Mass-Production of High Reliability GaN HEMT for Wireless Communication

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Abstract

GaN HEMT has been used widely for high power and high frequency applications such as cellular base station owing to its superior material properties. Although there were some technical issues in the early development stage, now GaN HEMT is completely in mass-production phase. In this paper, we report the latest status of Sumitomo GaN HEMT characteristics and reliability in the view points of the commercialization.

INTRODUCTION

Recently, smartphones and tablets have become widely popular. Users frequently handle large volumes of data, such as high resolution picture, motion video and so on. Under this situation, the amplifiers used in base stations must exhibit high output power and high efficiency performance. However, it is difficult to meet these requirements with Si or GaAs based devices.

A GaN HEMT is a suitable device to resolve these issues owing to its excellent material properties such as wide band gap, high breakdown voltage and high saturated electron velocity. Therefore, there are many reports regarding the excellent performance of GaN HEMT [1-3]. Sumitomo has been a leading manufacturer of GaN HEMT for base station since the successful development of 50 V operation GaN HEMT in 2005, and release of the world's first products in 2006.

In this paper, we address our various efforts made for commercialization of GaN HEMT, especially focusing on the mass-producibility and reliability. Also, we introduce the prospects of GaN device for future base station application like 5G mobile communication system.

ISSUE OF EARLY MASS-PRODUCTION STAGE

Table 1 shows the key material parameters of the major semiconductor materials used in the devices for wireless communication. Compared to Si, GaN has approximately 3 times wider band gap energy, 10 times larger critical breakdown field and 3 times higher saturated electron velocity. Generally, the epitaxial layers of GaN HEMT are grown on semi-insulating SiC substrate by MOCVD, because of the excellent thermal conductivity of SiC.

Figure 1 shows the surface morphology image of the epitaxial wafer on SiC substrate fabricated in the early development stage. There were many scratches and defects such as micro-pipes, hexagonal pits and contamination-induced defects on the epitaxial wafer due to their growth immaturity. The defects cause large leakage current and degradation of RF performance of the GaN HEMT devices which operates at 50 V under high temperature condition.

Therefore the screening of these abnormal dies on the defects became a critical issue at the shift from development or sample-level production phase to actual mass-production. Figure 2 shows the map of drain leakage current measured with on-wafer DC probing test of the wafer shown in Figure 1. The red marks indicate the defective dies which have higher drain leakage current. The areas which show high drain leakage current clearly correspond to the defect areas in the surface morphology image. With this screening procedure, Sumitomo could start reliable and stable mass-production of GaN HEMT [4]. These defects of SiC substrate are much less of an issue now than they used to be.

TABLE I
MATERIAL PARAMETERS COMPARISON

Material	Band Gap Energy (eV)	Critical Breakdown Field (MV/cm)	Thermal Conductance (W/cm/K)	Mobility (cm^2/V/s)	Saturated Velocity (x10^7 cm/s)
Si	1.1	0.3	1.5	1300	1.0
GaAs	1.4	0.4	0.5	6000	1.3
SiC	3.2	3.0	4.9	600	2.0
GaN	3.4	3.0	1.5	1500	2.7

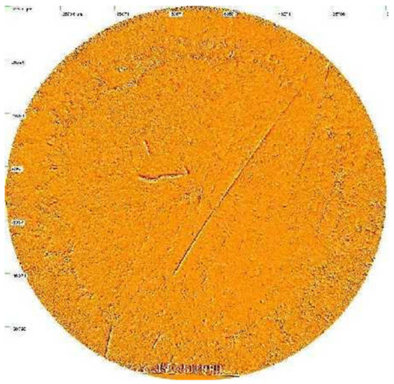

Fig. 1. Surface morphology image of epitaxial wafer on SiC substrate.

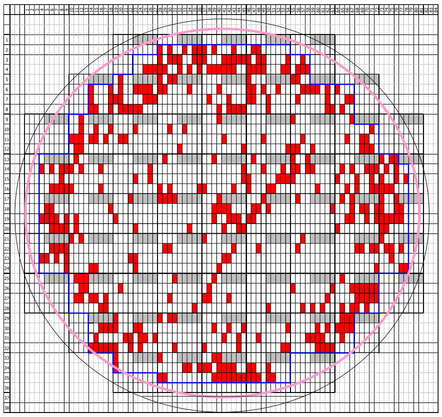

Fig. 2. Map of drain leakage current measured with on-wafer DC probing test.

CHALLENGE FOR HIGH RELIABILITY AND HIGH VOLUME MASS-PRODUCTION

When it comes to mass-product reliability, long term reliability well known as MTTF is usually in focus. However, for the commercialization of GaN HEMT, ruggedness is also very important to be operated under various RF conditions [5].

Basically, RF devices can be damaged by thermal breakdown or electric field breakdown, if the bias condition under RF operation is outside of the ASO (Area of Safe Operation). Therefore, the device should be designed to have the largest possible ASO. Figure 3 shows the simulated load lines of inverse class-F operation with Vds of 50 V at 2.1 GHz up to output power of P5dB and ASO at channel temperature of 200 deg. C. This temperature is defined as the channel temperature generally required for high power amplifier used in base station while maintaining MTTF. We confirmed our GaN HENT achieved 3-terminal breakdown voltage of 220 V at 200 deg. C, which was sufficiently high for expected peak drain voltage of 160 V. Also note the simulated load lines were well inside of ASO. Figure 4 shows the simulation result of drain voltage waveform with high VSWR and all angle of 0 to 180 deg. with Vds of 50 V at 2.1 GHz. The simulated peak drain voltage reaches 200V. It suggests our GaN HEMT has sufficient ruggedness for mismatched or unexpected load impedance condition.

We also carried out DC high temperature operating life (DC-HTOL) test of the GaN HEMT [6]. In order to determine activation energy (E_a), the DC-HTOL test consisted of four temperature life test with channel temperature of 250 deg. C, 275 deg. C, 300 deg. C and 315 deg. C and all the devices were biased at Vds of 60 V. Ea was estimated to be 2.1 eV and MTTF was to be 2.3×10^7 hours at channel temperature of 200 deg. C as shown in Figure 5.

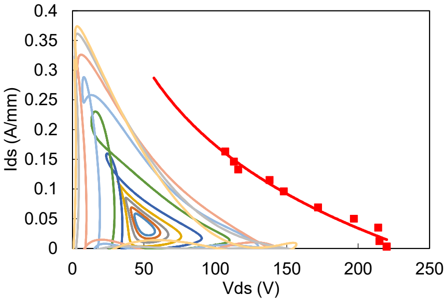

Fig. 3. Simulated load lines of an inverse class-F operation up to output power of P5dB and ASO measured by pulsed DC bias at 200 deg. C.

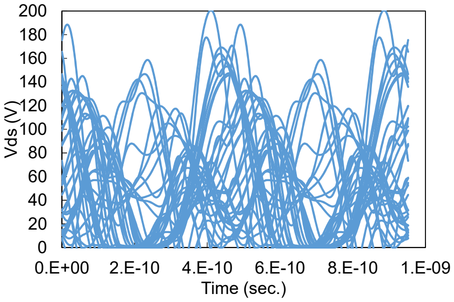

Fig. 4. Simulation results of drain voltage waveform with high VSWR and all angle of 0 to 180 deg. with Vds of 50 V at 2.1 GHz up to output power of P5dB.

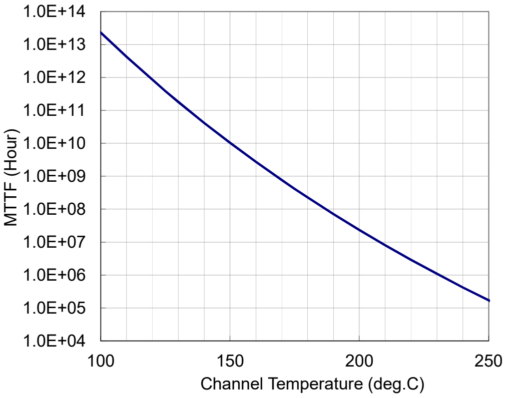

Fig. 5. MTTF estimated with DC-HTOL.

PLASTIC PACKAGED DOHERTY AMPLIFIER

In today's base stations, multiple-input and multiple-output (MIMO) system is important to increase the data rate of communication networks. Well known issues of MIMO system are power dissipation and physical circuit size. Therefore, the power amplifier for a MIMO system must have high efficiency with low cost and small size. In the next generation system, 5G mobile communication system, these requirements will increase. In order to achieve these demands, the plastic packaged device is an essential solution. However it requires significant die level humidity protection technology. We developed the GaN HEMT with humidity protection structure by improvement of the surface passivation film. We carried out HAST (Highly Accelerated Temperature and Humidity Stress Test) at temperature of 130 deg. C and relative humidity of 85 % with Vds of 55 V at pinch off bias condition and found no failure over 200 hours. This demonstrates HAST compliance

We have developed a 20 W peak power symmetric Doherty amplifier using plastic packaged GaN HEMTs with die level humidity protection. A top view of this symmetric Doherty amplifier is shown in Figure 6. Figure 7 shows the performance of this symmetric Doherty amplifier at 3.5 GHz frequency band. A drain efficiency of 45 % and corrected ACLR (Adjacent Channel Leakage Ratio) of -52 dBc were achieved at the average output power of 36.5 dBm using commercially available DPD [7]. These results show the superiority of GaN HEMT for a MIMO system, which requires high RF performance with low cost and small size.

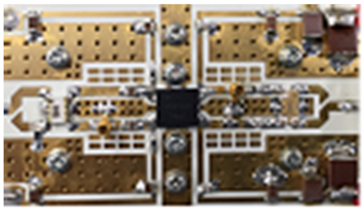

Fig. 6. Photograph of the developed plastic packaged device and the test fixture.

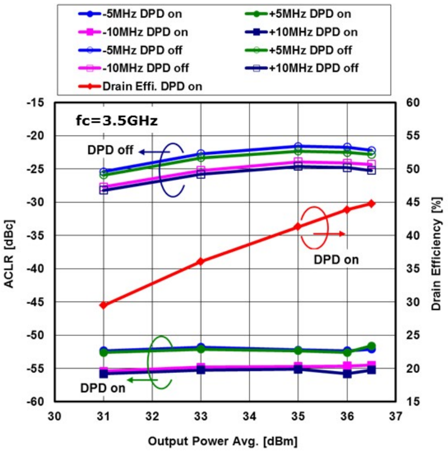

Fig. 7. RF performance with Doherty operation.

CONCLUSIONS

GaN HEMT has already been a leading device for wireless communication system. Sumitomo succeeded in the first GaN HEMT commercialization to be used for cellular base station in the world. GaN HEMT shows excellent long term reliability and ruggedness under high temperature with high voltage operation. These characteristics are impossible to be achieved with Si or GaAs based devices. Additionally, we demonstrated the superiority of a 20 W peak power plastic packaged GaN Doherty amplifier. Activities with GaN HEMT are already in progress to address further 5G applications. Furthermore, GaN HEMT will be expanded to various applications beyond cellular base station.

ACKNOWLEDGEMENTS

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ACRONYMS

HEMT: High Electron Mobility Transistor
MOCVD: Metal Organic Chemical Vapor Deposition
MTTF: Mean Time To Failure
VSWR: Voltage Standing Wave Ratio
DPD: Digital Pre Distortion