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High Power GaN/AlGaN/GaN HEMTs Grown by Plasma-Assisted MBE Operating at 2 to 25 GHz

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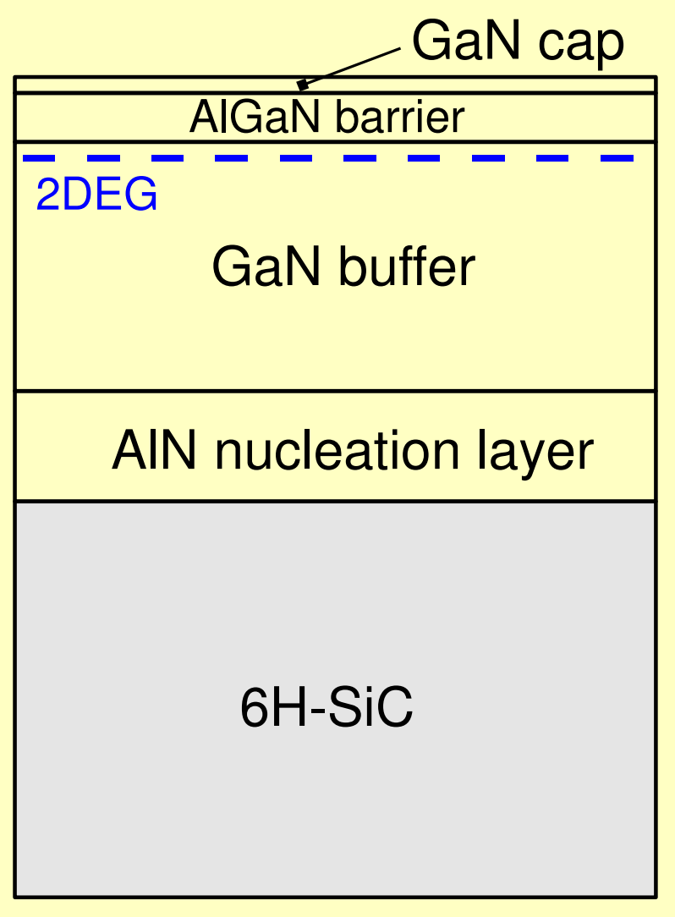
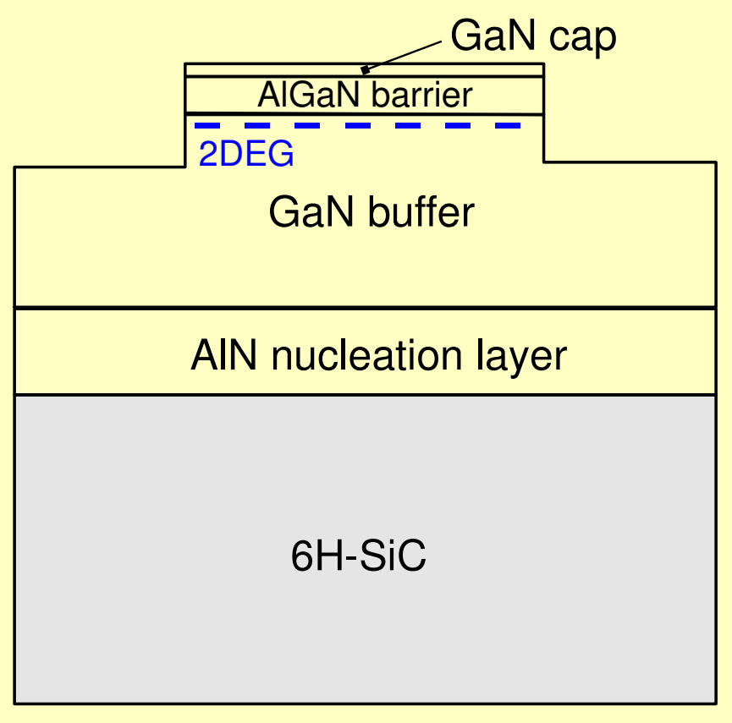
Outline of the Technology



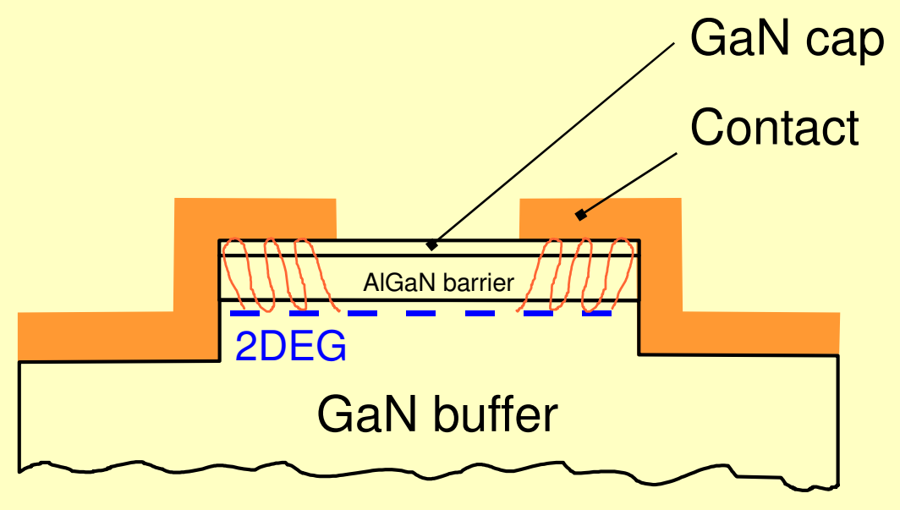
Layer	Thickness [nm]
GaN cap	5
AlGaN barrier	30 ⋯ 40
GaN buffer	2000
AlN nucleation layer	30 ⋯ 60

- Si doping of upper half of AlGaN barrier and GaN cap up to 10^{18} cm^{-3}
- GaN buffer semi-insulating
- Sheet charge densitiy: 1.2 x 10^{13} cm^{-2}
- Room temperature mobility: 1400 cm^2/Vs

MBE growth of the heterostructure

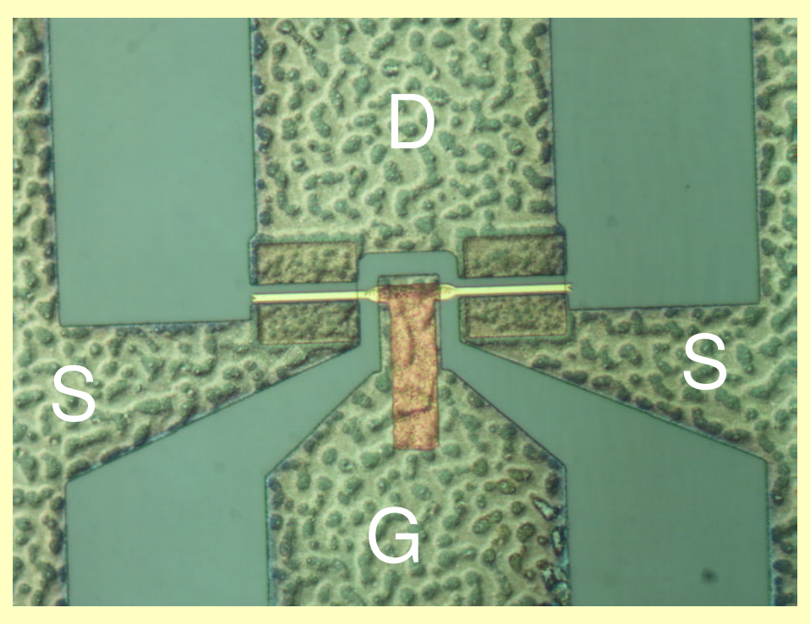


Mesa definition by ICP etching in Cl_2/Ar plasma



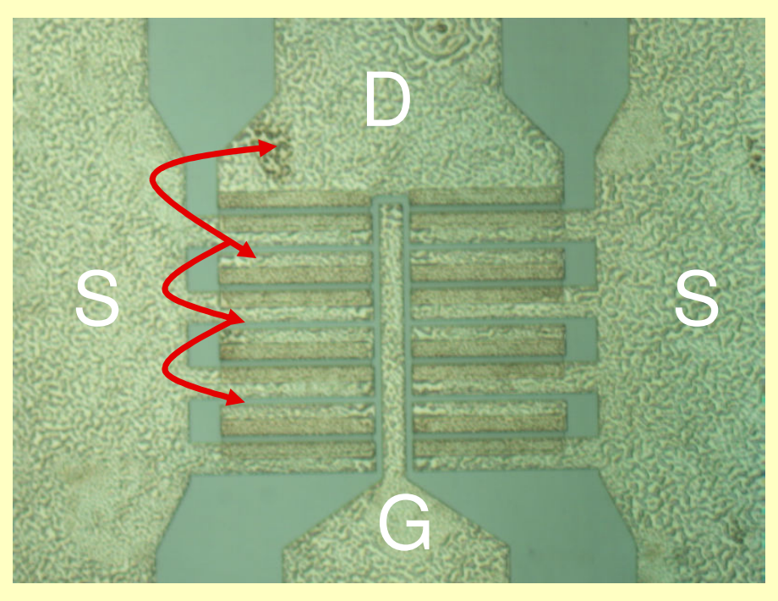
- Metal stack formed by 20 nm Ti, 100 nm Al, 55 nm Ni and 45 nm Au
- Rapid Thermal Annealing (RTA) in N_2 atmosphere at 780 °C to 800 °C for 30 sec

Formation of the ohmic contacts

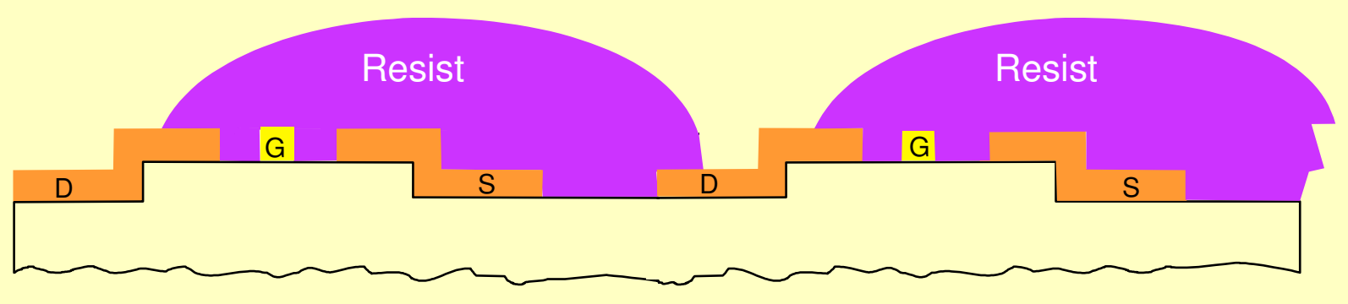


Small periphery device with gate width W_G = 2 x 25µm, and length L_G = 2µm

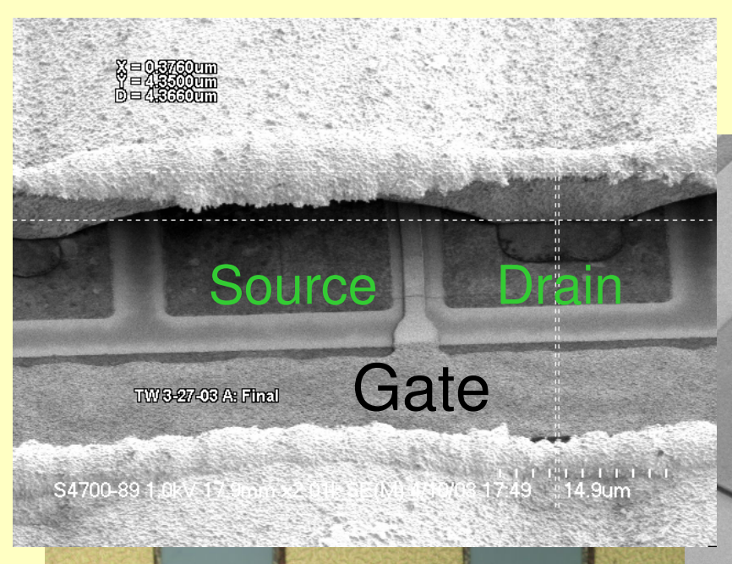
Deposition of the Schottky gates: 30 nm Ni, 300 nm Au

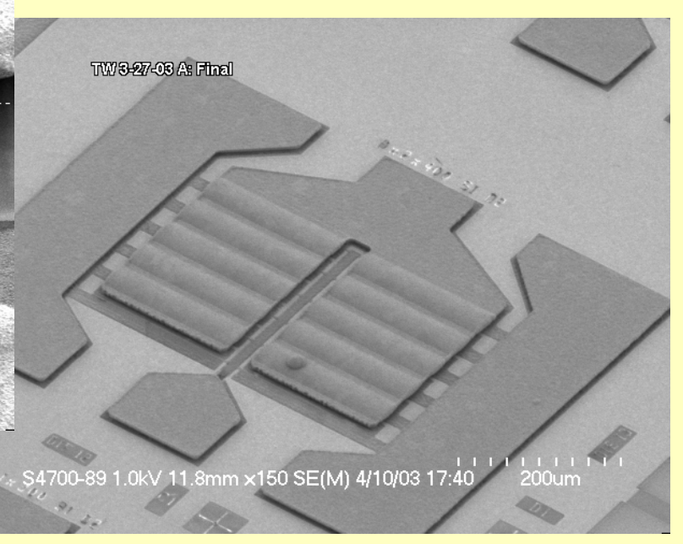


Goal: Connecting the drain contacts of the fishbone structure

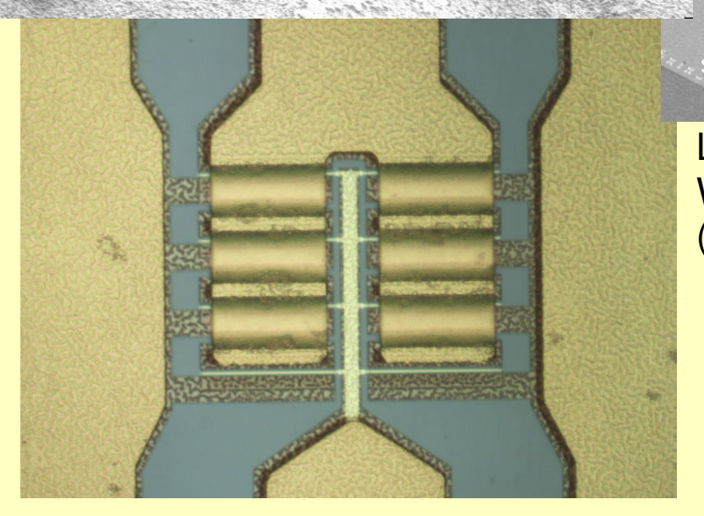


Pillar definition





Large periphery device with gate width W_G = 4 mm, and length L_G = 2 µm (SEM micrograph)



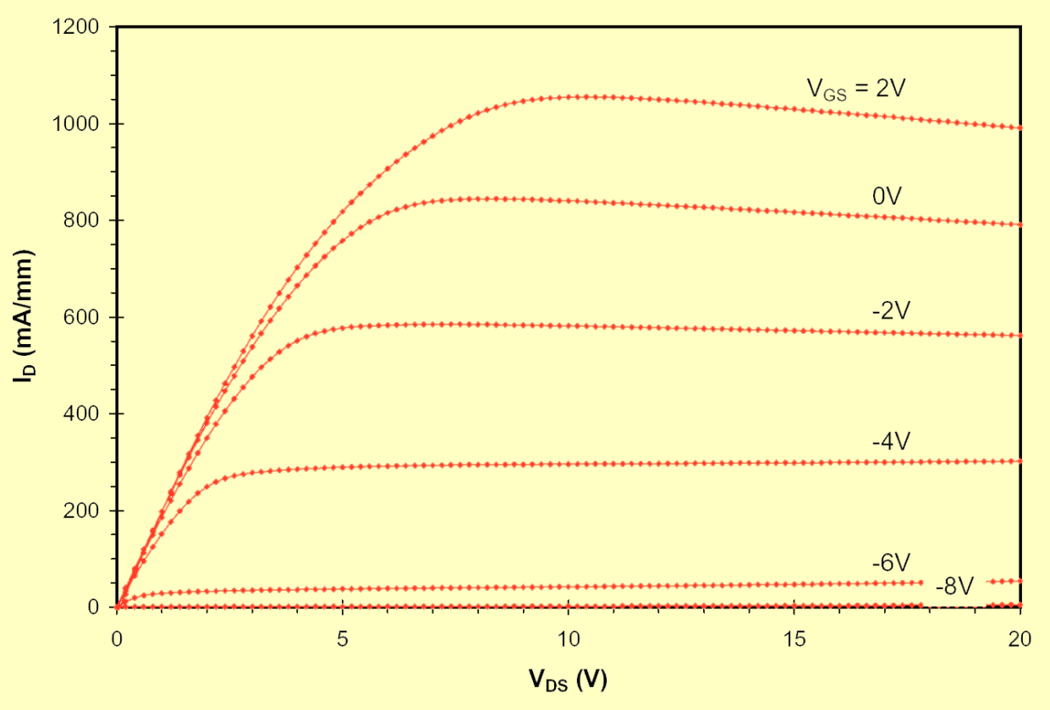
Large periphery device with gate width W_G = 0.8 mm, and length L_G = 2 µm (optical micrograph)

Au electroplating after seed layer evaporation (5 nm Ti, 20 nm Au)

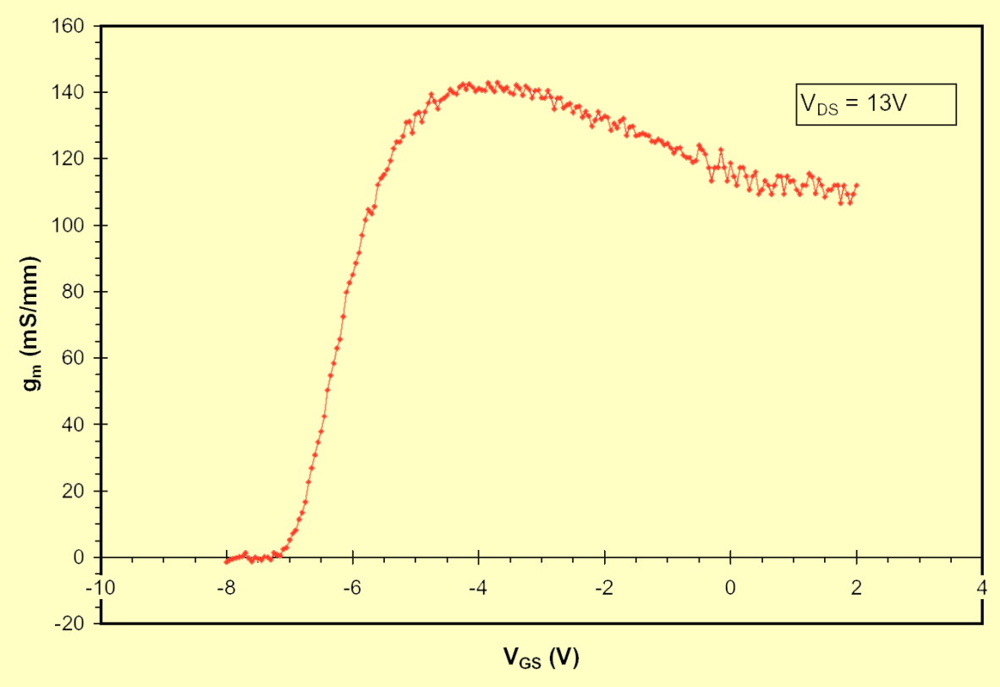
Air bridge formation for drain interconnects of large periphery devices

Results

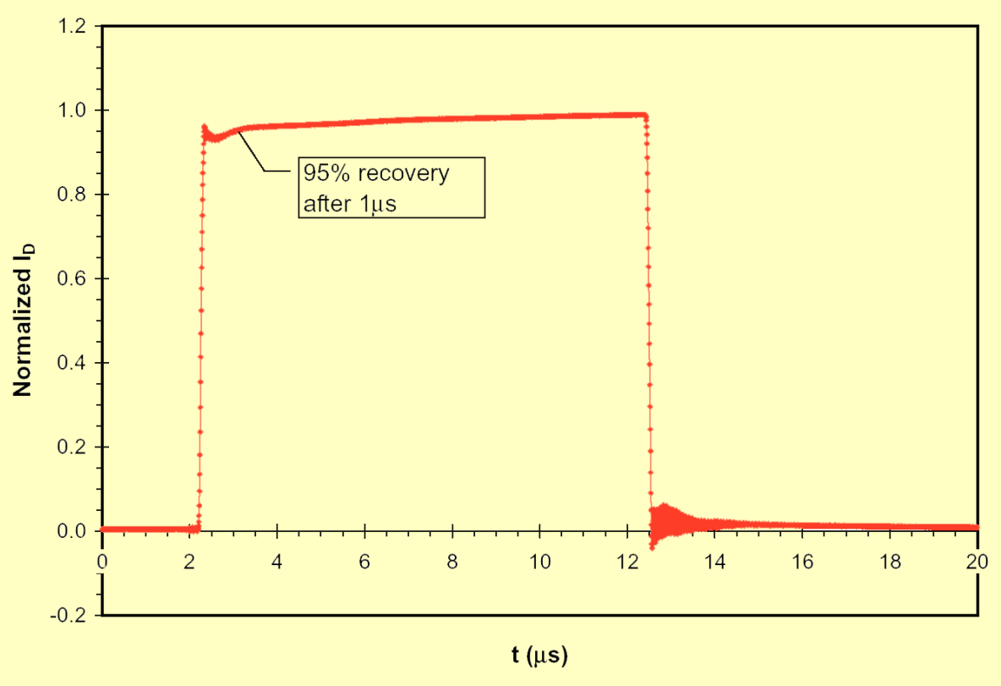
- Small periphery devices:
  - Drain current I_D of up to 1100 mA/mm, and an average of 1000 mA/mm
  - Transconductance g_m 120 ⋯ 140 mS/mm



I_D vs. V_{DS} for device with gate length L_G = 2 µm, a periphery of 150 µm and a drain-source opening of 6 µm. A maximum drain current of 1055 mA/mm has been measured.

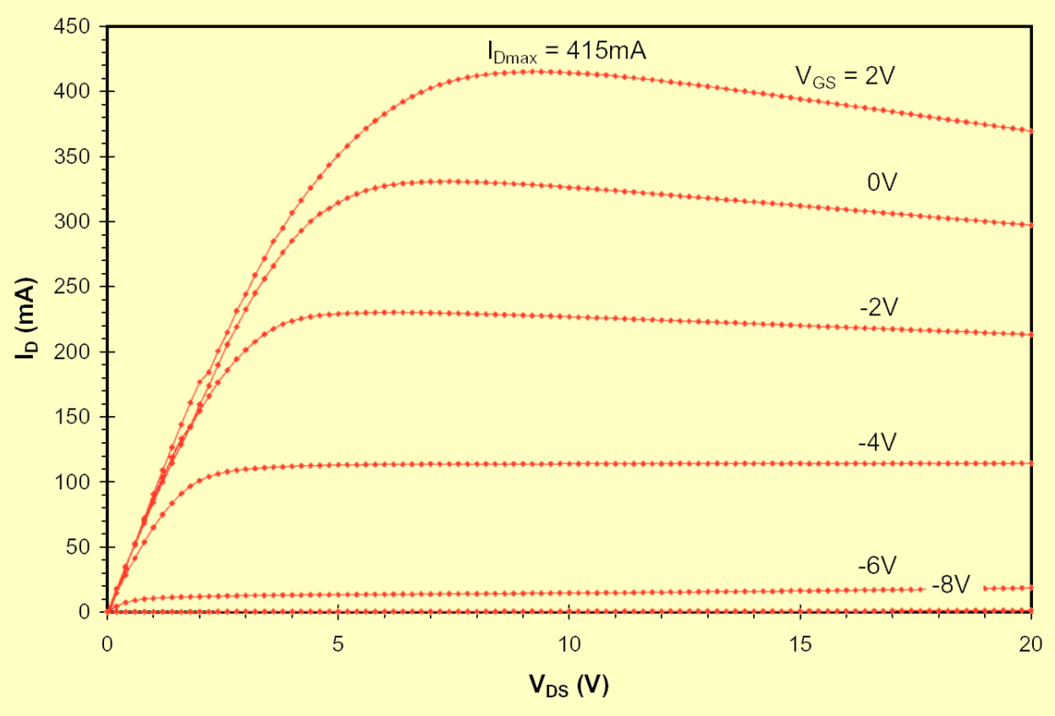


Transconductance for the same 150 µm device, measured at a drain bias of 13 V.



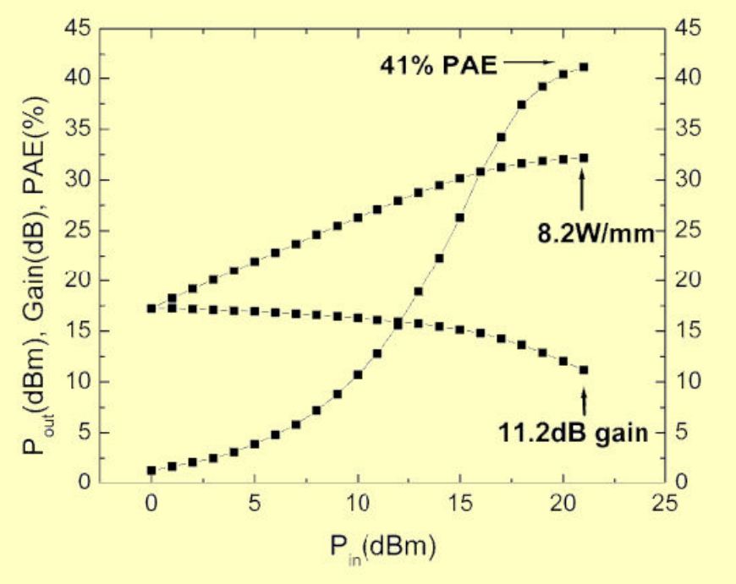
Behavior of the drain current when pulsed from pinch-off to V_{GS} = 0 V for a similar device on the same wafer. After 1 µs, the drain current has recovered to 95% of its DC value.

- Air bridged devices:
  - Total gate length of up to 4 mm
  - I–V characteristic scales well with periphery due to good heat dissipation by SiC substrate and Au air bridges

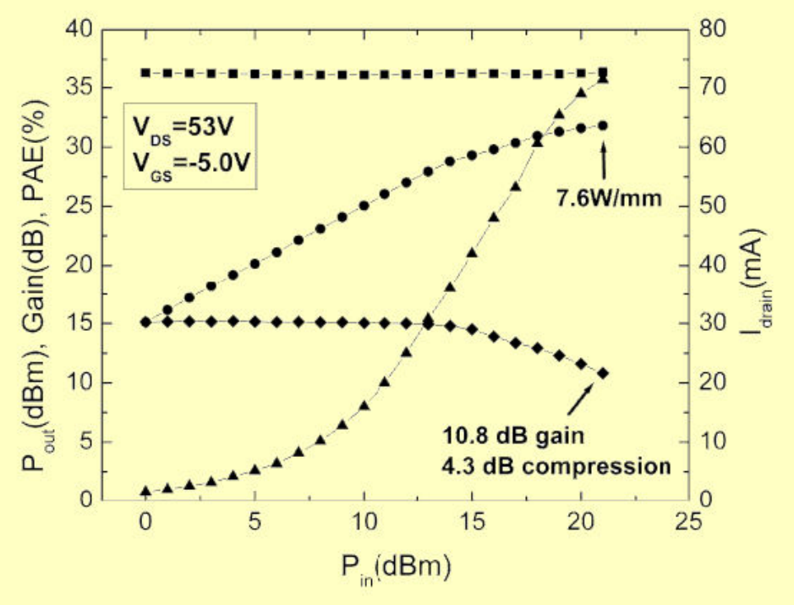


I-V characteristics of an air-bridged HEMT with a periphery of 0.4 mm and a gate length of 2 µm. The transistor displays a maximum drain current of I_{Dmax} = 415 mA and 1037 mA/mm, respectively.

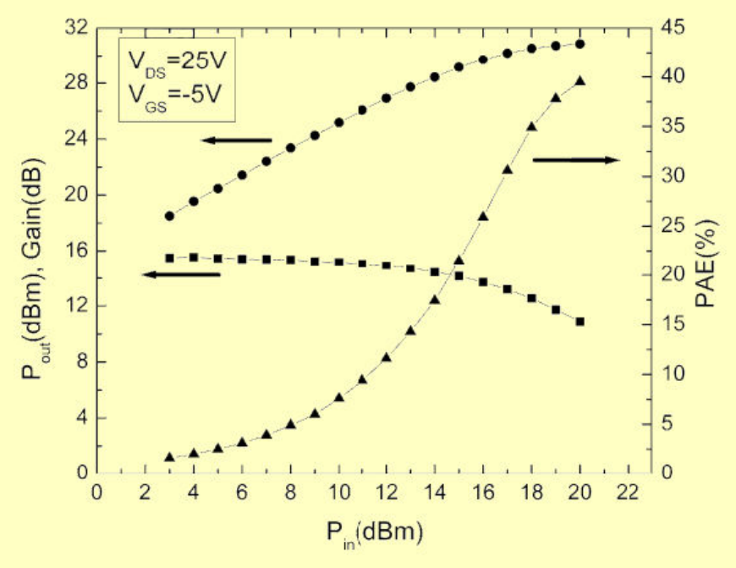
- Load–pull data:
  - HEMTs with gates of 1 µm displayed an output power of more than 8 W/mm together with a power added efficiency (PAE) of 41% at 2 GHz.
  - For submicron gates defined by electron beam lithography power values of 6.1W/mm (7 GHz) as well as 3.16 W/mm (25 GHz) have been obtained.
  - RF dispersion is remarkably low considering that no SiN passivation is used.



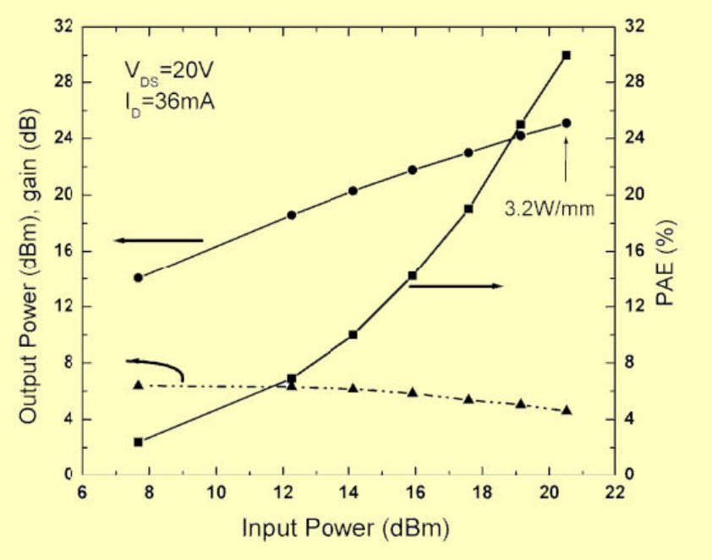
Load-pull data of a device measured at 2 GHz. V_{DS} = 45 V, V_{GS} = -4.7 V, L_G = 1 µm, W_G = 200 µm, Source-Drain spacing: 5 µm



Load-pull data of a device measured at 2 GHz. The gate length is 2 µm, with a total periphery of 200 µm and a source-drain separation of 6 µm.



Load-pull data at 7 GHz for a 0.2 x 200 µm^2 device. A power density of 6.1 W/mm along with 40% PAE and 4.6 dB gain compression has been measured.



Load-pull data at 25 GHz. V_{DS} = 20 V, V_{GS} = -7.3 V, L_G = 0.2 µm, W_G = 100 µm. A linear gain of 6.5 dB together with a PAE of 30% and 1.8 dB compression has been obtained.

Future directions and challenges

- Load–pull data on large periphery devices needed
- Control of parasitic buffer conduction in MBE growth on 4H–SiC substrates
- High breakdown fields needed for high power operation
- Better understanding of RF dispersion in MBE GaN/AlGaN/GaN HEMTs

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