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Breakdown enhancement of Super-HFET using high-K passivation layers- A comparative analysis

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Devices fabricated with wide bandgap semiconductor material are being considered the best contenders for the field of power electronics and microwave electronics sector and to replace the conventional materials such as Silicon (Si) and Gallium Arsenide (GaAs). GaN and SiC are the two major contenders due to their higher value for bandgap and the thermal conductivity. This work focuses on AlGaN/GaN high electron mobility transistors (HEMTs) in particular the super HFET proposed by Nakajima et al. [1], with the aim of gaining the maximum potential out of them with regards to breakdown voltage. GaN based devices are able to breakdown at higher voltages compared to Si or GaAs due to its wider band gap (3.4 eV compared to 1.1 eV and 1.4 eV respectively). Researchers have been working constantly in this area for last two decades and still a lot of areas are yet to be explored to utilise the full potential of GaN based devices. The purpose is to provide a completely optimised device, which is the solution to the limitations of the existing technologies so that such devices can be commercially viable. One of the main obstacles is the high electric fields generated at the drain-side of the gate, which have prevented these devices from reaching their theoretical breakdown field of around 300 V/μm. Moreover a trade-off between the breakdown voltage (BV) and area specific on-Resistance (R_{ON}*A) exists in the existing technologies which limits the increase of breakdown voltage to higher values as the on-resistance increases and drain current decreases. In an attempt to overcome this, a super HFET proposed by Nakajima et al. [1] has been discussed and the corresponding results reproduced and a comparative analysis of the super HFET having substituted the passivation layer by higher-k materials has been carried out. The results given show that high-k materials like Sapphire and Hafnium Oxide(HfO_2) indeed have an effect on the breakdown voltage compared to the device passivated with SiO_2 [1] which is clarified through qualitative simulated electric field at the drain-side gate-edge of the device. The breakdown field is increased from 56 V/μm to 79 V/μm for gate-drain separation of 10 μm and from 50 V/μm to 84.09 V/μm for a gate-drain separation of 22 μm.

Thus, it is concluded that using a passivation layer of high-k materials increases the breakdown voltage and also increased gate-drain separation distributes the field at the drain-side gate-edge of the super HFET where the electrons have a tendency to leak into the AlGaN surface and form a 'virtual gate' which is responsible for device degradation.

Table 1: Comparison of Breakdown fields and Electric fields of super HFET with passivation of different di-electrics

Passivating Material	Di-Electric Constant (k)	Break-down Field@ L_{gd}=10μm (V/ μm)	Break-down Field@ L_{gd} =22μm (V/ μm)
SiO_2	3.9	56.0	50.0
Si_3N_4	7.5	59.0	56.8
Alumina	9.3	61.4	60.0
Sapphire	12	63.8	65.3
HfO_2	22	68.0	77.5
TiO_2	80	79.0	84.0

Reference

1. Akira Nakajima, Yasunobu Sumida, Mahesh H. Dhyani, Hiroji Kawai, and E. M. Sankara Narayanan, Senior Member,IEEE , "GaN-Based Super Heterojunction Field Effect Transistors Using the Polarization Junction Concept," IEEE Electron device letters, vol. 32, no. 4, April 2011.