Reliability of GaN-Based Devices Integrated with Silicon

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There is strong interest in monolithic integration of AlGaN/GaN high electron mobility transistors (HEMTs) and light emitting diodes (LEDs) with Si-complementary metal-oxide semiconductor (CMOS) circuits. Also, the use of Si substrates for fabrication of GaN-based HEMTs and LEDs allows less expensive large-scale production and also opens up many new applications. However, the constraints on the reliability of these devices are still not fully understood.

Dislocations are known to be associated with both physical and electrical degradation mechanisms of AlGaN/GaN-on-Si HEMTs. We have observed evidence for threading dislocation movement toward the gate-edges in AlGaN/GaN-on-Si HEMT under high reverse bias stressing (Figure 1). Stressed devices have higher threading dislocation densities (i.e., $\sim 5 \times 10^9$/cm$^2$) at the gate-edges, as compared to unstressed devices (i.e., $\sim 2.5 \times 10^9$/cm$^2$). Dislocation movement correlates well with high tensile stress (~1.6 GPa) at the gate-edges, as seen from inverse piezoelectric calculations and X-ray synchrotron diffraction residual stress measurements. Based on Peierls stress calculations, we believe that threading dislocations move via glide in $\langle 11\bar{2}0 \rangle \{1\overline{1}00 \}$ and $\langle 11\bar{2}0 \rangle \{1\overline{1}01 \}$ slip systems. This result illustrates the importance of threading dislocation mobility in controlling the reliability of AlGaN/GaN-on-Si HEMTs.

We have also investigated the influence of the two-dimensional electron gas (2DEG) in AlGaN/GaN HEMTs on their reliability under ON-state conditions. Devices stressed in the ON-state showed a faster decrease in the maximum drain current ($I_{D\text{max}}$) compared to identical devices stressed in the OFF-state with a comparable electric field and temperature. Scanning electron microscope (SEM) images of ON-state stressed devices showed pit formation at locations away from the gate-edge in the drain-gate access region. Cross-sectional transmission electron microscope (TEM) images also showed dark features at the AlGaN/SiN interface away from the gate edge (Figure 2). Electron energy loss spectroscopy (EELS) analysis of the dark features indicated the presence of gallium, aluminum and oxygen. These dark features correlate with pits observed in the SEM micrographs. We propose that in addition to causing joule heating, energetic electrons in the 2D electron gas contribute to device degradation by promoting electrochemical oxidation of the AlGaN.

In ongoing research we are investigating the effects of density of SiN passivation layers on the reliability of AlGaN/GaN-on-Si HEMTs and characterizing defects generated during constant current stressing of InGaN-on-Si LEDs.

**FURTHER READING**