

# Transfer of the AFRL 0.14μm AlGaN/GaN-on-SiC MMIC Process to MACOM's Commercial Fab

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## Abstract

In this paper we report on the transfer of the AFRL 0.14μm AlGaN/GaN-on-SiC Monolithic Microwave Integrated Circuit (MMIC) Process to MACOM's Fab and present a comparison of the initial performance of both a 27-31GHz power amplifier with output power in excess of 35dBm and a 2-20GHz wide-band power amplifier, fabricated at both AFRL and MACOM.

## INTRODUCTION

AFRL built an in-house 4-inch AlGaN/GaN-on-SiC Monolithic Microwave Integrated Circuit (MMIC) research prototyping capability based on two decades of GaN research and development. AFRL reported Transmit and Receive (T/R) and Power Amplifier (PA) results on a MMIC process based on their non-field plate microwave AlGaN/GaN 0.14μm RF device process (GaN140) [1]-[2]. Here, AFRL and MACOM show first pass success on GaN140 process transfer in the design of Ka-band and a wide-band 2-20GHz distributed amplifier.

## PROCESS TRANSFER APPROACH

Device performance is determined primarily by the front-end processes, ohmic contact and gate electrode formation and device Si<sub>3</sub>N<sub>4</sub> passivation, and these were copied directly or adapted as closely as possible to the AFRL processes.

Adaptations to the flow at MACOM include the use of both sputtered Ta alignment keys and implant isolation. MACOM chose to use their existing evaporated NiCr thin-film resistor and GaAs pHEMT 3-metal layer (0.95μm, 2.35μm and 3.15μm) back-end processes in order to preserve in-fab process commonality and to aid in batching for metallization.

The formation of the ohmic contact is a crucial step and a SiC wafer with thermocouples was used to characterize both the AFRL and MACOM RTA tools to ensure matching alloy conditions.

AFRL defines their 0.14μm T-gate using electron-beam lithography at 100kV. As MACOM currently uses their

electron-beam lithography tool at 50kV for other processes, MACOM developed a process that duplicates the AFRL gate dimensions and profile at 50kV. A SEM image of a FIB cross-section of the MACOM T-gate is shown in Fig. 1.

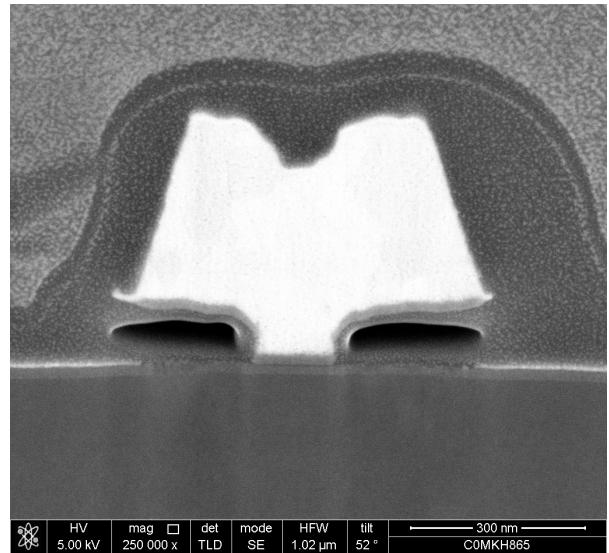


Fig. 1. SEM image of a FIB cross-section of the MACOM electron beam defined gate.

AFRL has shown that the conditions of the PECVD Si<sub>3</sub>N<sub>4</sub> deposition process significantly affect the device breakdown and dc-to-RF dispersion [3]. Si<sub>3</sub>N<sub>4</sub> deposition conditions were optimized to match stress and index of refraction to that of the AFRL film.

## INITIAL DEVICE TEST RESULTS

Completed 2x100μm devices were tested and the pulsed IV results are shown in Fig. 2. Imax of 1290mA at V<sub>ds</sub>=6V was measured at the V<sub>gg</sub>=0V, V<sub>dq</sub>=0V quiescent condition. At the V<sub>dq</sub>=25V, I<sub>dq</sub>=100mA/mm quiescent condition, 21.8% gate and drain lag was observed.

Fig. 3 shows the results of pulsed RF power measurements at 10GHz on completed 2x100μm devices. The devices

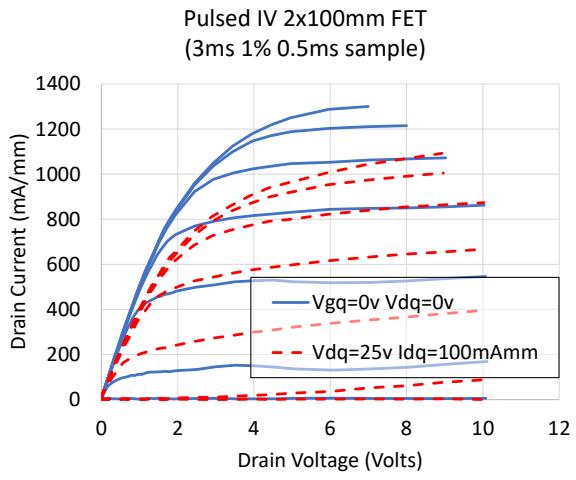


Fig. 2. Pulsed IV response of a 2x100 $\mu$ m FET. At  $V_{ds}=6$  V, an  $I_{max}$  of 1290mA ( $V_{gq}=0$ V,  $V_{dq}=0$ V) and 21.8% gate and drain lag ( $V_{dq}=25$ V,  $I_{dq}=100$ mA/mm) were observed.

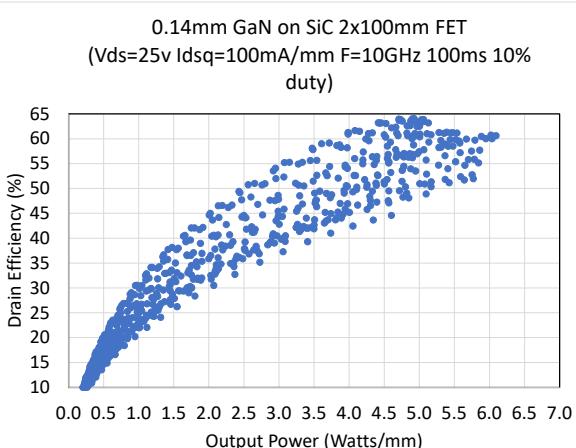


Fig. 3. Drain efficiency plotted as a function of output power for a 2x100 $\mu$ m FET at 10GHz.

deliver a maximum of 6.1W/mm and demonstrate a maximum drain efficiency of 64% operating at the  $V_{dq}=25$ V,  $I_{dq}=100$ mA/mm quiescent condition.

#### INITIAL PRODUCT DEMONSTRATOR RESULTS

A 3-stage 27-31GHz Ka-band power amplifier and a 2-20GHz power amplifier were designed using the AFRL Process Design Kit (PDK) and were fabricated on both the MACOM and AFRL processes.

An SEM micrograph of a 6-finger device in one of the stages of the Ka-band power amplifier showing the 3-metal layers, including the air-bridges, is shown in Fig. 4. The power performance of the power amplifier producing over 35dBm of output power at a 6dB compressed condition is shown in Fig. 5. The average input power was 25.6 dBm. Fig.

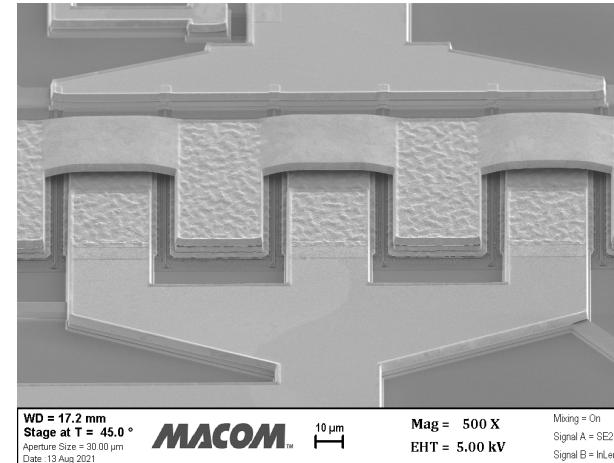


Fig. 4. SEM micrograph of a 6-finger device in one of the stages of the 27-31GHz Ka-band power amplifier fabricated at MACOM.

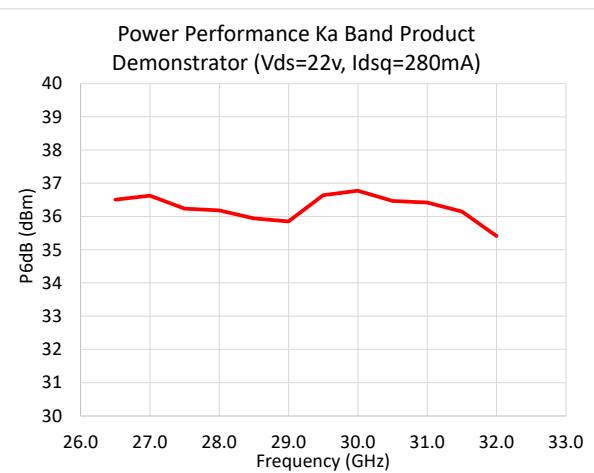


Fig. 5. 6dB compressed output power of 27-31GHz amplifier fabricated at MACOM. Average input power was 25.6dBm.

6 shows an optical image of a MACOM fabricated Ka-band amplifier die and a comparison of the measured small signal s-parameters to those of an AFRL fabricated amplifier of the same design showing good matching of the small signal responses between the two.

Similarly, Fig. 7 shows an optical image of a MACOM fabricated wide-band distributed 2-20GHz amplifier die and a comparison of the measured small signal s-parameters to those of an AFRL fabricated amplifier, showing good matching of the small signal responses between the two.

#### CONCLUSIONS

AFRL's 0.14 $\mu$ m AlGaN/GaN MMIC Process has been transferred to MACOM's Lowell, MA Fab. Initial circuit results show good matching of s-parameters between amplifier circuits fabricated at MACOM and at AFRL for

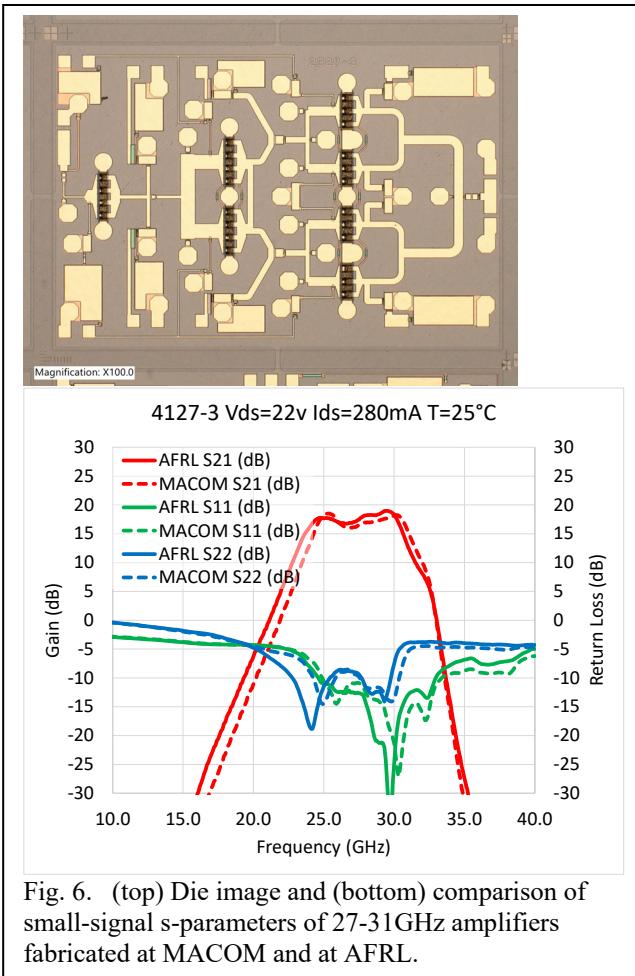


Fig. 6. (top) Die image and (bottom) comparison of small-signal s-parameters of 27-31GHz amplifiers fabricated at MACOM and at AFRL.

both a 27-3GHz amplifier with over 35dBm of 6dB compressed power and a 2-20GHz amplifier.

The targeted reliability for a failure criterion of a 20% drop in  $I_{dss}$  is  $1e^6$  hours at  $V_{ds}=25V$  and  $4W/mm$ , at a channel temperature of  $200^\circ C$ . A preliminary estimate of  $E_a$  is  $2.4eV$ . Reliability testing is in progress.

MACOM's 0.14um GaN-on-SiC (GSiC140) MMIC process will be made available to strategic customers for foundry access. MACOM will support this with complete Process Design Kits (PDKs), web-based DRC/LVS and back-end services including dice, test and AVI.

#### ACKNOWLEDGEMENTS

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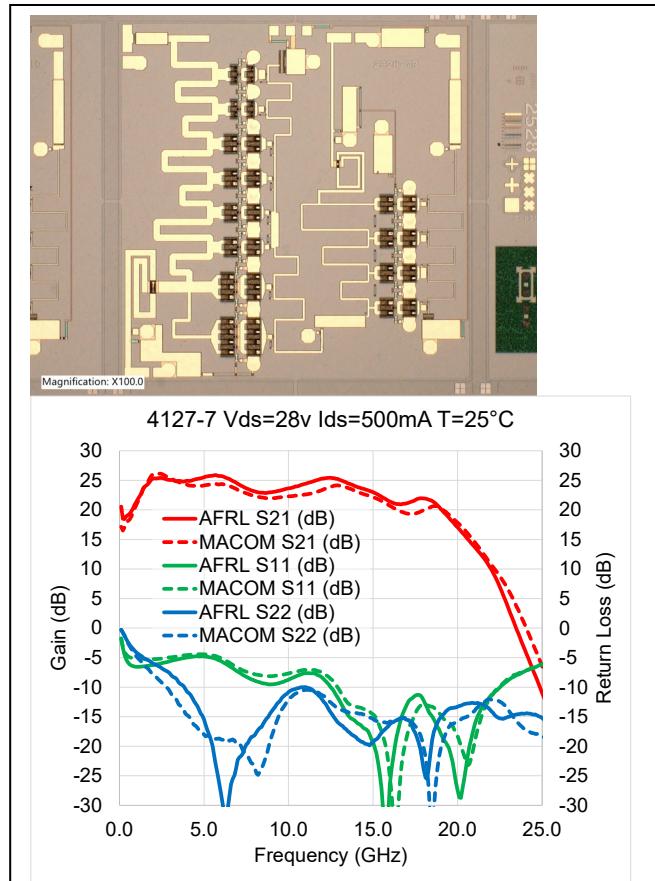


Fig. 7. (top) Die image and (bottom) comparison of small-signal s-parameters of 2-20GHz amplifiers fabricated at MACOM and at AFRL.

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#### ACRONYMS

MMIC: Monolithic Microwave Integrated Circuit

PA: Power Amplifier

PDK: Process Design Kit

PECVD: Plasma-Enhanced Chemical Vapor Deposition

pHEMT: pseudo-morphic High Electron Mobility Transistor

RF: Radio Frequency

RTA: Rapid Thermal Annealing

T/R: Transmit and Receive

