SILVACO Simulation and Performance Analysis of AlN FinFET Devices for High-Power Applications

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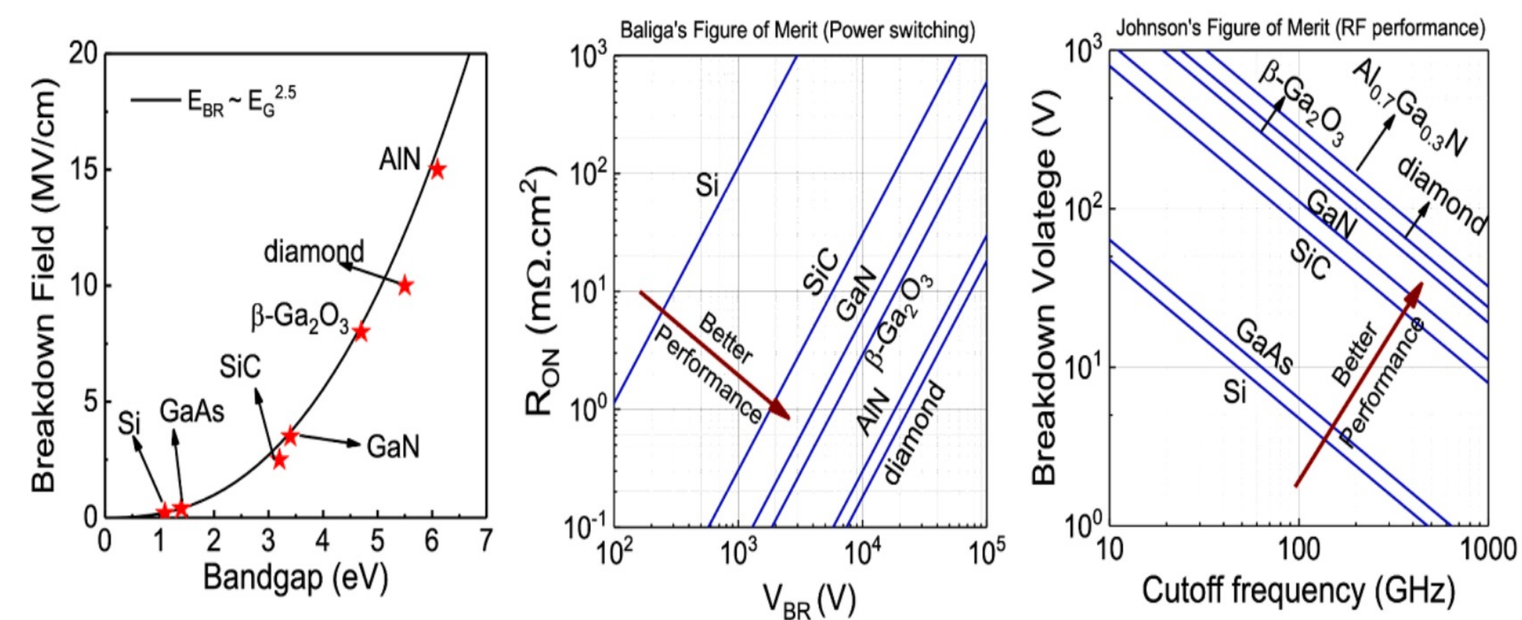
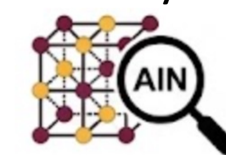
Ultra-Wide Bandgap Semiconductor for RF Devices



- UWBG semiconductors enables high breakdown voltages and low leakage currents.
- AlN exhibits a significantly higher Johnson's Figure of Merit compared to GaN and SiC due to its high breakdown field and saturation velocity.
- Efficient heat dissipation compared to GaN or SiC devices **~320 W/m · K**

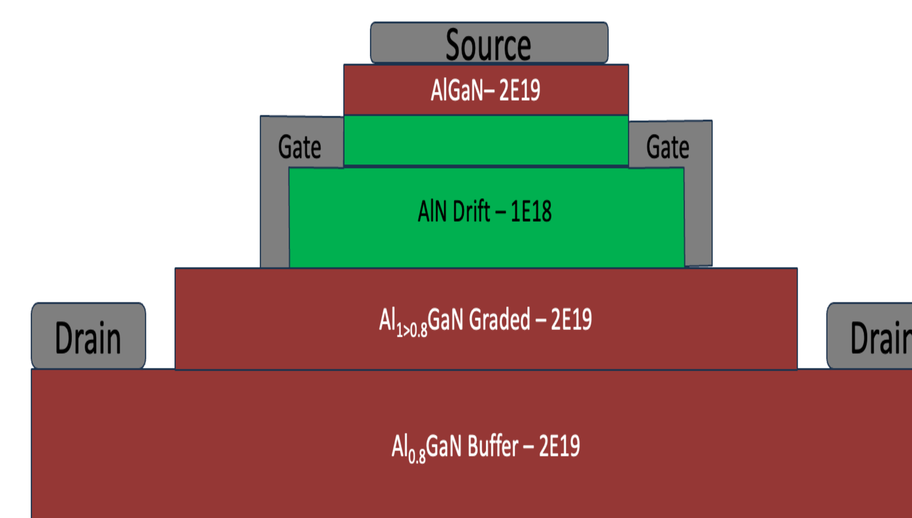
The AlN Advantage

- Aluminum Nitride (AlN) is a highly promising ultra-wide bandgap semiconductor that offers transformative advantages for next-generation high-power and high-frequency RF applications. With a massive bandgap of **6.2eV** , AlN enables exceptionally high breakdown voltages —featuring a critical breakdown field of **15 MV/cm** —while maintaining remarkably low leakage currents.
- This allows it to vastly perform better theoretically than traditional materials like GaN and SiC in terms of Johnson's Figure of Merit. Furthermore, AlN possesses an excellent thermal conductivity of **~320 W/m·K** , which facilitates highly efficient heat dissipation during high-power operation.
- Coupled with its inherent material stability , AlN is exceptionally well-suited for reliable performance in extreme temperatures, radiation-heavy environments, and densely packed 3D device architectures.

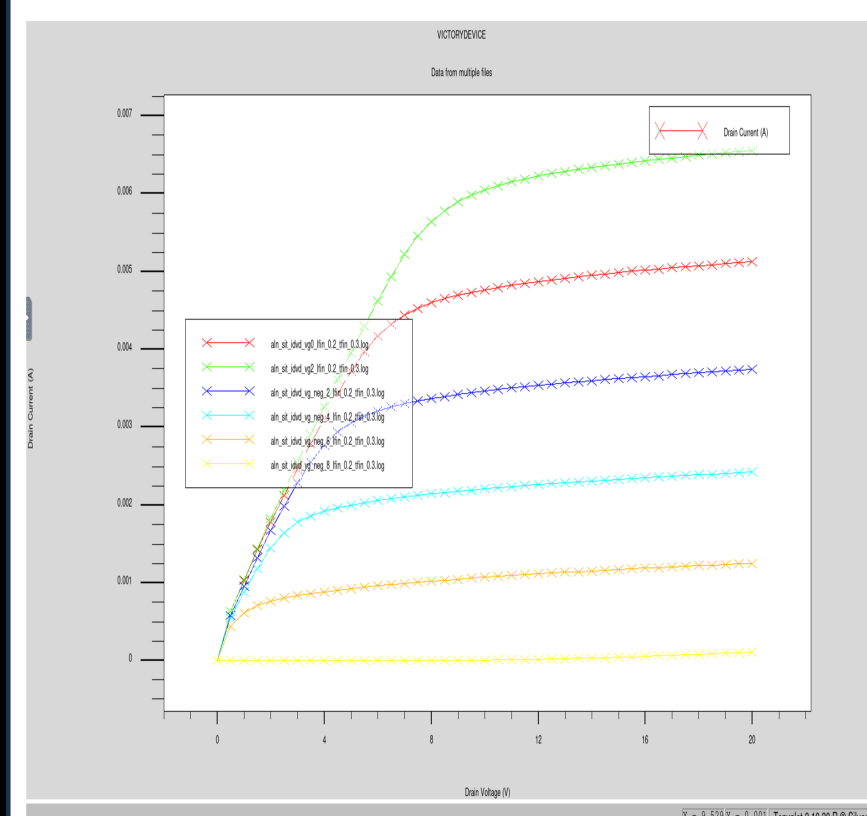


AlN FinFET Transistors

- **High Contact Resistance:** The ultra-wide **6.2 eV** bandgap and significant electron affinity mismatch make it difficult to form low-resistance ohmic contacts. This often results in contact resistances exceeding **10^{-3} Ω·cm²** which acts as a major bottleneck for current injection efficiency.
- **Acceptor-Level Effects:** AlN exhibits **deep acceptor levels (~0.27eV above the valence band)**, which trap carriers and reduce effective carrier concentration in the channel. This limits current conduction and contributes to the semi-insulating behavior commonly observed in AlN-based devices.

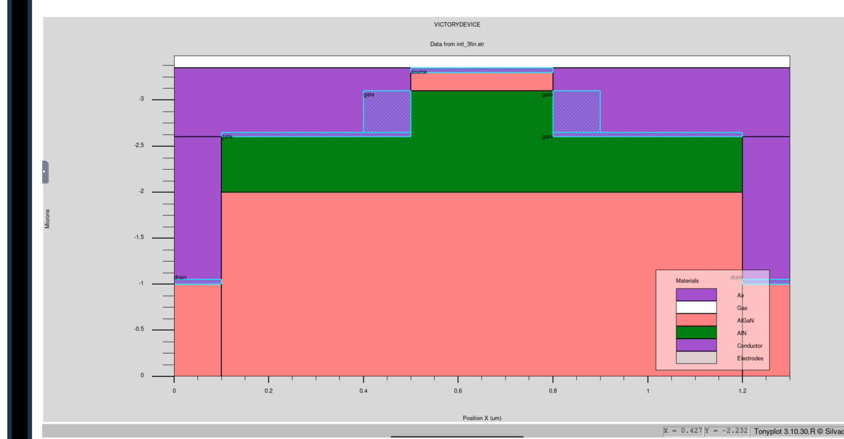


- **Low Intrinsic Carrier Concentration:** Due to the wide bandgap of AlN, the intrinsic carrier concentration is extremely low, which limits off-state leakage but also makes achieving high on-state current more challenging.

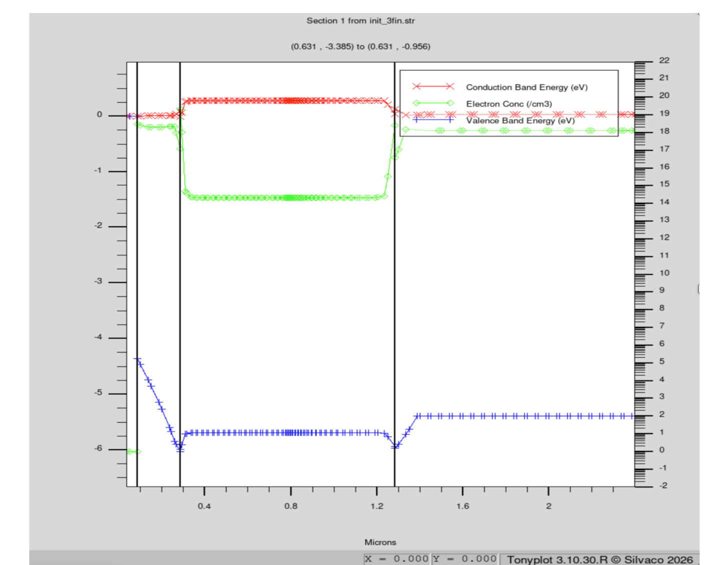


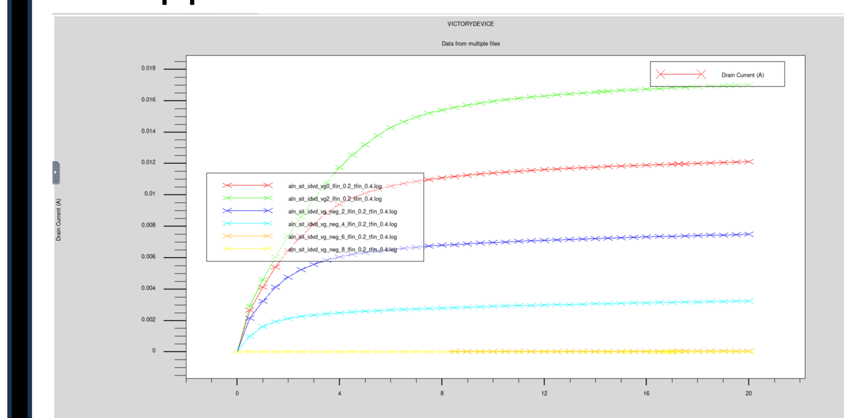
- The device features a **fin-shaped AlN Fin region** with a thickness of **1 µm**, designed for vertical current conduction.
- A **graded AlGaN buffer layer** (Al composition: 1 → 0.8) is included to manage polarization and improve interface quality.
- The **buffer region** is **2 µm thick**, with a donor concentration of **$2×10^{19}$ cm^{-3}**, supporting high current handling.
- An **insulating AlN substrate** (**200 µm**) provides mechanical support and electrical isolation.

AlN Fin Simulation



- The simulated drain current vs. drain voltage characteristics of the **AlN FinFET device** exhibit the expected transition from a linear (ohmic) region at low drain bias to a saturation region at higher voltages, indicating proper channel formation and carrier transport within the fin structure.
- A clear dependence on **doping concentration** is observed, where higher doping levels result in significantly increased drain current across all bias conditions.
- **Wide Bandgap Advantage:** AlN has a large bandgap (~6.2 eV), which enables operation at high voltages and temperatures while maintaining low intrinsic carrier concentration, making it suitable for high-power and high-frequency application





- Overall, the results demonstrate that **increasing doping concentration enhances current drive in AlN FinFETs**, but careful optimization is required, as higher doping can lead to increased electric field crowding, potential leakage, and reliability concerns in high-field regions of the device.

Conclusion

- **Feasibility:** 3D TCAD simulations confirm that AlN FinFETs are viable candidates for next-generation RF power devices, outperforming GaN and SiC in potential breakdown voltage.
- **Optimization:** Future work will focus on scaling the **fin width** and **gate length** to maximize the **Johnson's Figure of Merit** while implementing advanced thermal management strategies to mitigate self-heating.

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