AlGaN/GaN HEMTs and HBTs for Microwave Power

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The AlGaN/GaN based material system offers the three most important materials properties required for efficient microwave power generation; very high breakdown electric field (~2MV/cm), high electron mobility and velocity ($\mu_e \sim 1000\ cm^2\ V^{-1}s^{-1}$ and $v_s \sim 2 \times 10^7\ cm\ s^{-1}$ in bulk materials) and heterojunction technology to optimize device design. This has led to the rapid development of AlGaN/GaN HEMTs, grown heteroepitaxially on either sapphire or SiC substrates. Khan et al. first demonstrated the AlGaN/GaN HEMT[1], and Wu et al. made the first microwave power measurement of an AlGaN/GaN HEMT with a power density of 1.1W/mm at 2GHz on a sapphire substrate[2]. The structure was limited by the quality of the buffer layer, leading to reduced charge in the channel, and the high thermal impedance of the sapphire substrate. Improvements to the AlGaN/GaN HEMT have included improvements in the semi-insulating buffer layer, as well as the AlGaN barrier layer leading to increased charge in the channel. Low temperature mobility measurements of 2DEGs in AlGaN/GaN HEMT structures grown by plasma assisted MBE have demonstrated world record values over $5 \times 10^4\ cm^2\ V^{-1}s^{-1}$ (Smorchkova et al.[3]). Recent results by Wu et al. have shown record total power of 9.1 W at 7.4 GHz for an AlGaN/GaN HEMT on SiC[4]. Also, Zhang et al., utilizing a overlapping gate structure, demonstrated world record breakdown voltages of 570V. Donor states are necessary for channel charge in GaN HEMTs, and Vetury et al. have investigated the persistent photoconductivity effects and frequency dependent drain current compression effects resulting from deep donor states in AlGaN/GaN HEMTs.

AlGaN/GaN HBTs also show promise for power amplifier and switching applications. Inherent strengths of the HBT structure include high current densities and low phase noise, as well as improved linearity and threshold control. McCarthy et al. demonstrated the first GaN bipolar transistor, an AlGaN/GaN HBT using a selectively regrown extrinsic base, with common emitter operation to 30V and a current gain of 3[5]. Preliminary devices suffered from a large parasitic common emitter offset voltage caused by high base contact resistance and high lateral base resistance. Limb et al. demonstrated a device with a selectively grown emitter with a reduced offset voltage, common emitter current gain of 4 operating to 80V[6]. Recently, Xing et al. demonstrated a regrown emitter bipolar transistor with a current gain over 6, and common emitter operation over 80V. To understand the effect of threading dislocations on GaN HBTs, McCarthy et al. fabricated an AlGaN/GaN HBT on an LEO substrate, reducing collector emitter leakage by 4 orders of magnitude vs. adjacent devices with a dislocation density of $\sim 10^8\ cm^{-2}$.

The progress in HEMTs DC and RF performance has been spectacular and the possibility of insertion inot high power systems is a distinct possibility. The HBTs continue to have to battle the problem with p-type doping and associated processing difficulties. However, sustained progress in engineering around this problem holds promise for the future.

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