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Study and optimization of a 600V Pseudo-vertical GaN-on-silicon rectifier by finite elements simulation

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Real performance breakthrough have been demonstrated for high voltage, high power, high temperature and high frequency devices by using wide band-gap semiconductors, such as 4H-SiC, GaN and AlGaN, over the previously existing devices based on group-IV and III-V lower band-gap semiconductor material.

One of the key devices for high power switching converter is a fast rectifier. 4H-SiC based Schottky diodes are now commercially available from many companies with breakdown voltage up to 1,7 kV. However, bulk SiC substrates are very expensive and the hetero-epitaxial SiC layers on low cost substrates have too many crystal defects. These are the main reasons for the on-going research programs toward GaN based-rectifiers on Silicon substrate for medium voltage range applications ($600 \text{ V} < V_{br} < 1.2 \text{ kV}$).

The insulating buffer between the Si substrate and GaN epilayer limits the rectifier architecture to a lateral structure. Fig. 1 displays two types of GaN based rectifier architectures. The first one (Fig. 1-a) derived from a HEMT structure where the gate becomes the anode and the Drain/Source become the cathode. If this architecture offers interesting prospects for low resistance devices due to the high mobility of the 2DEG electron gas at the AlGaN/GaN interface, the HEMT based rectifier suffer of many points of vulnerability like current collapse phenomenon [1], lag effect [2] and the lack of an efficient edge-termination [3].

Recent advances on the development of thick n-type GaN epilayers (slightly and highly Si doped) on Si substrate and on the deep GaN etching [4] offer new prospects for the development of a pseudo-vertical GaN rectifier as reported on Fig.1-b. The advantages of such device architecture are numerous. First, the use of pseudo vertical architecture allowed a significant reduction of the GaN Schottky diode on-resistance due to the vertical current conduction in the drift region under forward bias. Then, a vertical extension of the electric field in the drift region under reverse bias is expected with a good efficiency of the “mesa + guard ring” edge-termination.

The optimization of the pseudo-vertical structure have been performed by finite elements simulation using SYNOPSIS SENTAURUS software with a breakdown voltage target of $V_{br} > 600 \text{ V}$.

The influence of the geometrical and physical parameters reported on Fig. 2 on the specific on resistance and the breakdown voltage have been studied. All simulations have been performed with a Schottky barrier height and an ohmic specific contact resistance of $\Phi_b=1 \text{ eV}$ and $\rho_c = 10^{-5} \Omega.\text{cm}^2$, respectively. The doping level of the n^- layer and the n^+ layer was $N_{d-n} = 7 \times 10^{15} \text{ cm}^{-3}$ and $N_{d-n^+} = 4 \times 10^{18} \text{ cm}^{-3}$, respectively.

Regarding the forward static properties, the most influent parameter is the thickness of the n^+ layer (*thick_cath*). Fig. 3 displays the evolution of the specific on-résistance with *thick_cath*. One can see that for *thick_cath* = 2 μm the specific on-resistance is close to $R_{on} = 5.8 \text{ m}\Omega.\text{cm}^2$ while this value strongly decreases down to $1.6 \text{ m}\Omega.\text{cm}^2$ for *thick_cath* = 10 μm . For information the specific on-resistance of a vertical structure with the same epitaxial layers properties is close to $0.5 \text{ m}\Omega.\text{cm}^2$. This result tends to demonstrate that a thick n^+ layer is needed to get a good pseudo-vertical-behaviour. The evolution of the electrostatic potential (Fig. 4) illustrates the influence of *thick_cath* on the vertical behavior of the structure. The influence of the other parameters (Fig. 1-b) on the specific on-resistance will be described in the final paper and compared to measurements made on specific test devices.

Fig. 3 reports the evolution of Breakdown Voltage as a function of the p^+ guard ring doping concentration for *thick_drift* = 6 μm . One can see that even for a low guard-ring doping concentration, the breakdown voltage exceeds the 600 V targets, theoretically. This result is promising for the development of an efficient edge-termination based on “Mesa + Guard Ring” for the GaN technology even if the post-implantation activation process is still an important technological obstacle. The final paper will give more details on the influence of other parameters on the Breakdown Voltage.

In conclusion, the advantage of the pseudo-vertical architecture is the possibility to get an efficient edge-termination. However, the main drawback is the need of a thick ($> 10 \mu\text{m}$) n^+ layer to reach low enough specific on-resistance. Unfortunately, the thickness of the n^+ layer is limited to $2\sim 3 \mu\text{m}$ due to the stress induced by the high doping concentration. As a result, it appears that the pseudo-vertical GaN rectifier is not competitive face to 4H-SiC Schottky rectifier ($R_{\text{on}} \sim 1\text{m}\Omega\cdot\text{cm}^2$) at the actual state of the art of the GaN epitaxy technology.

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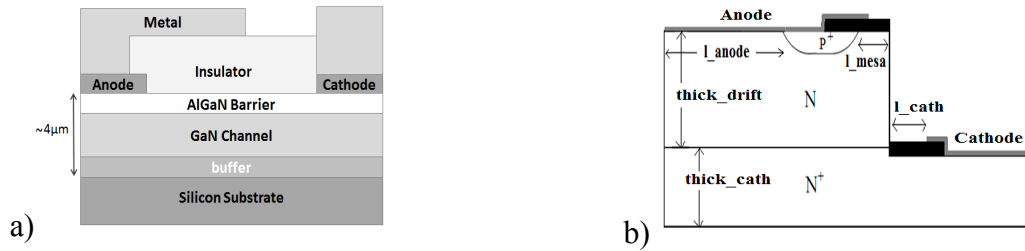


Fig. 1. Schematic cross-section view of a) a lateral HEMT based Schottky rectifier and b) a pseudo-vertical rectifier. l_{anode} , l_{mesa} , l_{cath} , thick_cath and thick_drift are the tuned parameters.

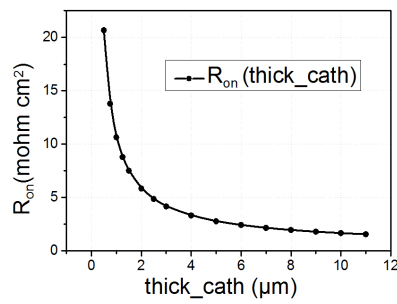


Fig. 2. Simulated on-resistance as a function of thick_cath

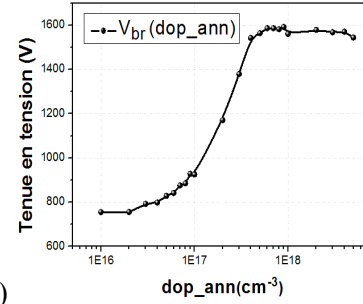


Fig. 3. Simulated breakdown voltage as a function of the guard-ring doping.

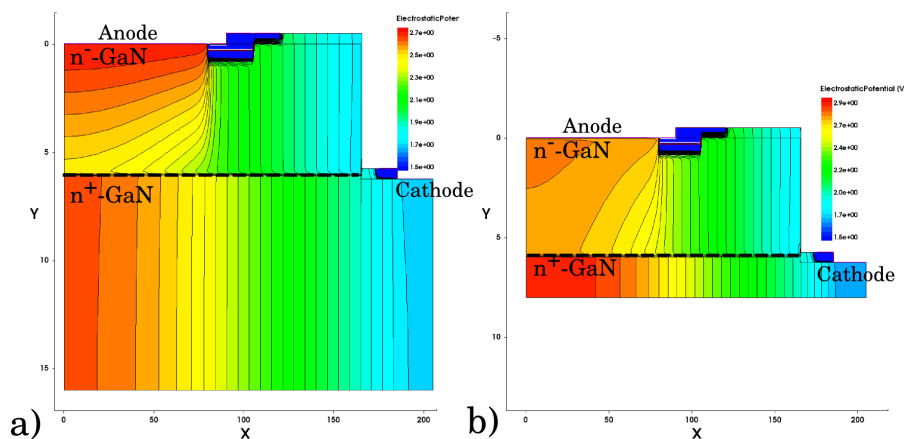


Fig. 4. Evolution of the electrostatic potential at $V_{\text{ak}} = 2\text{V}$ for a) $\text{thick_cath} = 10 \mu\text{m}$ – b) $\text{thick_cath} = 2 \mu\text{m}$