GaN on Diamond vs. GaN on SiC HEMT and MMIC Performance

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Abstract

This paper discusses the result of an effort by Raytheon and Group4 Labs to determine the performance difference between GaN HEMTs and a GaN MMIC when fabricated on silicon carbide and diamond substrates. DC, RF, and thermal data are compared.

INTRODUCTION

As GaN device technology matures into production it has become clear that thermal impediments are limiting GaN from achieving its full potential. One heat management strategy is to replace the silicon carbide (SiC) substrate with a much higher conductivity diamond substrate. Here we describe the results of an effort to fabricate identical GaN HEMTs on both SiC and diamond substrates to enable RF and thermal measurements for direct performance comparisons. In addition, we have designed, fabricated, and tested a MMIC on a diamond substrate, which to our knowledge is the first time this has been demonstrated and published.

GaN on Diamond and GaN on SiC wafers were supplied to Raytheon by Group4 Labs, an industry leader in GaN on Diamond wafer development. Careful consideration was given to make epitaxial layers as similar as possible to lessen near-junction differences that may influence thermal performance (Figure 1). For GaN on Diamond, the GaN epi is derived from Silicon and transferred to diamond using Group4 Labs' patented transfer process.

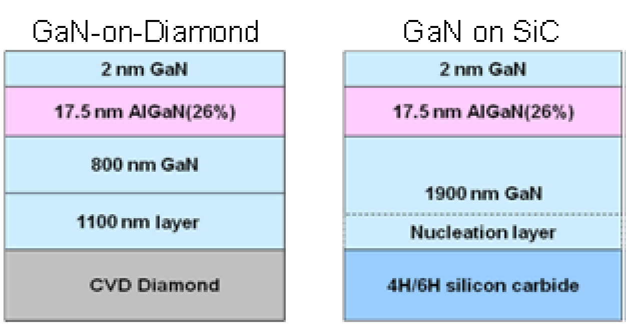

Figure 1. GaN epitaxial layers for diamond and SiC substrates were selected to be as close to each other as possible.

The GaN on SiC wafers were processed in the 100mm production GaN line at Raytheon's foundry in Andover, MA. The 2-inch diamond wafer was mounted on a thermal expansion-matched thick carrier plate for robust wafer handling and reduction of wafer bow and was then processed in Raytheon's development foundry, also located in Andover, MA (Figure 2). Both wafers were processed using stepper photolithography with HEMT gates formed using e-beam. Each wafer was patterned with near identical masks that included test structures, multi-fingered HEMTs, and separate MMICs, each optimized for optimal performance on its corresponding SiC or diamond substrate. In addition to standard multi-fingered HEMTs, each mask included an enhanced HEMT layout to take advantage of the higher thermal conductivity of diamond. With decreased channel temperatures, HEMTs on diamond can now have gate fingers spaced closer together, increasing power handling density with the potential to shrink overall MMIC size and reduce total cost. HEMTs were fabricated on both substrates with reduced gate to gate spacings to test the resolution limits of photolithography capability.

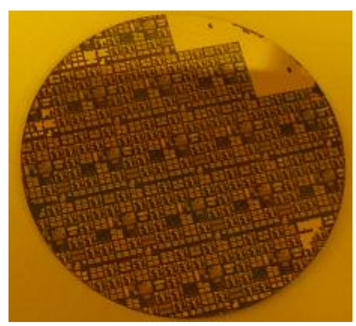

Figure 2. Picture of the 2-inch GaN on Diamond wafer

To evaluate the impact of diamond substrates, DC, RF, and thermal measurements were taken on identical devices on both diamond and SiC substrates. DC characterization is presented using pulsed IV curves that examine the quality of the epi by analysis of trapping, knee voltage, and Imax. Pulsed IV curves are plotted on top of each other for easy comparison. RF characterization is accomplished by using both small-signal and large-signal transistor performance. Small-signal measurements compare gain and f_{max}. Large-signal measurements are taken on a Maury loadpull system where individual HEMTs are optimized for Power and PAE under identical bias and hot plate temperature conditions.

By comparing peak Power and PAE, we ascertain how different thermal properties of substrates impact RF performance of HEMTs.

Thermal characterization is performed by using DC bias to dissipate a known amount of power in a HEMT and then measuring the resulting device temperature. This is tested for identical devices on both substrates, as well as devices with varying gate to gate spacings. Channel temperatures are measured using liquid-crystal thermography, which has been successfully demonstrated in prior work by Group4 Labs[1]. A resulting graph is generated as in prior work that shows how channel temperature varies with dissipated power, with SiC and diamond substrates having different slopes. Thermal resistance is then calculated using these slopes.

In addition to HEMTs, MMICs optimized for each substrate are measured at RF probe to determine performance using parameters of Pout, PAE, and Gain. Performance comparisons are shown versus each other, a well as against expected performance. This validates design simulations and assumptions about designing matching networks on a new substrate technology.

ACKNOWLEDGEMENTS

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REFERENCES

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ACRONYMS

GaN: Gallium Nitride
SiC: Silicon Carbide
PAE: Power Added Efficiency
MMIC: Monolithic Microwave Integrated Circuit