Modeling of High Voltage AlGaN/GaN HEMT

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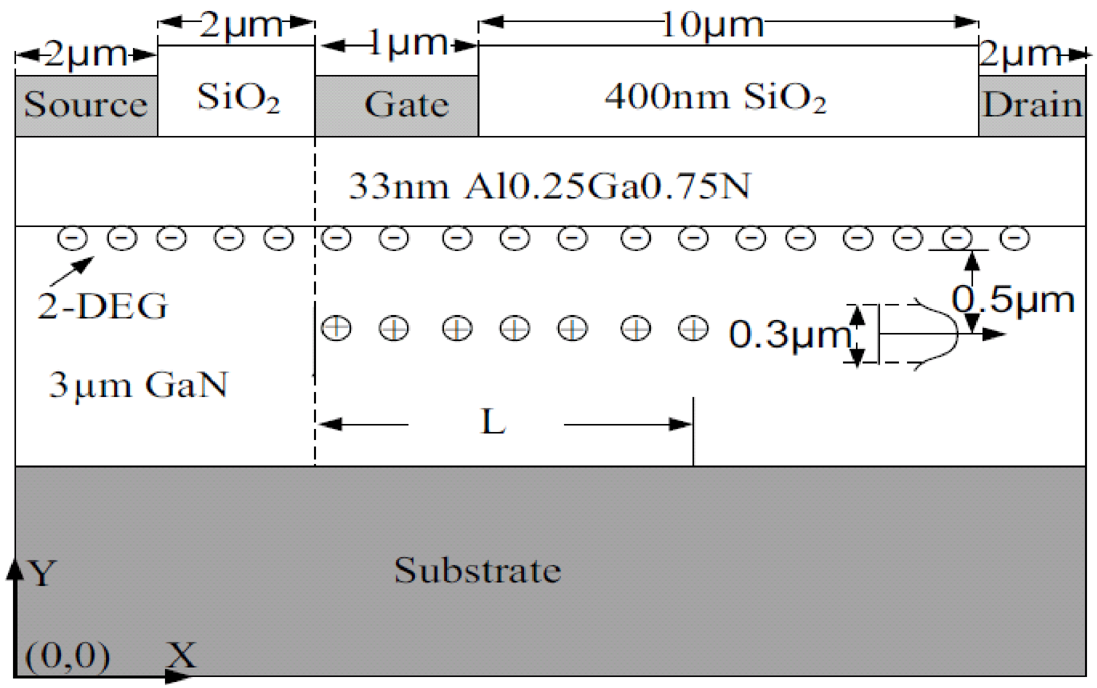
Introduction

- AlGaN/GaN HEMTs - potential to be operated at high power and high breakdown voltage not possible for silicon or GaAs based technologies.
- Numerous efforts explored to enhance the breakdown voltage of GaN based HEMT devices.
- The field plate (FP) structure effective for the high breakdown voltage AlGaN/GaN HEMT design but the field distribution in the drift region needs optimization to minimize the specific on-resistance.
- In this work, modeling and optimization performed with the demonstration of remarkably high breakdown voltage (900 V) for AlGaN/GaN HEMT with a magnesium doping layer under the 2-DEG channel by using Crosslight APSYS.

Device structure



Cross-section view of AlGaN/GaN HEMT structure with a Mg doping layer.

Charge density of 1.1×10^{13} cm^{-2} caused by the piezo-electric & polarization dipole modeled along the upper side of the AlGaN/GaN interface to determine the 2DEG sheet carrier concentration.

Traps with its maximum concentration $1\times10^{14}cm^{-3}$, relative energy level of 1.1eV also defined to ensure an semi-insulating substrate. The substrate semi-insulating traps effective in suppressing substrate parasitic conduction.

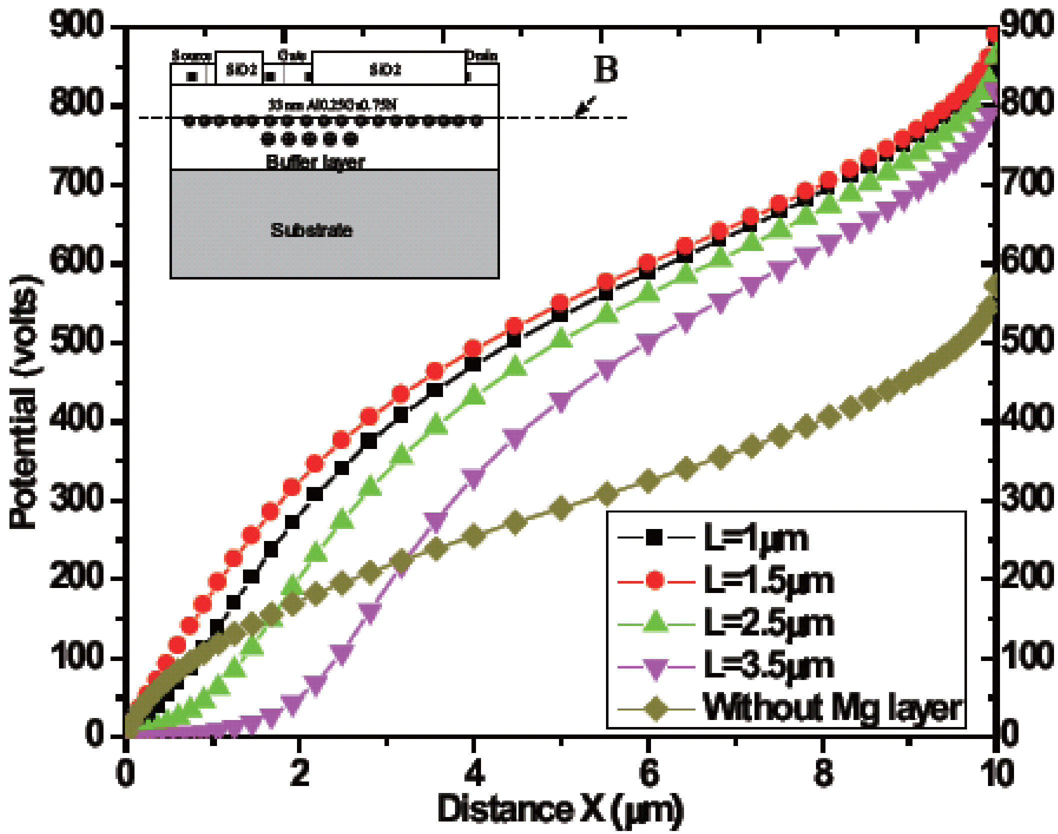
Ref: G. Xie et al, in Proceedings of The 22nd International Symposium on Power Semiconductor Devices & ICs, Hiroshima, Japan, June 6-10, 2010

Material parameters used

TABLE I. MATERIAL PARAMETERS FOR SIMULATION

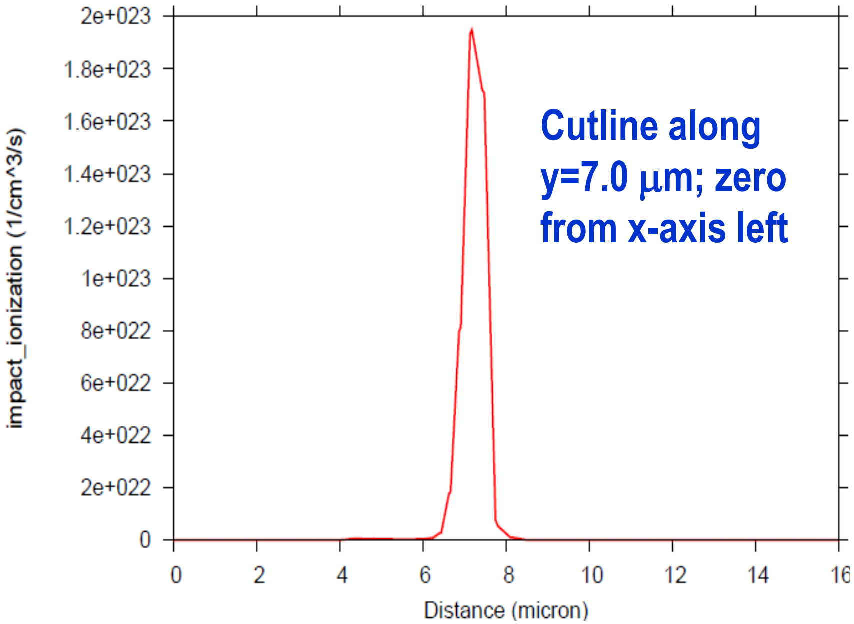
Parameter	AlGaN	GaN
Bandgap (eV)	4.15	3.47
Electron mobility ($cm^2V^{-1}S^{-1}$)	550	1100
Electron saturation velocity (cms^{-1})	1.5×10^7	2.1×10^7
Dielectric constant	9.6	9.5
Critical electric field (MV/cm)	5.5	3.3

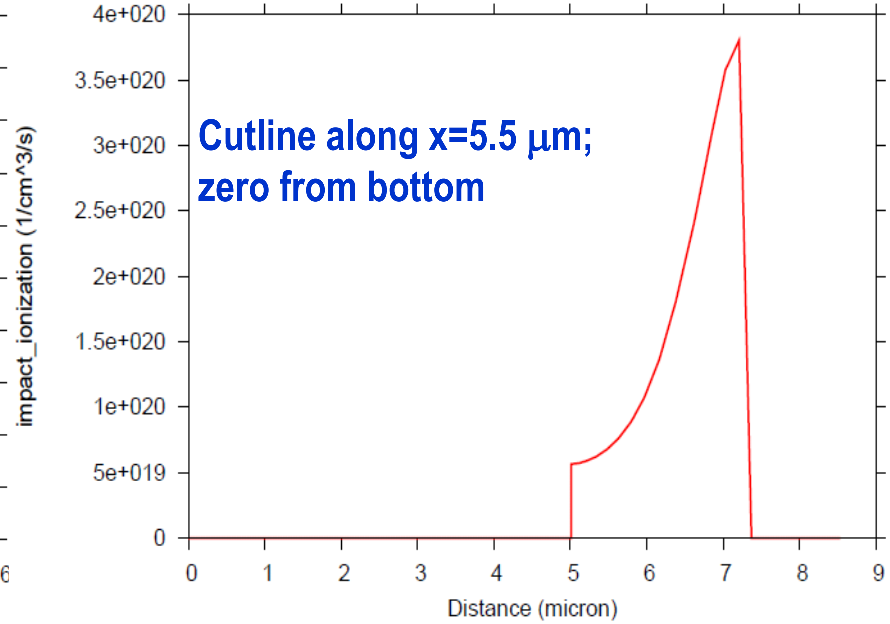
Surface potential distribution

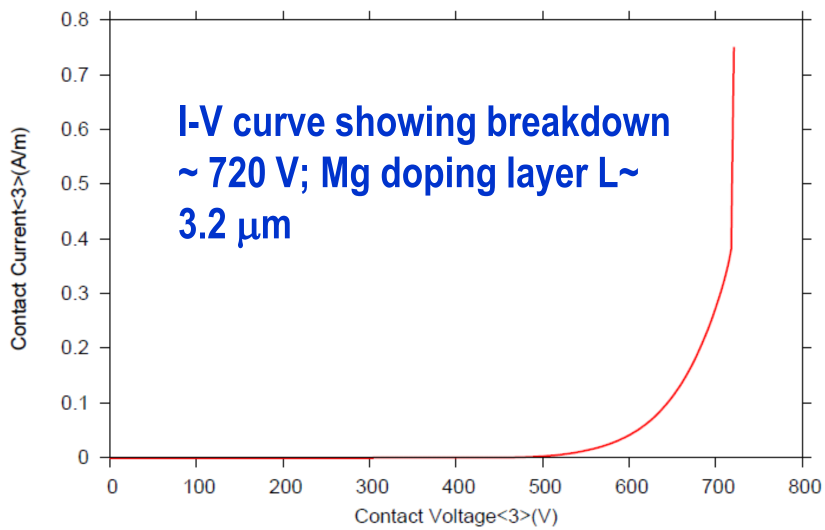


Reverse characteristics, along the AlGaN/GaN interface (line B) for different Mg doping layer length L, V_{GS}=-5 V, drain voltage increased till breakdown; breakdown voltage as high as 900V achieved with L=1.5 µm while only 560V for the conventional device without the magnesium layer.

Impact ionization & breakdown I-V







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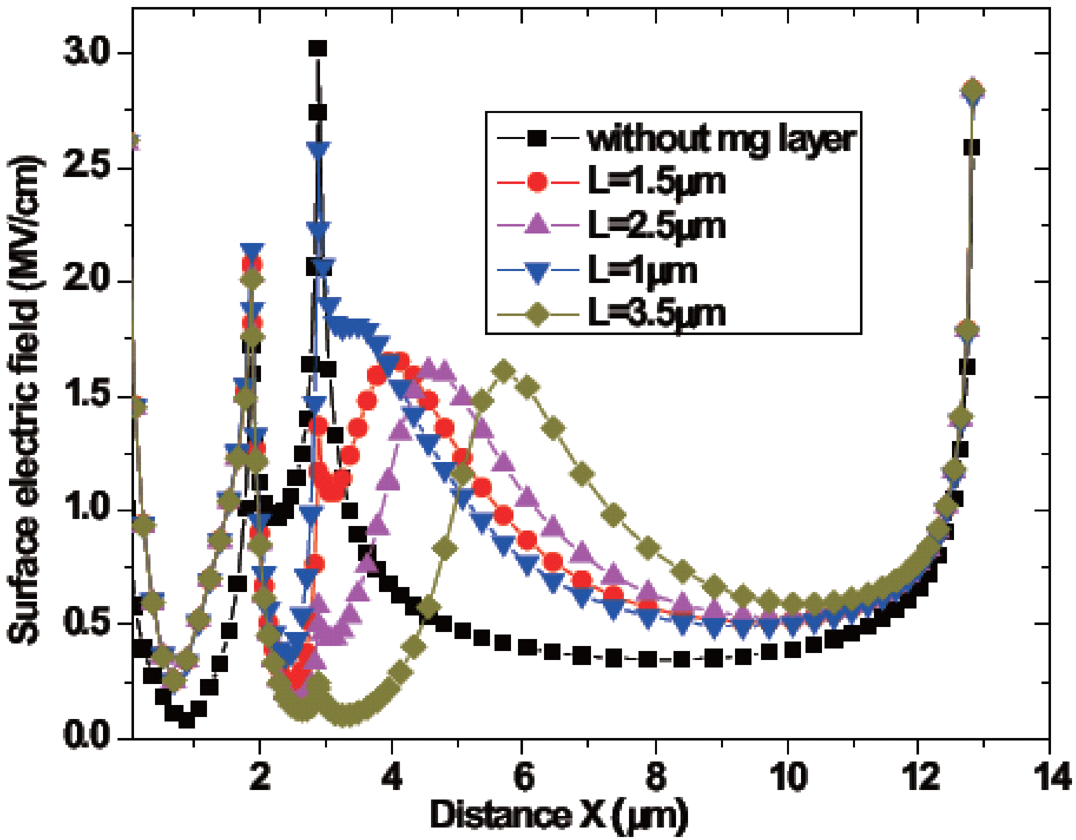
Electric field distribution



- Reverse characteristics, along the AlGaN/GaN interface (line B) for different Mg doping layer length L, V_{GS}=-5 V.
- With a Mg layer, the electric field is spread between the drain and the gate.
- Without the Mg layer, the field peaks near the edge of the gate electrode.

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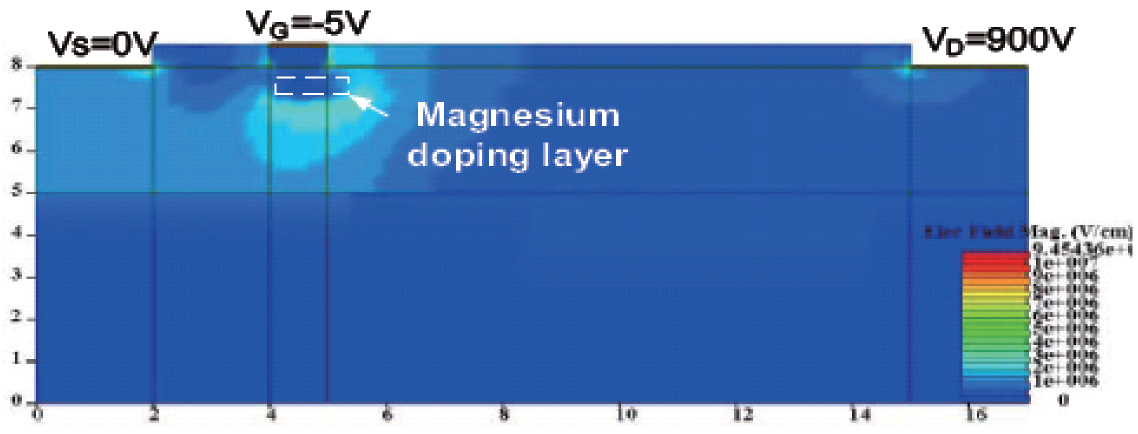
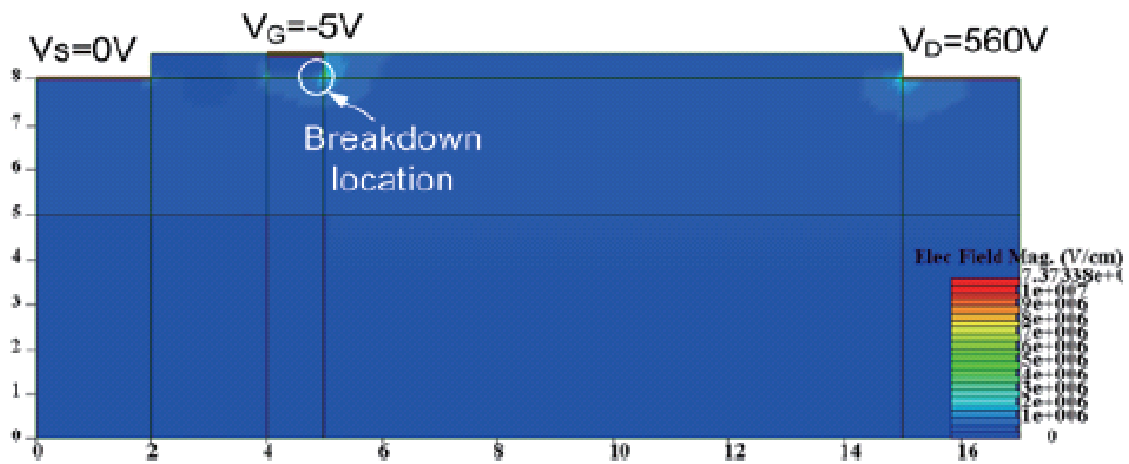
Electric field 2D contours

The proposed AlGaN/GaN HEMT device with V_{GS}=–5, V_{DS}-breakdown= 900 V, L=1.5 μm



(a)

Conventional HEMT structure of the same device dimension but without the Mg doping layer showing breakdown only around 560 V



(b)

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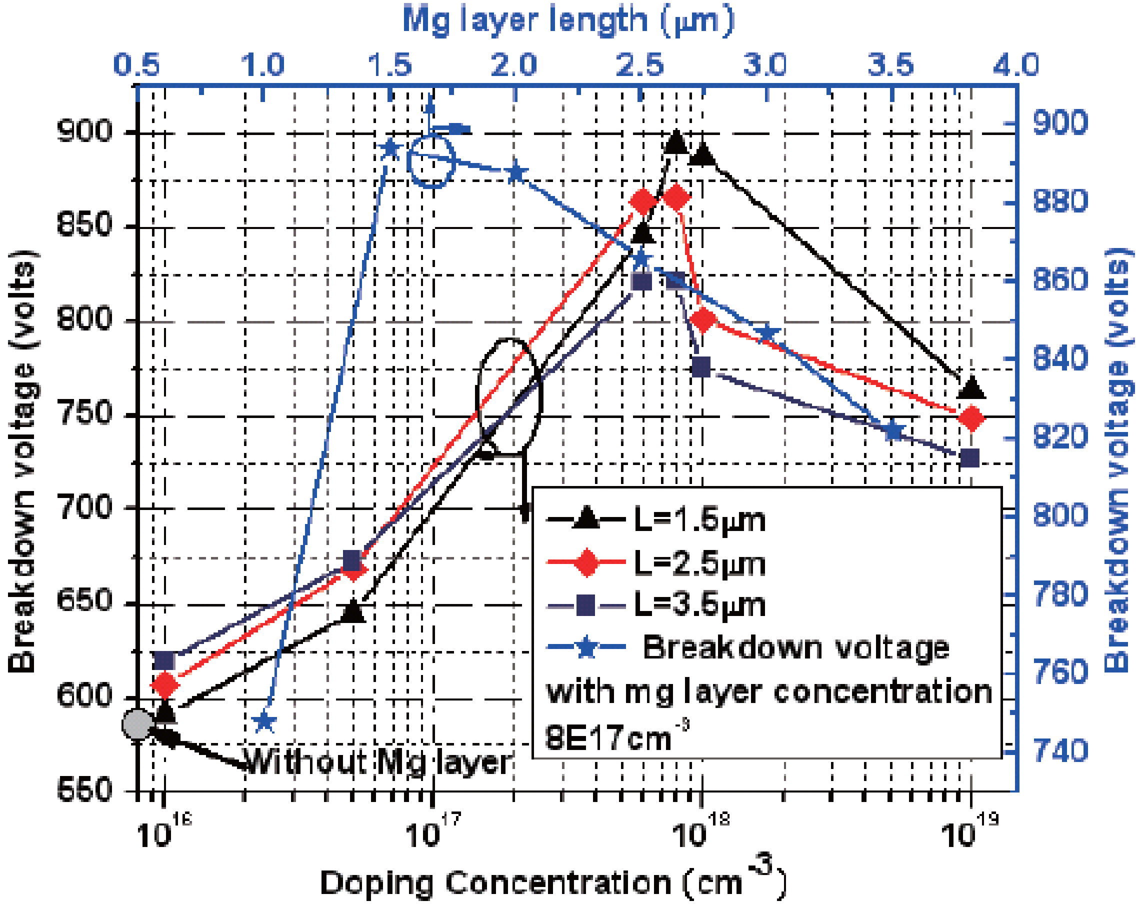
Breakdown vs Mg doping layer



- Breakdown voltages as a function of the Mg layer's doping concentration and width(length) at V_{GS}=–5V.
- Breakdown voltage reaches its highest value with a Mg doping concentration of $8\times10^{17}cm^{-3}$ for L=1.5, 2.5 and 3.5 μm.

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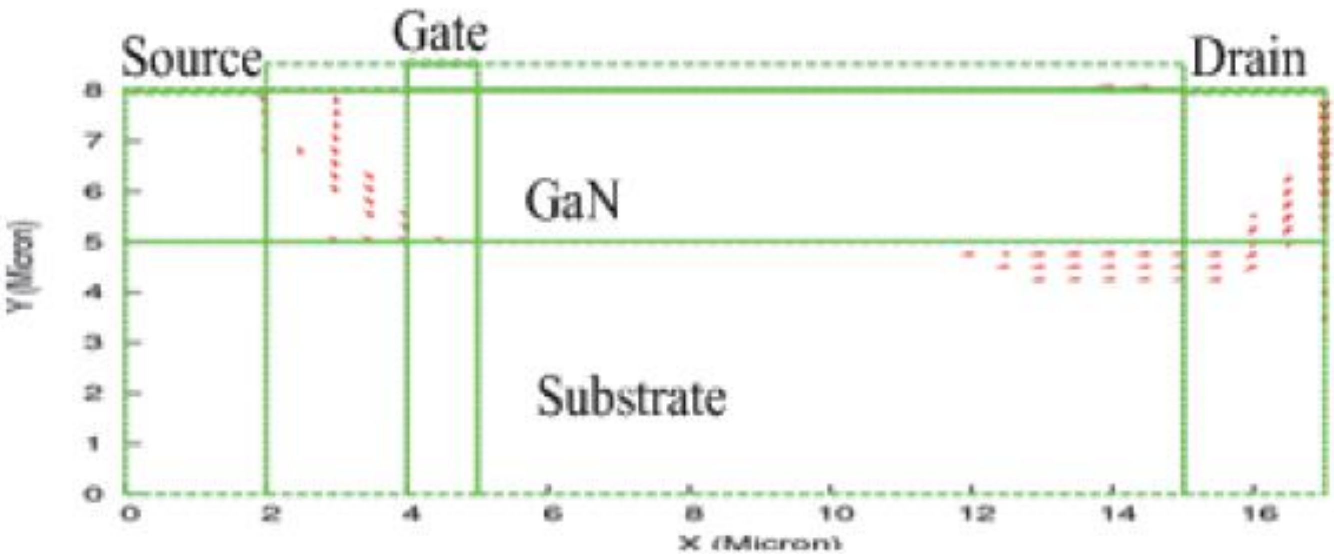
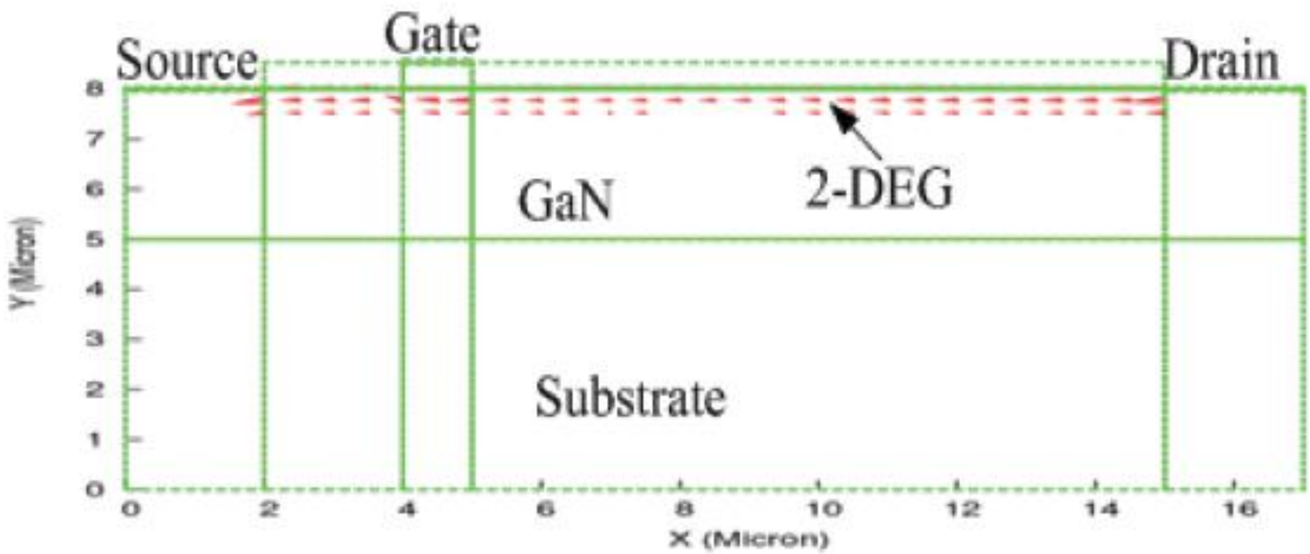
2D current vectors – reverse



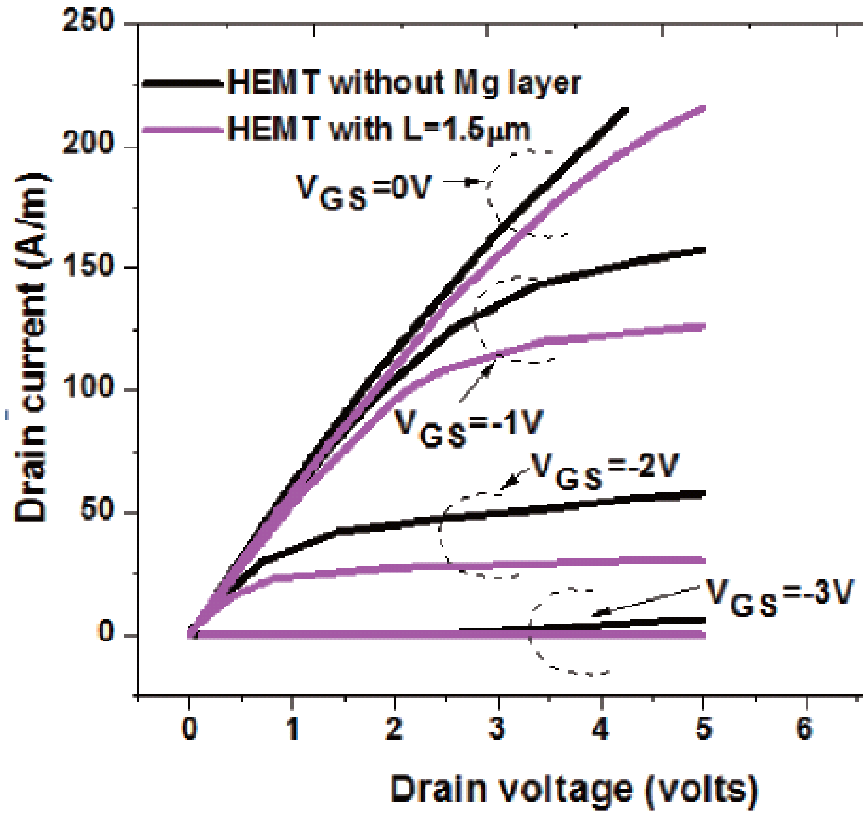
Reverse characteristics, 2D current vectors the proposed HEMT after breakdown, showing majority of current flow through the substrate,V_{DS}-breakdown= 900 V, V_{GS}=–5 V

2D current vectors – forward



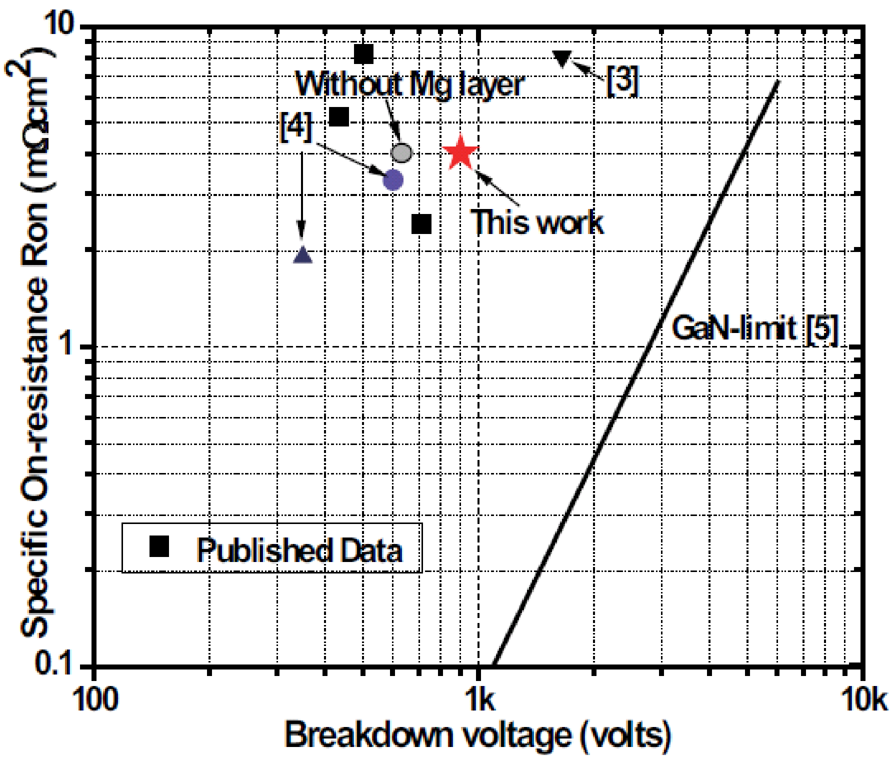
Forward characteristics with applied V_{DS}= 5 V, V_{GS}= 0 V, the electron current flows through the quantum well.

Forward IV characteristics



The transistor exhibits good pinch-off characteristics and a maximum drain current density of around 230A/m (per unit channel width) at a gate voltage of 0V.

Comparison of breakdown voltage versus specific on-resistance



Another important technique, device area management, can be used to improve the specific on-resistance and the breakdown voltage trade off. Ron-sp can be reduced by shrinking excess areas such as contacts, gate-source offset and channel regions, depending on the process.

Conslusion

- **High breakdown voltage AlGaN/GaN HEMT with the magnesium layer structure simulated.**
- **Breakdown voltage of 900V is obtained by optimizing the magnesium layer's length and its doping concentration.**
- **The specific on resistance was 4 m$\Omega \cdot cm^2$ with a breakdown voltage of 900 V using a magnesium layer length of 1.5 μm; its doping concentration is $8 \times 10^{17} cm^{-3}$ and the drift region length is 10 μm.**
- **The magnesium layer is deemed to be an effective mean to enhance the breakdown voltage of AlGaN/GaN devices.**