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GaN/AlGaN high electron mobility transistor characteristics after 1016 neq/cm2 neutron irradiation

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Gallium nitride (GaN) and its related hetero-structure alloy AlGaN are wide band gap semiconductors which offer radiation-hard alternatives to silicon, particularly as the focus in the HEP community shifts toward technologies capable of operating in extremely high radiation fields such as fast hadron fluence greater than 1017 neq/cm2. High-electron mobility transistors (HEMTs) fabricated in epitaxial barrier/channel layers of AlGaN/GaN take advantage of the two-dimensional electron gas (2DEG) that forms naturally at the hetero-interface, producing a high density (1013 e-/cm2), high mobility (2000 cm2/V-s) conductor with a sheet resistance of ˜ 300 Ω/square. This enables RF amplifier designs that can operate up to 40 GHz with 10 dB gain for 150 nm gate length, and switch designs with slew rates (dV/dt) greater than 100 V/ns, which is superior to Si MOSFETs. GaN and related alloys also have a higher critical field and higher threshold displacement energy than silicon, which inherently makes them more radiation-hard than Si.

In this work, irradiation results from NRC's standard AlGaN/GaN HEMT process are presented. Nine chips, each containing a pattern of four discrete HEMTs with different gate lengths (Lg = 500 nm, 1000 nm, 1500 nm, 2450 nm) and constant gate width (Wg = 80 µm) were fabricated in-house on a SiC substrate then diced. HEMT DC I-V characteristics were subsequently measured before and after neutron irradiation at 1016 neq/cm2. Pre-irradiation values of the output current density and drain leakage current density were ˜ 1.0 A/mm and ˜ 10-6 A/mm, respectively at room temperature, falling within the yield norms for the NRC GaN HEMT process and indicative of good quality devices. After 1016 neq/cm2 neutron irradiation, the threshold voltage between ON and OFF states remained stable from an IC-design point of view, shifting consistently by ˜ +0.4V (-4.1V before, -3.7V after) for all gate lengths. The average drain output current density was reduced by 16% for all gate lengths except 500 nm which fell by 21%. Since Lg primarily determines RF characteristics (fmax > 40 GHz measured for Lg = 500 nm pre-irradiation), this implies that future IC designs such as TIAs would not need to trade-off Lg (hence fmax) for radiation resistance. The average OFF-state drain leakage current density also fell (i.e., improved) between 77% and 86% on average from the initial ˜ 10-6 A/mm values, but in this case a negative linear dependence for all gate lengths was measured, suggesting that two different mechanisms are affecting output current and leakage current densities during neutron irradiation.

These irradiation results show the relative stability of standard NRC GaN HEMTs subjected to 1016 neq/cm2, and are promising for our upcoming next generation GaN HEMTs incorporating process improvements for high-temperature and high-dose operation. The results also validate the parallel phase of the project plan to fabricate Schottky diode test structures for DC and DLTS measurements using 2"GaN wafers epitaxially grown on bulk GaN substrates. In the last part of this presentation, our first experience with the new GaN on GaN material and the follow-up steps in preparation of Schottky diode fabrication will be given.

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