Production of High-Reliability 150mm GaN HEMT for 5G Base Station

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Abstract

The Gallium Nitride (GaN) high-electron-mobility transistor (HEMT) is widely used for wireless communication applications, such as for 5G base stations. The market demand for GaN HEMT products is expected to rapidly increase. To meet the demand, it is necessary to increase production volume by scaling up wafer size. Sumitomo Electric Device Innovations (SEDI) and Coherent have developed 150mm GaN HEMT on SiC technology for base station. We report on wafer development, fabrication process, device characteristics and reliability of GaN HEMTs on 150mm SiC.

INTRODUCTION

GaN is suitable for high-frequency, high-voltage device applications because of its wide-bandgap and high-saturation velocity. It is a key component of a HEMT structure that enables GHz-range operating frequencies. The GaN HEMT is widely used for wireless communication because of these advantages. SEDI has manufactured high-reliability GaN HEMT products since 2006 and is leading manufacturer of devices for the 5G base station market [1-2]. The market demand for GaN HEMT products is expected to rapidly increase as internet communication speeds and bandwidth continue to grow to satisfy higher network capacities. To meet the demand, it is necessary to increase production volume by scaling up wafer size. This allows for a greater economy of scale in manufacturing. This paper describes the latest results of our 150mm Silicon Carbide (SiC) substrate GaN HEMT technology, including device characteristics and long-term reliability performance.

WAFER AND PROCESS

The most important requirement for expansion of crystal diameter is to ensure that both the bulk crystal quality as well as other substrate parameters such as surface quality and flatness are preserved or improved. With over 25 years of SiC manufacturing experience and past transitions from 50mm through 100mm diameters, Coherent has developed extensive processes and technologies which have enabled the successful mass-production of high quality 6-inch (150mm) SiC substrates.

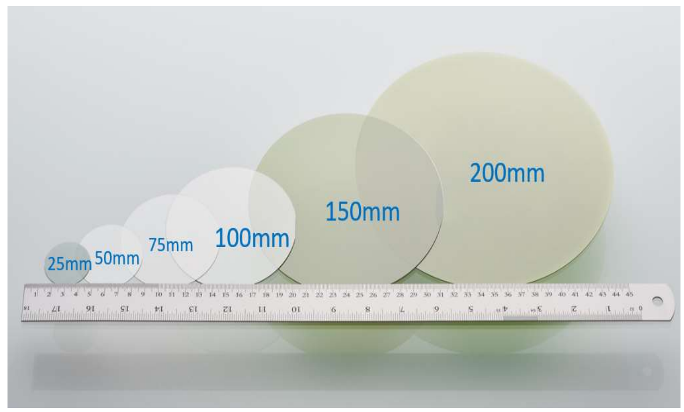

Fig. 1: Image of the Silicon carbide wafers.

GaN/AlGaN/GaN epi was grown by MOCVD on 150mm semi-insulating SiC substrates. Wafer warpage is of concern on larger diameter, 150mm substrates hence epi growth conditions were optimized to suppress warpage. The SEDI GaN HEMT process technology was transferred to and established on Coherent's existing 150mm wafer fab process equipment. It is important to control critical vertical dimensions such as the thickness of each electrode, the thickness of the surface passivation films and protective films. It is also necessary to control critical lateral dimensions such as the gate and the registration of each layer. Table 1 shows the key parameters for the process and the capability of each. The thickness of the electrodes and insulating films were designed to have sufficient margin against the specification. In addition, the gate length, over gate length, through-via diameter, and other device features have sufficient process capability. Our 150mm technology exhibits good manufacturability and process control. For example, silicon nitride (SiN) thickness, a key factor in determining DC and RF characteristics, shows C_{pk} of 1.3 or higher.

TABLE I: THE PROCESS CAPBILITY OF CRITICAL DEVICE PARAMETERS.

Measurement Items	C_p	C_{pk}
Passivation thickness	1.83	1.66
Interlayer dielectric thickness	2.45	2.22
Ohmic metal thickness	2.64	2.47
Gate metal thickness	1.51	1.30
SiC substrate thickness	3.14	3.02
Gate length	1.32	1.30
Over Gate length	1.25	1.02
Ohmic / Gate registration	1.30	1.17
Gate / Over Gate registration	1.77	1.63
Through-via size	3.22	3.03

It is important to shorten cycle time and increase process capacity for mass production. It takes time to form through-vias in the SiC substrate due to the strong bond energy and chemical inertness. Plasma etching with extremely high-power is required to enable higher throughput capacity of the via etch process. Our optimized process achieves good in-plane uniformity and high etch rate within a 150mm substrate. In addition, sufficient processing capacity is ensured for mass production by using recipes tuned for each phase of the via etch.

ON-WAFER PERFORMANCE

All dies are screened by 100% DC measurement test on the whole wafer. Table 2 shows the nominal value and standard deviation of DC characteristics on the 150mm wafers. Typical values of the device characteristics were matched to existing technologies. The in-plane variation of the wafer was also very small regardless of the scaling of wafer diameter from 100mm to 150mm. This was achieved by optimization of unit process parameters, tightening the equipment controls, and applying a rigorous statistical process control methodology.

TABLE II: THE NOMINAL VALUE OF DC CHARACTERISTICS AND VARIATION FOR 150mm GAN HEMT.

Measurement Items	Units	Typical Value	Standard Deviation
On-Resistance	Ohm-mm	3.10	0.05
Threshold Voltage	V	2.90	0.04
Maximum Current	mA/mm	945	10
Transconductance	mS/mm	245	5
50V Off-State Leakage	µA/mm	5.0	2.0
50V Gate Current	µA/mm	2.0	1.0

RF CHARACTERISTICS

RF measurements were performed on 6x200µm structures of the GaN HEMT with a Load-Pull system with these conditions: drain voltage (V_{ds})=50V, drain current (I_{ds})=8mA, f=4.8GHz, Pulsed RF signal (duty=10%, pulse width=10µsec). Figure 2 shows the relationship between output power and gain and efficiency on load-pull measurements for this device. The device achieves a gain of 20.0dB and a drain efficiency of 78% with optimal tuning. A maximum power output of 11.7W/mm was obtained on same device under maximized power tuning conditions.

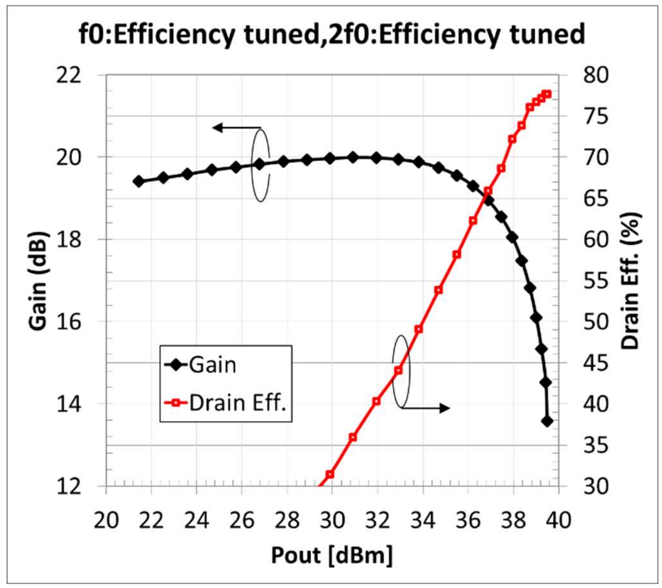

Fig. 2: Load-pull under the maximum efficiency tuning on 6x200µm GaN HEMT structure with V_{ds}=50V, I_{ds}=8mA, f=4.8GHz, and Pulsed RF signal (duty=10%, pulse width=10µsec).

RELIABILITY

The DC high-temperature operating life test (HTOL) was performed with device channel temperatures of 300 °C, 320 °C, and 340 °C to obtain the activation energy (E_a) at V_{ds}=55V. The E_a value was calculated to be 2.14 eV, which was the same value as previously reported; and the same failure mode was confirmed [3]. A mean time to failure (MTTF) of 1E6 hours or more at 200 °C operation was calculated from the HTOL results. A multitude of reliability tests were conducted such as HTRB test, B-HAST, etc., and all tests have passed.

CONCLUSIONS

We have begun manufacturing 150mm GaN/SiC HEMTs and reported that the device characteristics are equivalent to those of the prior technologies. This will allow us to supply high-reliability and lower cost GaN HEMT products to the 5G base station market to meet the growing demands expected in the near future.

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ACRONYMS

MOCVD: Metal Organic Chemical Vapor Deposition
HTRB: High Temperature Reverse Bias
B-HAST: Biased Highly Accelerated Stress Test