Tu1B-6

Low-Voltage Operation AlInN/GaN HEMTs on Si with High Output Power at sub-6 GHz

Katsuhiko Takeuchi, Kunihiko Saruta, Shinya Morita, Katsuji Matsumoto, Masashi Yanagita, Satoshi Taniguchi, Shinichi Wada, Kunihiko Tasai, Masayuki Shimada, and Katsunori Yanashima

Analog LSI Business Division, Sony Semiconductor Solutions Corporation, Japan

Outline

- Required Performance for PAs at 5G
- Device structure
- DC/RF characteristics
- Summary

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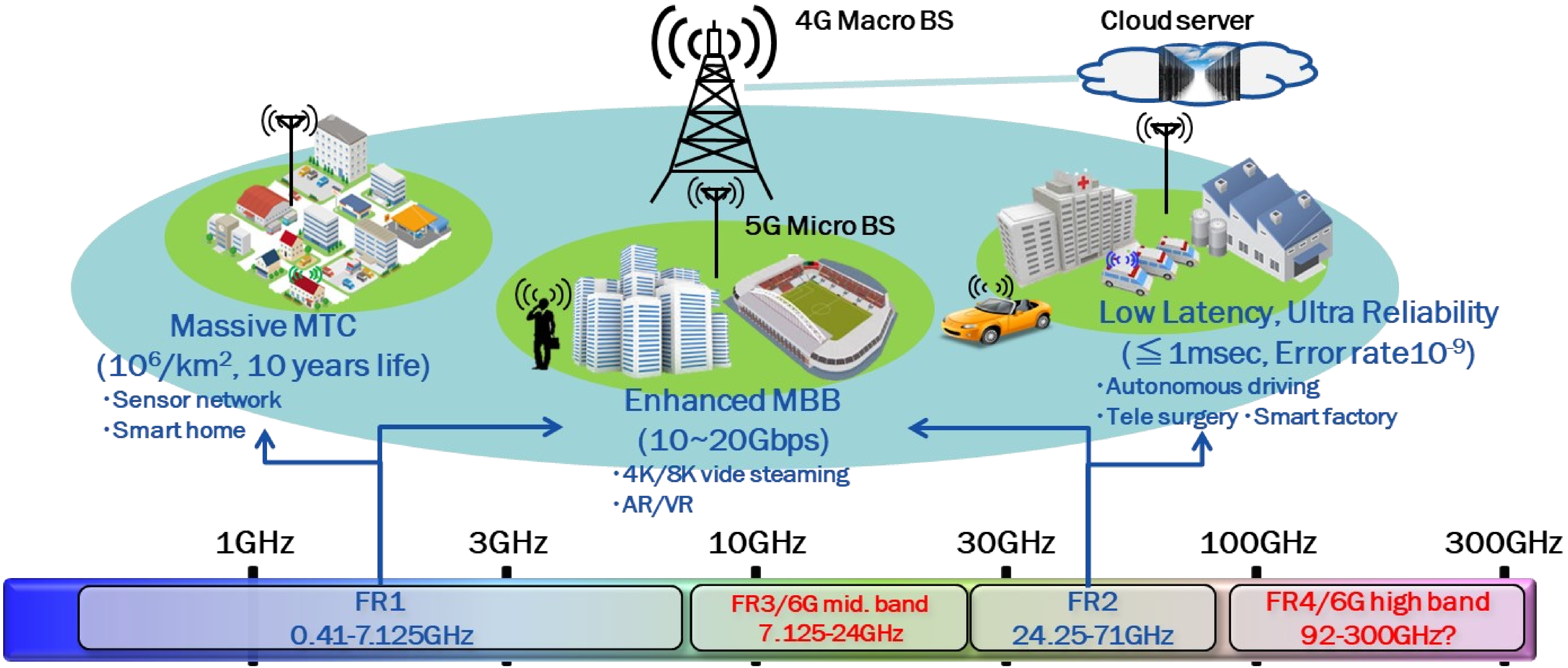
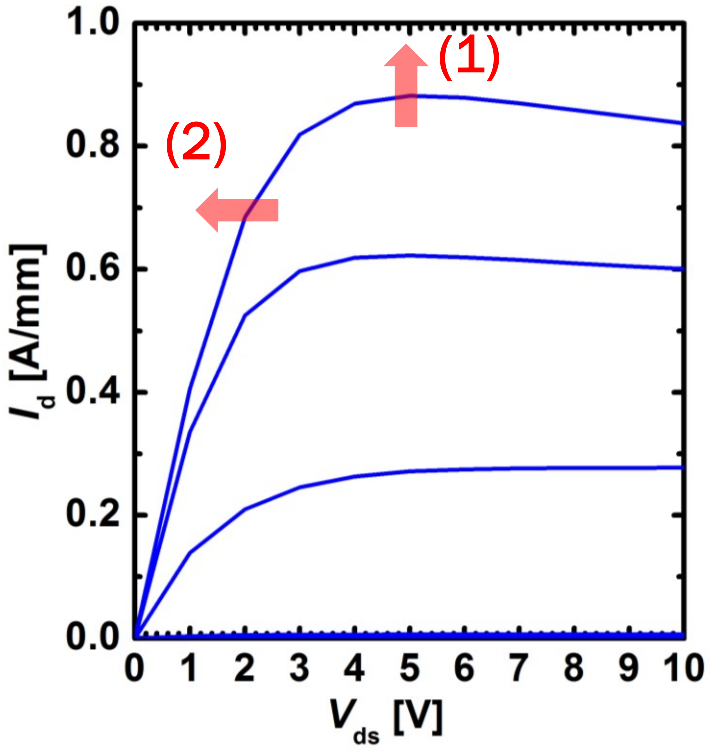
5G usage scenarios



Required items of PAs for user equipment

- Higher P_{out} /PAE
  - > high current density (1)
- Lower voltage operation
  - > low knee-voltage (2)
- Lower costs
  - > GaN on silicon substrate
  - > mature process technology

Representative output characteristics



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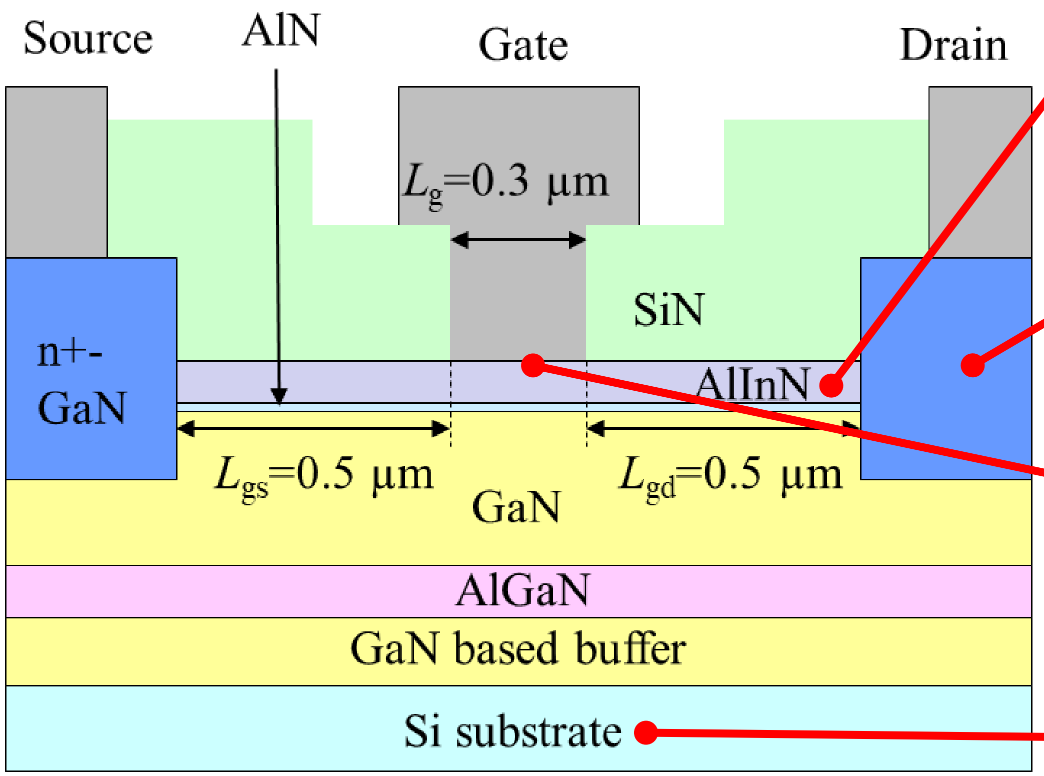
Device structure



1. AlInN barrier
   > high 2DEG density
   > high g_m
2. regrowth ohmic structure
   > low contact resistance
3. optimized Schottky gate process
   > leakage current suppression
4. GaN on 6-inch Si substrate
   > scalability benefit

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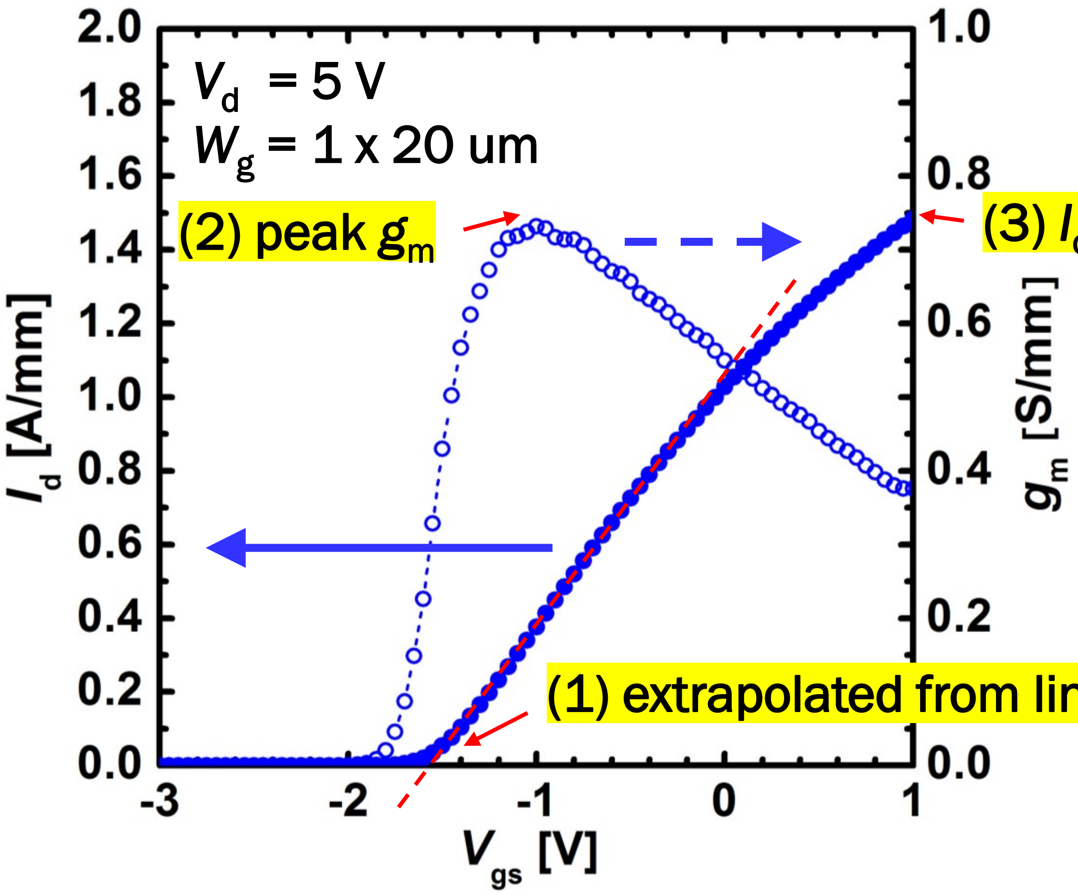
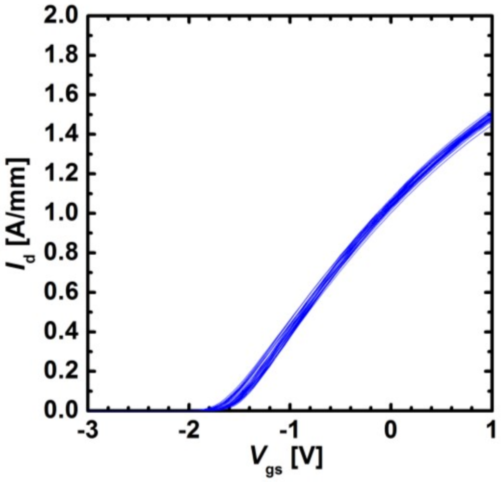
Transfer characteristics



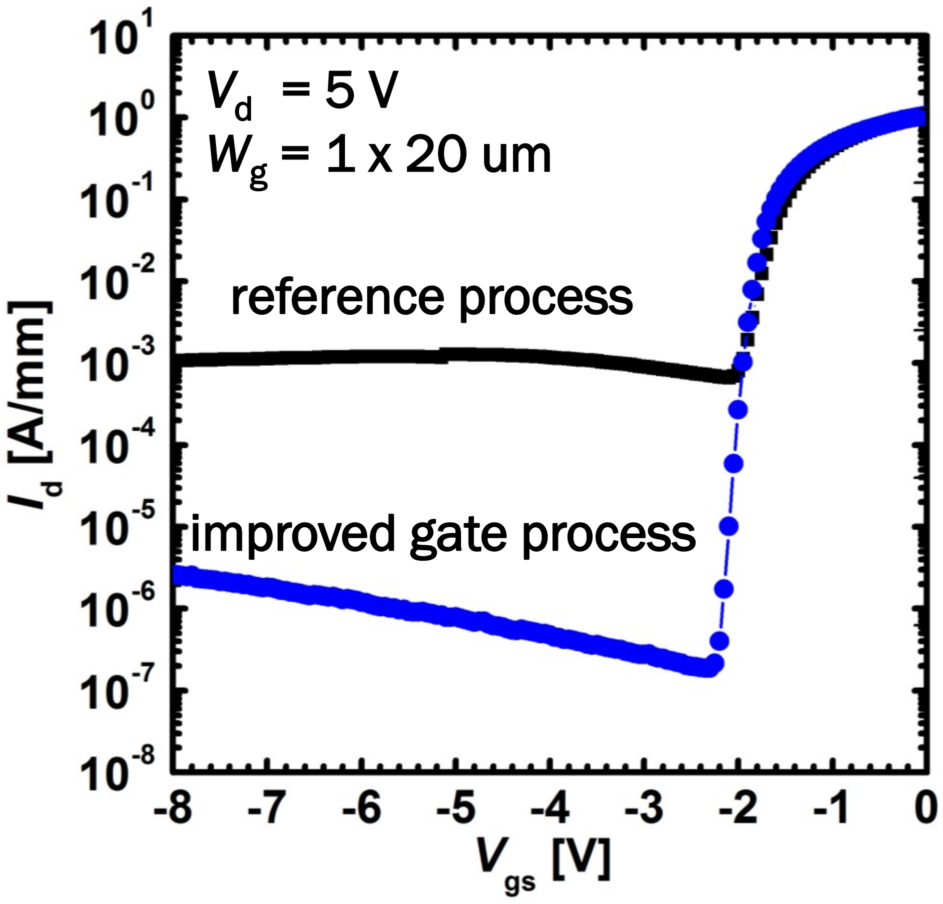
On-wafer uniformity (32 samples)



		Average	σ
(1)	V_{th} [V]	-1.6	0.05
(2)	g_m [S/mm]	0.72	0.02
(3)	I_{dmax} [A/mm]	1.5	0.02

➢ Good performance and uniformity

Off leakage current



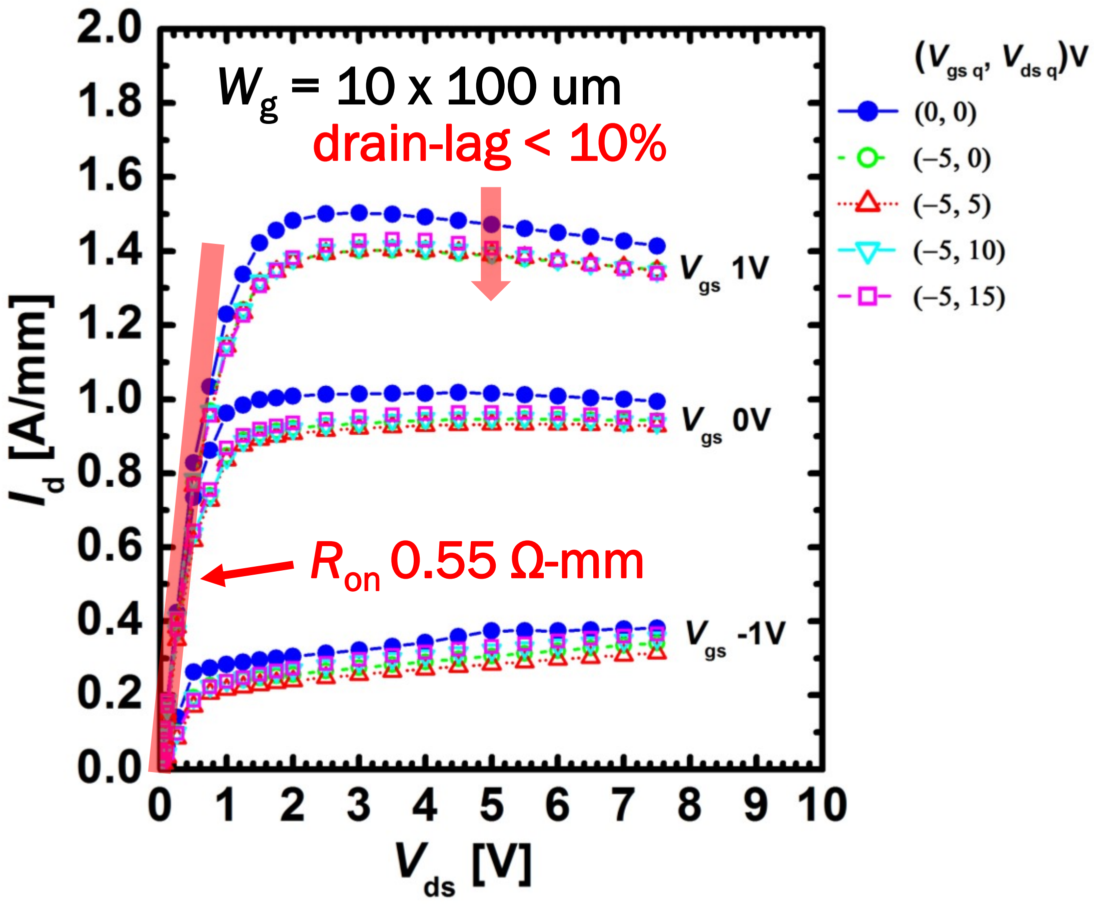
* The value of the drain off leakage current is the same as the gate leakage current.

Challenge to reduce the leakage current

- Low damage dry etching process
- Pre-treatment before gate metallization
- Estimation of the thermal budget impact

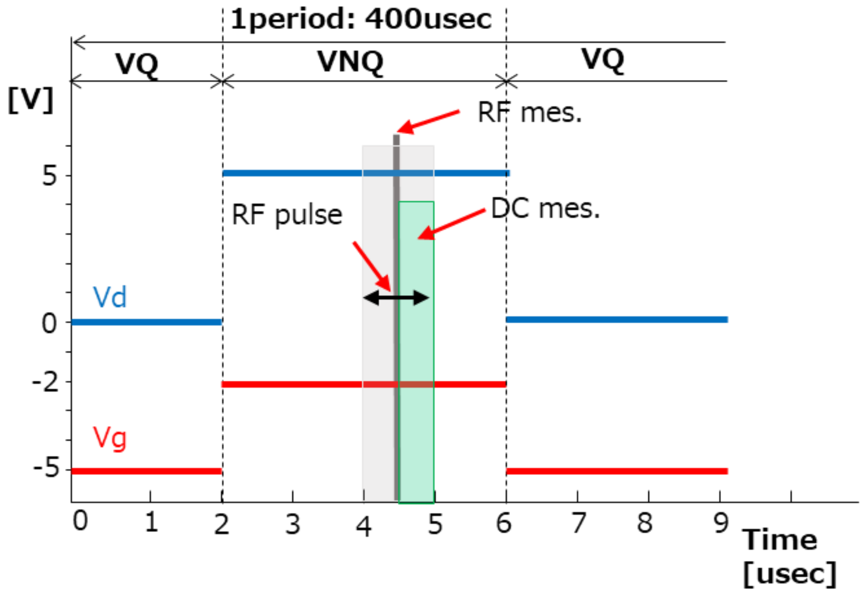
➢ Extremely low leakage current is achieved for Schottky gate of AlInN/GaN HEMTs.

Pulsed I_d-V_{ds} characteristics



Measurement timing chart

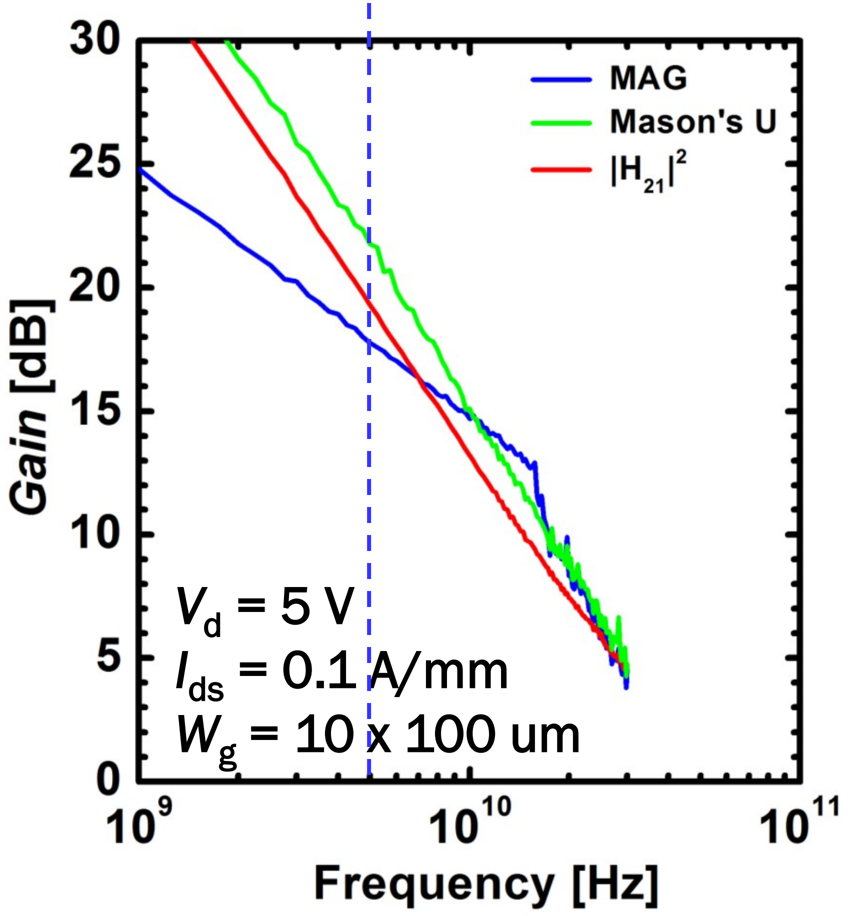
ex. VQ(Vgs, Vds)=(-5,0), VNQ=(-2,5)



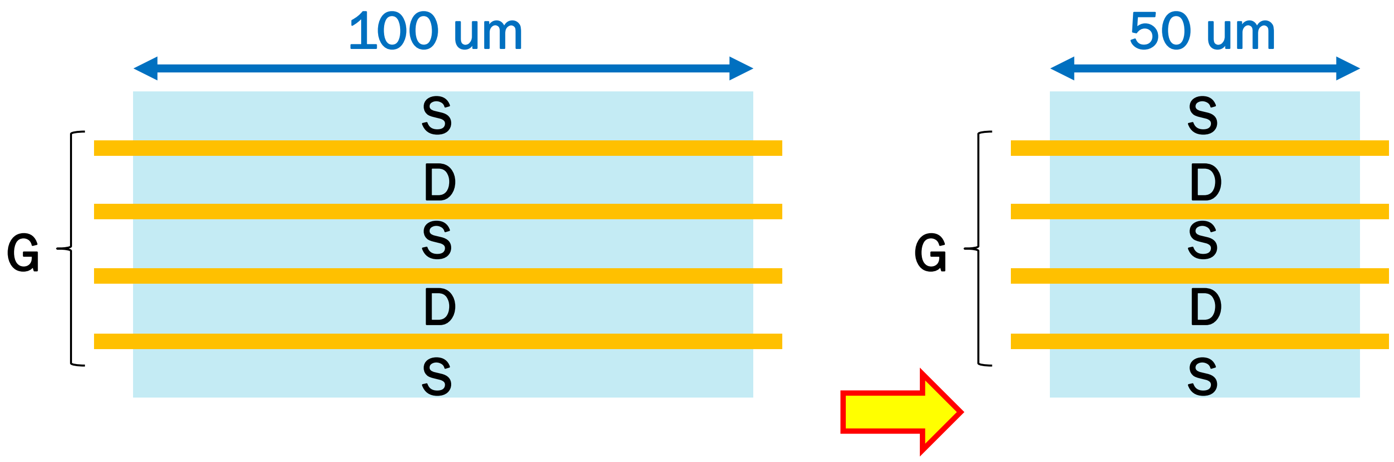
- ➢ Low R_{on} by the regrowth ohmic
- ➢ Low drain-lag based on the sufficiently small effect of traps.

RF gain characteristics

MAG (MSG) = 17.8 dB
(L_g = 0.3 um, frequency = 5 GHz)



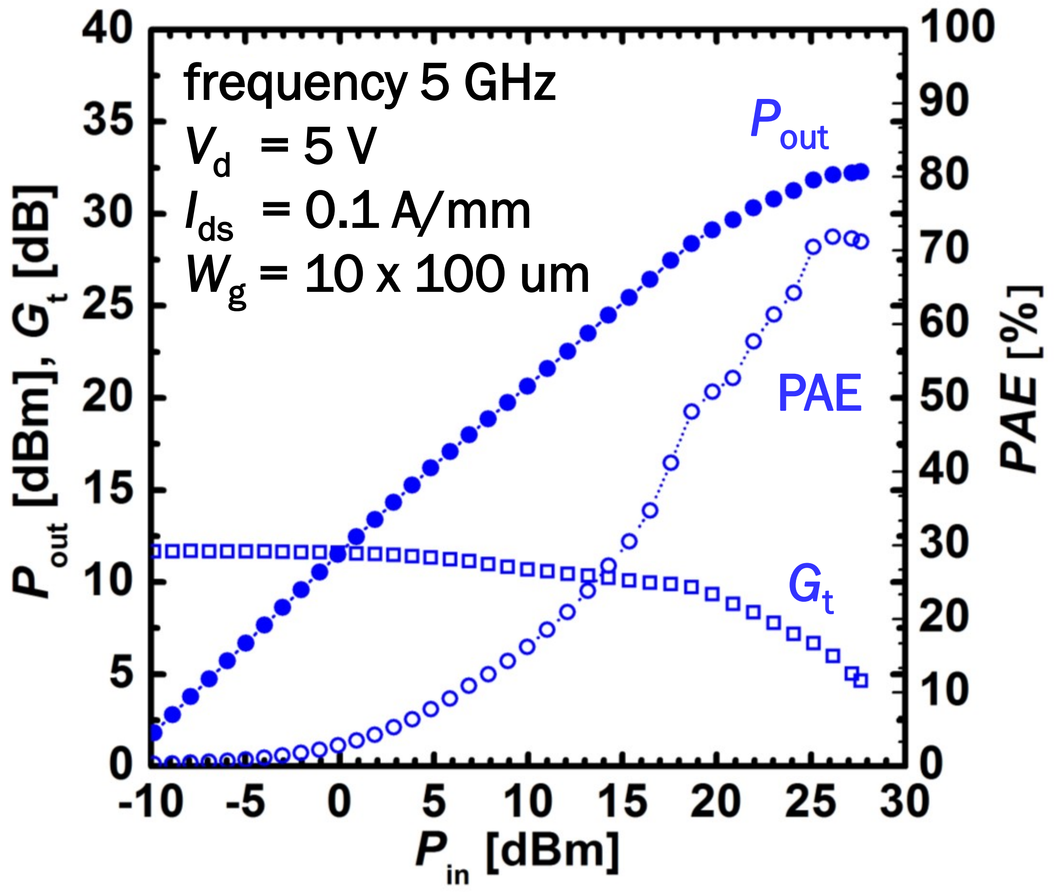
- f_t = 30.4 GHz
- f_{max} = 53.8 GHz
  > extrapolated by using -20 dB/decade slopes



> 50 % fmax increase

➢ Higher f_{max} can be obtained by the reduction of *unit*W_g

Large-signal characteristics

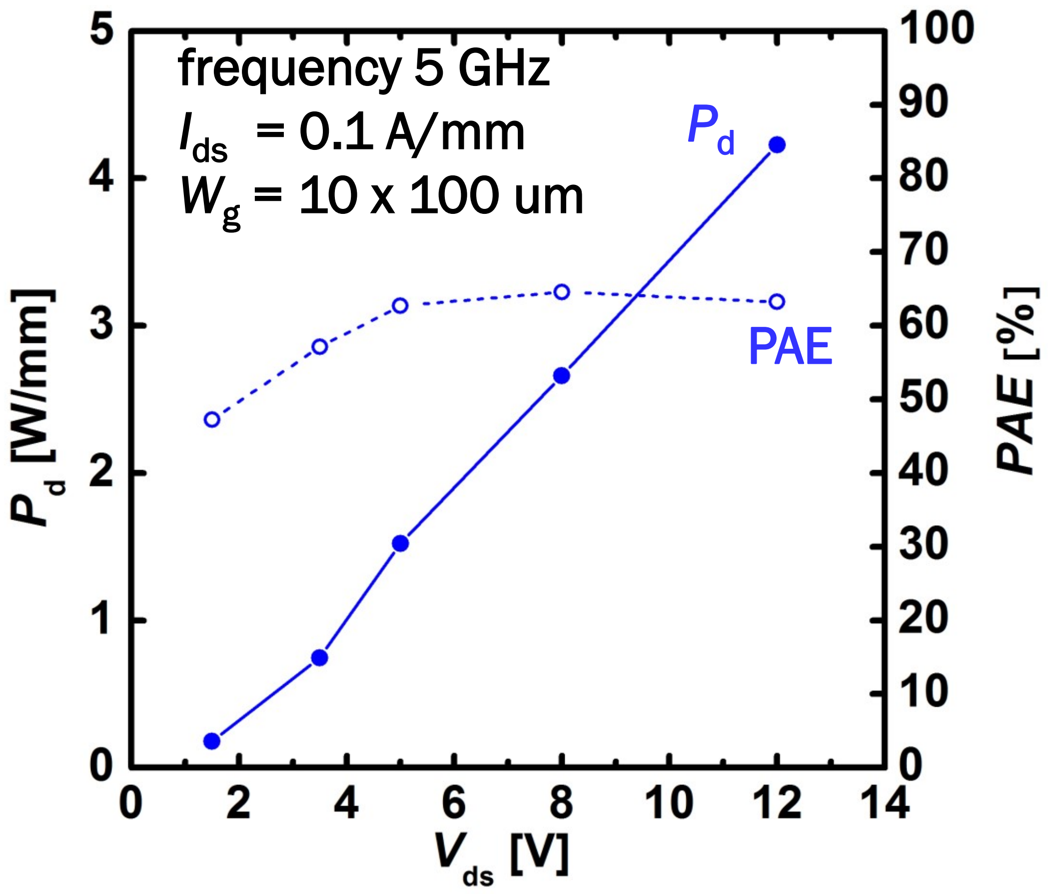


- P_d = 1.52 W/mm
- PAE = 62.7 %

-> P5dB compression under optimum P_{out} load

➢ Excellent performance for low voltage operation

Large-signal characteristics as a function of V_{ds}

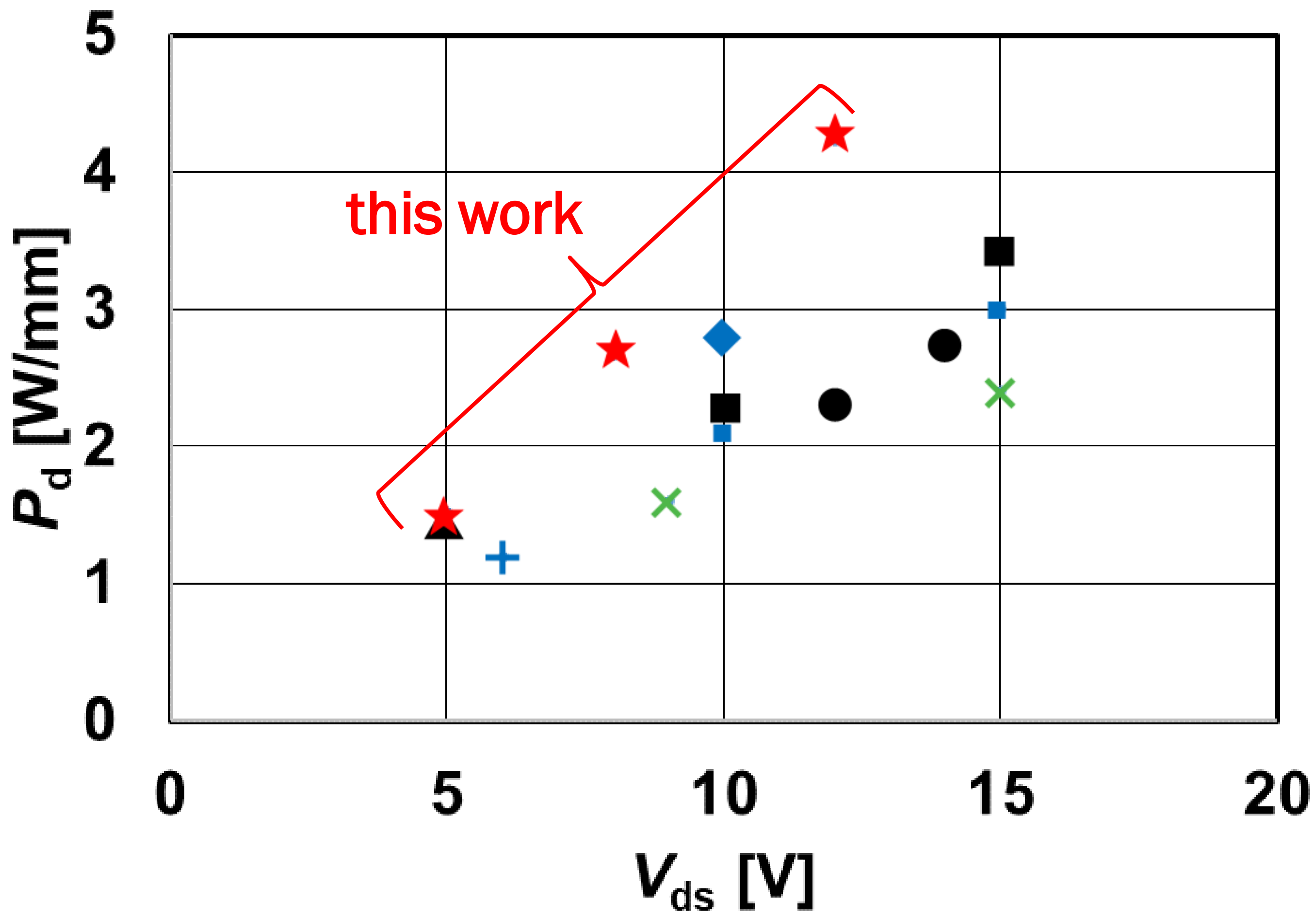


- 2.66 W/mm @V_{ds} = 8 V
- 4.23 W/mm @V_{ds} = 12 V

-> P5dB compression under optimum P_{out} load

➢ Significant P_d improvement by increasing V_{ds}

Benchmarking P_d – V_{ds}



low voltage operation PAs references

mark	Ref.	L_g [µm]	frequency [GHz]
●	Siddiqi, G. et al.	0.04	26.5-40
■	ElKashlan, R. et al.	0.09	6
▲	Then, H. W. et al.	0.09	28
◆	Wang, W. et al.	0.1	34
+	Zhou, Y. et al.	0.15	30
▪	ElKashlan, R. et al.	0.19	6
×	Zhou, Y. et al.	0.2	8
★	this work	0.3	5

Higher P_d is achieved despite the relatively larger L_g of 0.3 µm thanks to lower knee-voltage, higher I_{ds} and higher breakdown voltage.

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- Low voltage operation AlInN/GaN HEMTs with Schottky gate on 6-inch Si substrates

High P_d : 1.52/2.66/4.23 W/mm @V_d = 5/8/12 V
High PAE : > 60 % @V_d = 5 – 12 V
Low cost : GaN on Si, mature fabrication technology

Excellent solutions for PAs in user equipment !

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Acknowledgement

The Coolest Ideas Under the Sun
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