ongoing and will be presented during the conference.

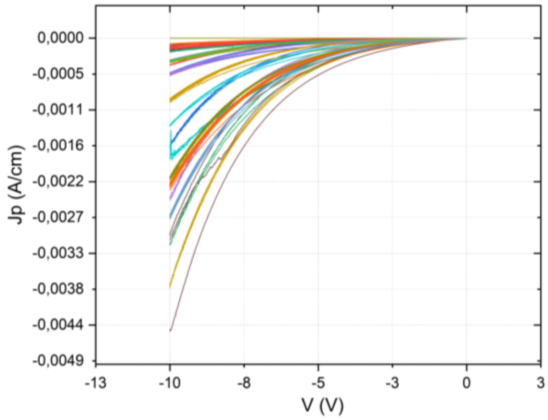

Figure 4. Perimeter normalization of reverse current (23 diodes with diameters ranging from 40 to 2 µm)

Conclusions

We presented the fabrication process of GaN Schottky diodes on silicon substrate fabricated through e-beam lithography. The main parameter of the diodes were extrapolated from forward characteristic. Reverse leakage current characteristics normalized with respect to the surface and to the perimeter were presented in order to identify the main source of the high leakage current.

Acknowledgments

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