600V-900V GaN-on-Si Process Technology for Schottky Barrier Diodes and Power Switches Fabricated in a Standard Si-Production Fab

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Abstract

This paper describes a GaN-on-Si Schottky process technology being developed in one of NXP's standard Si production fabs. It runs alongside standard Si-component manufacturing sharing the same production tools. It supports up to 900V-rated Schottky barrier diodes and power switches. Up to 8A-rated diodes and 100mΩ switches with breakdown voltage above 1000V are demonstrated.

INTRODUCTION AND MOTIVATION

Future high-efficiency power converters require fast switching, low conduction loss devices that can handle high voltages. GaN is a good candidate for voltages up to 1kV and shows excellent switching behavior in Schottky diodes and in HEMTs. Thanks to the advancements in GaN-on-Si epitaxy, the industry is now actively combining III-V specific device expertise with low-cost high-volume Si main-stream production facilities. Key issues to be resolved in GaN Schottky diodes and HEMTs are the reduction of leakage current, lagging behavior (dynamic R_{on} or current collapse) and optimization of the electrical field distribution for high breakdown voltage.

DEVICE PROCESSING

NXP's GaN-on-Si process technology is using Ti/Al-based ohmic contacts and Ni-based Schottky contacts. These are patterned in a silicon nitride passivation-first integration scheme by dry etching. Argon implantation is used for device isolation. Two Al-metal layers are used as interconnect and for high current routing. Plasma Enhanced Chemical Vapor Deposited (PECVD) silicon nitride layers are used as pre-metal and inter-metal dielectrics and final passivation.

PROCESS CONTROL MONITORING

During the process flow the following parameters were monitored for process control: ohmic contact resistivity ρ_c, Schottky diode forward voltage V_{ca} at 0.1A/cm^2, reverse leakage current I_r at 50V and diode ideality n. Circular TLM structures with varying metal to metal spacing were used to extract ρ_c. Circular diode structures with varying anode-cathode spacing were used for the Schottky forward voltage, ideality and reverse leakage. Each measurement set was performed on 24 dies. Intermediate testing was done after (i) the ohmic module and device isolation; (ii) Schottky formation and contact opening; (iii) metal 1 and 2 aluminum back-end and (iv) final silicon nitride passivation.

Typical measurements are shown in Fig. 1. As can be seen from Fig. 1a, ρ_c varies across the wafer, but is very stable throughout the process. End-of-process it ranges typically from 5×10^{-6} to $1\times10^{-5}\Omega\cdot$cm^2, which corresponds to 0.5-1Ω·mm and is close to best reported values for Au-free ohmic contacts on GaN. Figs. 1b and c show the diode performance. The end-of-process Schottky diode voltage at 0.1A/cm^2, used to characterize the effective Schottky barrier, ranges from 0.67 to 0.77V and n from 1.2 to 1.6.

DEVICE CHARACTERIZATION

This work focuses on reduction of the diode reverse leakage current by optimization of the Schottky module. Fig. 2 shows the evolution of the leakage for three different process types. For the optimized wafers *A*, *B* and *C*, leakage has been reduced to a 10^{-6} to 10^{-7} A/mm level. Breakdown voltages and lagging behavior are reported next for these wafers.

Shown in Fig. 3 is the reverse diode leakage measured up to 1100V. For all devices, breakdown is >1100V, which is the breakdown limit of the epi-structure.

Fig. 4 shows the dynamic R_{on} when pulsing from the off-state (10ms pulses, 10% duty-cycle) as function of the off-state drain-bias voltage V_d. A maximum increase of 20% in R_{on} is observed.

The scalability and reproducibility of multifinger SBDs is illustrated in Fig. 5, showing forward operation of 1 to 8A layouts.

Figs. 6 and 7 show our data in benchmarks on specific on-resistance vs. breakdown voltage and leakage current vs. drain source voltage [1,2].

CONCLUSIONS

We have demonstrated 600-900V GaN-on-Si power devices, fabricated in a standard Si production fab. Schottky diode reverse leakage current has been reduced to 1μA/mm at 600V through process optimization, which is best-in-class for Schottky-based devices. Dynamic Ron increase of below 20% indicates a good control of charge trapping phenomena.

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REFERENCES

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ACRONYMS

(Al)GaN: (Aluminum) Gallium Nitride
2DEG: 2-dimensional electron gas
HEMT: High Electron Mobility Transistor

SBD: Schottky Barrier Diode
PECVD: Plasma Enhanced Chemical Vapor Deposition

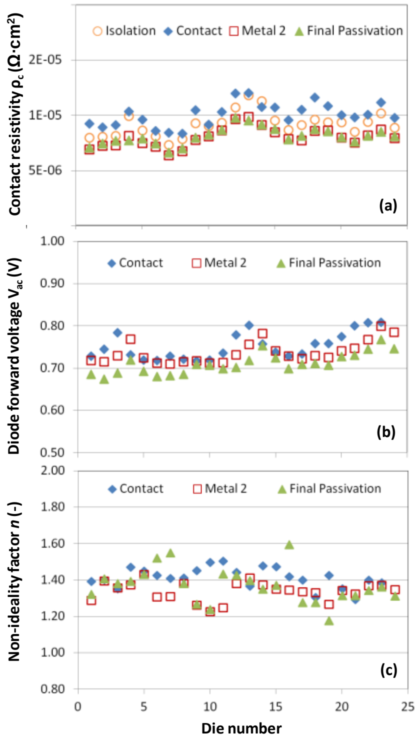

Figure 1: (a) Ohmic contact resistivity in $\Omega\cdot cm^2$, (b) Schottky diode forward voltage at $0.1 A/cm^2$, (c) Schottky diode non-ideality versus die number at different stages of manufacturing.

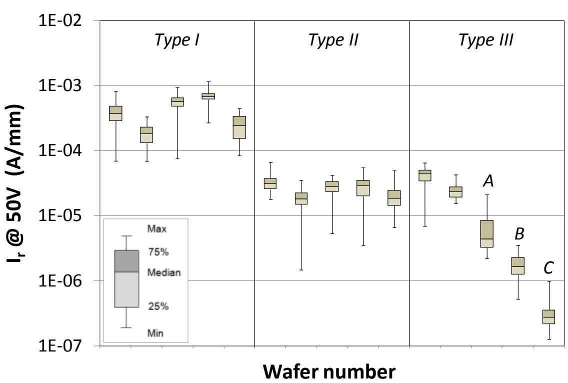

Figure 2: Evolution of Schottky reverse leakage current at V_{ds}=50V and at room temperature for 3 different process types, measured after diode formation and contact opening, showing the optimization of the Schottky module.

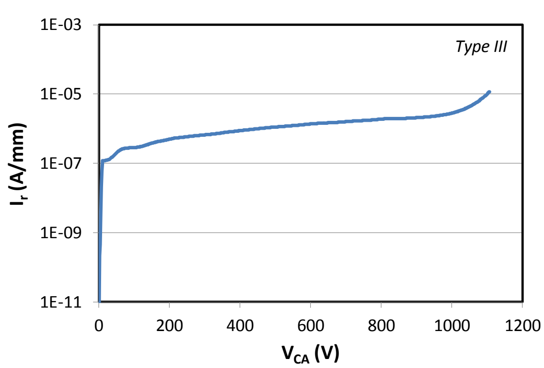

Figure 3: End-of-process Schottky reverse leakage current of a diode measured on wafer *C* of Fig. 2.

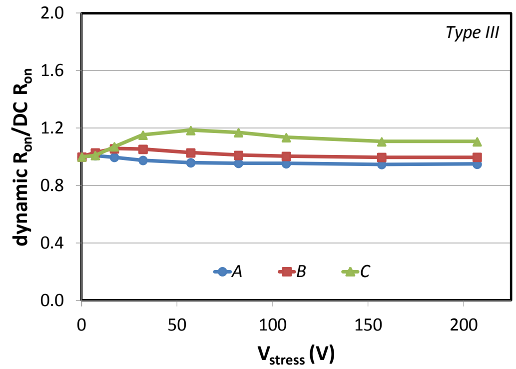

Figure 4: Ratio of dynamic R_{on} and DC R_{on}, measured end-of-process on wafers *A*, *B* and *C* of Fig. 2.

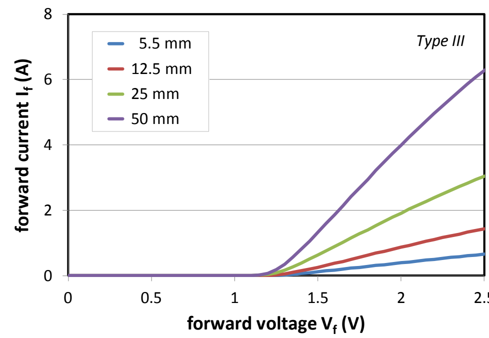

Figure 5: Forward characteristics of a Schottky barrier diode with a total device width of 5.5 to 50mm measured end-of-process on wafer *C* of Fig. 2.

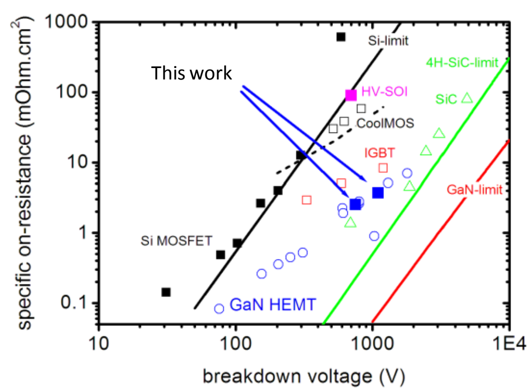

Figure 6: Benchmark on specific on-resistance versus breakdown voltage for Si, SiC and GaN devices.

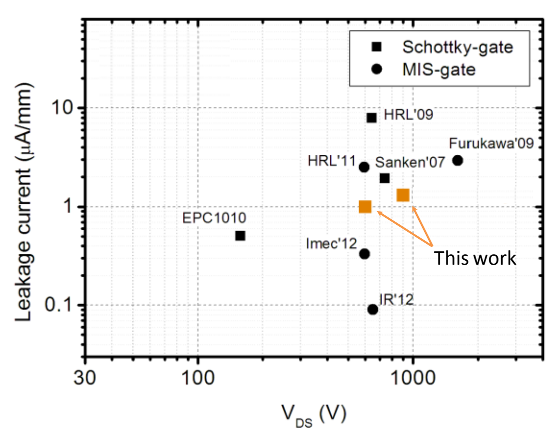

Figure 7: Benchmark on leakage current versus drain source voltage.