Improvement of breakdown voltage of GaN-on-GaN p-n Junction Diodes with Shallow Bevel Termination for High Power Applications

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One of the major factors limiting the performance of vertical GaN devices, is the electric field crowding at a device edge [1]. Very recently, Maeda et al. [2] showed that this problem can be effectively eliminated in beveled- mesa structures by introducing n and p-layers with comparable doping concentrations [2]. In this work, we propose another approach for reducing electric field crowding in the bevel mesa structures. We show, using two- dimensional TCAD simulations that due to implementation of P-type regions into the bevel mesa structures (see Fig. 1, P_2 areas) it is possible to obtain the uniform avalanche effect and thus significant enhancement of the breakdown voltage (BV).

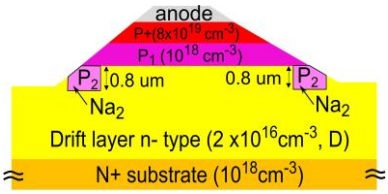

FIG. 1. Beveled-mesa structure with implemented *P*2 region.

Fig. 2 shows the calculated dependencies of BV as a function of the doping level (Na_2) of the implemented P_2 region for two different thicknesses (D) of the drift layer equal to 4 and 8 μm. It is clear that with increasing Na_2, BV first dramatically increases and subsequently rapidly decreases.

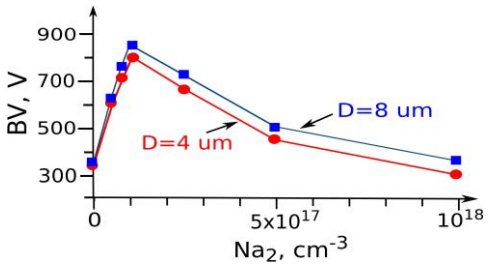

FIG. 2. Calculated dependencies of BV on Na2.

In order to understand these results, we presented in Figs. 3a-c the electric field distribution in the device under the breakdown voltage conditions, i.e. when the electric field reaches the critical field for GaN of 3.3 MV/cm. One can note that in the case of the structure without P_2 region, i.e. Na_2= 0 (Fig. 3a) the electric field is highly concentrated at the pn junction near the bevel surface, which strongly limits BV to 370-380 V (similar values to those reported in Ref. [2]). On the other hand, in the case of $Na_2=10^{17}$ cm^{-3} (Fig. 3b) the electric field is much more relaxed, i.e. the electric field peak is practically internal (shifted towards the bulk) which leads to the remarkable increase of BV up to 855 V. However, when Na_2 is too high, for example of 10^{18} cm^{-3} (Fig. 3c), the electric field becomes strongly localized near the surface similarly like in the case of Na_2= 0 and therefore BV is significantly reduced. Furthermore, when we assumed that Na2 gradually decreases from 10^{17} cm^{-3} to 10^{16} cm^{-3} with increasing distance from the bevel surface, the electric field crowding practically disappeared (see Fig. 3d) and BV was near the ideal value of 1200 V.

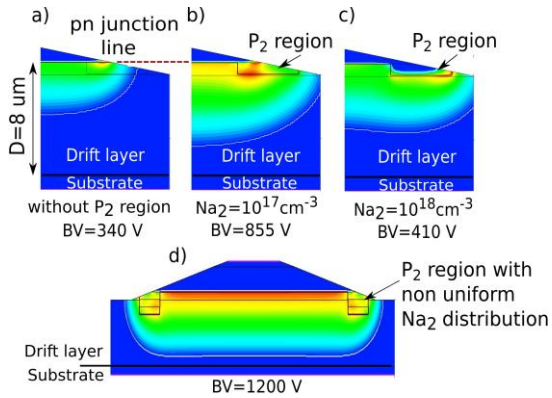

FIG. 3. Electric field distribution in structures: without *P*2 region (a), Na_2= 10^{17} cm^{-3} (b), Na_2= 10^{18} cm^{-3} (c) and non-uniform Na_2 (decrease from 10^{17} cm^{-3} to 10^{16} cm^{-3} with increasing depth up to 2.4 μm).

In conclusion, we showed that due to suitable doping concentration of the P_2 region, the uniform avalanche breakdown in the beveled-mesa structure can be obtained. Therefore, we believe that the proposed novel bevel mesa structure with implemented P-type regions should be promising for high power device applications.

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[2] Maeda, et al., IEDM Technical Digest, 30.1.1-30.1.4 (2018).