Benchmarking of Thermal Boundary Resistance of GaN-SiC Interfaces for AlGaN/GaN HEMTs: US, European and Japanese Suppliers

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Abstract

Benchmarking of thermal boundary resistance (TBR) of GaN-SiC interfaces for AlGaN/GaN HEMTs on SiC substrates is reported. Thermal resistance at this interface results in an additional sizable device temperature rise, and therefore reduced device reliability, beyond what is expected just from the thermal conductivities of the device materials. We demonstrate here that there is a large difference in GaN-SiC TBR, up to a factor of two, between different suppliers. Device structures from leading US, European, and Japanese suppliers were assessed, from commercial suppliers, universities and research institutes.

INTRODUCTION

AlGaN/GaN HEMT technology has proven to become a disruptive technology, with potential to replacing current key component technologies for high power and high frequency applications. Despite impressive device performances, reliability is still a major issue at present, and large financial resources, e.g. by DARPA, ONR, ESA and others, are invested to advance this new technology to a commercial stage. Device degradation is accelerated by high device temperatures, high electric fields, hot carriers and other mechanisms. It is well recognized that thermal conductivities of the device materials affect device temperature, however, the potentially detrimental role of interfaces in this device system is often overlooked.

There are several key interfaces in this device and corresponding packaging system, such as die attach, but here we concentrate on the interface closest to the AlGaN/GaN device channel which is the most important interface from a thermal management perspective, namely the GaN-SiC interface. This interface contains a nucleation layer, and high defect density GaN nearby (grain boundaries, dislocations, etc), resulting in a very much reduced thermal conductivity near the GaN-SiC interface, typically quantified by the so-called thermal boundary resistance (TBR) [1], hindering heat transport from the device into the substrate. We recently demonstrated that thermal resistance at this interface can give rise to an additional channel temperature rise, up to 30-50%, in metal-organic metal chemical vapor deposition (MOCVD) grown AlGaN/GaN devices on SiC substrates [2]. We also showed that hot-wall epitaxy can be used to achieve a reduced TBR at the GaN-SiC interface [3]. As this is not a standard growth technique, the question remains whether similar improvements are possible with the more commonly employed MOCVD by optimizing growth parameters, while obviously maintaining excellent electrical properties of the AlGaN/GaN material system for high performance HEMTs. There is the closely related question whether there are differences in GaN-SiC TBR in MOCVD grown device structures from different suppliers as those naturally use different growth conditions. In this work, we benchmark GaN-SiC TBR in AlGaN/GaN-SiC devices from leading suppliers, from the US, Europe and Japan.

EXPERIMENTAL DETAILS

AlGaN/GaN device structures from US, European and Japanese suppliers were assessed, all grown by MOCVD. Raman thermography was used to quantify TBR, as function of interface temperature. Raman thermography enables determination of device temperature with 0.5µm spatial resolution, and nanosecond time resolution in two and three dimensions. TBR was determined using a combination of two methodologies developed by the CDTR: (i) extracting TBR from the temperature difference measured between the GaN and the SiC near the interface (the higher this temperature difference the higher the TBR); (ii) extracting TBR from the time evolution of the AlGaN/GaN temperature after switching the device on, within the first 200-300ns (the presence of a TBR slows down heat transport from the AlGaN/GaN device into the SiC substrate, i.e., affects the rate of device temperature rise). The measurements were performed on ungated device structures. More details on Raman thermography can be found in Ref [2,4-6] and on methodologies to determine TBR in Ref [1,3].

RESULTS AND DISCUSSION

Figure 1 shows TBR of the GaN-SiC interface as a function of interface temperature for a series of AlGaN/GaN-on-SiC device structures from different suppliers, identified by the nature of the supplier

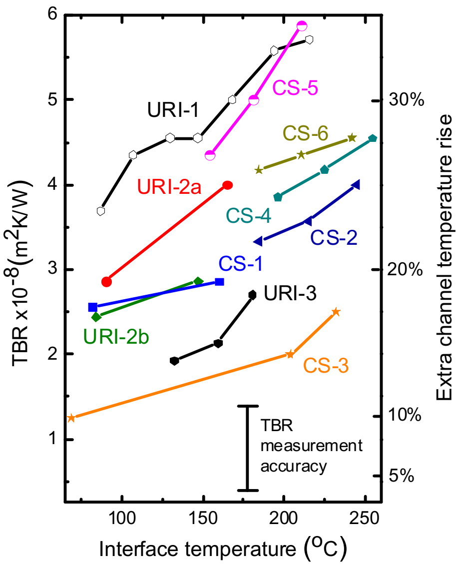

FIGURE 1: Thermal boundary resistance (TBR) of GaN-SiC interface as function of temperature for AlGaN/GaN-devices grown by MOCVD on SiC, from different suppliers (CS = Commercial Supplier, URI = University or Research Institute). Also displayed is the resulting additional temperature rise for an 8× multi-finger device.

(commercial supplier, university & research institute). Also displayed is the corresponding temperature rise caused by this TBR in an 8-finger AlGaN/GaN HEMT. This additional temperature rise in the device channel is clearly undesirable, as it impacts AlGaN/GaN HEMT reliability. We find sizable differences in TBR from supplier to supplier, by as much as a factor of two. The most optimal MOCVD interface in Figure 1 is comparable to the best hot-wall epitaxy grown interface achieved to date [3,7]. One may expect commercial suppliers having somewhat improved interfaces due to a higher degree of growth optimization. This was found to be partially the case, however, also excellent interfaces in university & research institute grown structures were found.

TBR rises with increasing interface temperature for device structure from all suppliers investigated. This illustrates that for all current state-of-the-art GaN-SiC interfaces the low thermal conductivity at and near the GaN-SiC interface is responsible for the observed TBR. The mismatch of elastic properties of GaN and SiC at this interface, which also contributes to the presence of a TBR, is in comparison negligible. It would results in a decreasing TBR with rising interface temperature [1].

Reducing TBR and therefore device channel temperature, either by choosing the supplier or by further improvement of the GaN-SiC interface beyond state-of-the-art is obviously of interest for AlGaN/GaN HEMT reliability. We emphasize that any optimization in thermal performance of the GaN-SiC interface needs to maintain excellent electrical AlGaN/GaN material properties. All investigated device structures studied, in particular those from the commercial suppliers, had excellent RF power performances. One may also raise the question, whether differences in failure mechanisms reported by different suppliers may in part be related to differences in the actual device channel temperature, resulting in temperature induced acceleration of different failure mechanisms with their different activation energies. This remains an open question to be assessed.

Finally, it needs to be noted that assessment of AlGaN/GaN HEMT device temperature only based on thermal simulation alone, needs to be done with great care. The results of Figure 1 show that simulation needs to take into account the presence of a TBR at the GaN-SiC interface, and consider that dependent on the supplier the value for the TBR is different.

CONCLUSIONS

Benchmarking of the thermal resistance of the GaN-SiC interface in AlGaN/GaN-on-SiC devices grown by MOCVD was performed. Large differences in thermal resistance of the GaN-SiC interface from supplier to suppliers were found, resulting in differences in peak channel temperature for devices operated at identical power dissipation. The results illustrate that optimization of the thermal properties of this interface is possible in MOCVD, maintaining excellent device performance, opening opportunities for the further improvement of thermal management of AlGaN/GaN HEMTs, beyond current state-of-the-art.

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ACRONYMS

HEMT: High Electron Mobility Transistor