Manufacturable GaN HEMT RF Power Technology for Wireless Infrastructure Applications

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Abstract

This presentation will focus on the development of a manufacturable Gallium Nitride High Electron Mobility Transistor (GaN HEMT) RF power technology that is suitable for wireless infrastructure applications, specifically base transceiver stations (BTS). This will include virtually all aspects of this technology including GaN HEMT material growth, device fabrication, materials and device characterization, thermal management, circuit considerations, and, perhaps most importantly, GaN HEMT device reliability.

INTRODUCTION

The major trend in mobile wireless applications for the foreseeable future is the convergence of standards for cell phone and wireless data applications. This convergence is giving rise to numerous challenges for wireless infrastructure applications including: 1) dramatically higher transmission data rates for wireless data; 2) more stringent linearity requirements for new modulation schemes; and 3) multiple band operation using a single amplifier. In particular, these requirements are being driven by Wide-Band CDMA and other 3G standards that are rapidly gaining a significant share of the $650M (US) annual market for base transceiver stations (BTS). Economic considerations are serving as a driving force for improved efficiency RF power amplifiers with reduced cooling requirements to enable future tower-mounting of the amplifiers which will dramatically improve BTS efficiency.

GaN HEMT RF Power technology offers several advantages that will help meet these new BTS requirements. Specifically, the dramatically increased power density inherent in GaN HEMTs (i.e., approximately 5X to 10X that of the incumbent Si LDMOS technology) results in smaller gate periphery devices for the same RF output power. This, in turn, enables much broader frequency band operation due to a much more straightforward RF matching in the amplifiers. The high power gain of GaN HEMTs reduces the number of line-up stages in the BTS amplifier chain. Also, GaN HEMTs are capable of high efficiency with good linearity along with both high temperature and high voltage operation critical for future tower-mounting of the amplifiers in the BTS.

RF Micro Devices is continuing to develop a GaN HEMT RF power technology specifically designed to meet the needs of wireless infrastructure applications. This technology is based upon multiwafer Flow Modulation OMVPE growth of AlGaN/GaN HEMT epilayer material on semi-insulating SiC substrates from 2-inches up to 4-inches in diameter. The GaN HEMT fabrication process is based upon 0.6 micron gate length devices that are passivated using silicon nitride and include an optional field plate structure. Thermally managed large gate periphery devices (i.e., up to 16 mm) are fabricated using either an air bridge processs for conventional SiC-down mounting or an advanced bumped process for flip-chip mounting on an AlN substrate. The RFMD GaN pilot production facility has approximately 50 wafers in progress with an average cycle time to final test of approximately 20 days.

Extensive GaN HEMT material, process, and device characterization measurements are carried out on these wafers, and this data is analyzed using an extensive wafer-tracking database. In addition, the thermal characteristics of GaN HEMTs under bias are analyzed using thermal imaging measurements in conjunction with extensive thermal modeling activities. Small-signal RF, pulsed I-V, and on-wafer RF load-pull measurements are used to characterize these GaN HEMTs and to provide input for nonlinear models used in RF power amplifiers fabricated using these devices. GaN HEMTs devices sawn and picked from fabricated wafers are used to fabricate packaged discrete devices and power amplifiers using RFMD's state-of-the-art packaging capabilities.

Using this fabrication and design process, RFMD has demonstrated 16 mm gate periphery GaN HEMT devices with a saturated RF power output of 27.8 Watts and a drain efficiency of 42%. These devices exhibit performance in several key parameters (i.e., power, linearity, drain efficiency, and operating temperature) that are comparable or superior to those of competing Si LDMOS devices. RFMD has also demonstrated 8 Watt GaN HEMT wideband power amplifiers with extremely flat gain (i.e., gain slope +/- 0.2 dB) and power across three major wireless infrastructure bands (i.e., DCS, PCS, and UMTS), thereby making it possible to use a single amplifier for all three bands

Initial DC high temperature operating lifetime (HTOL) reliability measurements have been carried out on 800 μm GaN HEMTs at 200 °C channel temperature under a DC bias at V_{ds} = 20V and I_{ds} = 150 mA. These devices exhibit only 7% to 10% degradation in I_{dss} after 500 hours of operation. RF stress test reliability measurements at a baseplate temperature of 25 °C have also been carried out on 800 μm GaN HEMTs under Class AB bias with the device operated 3 dB into compression. The RF output power of these devices degraded by 22% after the first 10 hours and a total of 27% after 24 hours. These results indicate that the reliability of GaN HEMTs of high power RF operation is a major challenge that needs to be met in order to successfully insert this technology into wireless infrastructure applications.