Transfer and Implementation of AFRL 140nm Technology on 6-in GaN on SiC

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Abstract

In this paper we report on the transfer and production implementation of AFRL's 4-in 140nm GaN-SiC technology to BAE Systems Microelectronics Center (MEC) foundry. We integrated the best of AFRL and BAE Systems GaN-SiC into a 6-in 140nm technology for Ka-band and Q-band, the industry's first 6-in 140nm GaN-SiC production process. Pulsed IV (pIV), FET load pull, MMIC performance and reliability results are presented.

INTRODUCTION

In 2018, the MEC foundry at BAE Systems collaborated with AFRL to transfer 140nm 4-in GaN-SiC technology to 6-in GaN-SiC. The key technical objectives of this program are to establish a best-in-class 140nm gallium nitride (GaN) production technology at BAE Systems foundry in Nashua, N.H. by transferring and integrating key process technologies developed by AFRL [1, 2], with existing GaN MMIC processes and capabilities at BAE Systems to achieve a high-performance, high MRL process on 6-in GaN on SiC[3]. Through this Short-Gate High-Efficiency Gallium Nitride (GaN) Monolithic Microwave Integrated Circuit (MMIC) Producibility program, BAE Systems is addressing the Department of Defense's (DoD) urgent need to establish an open GaN foundry accessible to the U.S. defense community and offering an advanced GaN MMIC process.

OPEN FOUNDRY SERVICE – BAE SYSTEMS

The BAE Systems III-V compound semiconductor foundry is a strategic asset that provides discriminating MMIC technologies to its Electronics Systems sector. Foundry services are offered to the U.S. DoD community in order to more efficiently utilize the capacity of our foundry, exercise and improve processes, and strengthen relationships with external DoD suppliers and government agencies. Completing the transition of GaN production to 6-inch wafer diameter is a key task under the 140nm technology activity. This alone will increase the effective foundry capacity by more than a factor of 2. BAE Systems is currently investing in its foundry by replacing tools, removing single points of failure, while meeting production demands.

In addition, an investment in Process Design Kits (PDKs) has enabled scalable statistically valid models over temperature. This allows the designer to predict yield under various operating conditions. BAE Systems offers foundry services for all our GaAs and GaN technologies where performance and wafer demands are a match to our high mix, low volume capability.

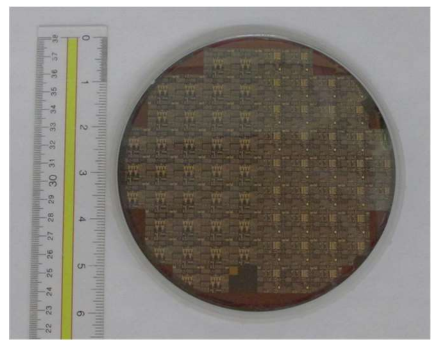

Fig. 1. The world's first 6-in, 2-mil 140 nm GaN Wafer

PROCESS TRANSFER APPROACH

We combined the best from both AFRL and BAE Systems GaN processing and transferred and implemented 140nm Gallium Nitride (GaN) on 6-in GaN as shown in Fig.1 above. Progress toward the validation of the GaN 140nm process is continuing and is expected to complete in 2023, at which time it will become available as part of our standard foundry service offering. Currently, the 140nm process is being offered through the Short Gate GaN contract to participants in the second and third AFRL GaN design challenges through an MPW service. These early access runs help to drive maturation of the technology and exercise our process design kits (PDKs) in order to aid transition.

RESULTS AND DISCUSSIONS

The 6-in GaN-SiC devices and MMICs are fabricated with the 140nm process. The pulsed IV results on 2x50um FET are shown in Fig. 2. Imax of ~1200 mA/mm at Vds=10V was measured at the Vgq=0V, Vdq=0V quiescent condition. Gate lag is only 6.5% and at Vds=10V, the drain lag is 18.7%.

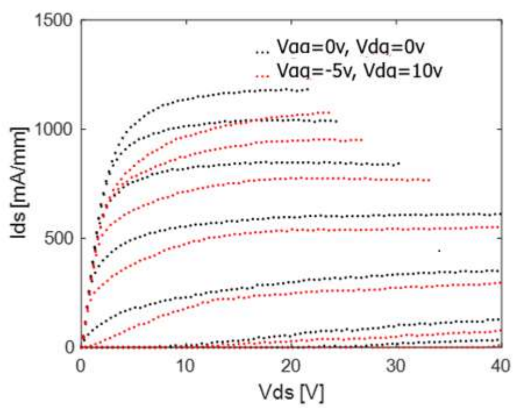

Fig. 2. Pulsed IV response of 2x50um FET showing drain lag of 18.7%.

Fig 3 shows load pull results for 4x65um devices mounted on shim. PAE is an important parameter and we achieved 43% PAE at 35 GHz at 20V with more than 3W/mm associated output power. The devices were measured with passive tuners with the device matched for optimum PAE, and the measured efficiency is limited by the maximum reflection coefficient of the source tuner.

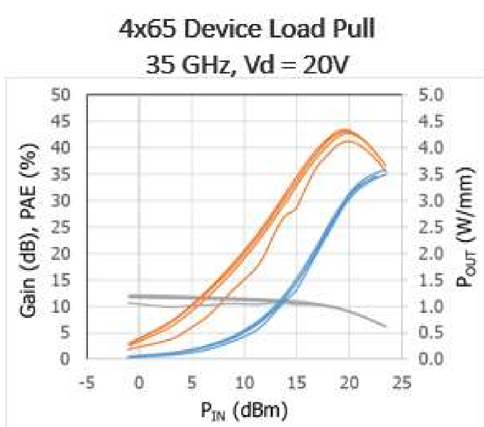

Fig. 3. Load pull results of 4x65um FET

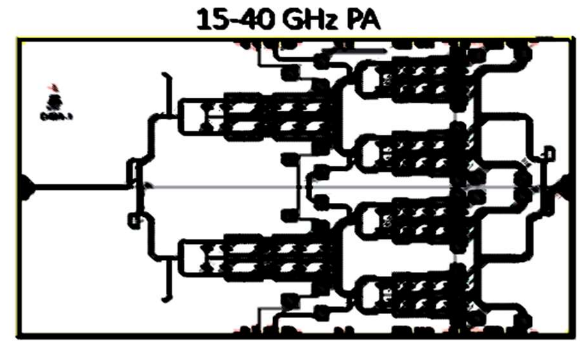

Fig. 4. Schematics of a wide band MMIC

A wide band power amplifier MMIC with frequency range from 15 to 40 GHz is fabricated with the 140nm technology and Fig.4 is a screen capture of the layout. The MMIC is a two-stage non-uniform distributed power amplifier in a balanced configuration with input and output Lange couplers. Although the circuit covers the full frequency band, it was optimized for maximum power and efficiency within the 15-22 GHz and 30-40 GHz frequency bands, as was driven by the requirements of the system. Small signal and power performance are measured as shown in Fig 5 and 6.

The MMIC has more than 14 dB of linear gain across the full frequency band, with peak output power and efficiency of 42 dB and 16% respectively in an on-wafer power measurement. To the best of our knowledge this is the first demonstration of a MMIC at this high output power level that covers the full 15-40 GHz frequency band.

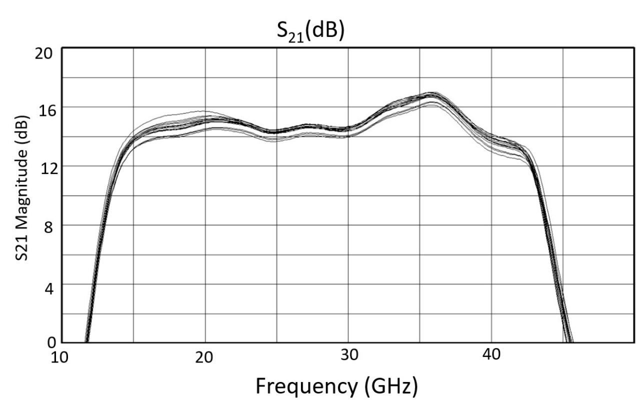

Fig. 5. Small signal S21 of the MMIC

MMIC RESULTS

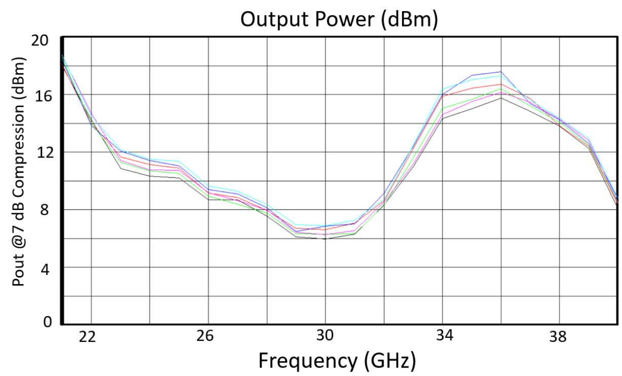

Fig. 6. Output power of the MMIC vs frequency measured on-wafer at 24V

RELIABILITY

We also tested the Reliability performance of the 140nm technology. Fig. 7 shows the Weibull fit. The test was done with a baseplate temperature associated with a junction temperature of Tj=320C, as determined by FEM thermal simulations. The median TTF is 1709 hours @Tj=320C, similar to BAE Systems' 180nm 4mil process, and associated with 3.3 x 10^7 hrs TTF at 200C junction temperature with Ea of 2.0 eV.

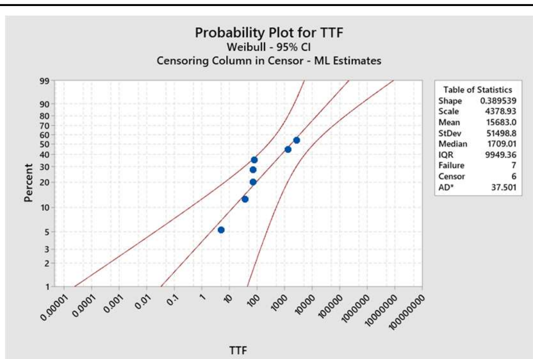

Fig. 7. Rel performance of the 140nm technology

CONCLUSION

We have successfully transferred AFRL's 140nm technology and demonstrated results on 6-in GaN on SiC at BAE Systems. By combining the best of both AFRL and BAE Systems' GaN technology, we achieved the world's first 6-in 2-mil 140nm GaN technology. The 140 nm GaN technology is a state of the art millimeter-wave power technology, which offers excellent power and efficiency for RF power amplifiers at frequencies up to 50 GHz.

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ACRONYMS

MMIC: Monolithic Microwave Integrated Circuit
MEC: Richard Reed Microelectronic Center AMP Center
PAE: Power Added Efficiency
MPW: Multi-Product Wafers
FEM: Finite Element Method
TTF: Time To Failure
AFRL: Air Force Research Laboratory
SiC: Silicon Carbide