Phonon-defect scattering and the thermal resistance of the transition layers for GaN heteroepitaxy

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GaN-based high electron mobility transistors (HEMTs) are promising for next generation radar applications due to their wide band gap, high electron velocity, and high breakdown field. However, due to the high power density in GaN HEMT devices, localized self-heating can be a critical issue. HEMT self-heating can degrade device performance and impair reliability and stability. Thus, in terms of thermal management, efficient heat removal from active semiconducting regions is a key task, which is often limited by the material quality of the GaN composites.

For the epitaxial growth of high-performance GaN/AlGaN HEMT structures, SiC is commonly used as a substrate material because SiC offers much higher thermal conductivity (~400 W/mK) than conventional Si (~142 W/mK) and sapphire (~35 W/mK). An AlN transition film is commonly used as an interlayer material in the heteroepitaxial growth of GaN on SiC substrates to minimize the lattice mismatch stress and enable the growth of a high-quality GaN buffer layer. But due to significant mechanical strain present in the AlN transition film, a high density of microstructural defects exist within the volume of the transition film and near its interface, which impedes heat transport into the substrate. Substrates containing CVD diamond can be a viable material solution due to their potentially high thermal conductivity (as much as 5 times higher than that of SiC). However, the current GaN on diamond technology often incorporates a low thermal conductivity transition layer at the interface of the GaN and the diamond, which can partly offset the benefit of using the high conductivity materials.

This presentation will describe our experimental and theoretical investigation of GaN composite substrates containing Si, SiC, and diamond. We measure the temperature-dependent thermal resistance of the transition layer between the GaN and the substrate, using picosecond time domain thermoreflectance (TDTR). We theoretically examine the relevant phonon scattering mechanisms responsible for the temperature trend of the resistance. The best available data in literature are also presented in comparison with our thermal modeling as well as our data.