Electro-thermal analysis and thermal management of ultra-wide bandgap Ga_2O_3 electronics

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β-phase gallium oxide (Ga_2O_3) is an emerging ultrawide bandgap semiconductor (E_G~4.8 eV) that offers potential for significant improvement in the performance and manufacturing cost of today's commercial wide bandgap semiconductor devices. However, due to the poor thermal conductivity of the Ga_2O_3 (10.9-27 W/mK), overheating has become a major bottleneck to the commercialization of Ga_2O_3 devices.

In response to this critical problem, a Ga_2O_3/4H-SiC composite wafer was fabricated. Thermo-physical properties of the composite wafer were characterized using a combination of laser-based pump-probe methods. Scanning transmission electron microscopy and modeling suggest that the interfacial thermal boundary resistance (TBR) is mainly limited by the low thermal conductivity of the interlayer used for the fusion bonding process. A n-type Ga_2O_3 channel layer was successfully grown on the composite wafer using low-temperature metalorganic vapor phase epitaxy (MOVPE). Metal-oxide-semiconductor field effect transistors (MOSFETs) were subsequently fabricated on the composite substrate. Nanoparticle-assisted Raman thermometry was used to compare the self-heating behavior of MOSFETs fabricated on a Ga_2O_3 substrate and the Ga_2O_3/4H-SiC composite wafer. Under steady-state operation, a 56% reduction in channel temperature was achieved in the devices fabricated on the composite wafer as compared to the homoepitaxial devices on the Ga_2O_3 native substrate. Transient Raman thermometry experiments and simulation results suggest that additional top-side cooling realized by a high thermal conductivity passivation overlayer such as polycrystalline diamond will allow to achieve high heat transfer performance under both direct-current (DC) and high frequency switching operation.