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Evaluation of Self-Heating Effects in AlGaN Channel Heterostructure field-effect Transistors grown on bulk AlN substrate

Jash Mehta, Yannick Guhel, Julien Bassaler, Yvon Cordier, Philippe Ferrandis, Bertrand Boudart and Farid Medjdoub

Ultra-wide bandgap semiconductors such as $\text{Al}_x\text{Ga}_{1-x}\text{N}$ alloys are emerging materials for high voltage power switching applications that can surpass the voltage handling capabilities of conventional GaN HEMTs. Moreover, Al-rich AlGaN channel HFETs show a superior high-temperature operation stability up to 600K with a lower rate of mobility degradation [1]. The demonstration of blocking voltage robustness of AlGaN channel HFETs up to 2kV on bulk AlN confirms the advantage of UWBG materials [2]. However, Lateral device architectures are prone to self-heating effects under continuous-wave operation which affect the device performance and especially the device reliability. Hence, investigation of channel temperatures in novel AlGaN based heterostructures is essential for evaluating the related thermal management requirements.

In this study, AlGaN channel and GaN channel heterostructures were grown on bulk AlN substrates using ammonia source molecular beam epitaxy. The AlGaN device structure consisted of a 90 nm AlN nucleation layer, a 500 nm $\text{Al}_{0.23}\text{Ga}_{0.77}\text{N}$ channel, a 1 nm AlN spacing layer, a 14 nm $\text{Al}_{0.6}\text{Ga}_{0.4}\text{N}$ barrier, and a 1 nm GaN cap layer. The GaN device structure consisted of a 150 nm AlN nucleation layer, a 500 nm GaN channel, a 1 nm AlN spacing layer, a 19 nm $\text{Al}_{0.3}\text{Ga}_{0.7}\text{N}$ barrier, and a 2 nm GaN cap layer.

The fabricated MIS-HFETs were spin-coated with cerium oxide (CeO_2) microparticles scattered in an ethanol solution, which acts as micro-Raman thermometers. The self-heating temperatures of the biased components were estimated using Raman spectroscopy. A linear increase in the AlN substrate temperature has been observed in both samples with an estimated thermal resistance (R_{th}) $< 3^\circ\text{C mm/W}$. The GaN channel HEMTs demonstrated linear progression in channel temperatures with an estimated R_{th} around 7.3°C mm/W . While considering the AlGaN channel HFETs, the temperature change follows a quadratic fitting showing a high rate of temperature change with dissipated power as compared to the GaN channel reflecting the lower thermal conductivity of AlGaN as expected from the incorporation of Al in the channel [3]. Considering a fixed dissipated power of 9W/mm , the AlGaN channel HFETs show almost 40°C higher temperatures as compared to GaN HEMTs. However, despite the lower thermal dissipation, the AlGaN heterostructures offer superior thermal stability [ref Sandia] and electrical robustness as shown from the initial reliability stress tests [ref Jash]. Thus, AlGaN alloys may enable the development of extreme temperature electronics able to operate with much higher channel temperatures beyond the limits of GaN HEMTs.

References:

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- [2] Mehta, J., Abid, I., Elwaradi, R., Cordier, Y., & Medjdoub, F. (2023). Robust $\text{Al}_{0.23}\text{Ga}_{0.77}\text{N}$ channel HFETs on bulk AlN for high voltage power electronics. *E-Prime - Advances in Electrical Engineering, Electronics and Energy*, 5, 100263.
- [3] Appl. Phys. Lett. 115, 153503 (2019)