Crystalline AlGaN & SiC Interlayers for Integration of Diamond with GaN

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Integration of diamond with AlGaN/GaN high electron mobility transistors (HEMTs) has been an area of interest in communication technologies for several years. This technology aims to exploit diamond's exceptional thermal properties to improve thermal management in these devices, allowing them to operate as the high-power, high-frequency amplifiers required for moving beyond 5G communications. Currently, thermal management is achieved using SiC substrates. However, high peak temperatures are still limiting device reliability. In practical terms, this results in GaN-on-SiC devices being derated to lower output power densities compared to their experimentally demonstrated performance. The use of diamond substrates, with a thermal conductivity of approximately 4-times that of SiC, should allow for increased heat extraction from the device active region, reducing the peak channel temperature and increasing practical output power densities.

This work is centred around replacing the Si growth substrate in GaN HEMT structures with diamond. This is achieved by growing diamond onto an $Al_{0.32}Ga_{0.68}N$ interlayer which has been incorporated below the GaN buffer in a HEMT structure. Since it is not possible to grow directly on GaN, conventionally a SiN_x seeding layer is used for diamond growth. This layer contributes significantly to the effective thermal boundary resistance (TBR_{eff}) between the GaN and diamond due to the low thermal conductivity of amorphous materials. If TBR_{eff} is too high, it limits the benefit of using a high thermal conductivity substrate. By using crystalline AlGaN, we hope to reduce TBR_{eff} and maximise the benefit of the diamond substrate.

A membrane-based technique has been used to selectively remove the Si substrate and strain relief layers (SLR), exposing the AlGaN layer. Diamond growth was carried out using the same recipe as that used for successful growth on AlN. Transient thermoreflectance was used to assess TBR_{eff}, whilst transmission electron microscopy and energy dispersive x-ray spectroscopy were used to investigate the diamond-AlGaN interface. It was found the AlGaN interlayer has been successfully exposed, although a crystalline SiC layer was present between the AlGaN and diamond. A TBR_{eff} of 30±5 m^2 K GW^{-1} was measured, comparable to the state-of-the-art using SiN_x interlayers of similar thickness. We postulate that the SiC is forming from migration of Si from the surrounding substrate and reaction with carbon species during diamond growth. A similar sample was fabricated with no source of Si substrate, removing the possibility of SiC formation. This sample was found to have a much higher

TBR_{eff} (107±44 m^2 K GW^{-1}), indicating the carbide layer significantly reduces TBR_{eff}. This is likely due to improved bonding.