"**Low Loss Metal on BCB Technology for Next Generation GaN MMICs"**

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GaN MMIC technology is of great interest for its ability to deliver high-power density at both high frequency and efficiency. In addition, patternable BCB films are desirable for their ability to reduce circuit loss, provide scratch protection, and create additional layers of circuit metal. However, to date, most reported work with BCB has involved its integration with GaAs MMIC technology. In this work, we describe a 4" GaN-on-SiC MMIC process that incorporates a metal-on-BCB process along with a state-of-the-art 0.1 um FET. The resulting MMICs built using this technology demonstrate extremely high levels of efficiency at X-band.

A cross section of high-frequency 0.1µm GaN FET used for this work is shown in Figure 1. The key features are a thin, high aluminum content AlGaN barrier, 0.1µm t-gate, and in-situ silicon nitride surface passivation. All epitaxial layers are deposited by metal organic chemical vapor deposition (MOCVD). The devices also include re-grown n^+ GaN layers in the source and drain regions to minimize parasitic resistance. Ohmic contact resistances are typically in the 0.1 to 0.15 Ω-mm range using this process. Typical output FET I_{ds}-V_{ds} characteristics are shown in Figure 2. The maximum device current is greater than 1 A/mm, with a pinch-off voltage of 1.6V and peak transconductance of 450 mS/mm. Typical operating voltage is 15V, with breakdown voltages generally in the 50V range. The small-signal rf performance of these HFETs is shown in Figure 3. Typical cutoff frequency (f_t) is 95 GHz and maximum oscillating frequency (f_{max}) is 210GHz.

These FETs have been integrated into a full MMIC process that includes a third layer of metal interconnects on BCB. Following completion of the first two layers of circuit metal, photo-definable BCB is coated on the wafers and developed to remove it in regions where connections to underlying metal are required (Figure 4). In addition, as part of this study, the effect of the BCB dielectric on FET performance was investigated. If the BCB remains on top of the FET active regions, a drop in ft of 6 GHz and a 1.2 dB loss in gain is observed, compared FETs with no BCB (Figure 5). As a result, for this work, the BCB was removed above the active FET regions. Following BCB patterning, plated metal lines are defined to route circuitry on top of the BCB and make connections to the underlying GaN. Finally, the wafers are thinned to 100 um thickness, followed by through-wafer via formation and backside plating.

To demonstrate the benefits of this technology, several MMIC designs were fabricated at X and Ku bands using this process. These designs employed Class E operation and were targeted for maximum power added efficiency (PAE). A baseline 3 Watt Class E X-band amplifier used BCB on the input and output matching networks to lower circuit loss. Figure 6 shows the PAE of this circuit, with a peak efficiency of 69% at 8 GHz. An identical design with the output matching circuit entirely on the SiC substrate was included to evaluate the effectiveness of the BCB. As shown in Figure 7, the inclusion of BCB resulted in a significant improvement in RF performance, with an average improvement of 4% is achieved across the band.

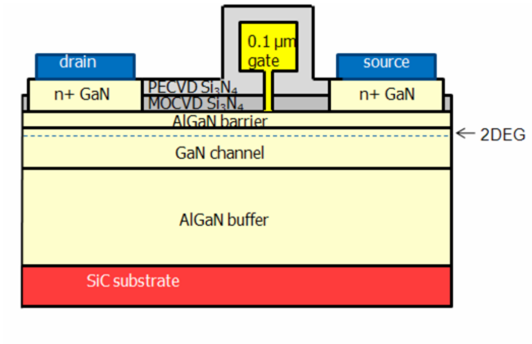

Fig. 1. Schematic cross-section of the GaN 0.1 um HFET unit cell.

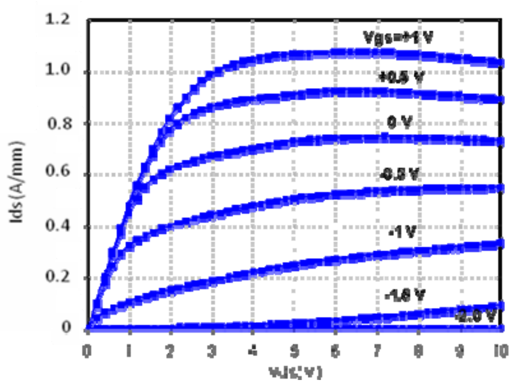

Fig. 2. Typical Ids-Vds curves for the GaN HFETs used in this work.

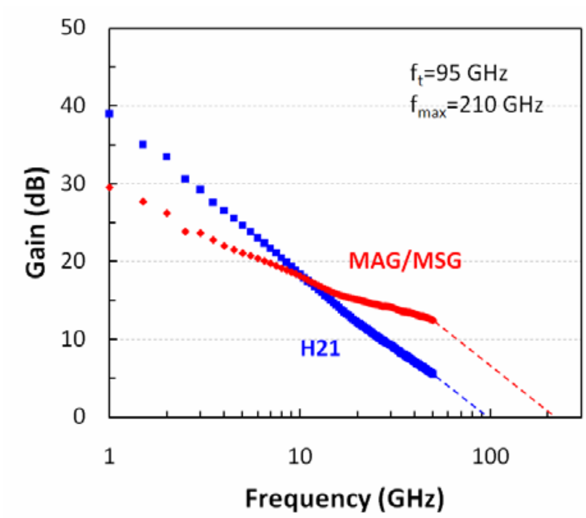

Fig. 3. Typical H_{21} and MAG/MSG plots for the GaN HFETs used in this work.

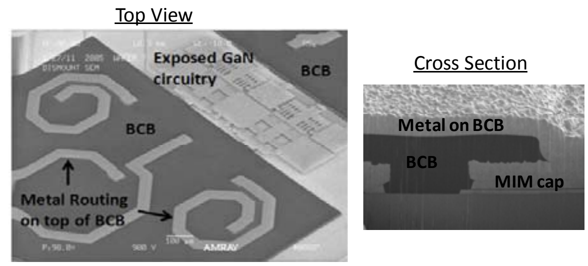

Figure 4: SEM image and cross section of a GaN circuit with metal routing on top of a BCB layer.

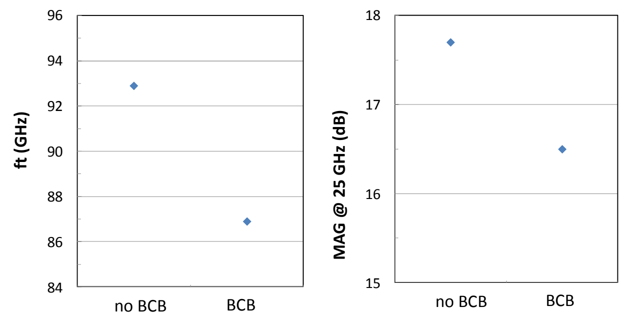

Figure 5: FET Performance comparison of GaN HFETs with and without BCB dielectric over the active area.

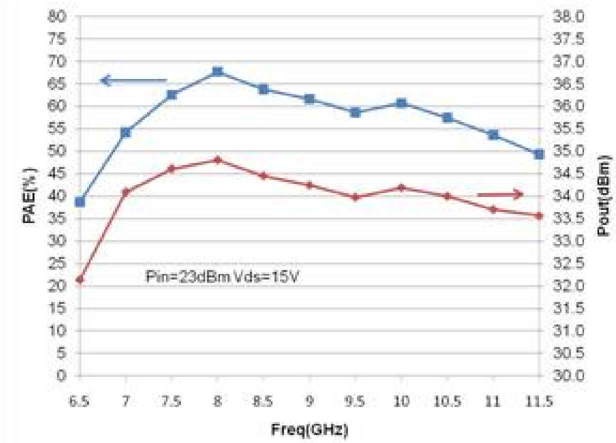

Figure 6: Measured on-wafer power output and power-added efficiency of a 3W class E MMIC using the baseline class E output circuit topology (P_{in}=23dBm, Vds=15V).

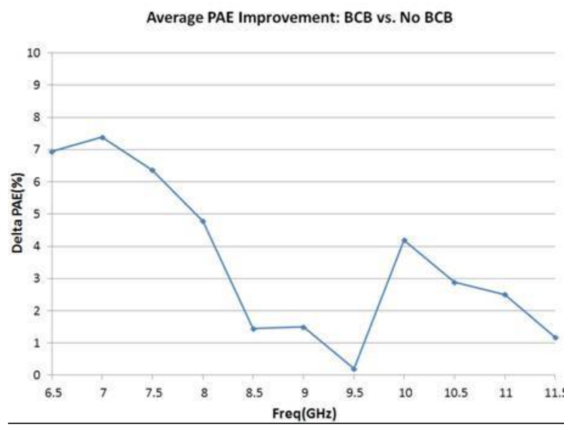

Figure 7: PAE difference between a baseline 3 Watt amplifier with vs. without BCB. An average improvement of 4% was achieved across the band.