Recent Progress in GaN-on-Diamond Device Technology

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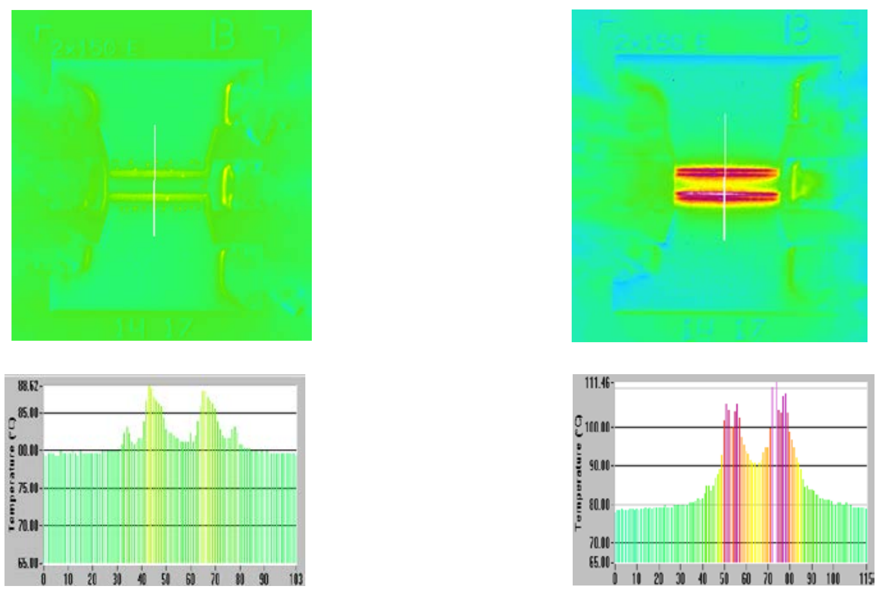
The intrinsic properties of gallium nitride (GaN) make it an ideal semiconductor material for microwave/millimeter wave power amplifiers. Numerous groups have demonstrated AlGaN/GaN high electron mobility transistors (HEMTs) with power densities exceeding 40 W/mm. Operation at their maximum potential is impractical due to the lack of a viable cooling solution. Due to the nascent state of native GaN development, the majority of high power GaN RF devices are fabricated on semi-insulating silicon carbide (SiC) substrates. This has been shown to be a viable solution albeit even SiC with its superior thermal conductivity (~350 W/m-°K), cannot overcome the heat loads being generated by the GaN HEMTs. It has become readily apparent as GaN device technology matures that thermal impediments are limiting it from realization of its true capability. One strategy under consideration is to substitute the SiC substrate with a much higher thermal conductivity diamond substrate (~1200 W/m-°K) to enhance localized thermal management.

In 2006 AFRL demonstrated the first working AlGaN/GaN HEMT on a diamond substrate fabricated by Group4 and Emcore.[1] Even with un-optimized epitaxial layers and device processing, AFRL was able to measure unpassivated DC and small-signal FET characteristics. This early technology demonstration provided a pathway for future exploration of producing GaN based devices on polycrystalline CVD diamond substrates. Recently, in conjunction with DARPA's Near Junction Thermal Transport (NJTT) Program, AFRL performed a study comparing devices fabricated on GaN/Si and GaN/Diamond substrates. Data from this study (Fig. 1) clearly shows measureable differences between GaN/Diamond and GaN/Si samples. Observed differences are consistent with improved thermal characteristics of GaN/Diamond relative to GaN/Si.[2]

AFRL has been instrumental in fostering the development of GaN/Diamond technology through technical oversight of numerous DoD sponsored research and developments efforts and utilization of unique inhouse research expertise with GaN device fabrication and characterization. Current DARPA thermal management initiatives are furthering the state of technological development associated with near junction cooling with the NJTT and Intrachip/Interchip Enhanced Cooling Applications (ICECool Apps) Program investments.[3] NJTT has focused primarily on the development of passive cooling approaches through integration of high thermal conductivity diamond in close proximity to the active transistor junction. The ICECool Apps Program is a follow on to NJTT and will pursue the development of microchannel cooled devices. AFRL and DARPA have partnered for the past decade in development of wide bandgap semiconductor (WBGS) device technology. Through its support and participation of DARPA WBGS, NJTT and ICECool Apps Programs, AFRL is well positioned to continue providing an independent assessment of these novel passive and actively cooled device technologies. This paper will discuss performer diamond integration approaches, electrical (DC/RF) and thermal performance of GaN/Diamond devices fabricated under the NJTT Program.

GaN-on-Diamond GaN-on-Silicon



R_{th} ~ 7.44 K/(W/mm) R_{th} ~ 16.6 K/(W/mm)

Figure 1. IR images of GaN/Diamond and GaN/Si devices. $R_{th} \sim (T_{peak} - T_{base})/(V_d{*}I_d)$. Representative R_{th} for GaN/SiC is 11.5 K/(W/mm).

References

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