MBE Growth and Characterization of GaN HFETs

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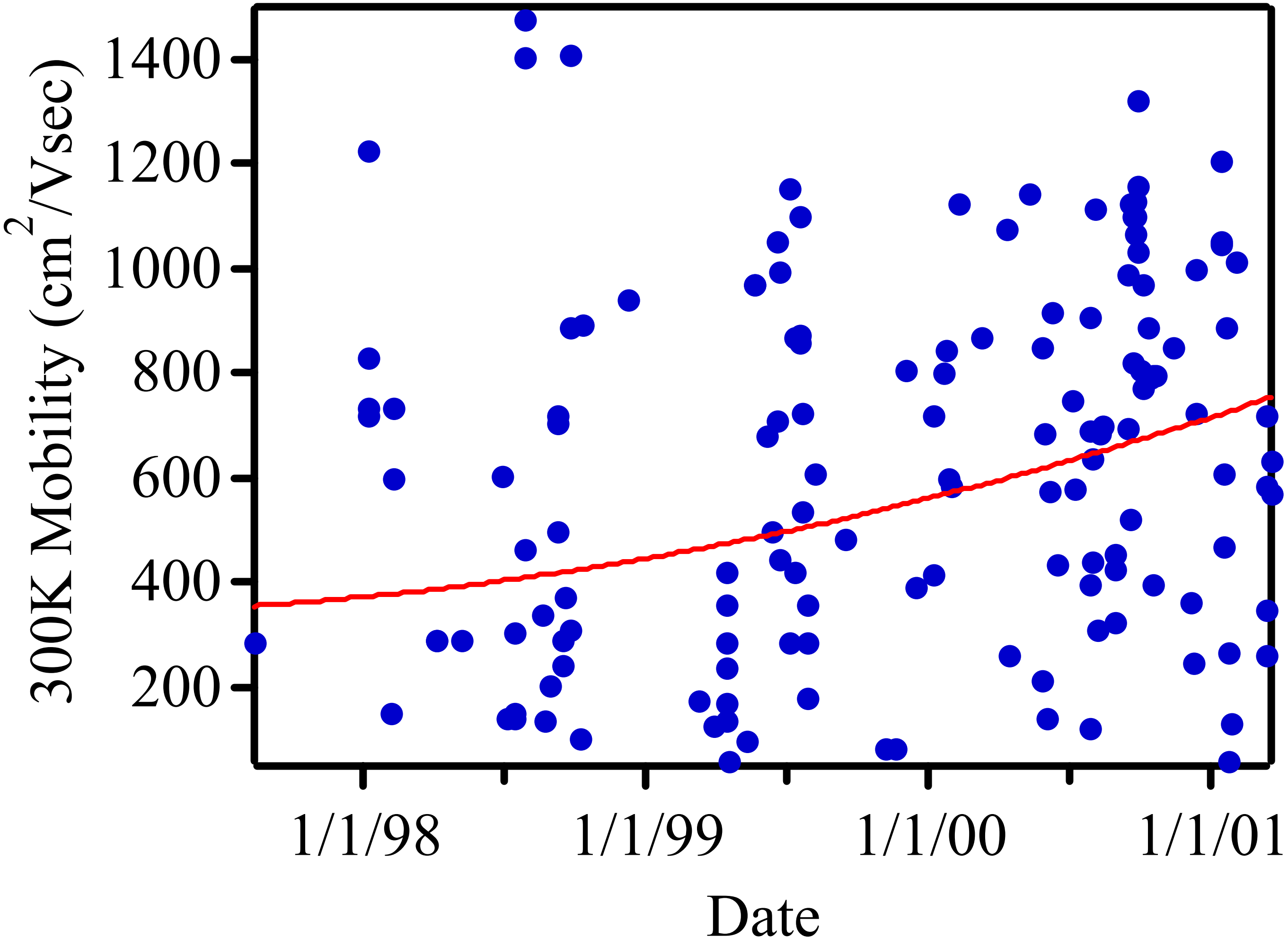
GaN HFET

- 2DEG growth summary
- AlN Passivation Process
- Conductance DLTS
- High Al mole fraction barriers

Future for MBE grown HFETs

Progress 1996-2001
Mobility vs. Date for 2DEG structures

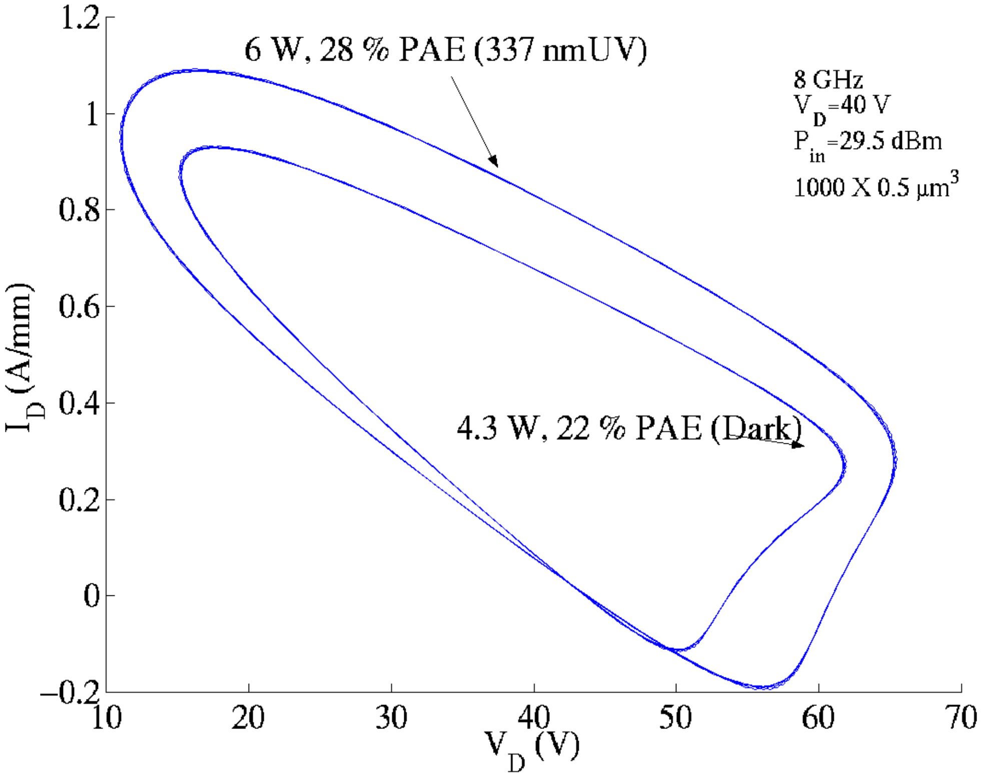


520 wafers grown

359 2DEG wafer starts

156 Hall measurements

8 GHz Dynamic Load Line for 1mm HFETs on sapphire

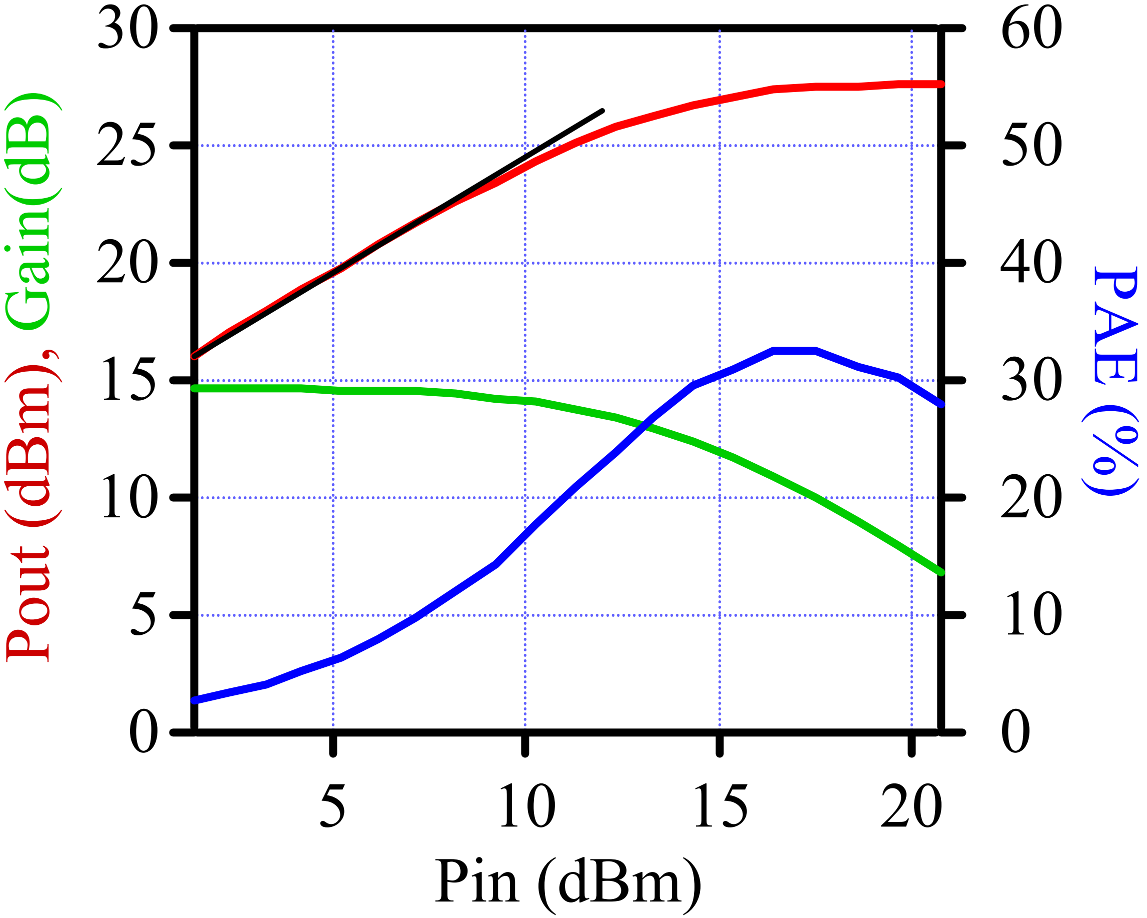


UV illumination lowers sheet resistance in ungated region while increasing sheet carrier concentration:

Higher realized current
Increase in PAE, increase in P_{out}

5 μm undoped GaN buffer

MBE HFET (w/ Si_3N_4 passivation) at 7Ghz



300 K

μ = 1478 cm^2/Vsec

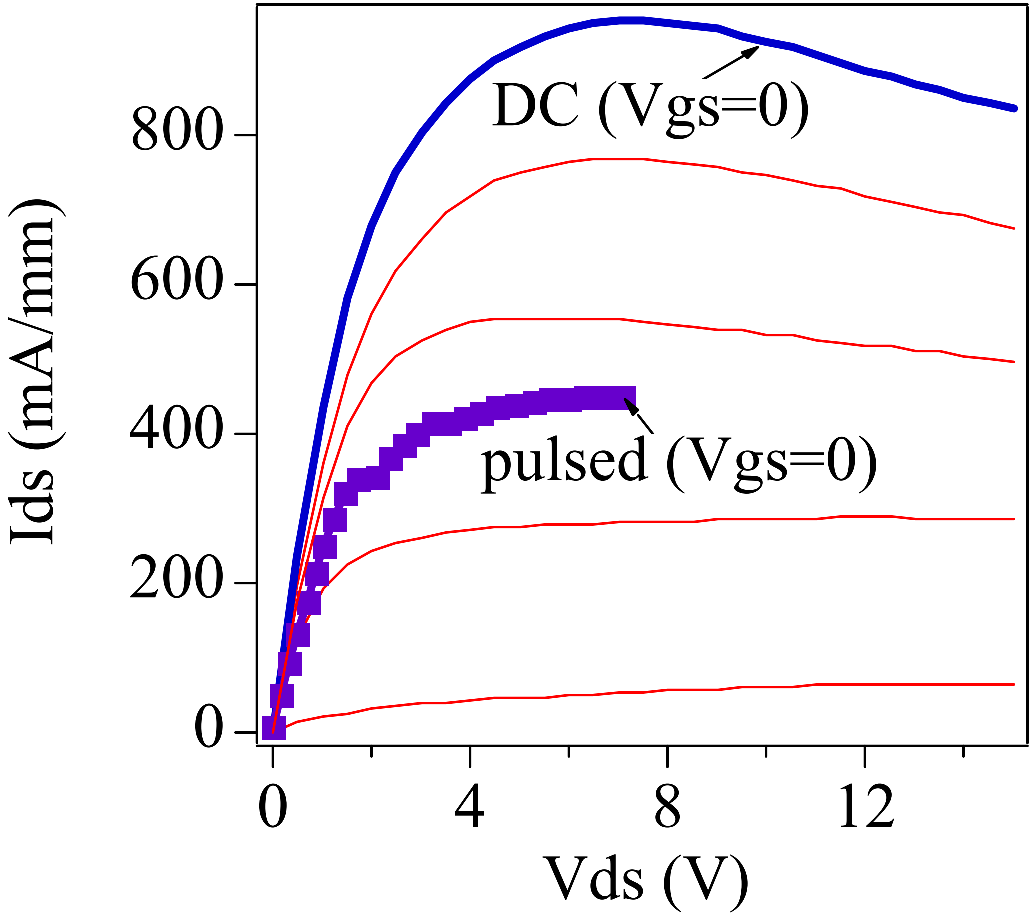
n=8.8x10^{12} cm^{-2}

0.3x150µm U shaped gate
V_{ds}=24V
V_{gs}=-2.5V
I_{ds}=66mA

Saturated P_{out}=**3.84 W/mm**

P_{out} at1dB compression=**2.36W/mm**

DC and Pulsed IV for unpassivated MBE HFET

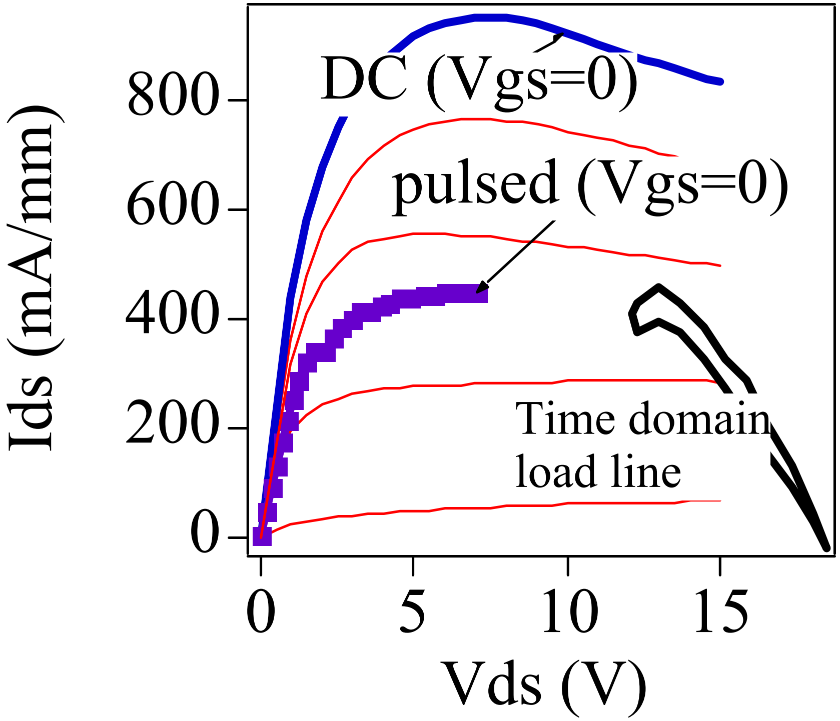


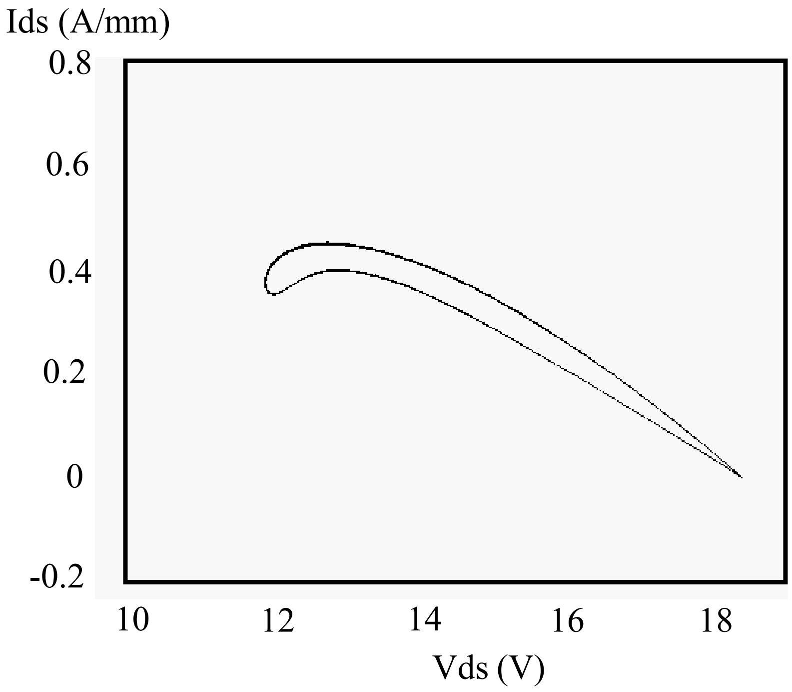
300K
μ = 1450 cm^2/Vsec
n_s=1.1x10^{13} cm^{-2}

0.3x100μm
V_{ds} Breakdown 60V
f_t 44.6 GHz
8 GHz 2.1 W/mm

1μm undoped GaN buffer

DC, pulsed and 8 GHz Real Time Load Line of MBE grown HFET





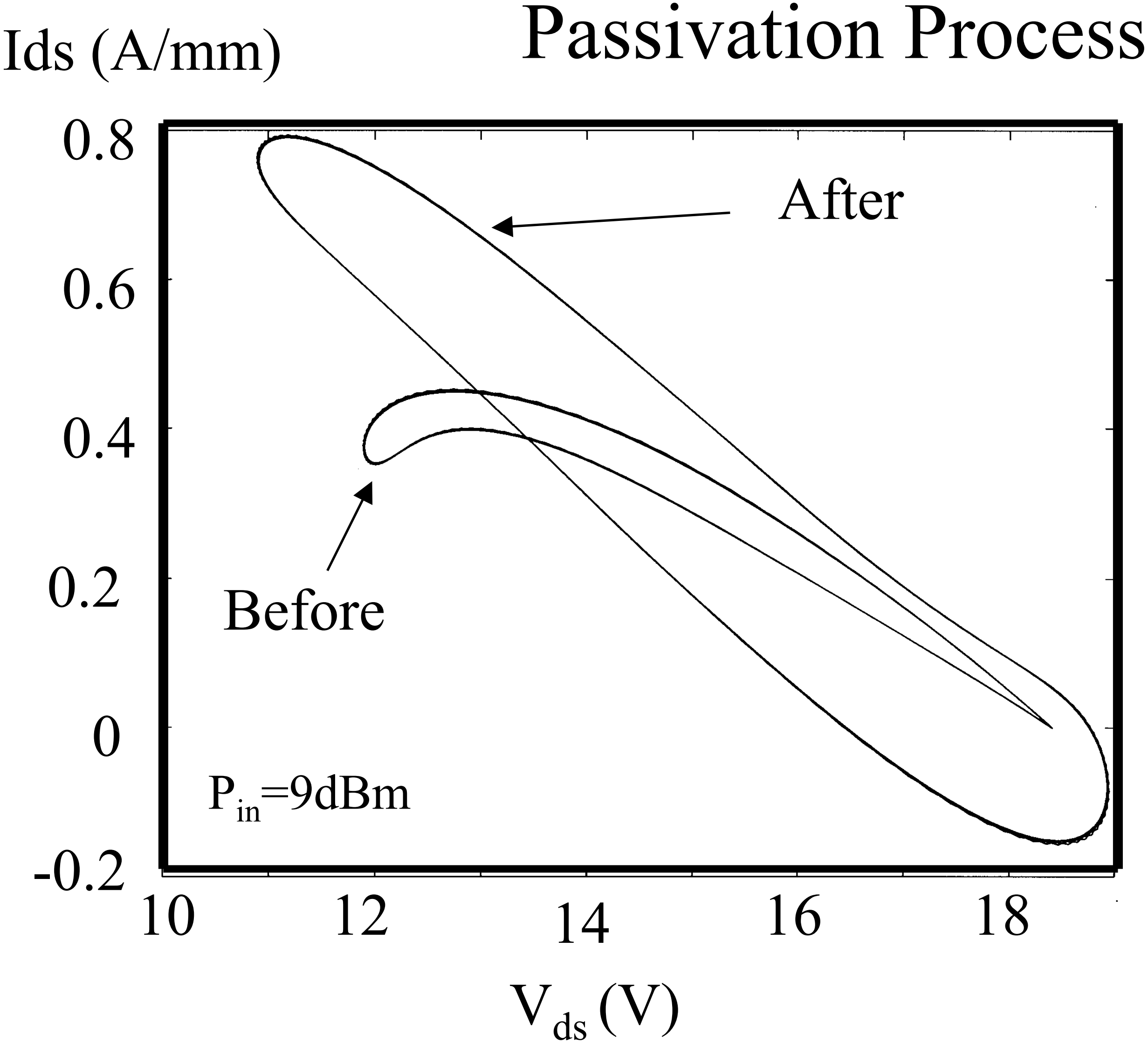
AlN as a post-process passivation

AlN is deposited on processed HFETs in the MBE machine as an alternative to Si_3N_4

Growth is by Migration Enhanced Epitaxy (MEE) at 150°C

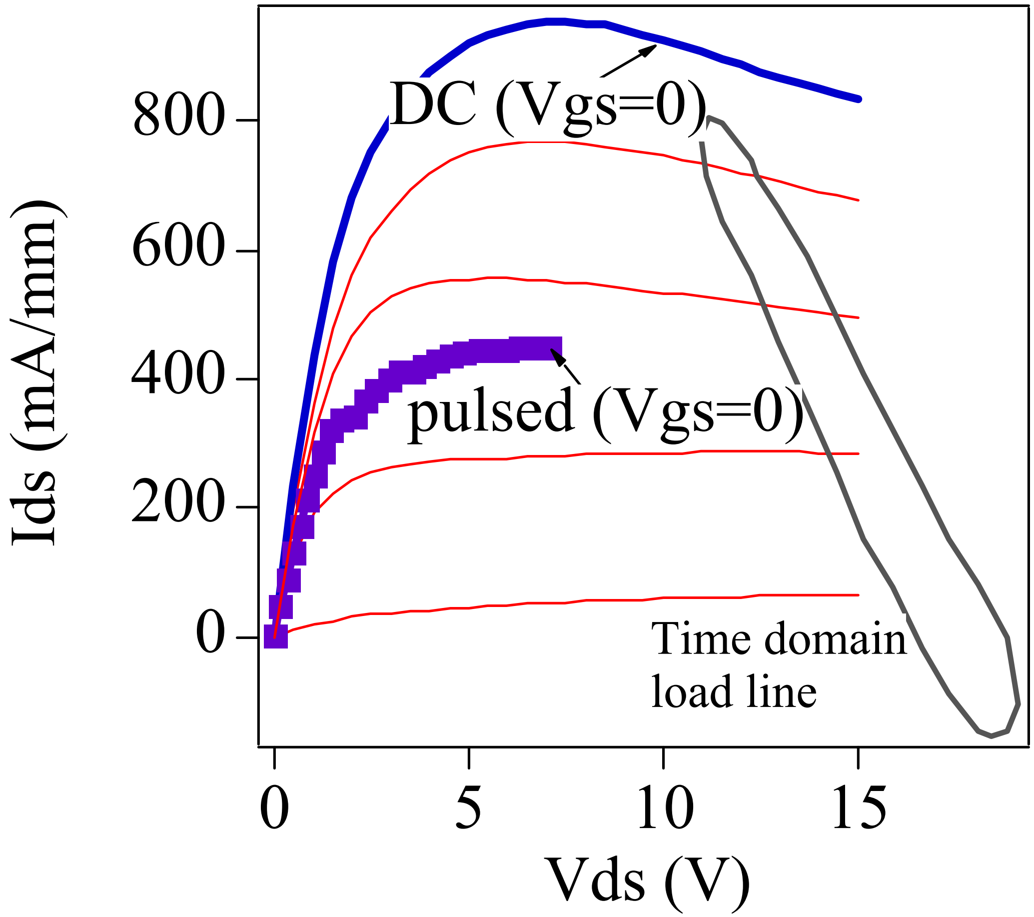
MEE is used to attempt a better gate sidewall coverage than would occur for MBE growth

Real time load-line before and after AlN Passivation Process

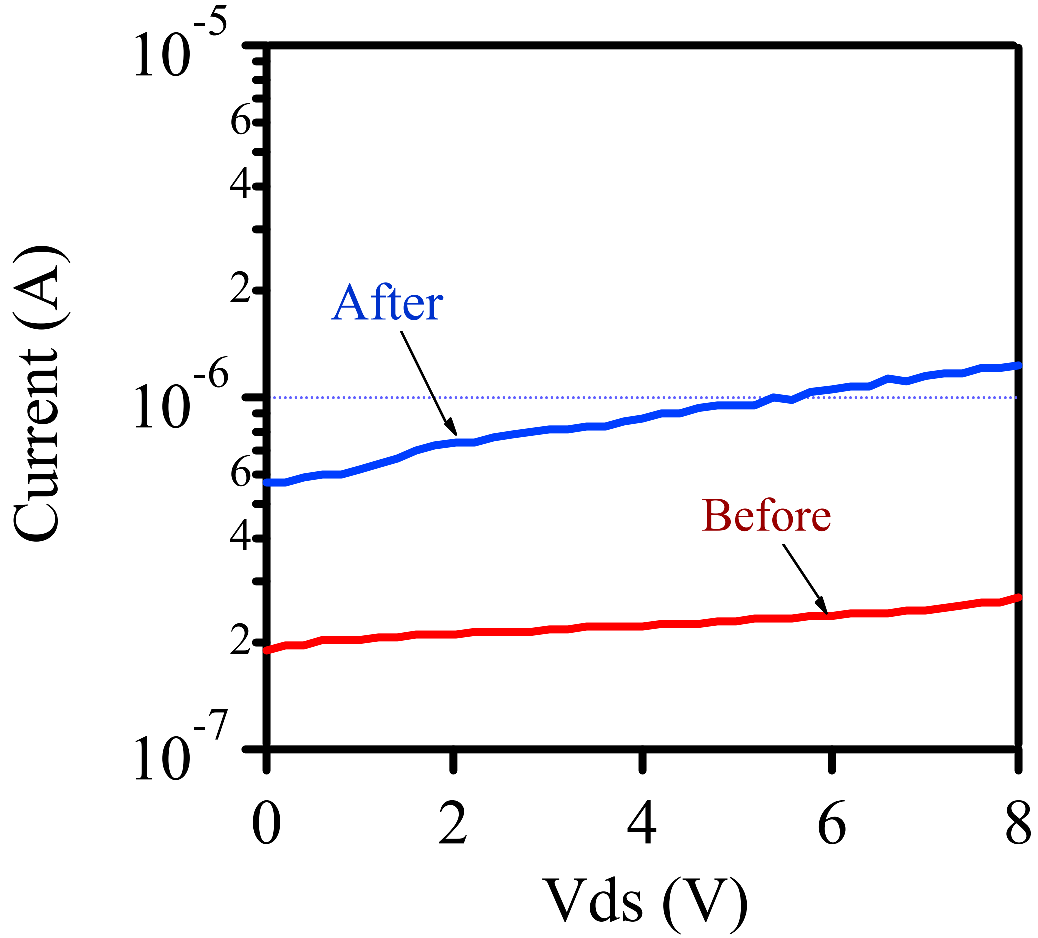


Nearly full DC channel current is available at 8 GHz

DC, pulsed and time domain load line for MBE HFET with AlN Passivation Process

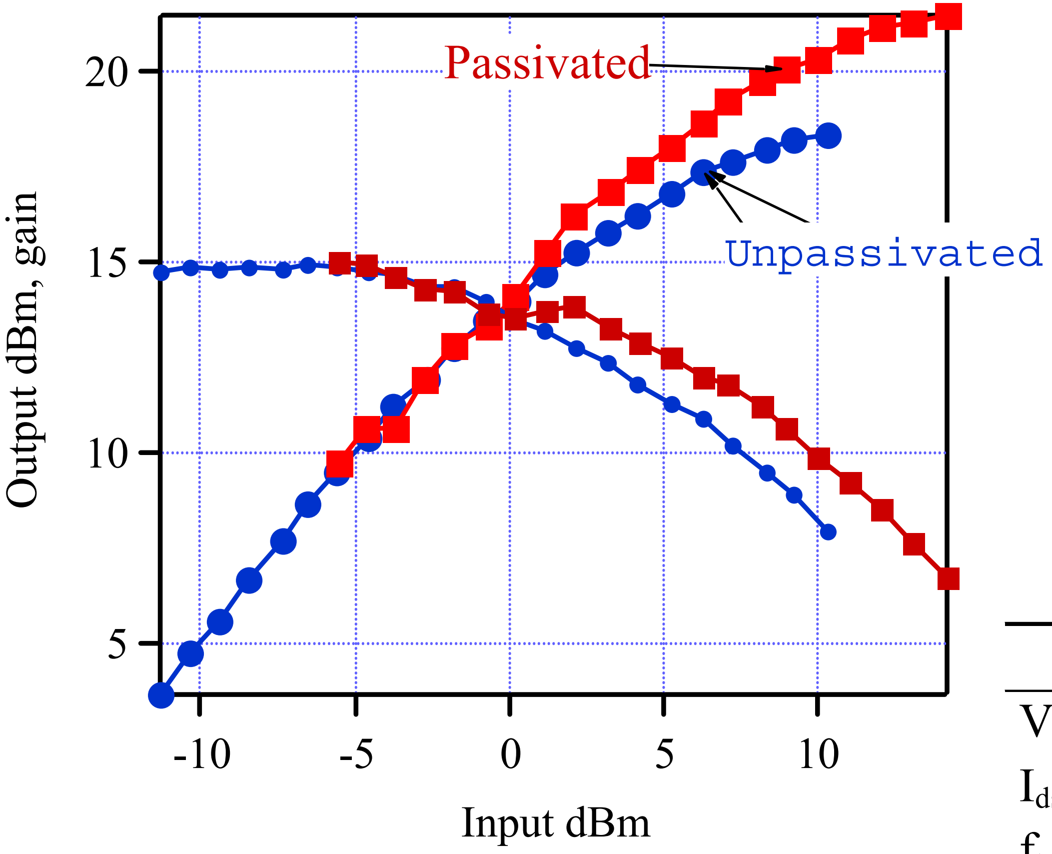


Gate Leakage Before and After AlN Passivation Process



Vgs=-6V

AlN Passivation Process



MBE growth w/ 1 μm GaN buffer

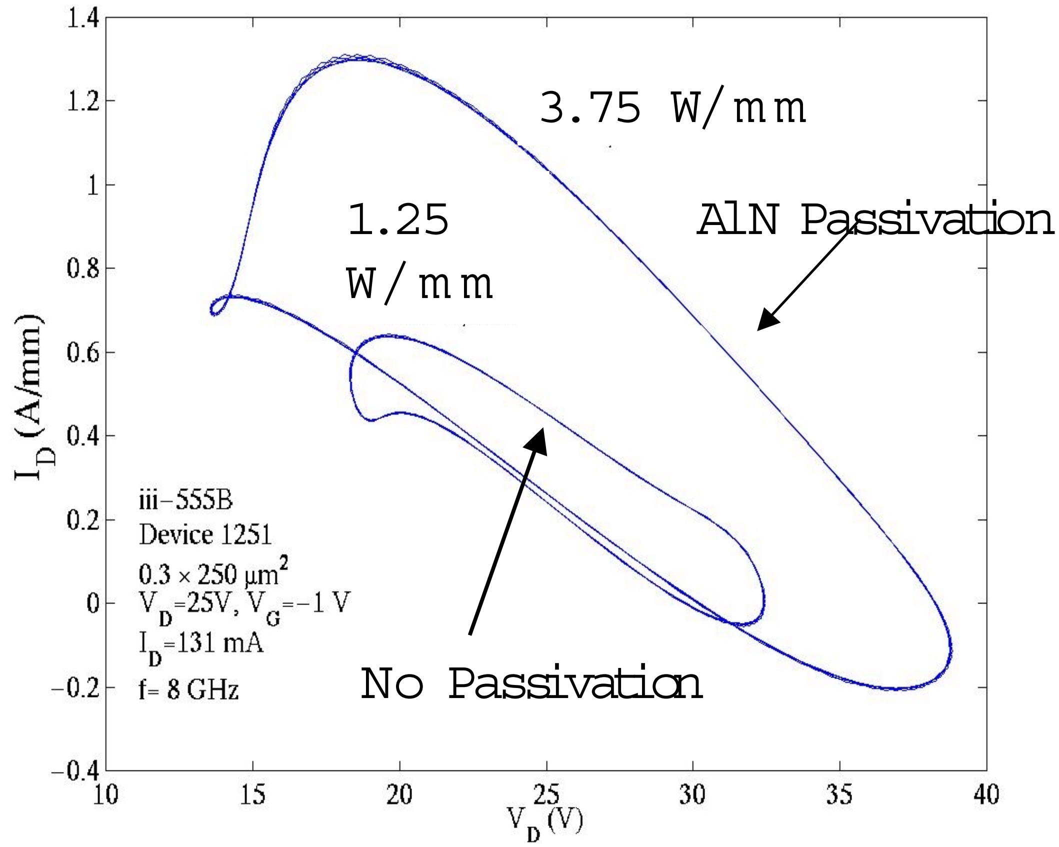
0.3x100μm T shaped gate
V_{ds}=15V
V_{gs}=-2.0V
I_{ds}=26mA

RF data is extracted from time domain analysis - no illumination

	Before	*After*
Vds breakdown	60 V	45 V
I_{dss}	1.0 A/mm	1.0 A/mm
f_t	44.6 Ghz	40 Ghz
-1dB compression	.24 W/mm	.42 W/mm

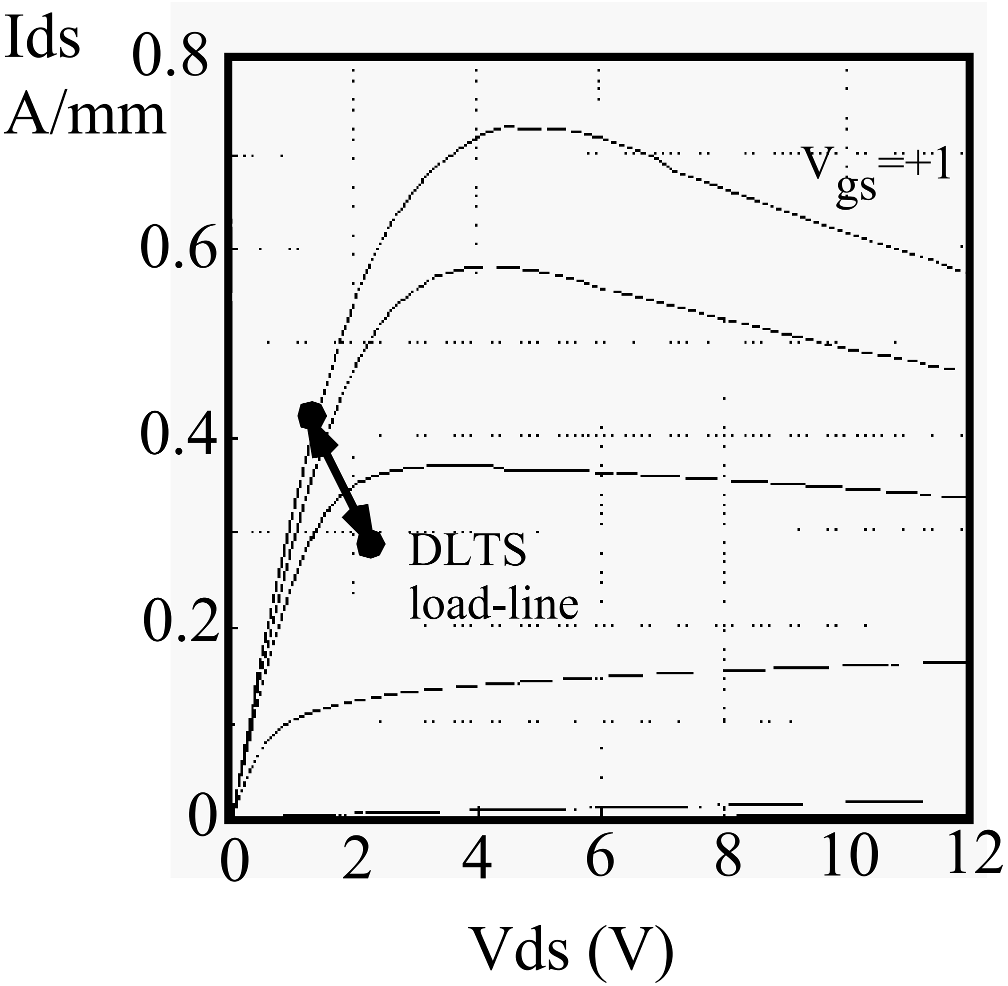
Nearly 3dB improvement in gain near saturation is seen

Effect of AlN Passivation on 8 GHz Dynamic Loadlines for OMVPE HFET



Power output increases by a factor of 3 for 150Å AlGaN barrier compared to a factor of 2 for 300Å barrier

MBE grown unpassivated HFET used for conductance DLTS

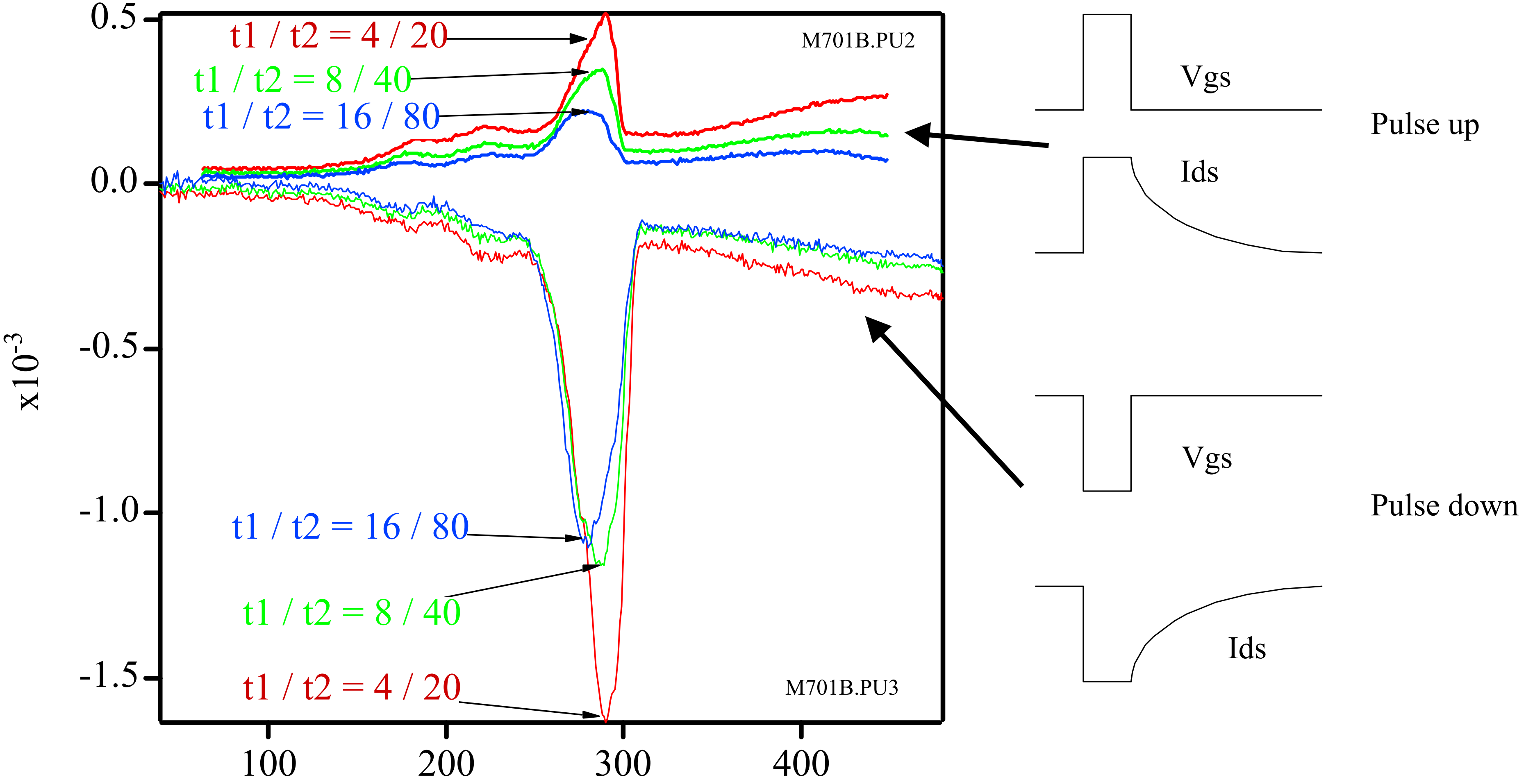


300K
μ = 1019 cm^2/Vsec
n_s=1.3x10^{13} cm^{-2}

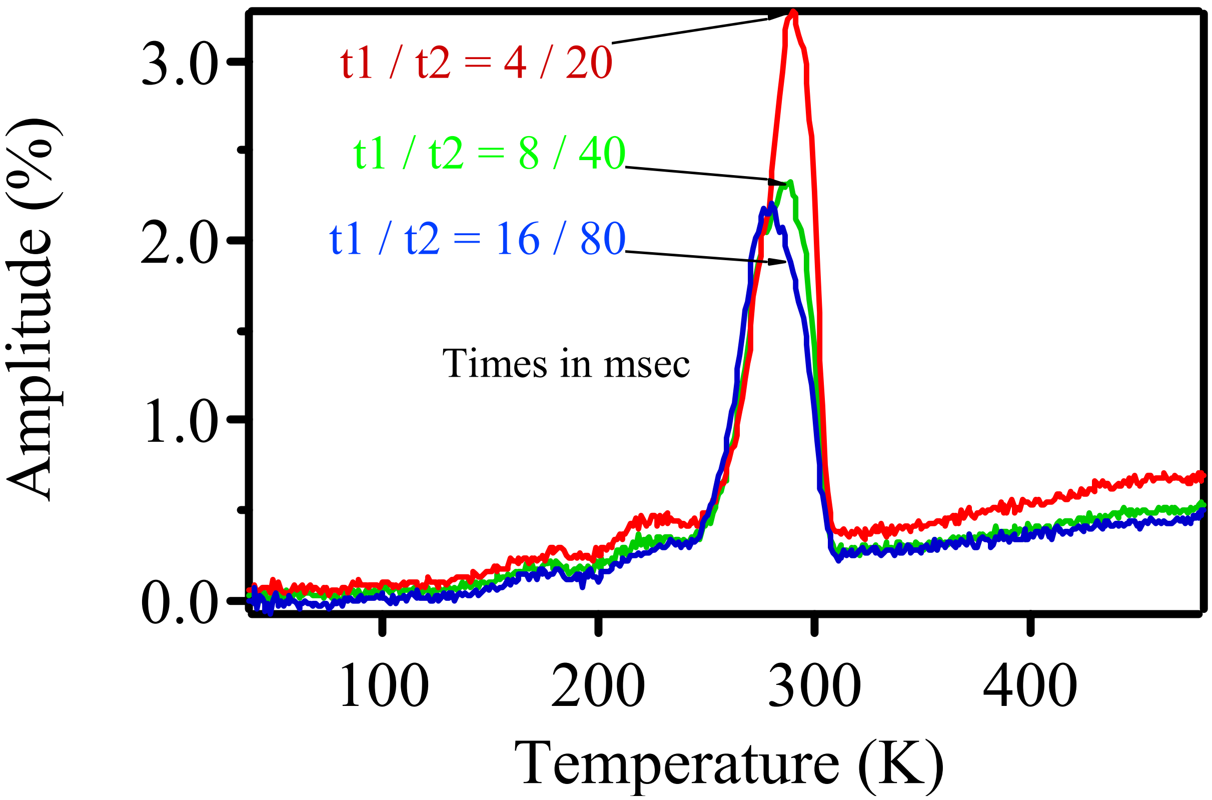
0.4x200µm
g_m=230mS/mm
I_{gs}~20µA
f_t=25.4 GHz
f_{max}=40.1 GHz
8 GHz 1.7 W/mm
@15V Vds

N00014-96-1-1223

Comparison of gate pulse-up vs. pulse-down transient responses for unpassivated MBE grown HFET



Boxcar Plot for Conductance DLTS of MBE Grown Unpassivated HFET

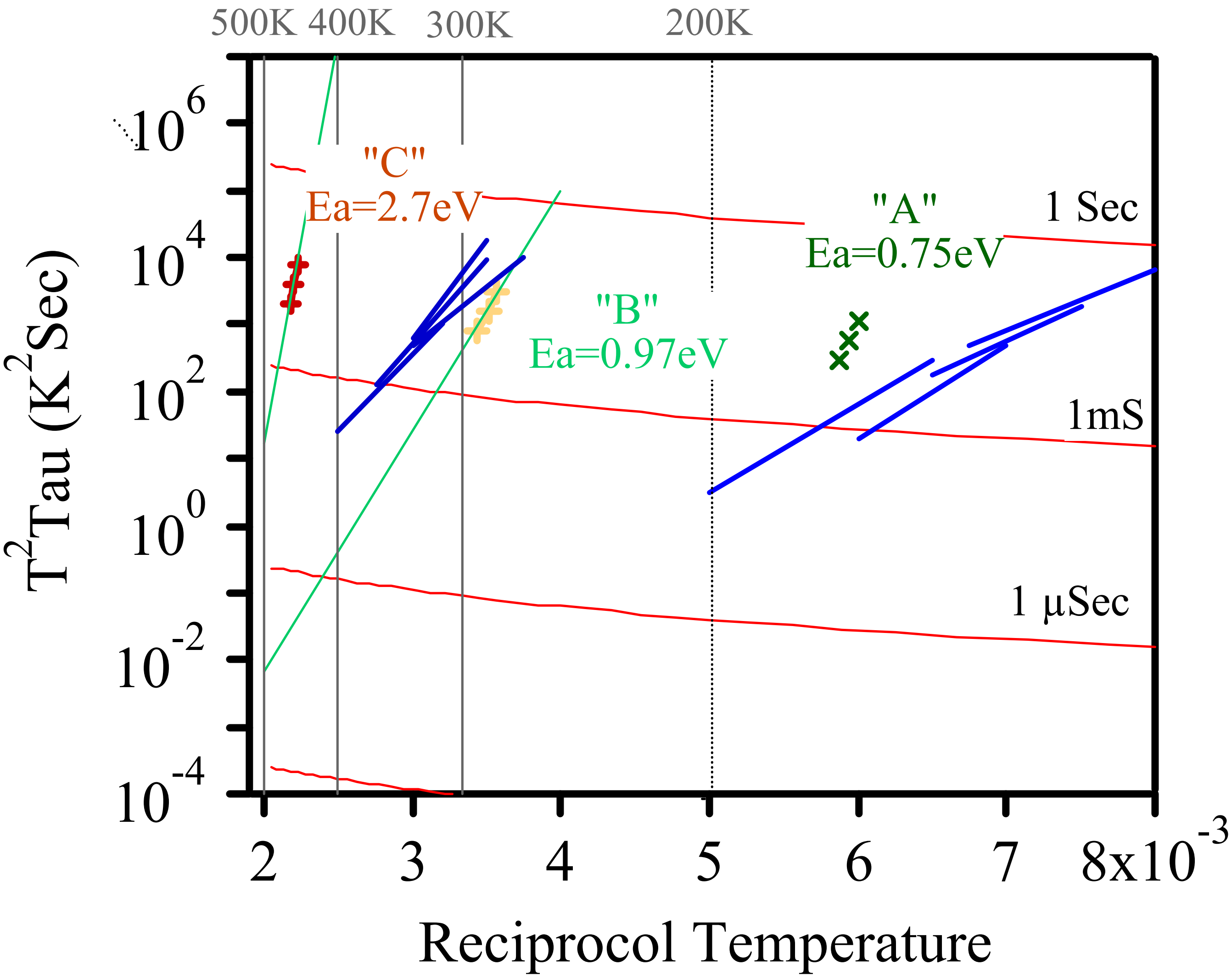


Amplitude is drain-source current transient signal normalized to DC current (15mA) at -2V Vgs

Peak heights should be identical for these constant ratios of t1/t2 for exponential transient decays

- Variation is indication that decays are slightly non-exponential
- Simple bulk model might not apply

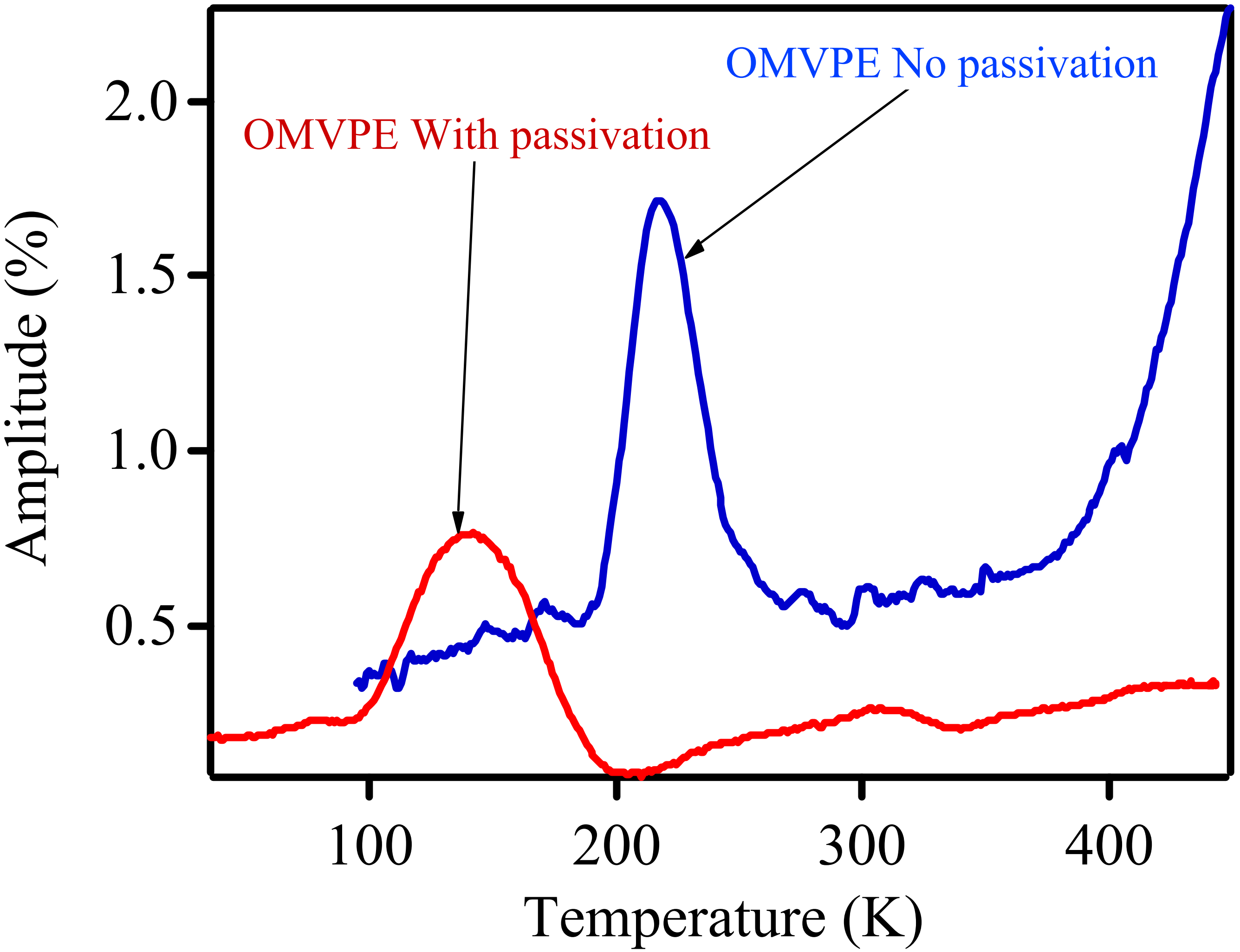
Activation Energy Analysis of GaN HFET DLTS transients



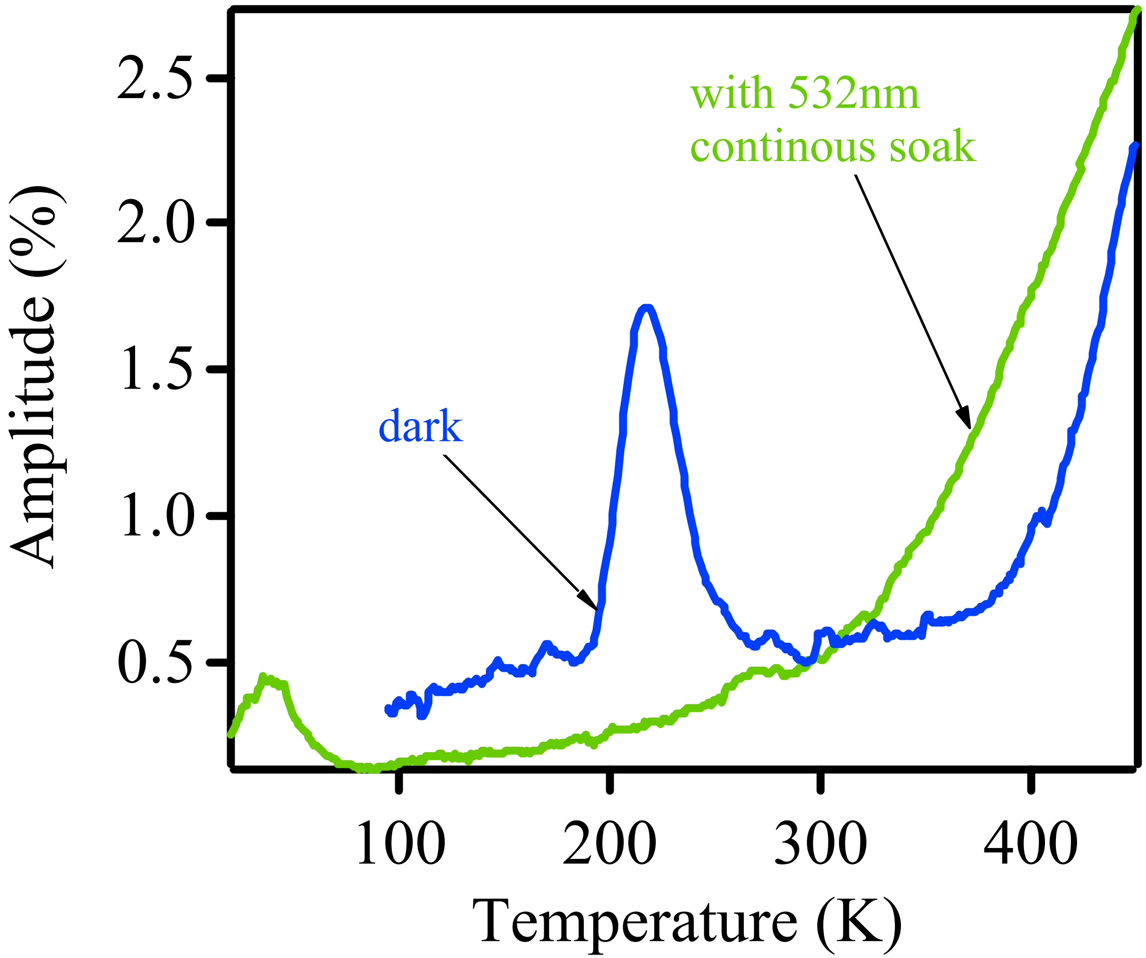
Blue curves are literature values for electron traps in GaN

Other symbols and fits are for unpassivated MBE GaN HFETs

Comparison of DLTS of OMVPE HFETs with and without Si_3N_4 passivation

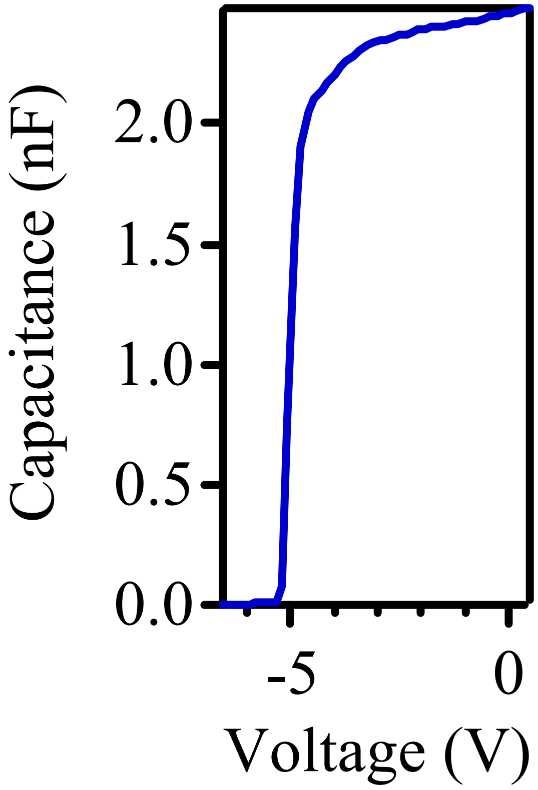


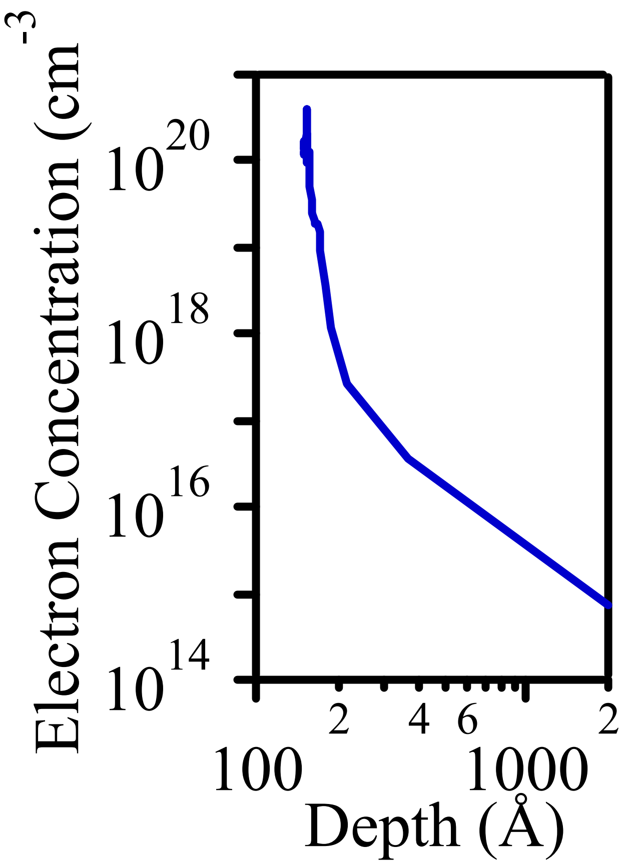
DLTS of unpassivated OMVPE HFET with and without 532nm continuous soak

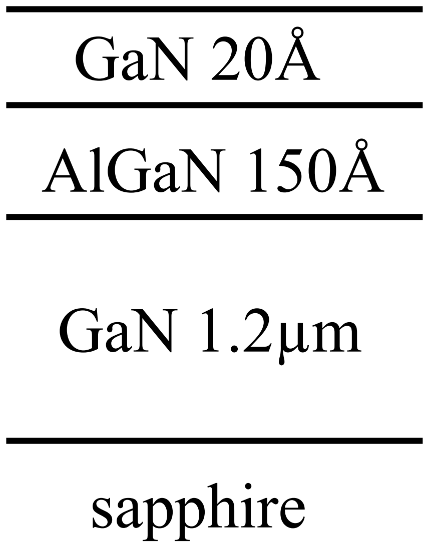


Sub-bandgap light completely eliminates response of one deep level, while creating a new response not seen in any other GaN HFETs

CV and Hall for $Al_{0.75}Ga_{0.25}N/GaN$ HFET







GaN 20Å

AlGaN 150Å

GaN 1.2µm

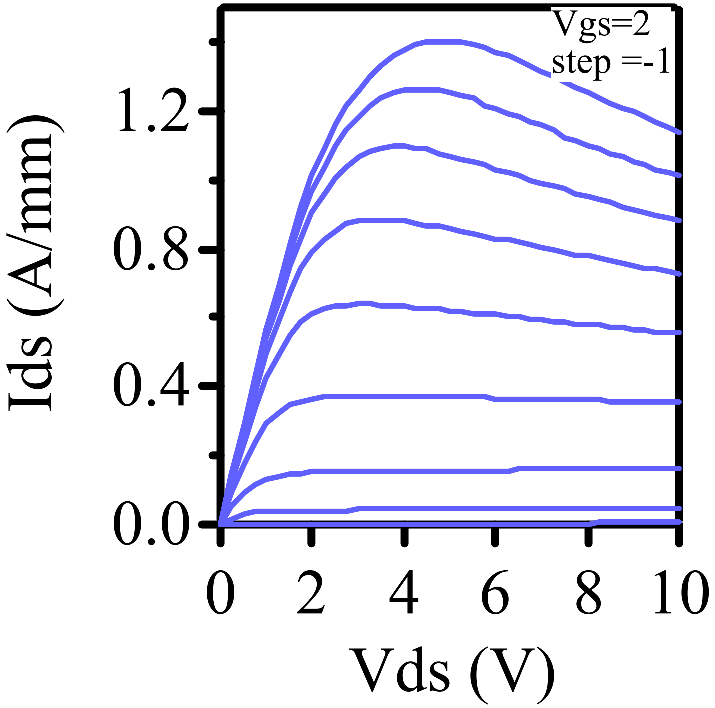
sapphire

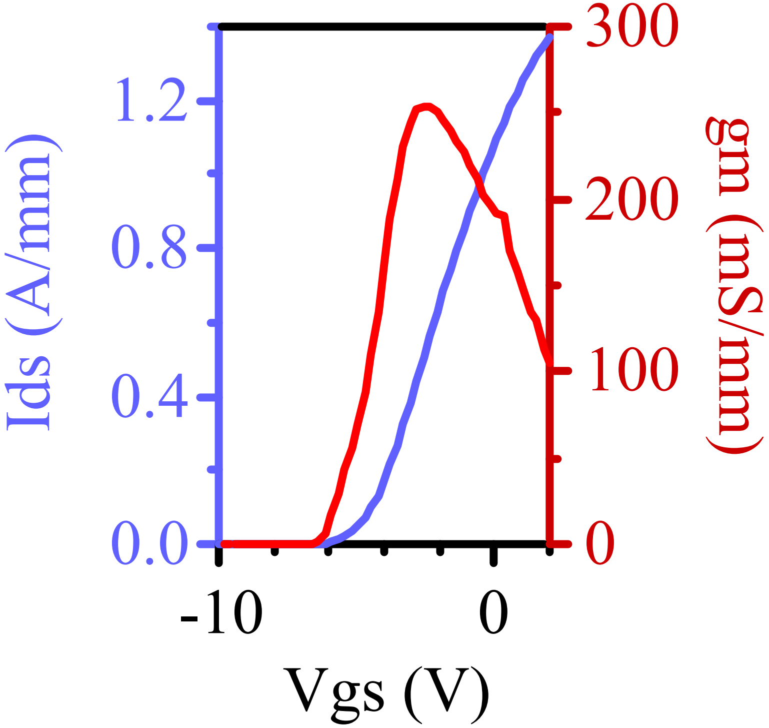
μ=720cm^2/Vsec

n_s=2.5x10^{13} cm^{-2}

Sheet resistivity 350 Ω/□

IV for 0.3x100μm $Al_{0.75}Ga_{0.25}N$/GaN HFET





Contact Resistance =0.3Ωmm

f_t=55 GHz

MURI wrap-up

Optimize AlN Passivation Process

Perform DLTS comparison of passivated/unpassivated HFETs

Optimize growth of High Al mole fraction barrier HFETs

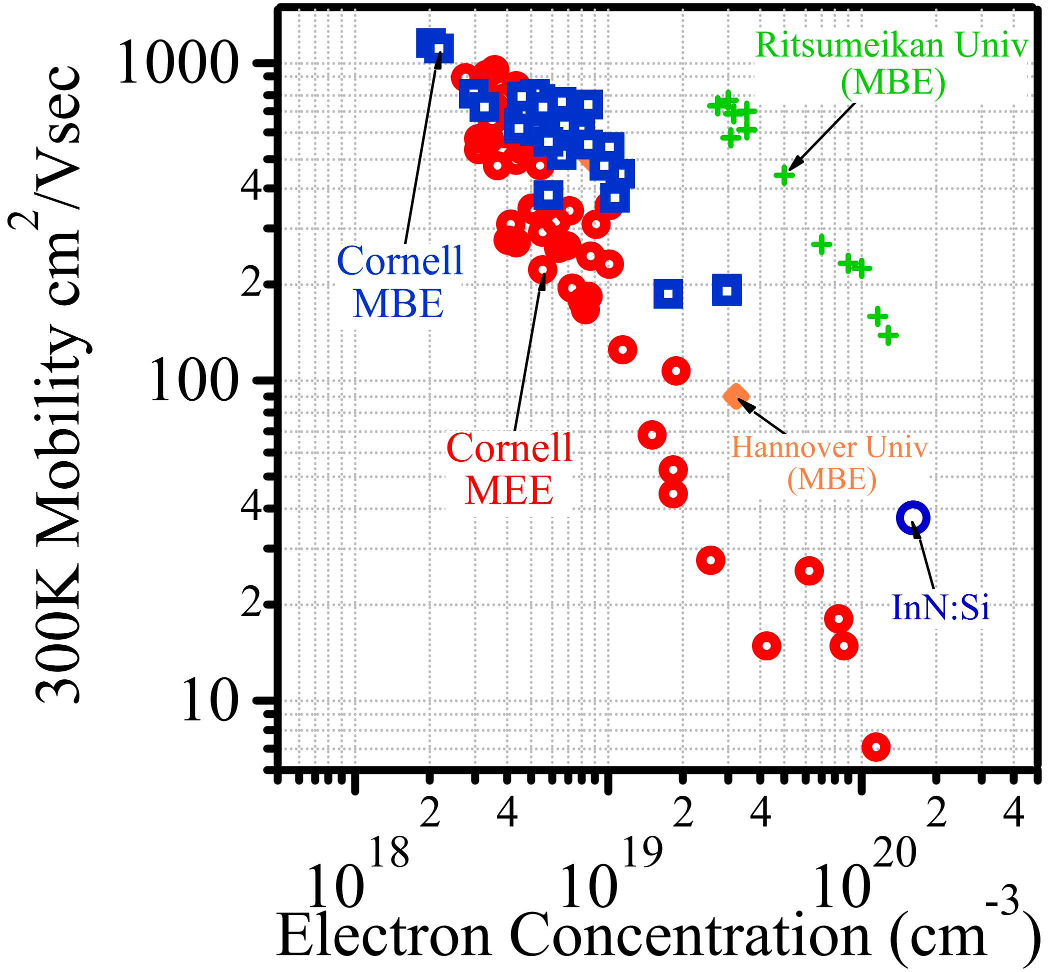
Grow High Al mole fractions on hydrogen etched SiC substrates

Future Plans

InN channel FETs

High Power, Broadband, Linear, Solid State Amplifier

InN channels for higher frequency operation than GaN



InN:

Low effective mass

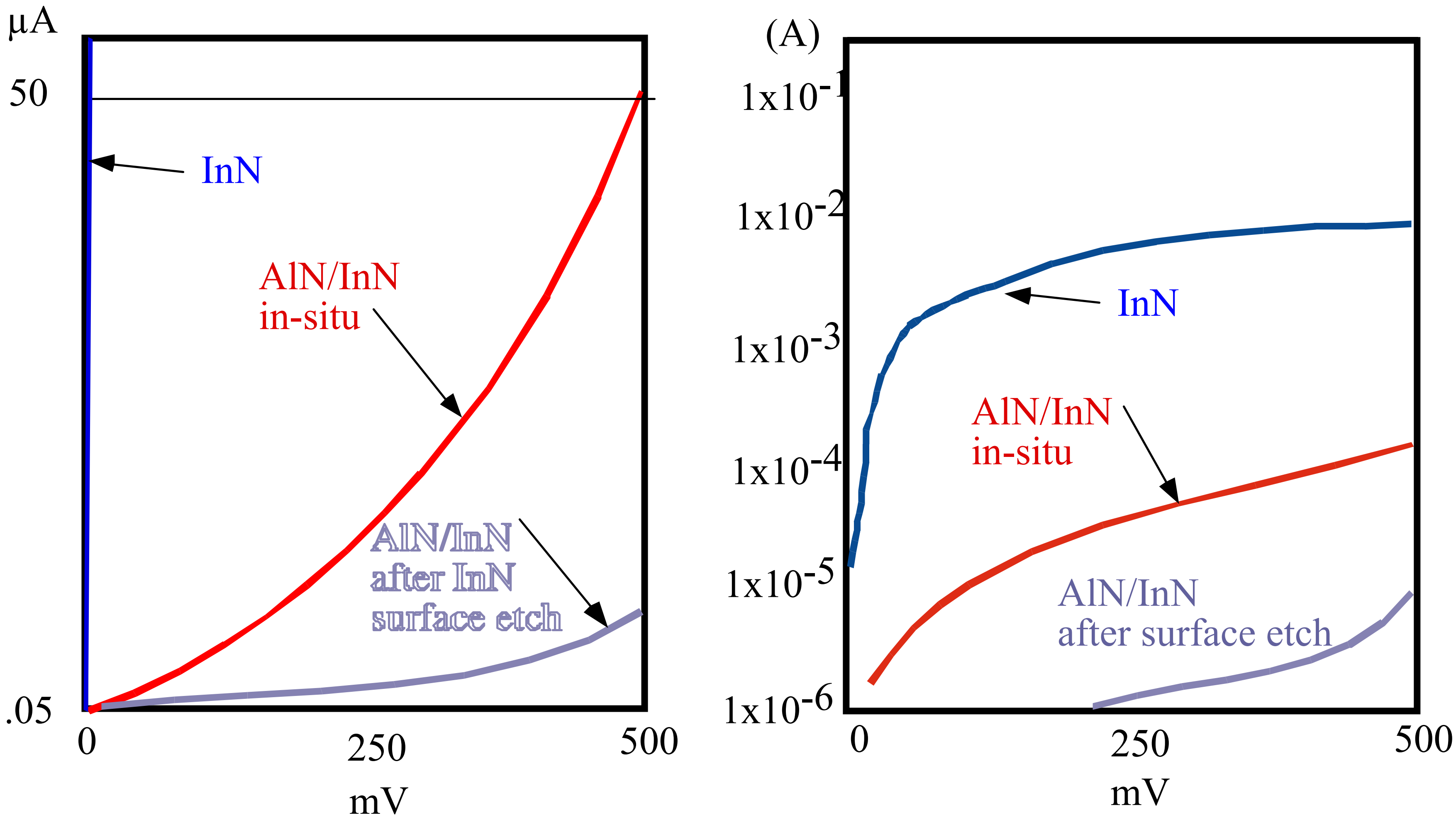
High mobility

Higher saturation velocity than GaN

Breakdown field 1.2M□V/cm

Johnson figure of merit 40x GaAs

I-V using Hg probe contacts of AlN/InN with and without surface etch compared to InN surface



Linear and log curves are not the same device, but representative of typical comparison