Performance of 0.3 um gate length GaN HEMT by using i-line stepper for high power c-band applications

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Abstract

GaN HEMT devices with 0.3 um gate length has been developed with i-line stepper based process. Device fabrication process includes Si+ ion implant ohmic, Ni based gamma gate, Au electro-plated source connected field plate, through hole SiC via directly connected to the source ohmic. The current gain cut off frequency was measured about 21 GHz and the power density about 8.5 W/mm at 3.5 GHz. Angelov GaN HEMT large signal model has been developed and available in ADS software. A wideband PA at 5.1 – 5.8 GHz has been designed and fabricated with 2 of 350umx20 finger devices. The PA shows 13~15 dB small signal gain, 10~12 dB power gain, >49 dBm peak power, >42% drain efficiency. The measured performance of the PA was well matched to the simulation.

INTRODUCTION

Traditionally, c-band frequency range has a number of applications such as satellite communications, satellite TV networks, weather satellite, 802.11a wifi, radio LAN services, data link for UAVs and wideband jammer etc. [1, 2, 3, 4] As 5G mobile service has been deployed in 2020 globally mostly in sub-6 GHz frequency range, the demand of high power, high efficiency, high gain power amplifiers with affordable price in c-band has never been higher before. Though GaN HEMT technology is the most promising solution for this demand, actual devices meet all those requirements are scarcely found in the RF PA market. The devices developed for s-band applications using 0.4 um or 0.5 um gate length shows high power at affordable price but once the frequency is raised to c-band, it suffers low gain and efficiency. On the contrary, 0.25 um gate length devices, developed for x-band, shows excellent gain and efficiency at c-band but the maximum power of a single device is limited, and the manufacturing cost is very high. 0.3 um gate length devices with similar power performance to 0.4 um gate fabricated with a mass producible photo lithography such as i-line stepper seems to be an obvious solution for high power c-band applications. 0.3 um gate was defined by i-line stepper with high resolution photo resist on top of SiNx dielectric layer. The rest of the device structures were similar to the high-power devices with 0.4 um gate process to maintain the power performance.[5]

RESULTS AND DISCUSSIONS

1) Device design and fabrication process: The epi structure, device design and fabrication process are same as Wavice baseline process of 0.4 um gate technology published elsewhere [5], except the gate length. 0.3 um gate length was achieved using i-line stepper and subsequent pattern treatment and ICP etching of SiNx dielectric layer. Fig 1 shows schematic diagram and SEM picture of the cross section of the device.

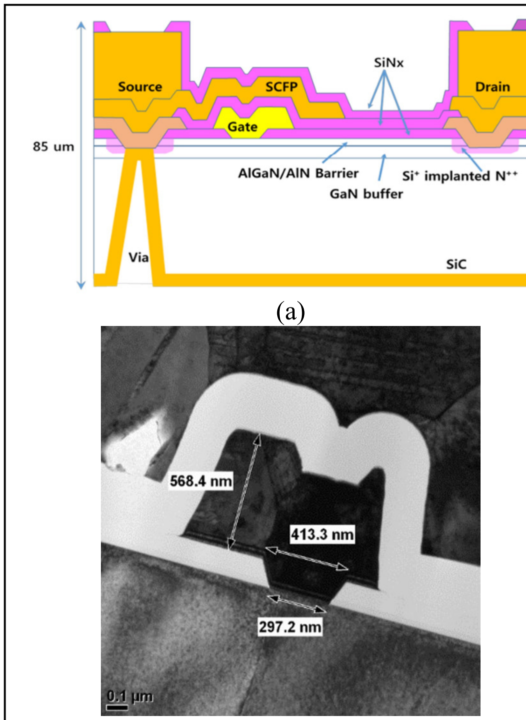
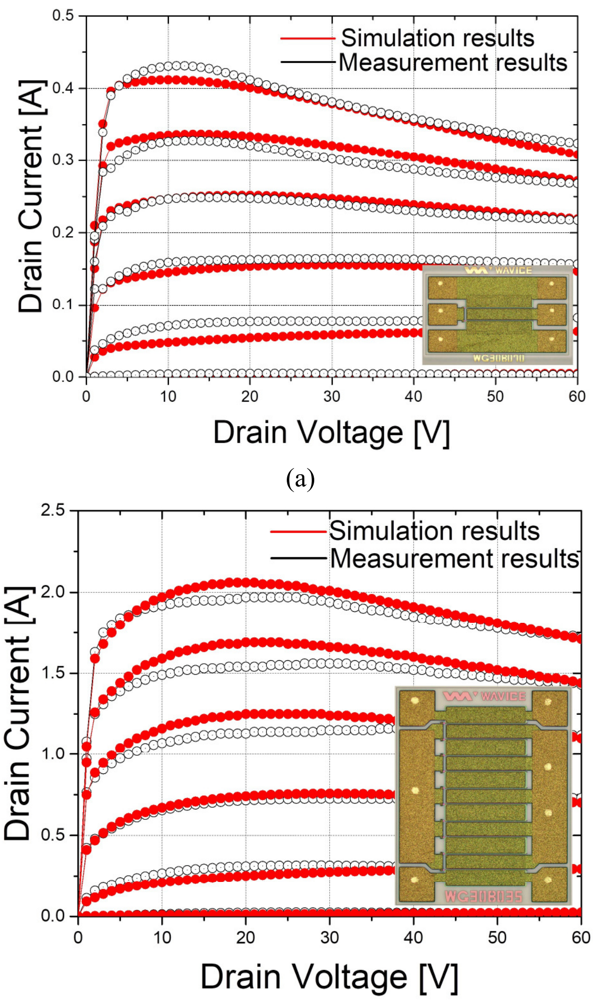


Fig. 1. (a) a schematic diagram and (b) a SEM cross-section picture of 0.3 um gate length GaN HEMT device

2) Device performance and large signal model: Table 1 shows key DC performance of 0.7 mm gate periphery devices. The ft and fmax were measured as 21 and 39 GHz respectively.

TABLE I
DC performance of 0.3 um gate length devices with 0.7 mm gate periphery.

Parameter	Test Condition	Unit	Mean
Gm_max	Vd=10V, maximum gm	S/mm	0.32
Id_Max	Vd=10V, Vg=2V	A/mm	0.98
Ig10_n8	Vd=10V, Vg=-8V	uA/mm	11
Id10_n8	Vd=10V, Vg=-8V	uA/mm	12
Vth	Vd=10V, Id=1mA/mm	V	-2.3



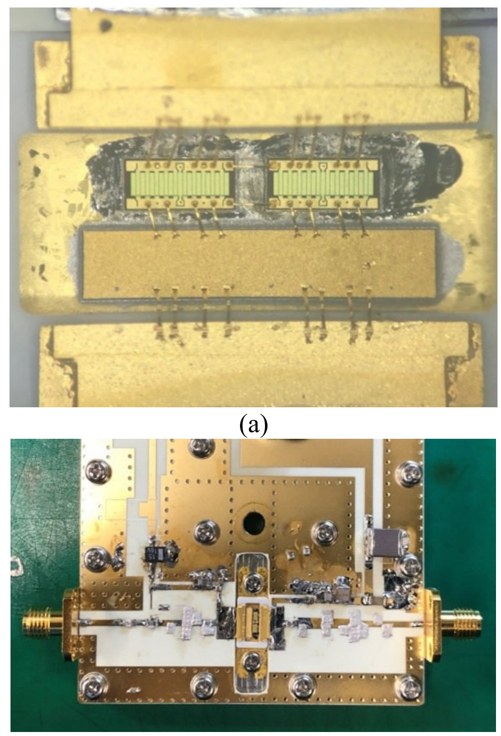
(a)

(b)

Fig. 2. DC IV characteristics of (a) 0.7 mm and (b) 3.5 mm gate periphery devices. Optical microscope pictures of actual devices are enclosed in the graph.

The DC IV characteristics of 0.7 mm and 3.5 mm gate periphery devices are shown in figure 2. ADS simulated IV curves from Angelov GaN large signal models are well matching to the measured data.

3) Wideband PA: Using the device model described above, a wideband power amplifier has been designed and fabricated. Figure 3 shows the picture of packaged transistor and the evaluation board. 2 of 7 mm gate periphery devices and 6.47 pF SLC were used in a package. GaN HEMT devices were AuSn eutectic bonded and the 2 mil Au wires were ball bonded to the devices. Fig. 3 shows the picture of packaged device and the evaluation board.



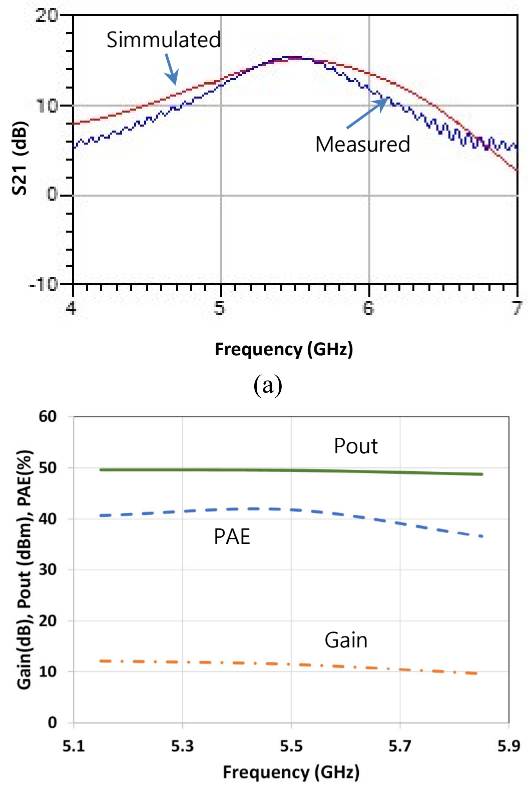
(a)

(b)

Fig. 3. Optical microscope picture of (a) a packaged transistor showing 2 of 7 mm gate periphery devices and a SLC and (b) an evaluation board with the packaged transistor

Figure 4 shows small signal gain and the power performance of the PA. The computer simulated and measured S21 gain show 13~15 dB and well match each other for 5.1 – 5.8 GHz. Peak power was measured as 49.6 dBm at 5.5 GHz and the PAE 44.6%. For the frequency range, the output power was >49 dBm, PAE >42% and gain >10 dB.
Figure 5 shows previous works for 1 stage power amplifiers in C-band (4-8 GHz). [6-15] The PA reported in this work shows the 2nd highest power gain.

The highest gain in C-band was reported by Ma et. al., 13.5 dB using 0.25 um gate length and 100 um unit gate width 24 mm total gate periphery. (2 devices with 120 gate fingers) [7] In this report, however, 350 um unit gate width devices were used and thus the total number of gate fingers is only 40. With this technology, it seems probable to realize higher power amplifiers(>300W) with high power gain(>12dB) in a compact footprint.



(a)

(b)

Fig. 4. (a) Small signal gain (S21) by measurement and simulation (b) peak output power (Pout), PAE and power gain as a function of frequency

Conclusions

GaN HEMT devices with 0.3 um gate length have been successfully developed by using i-line stepper photo lithography process. The ft of 21 GHz and power density of 8.5 W/mm have been measured. Angelov GaN large signal model has been made and is available in ADS. The wideband PA designed by this model shows high power and high gain performance at 5.1-5.8 GHz. Currently a list of reliability test is in progress and higher power devices have been in development to improve the power and efficiency performance with this technology.

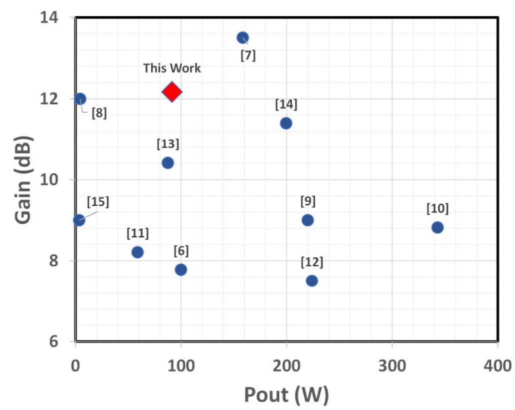


Fig. 5. Previously reported 1 stage PA performances in C-band

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ACRONYMS

ADS: Advanced Design System (®Keysight)
LAN: Local Area Network
UAV: Unmanned Aerial Vehicle
ICP: Inductively Couple Plasma
SEM: Scanning Electron Microscopy
HEMT: High Electron Mobility Transistor
PA: Power Amplifier
PAE: Power Added Efficiency
SLC: Single Layer Capacitor