Demonstration of a Low V_{ref} PA Based on InGaAsN Technology

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No Pain in GAIN!

This is NOT another GaN Talk

Gallium
+ Arsenic
+ Indium
+ Nitride

GAIN-HBT

Outline

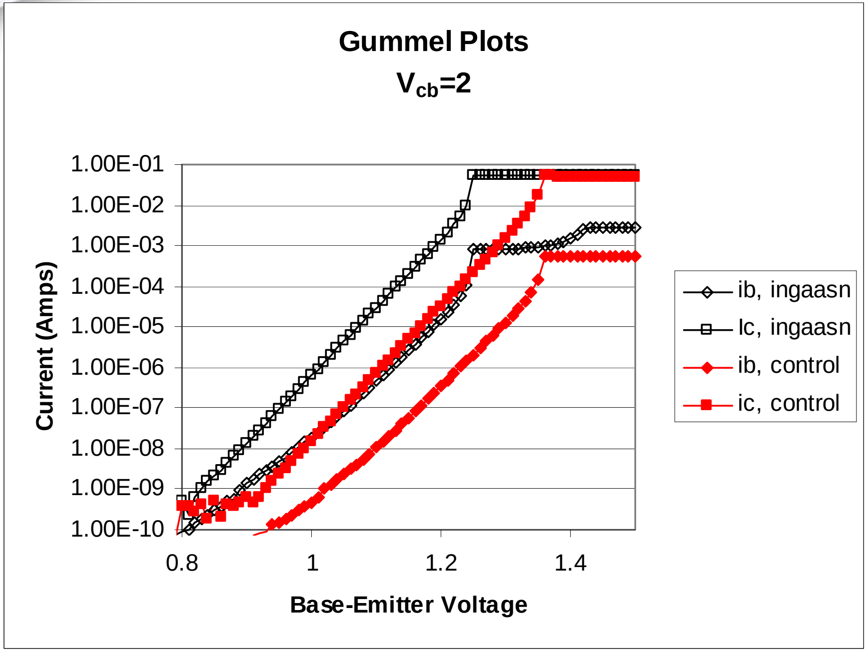
- What do we gain from GAIN?
  - Motivation for using dilute nitride GAIN-HBT™ material
- Device Level Characteristics
  - Reduction in turn-on voltage (100 mV)
  - Lower offset voltage (but does not correlate with PAE)
  - Softness in knee mitigated with adjustments to base-collector junction
  - Thinner base with compositional grade enhances f_t and f_{max}
- Circuit Results
  - Integrated PA fully functional at V_{ref} = 2.6 V and cold!
  - 2nd round of material with higher spacer doping improved performance
- Summary

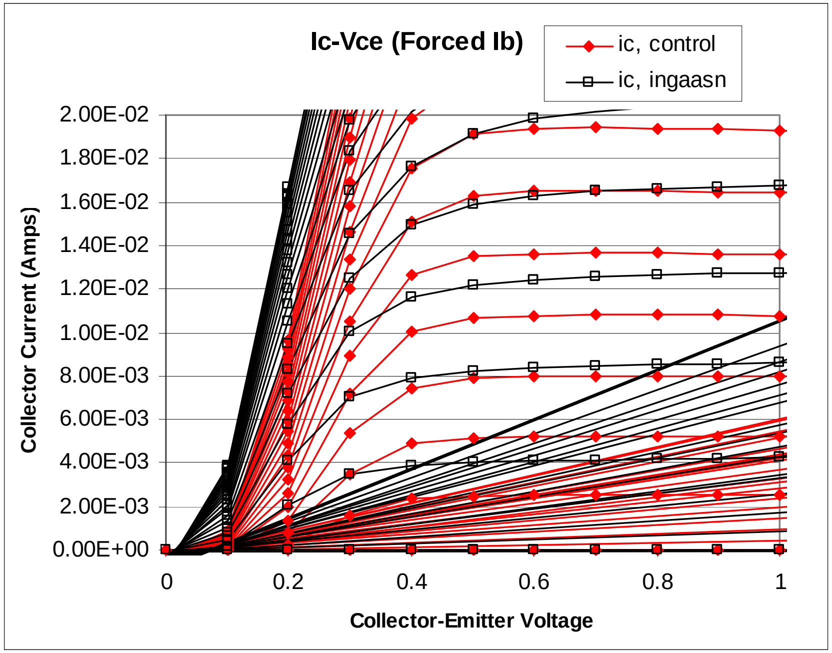
GAIN-HBT™ is trademarked by Kopin Corporation

What do we gain from GAIN?

- The turn-on of an HBT is related to the base layer band gap
  - Addition of Indium (In) to GaAs Lowers the Band gap ⇨Lower Turn-On
  - Nitrogen (N) Reduces Lattice Strain
- Typical Bias Circuits Use 2V_{be} ⇨ At Low V_{ref} & T This Chokes I_{ref}
  - Causes Circuit Performance to Fail at Cold for Low V_{ref}
- Using InGaAsN base (i.e. GAIN-HBT material) allows enough turn-on reduction (100 mV) to achieve device operation at V_{ref}=2.6 Volts and T=-30 C with less degradation to circuit performance
- Epi change only, *no fab re-tooling*

Device Characteristics

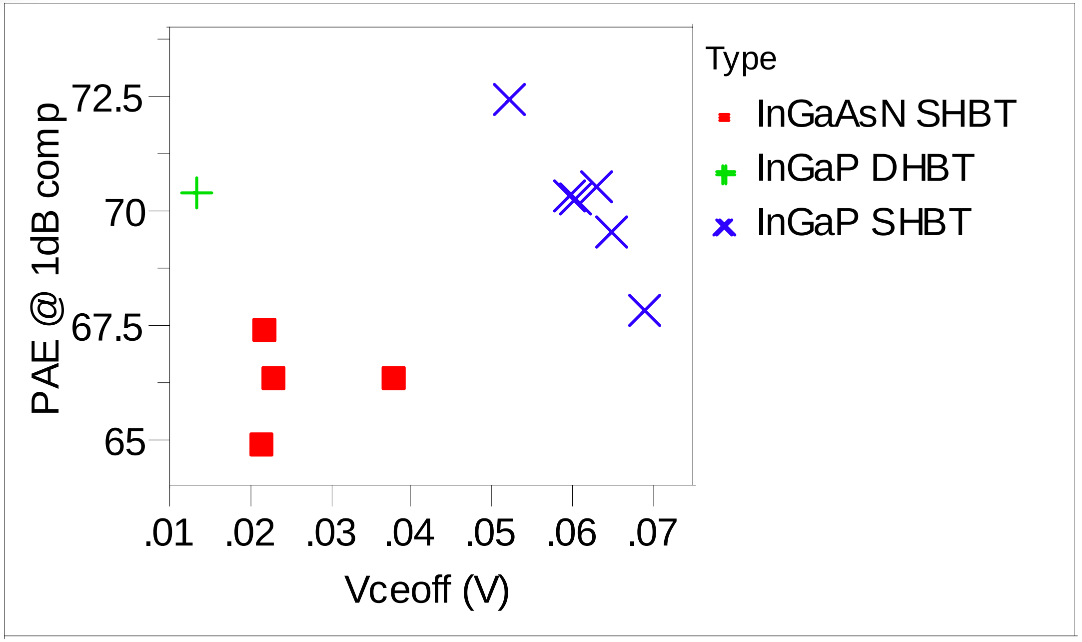


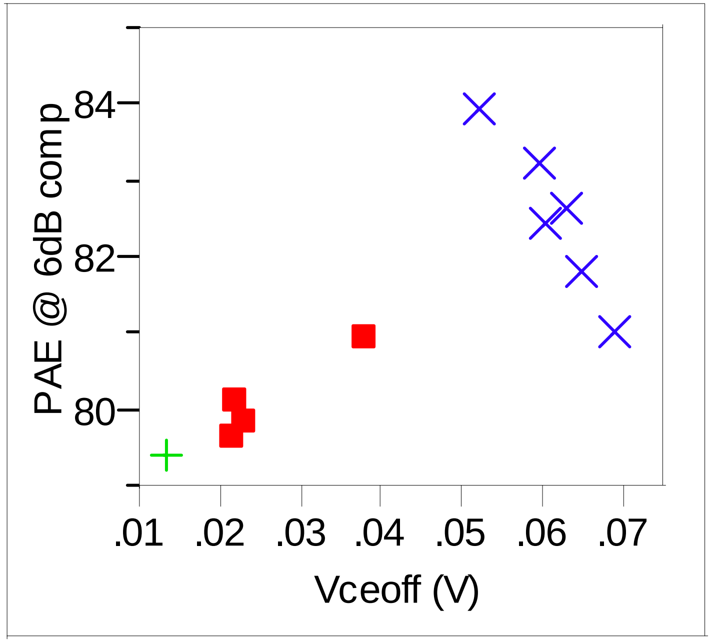


56 μm² Device

- Turn-on Improved by 0.1 Volts
- Off-set slightly improved (no real impact observed for circuit or RF performance, in general)
- Soft-knee (affecting ACP1) – like SiGe device – fixed in later rounds of material

$V_{ce,offset}$ Correlation Coefficients



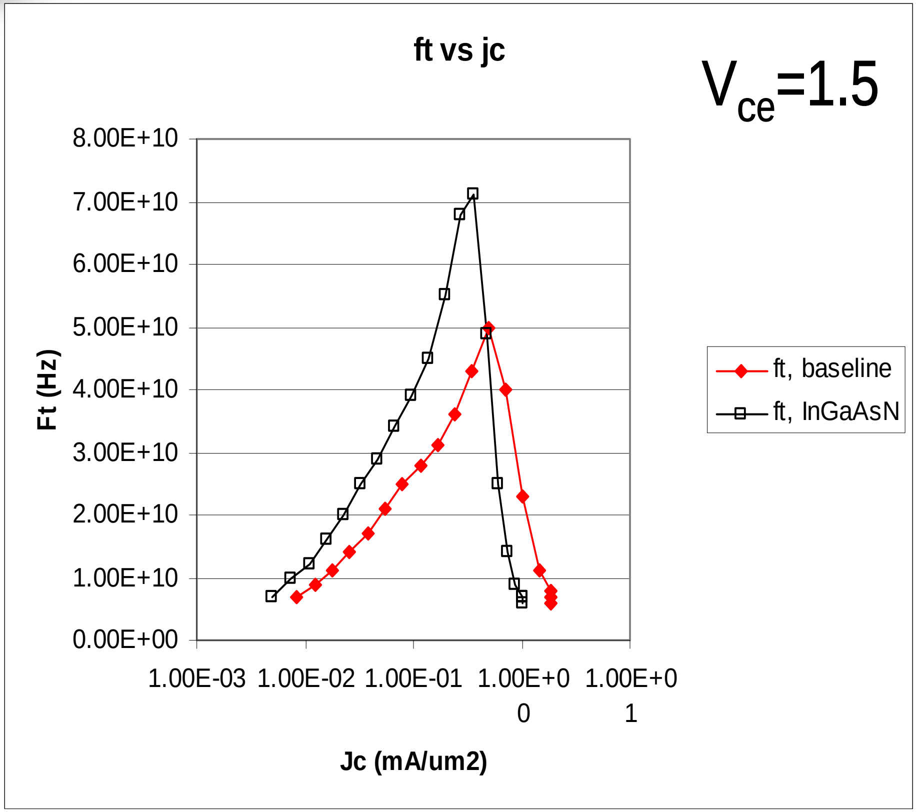


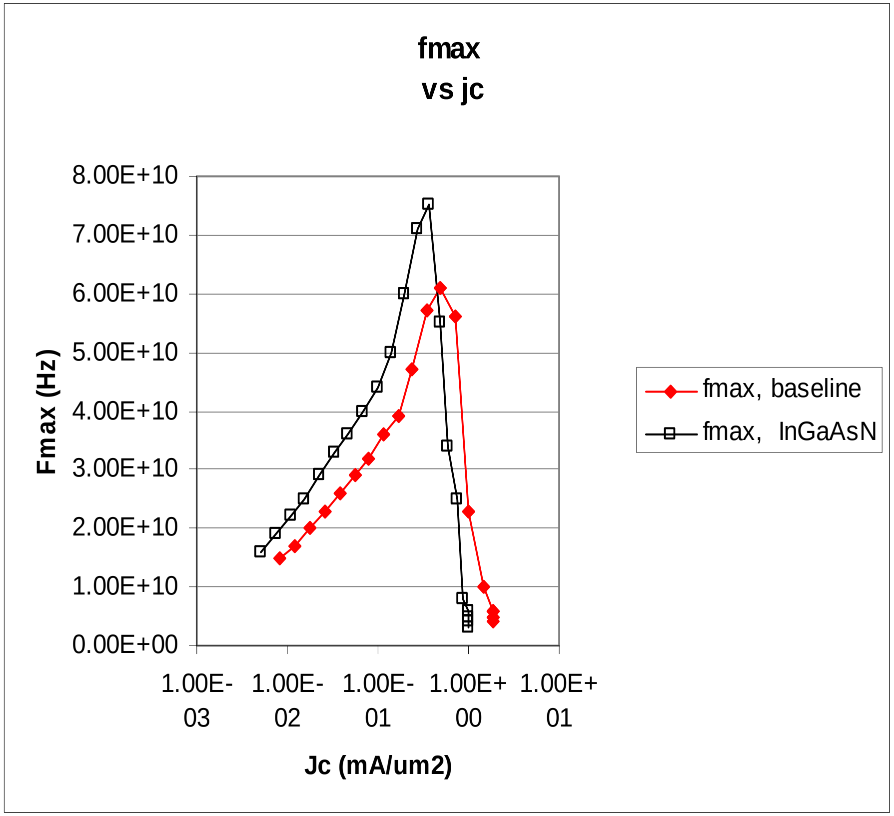
- No overall correlation between PAE and $V_{ce,offset}$
- Good correlation for InGaP SHBTs (no change in collector design)

Cristian Cismaru, et al, “Experimental Comparison of I_c-V_{ce} Parameters and Large-Signal Performance for III-V HBTs”, BCTM 2005

Shameless Plug

InGaAsN AC Results





56 μm^2 Device

Improved AC performance due to thinner base and built-in field (40% thickness reduction)

Power Amplifier Test Results

- Part shown is designed for standard InGaP material
- InGaAsN material seamlessly substituted into a standard InGaP HBT process
- The PA was NOT RETUNED for InGaAsN material
- Material/Epi-specification accounts for ACP1, PAE degradation at higher V_{ref} (fixed in subsequent rounds of material)
- First Demonstration of a fully integrated InGaAsN HBT PA!

LoadPull (V_{ref}=2.6V, P_{OUT}=28.0dBm)

Vcc=3.4V, Vref=2.6V, T=25°C, f_0=1.88GHz, IS-95 modulation

ACPR1 Offset=1.25MHz, ACPR2 Offset =2.25MHz,
Main Channel bandwidth=1.23MHz, Adjacent / Alternate channel bandwidth=30kHz

Type	I_{cq}(mA)	P_{out}(dBm)	ACPR1(dBc)	ACPR2(dBc)	PAE(%)	P_{gain}(dB)
Control	38	28	49	55	41.4	25.6
Type	I_{cq}(mA)	P_{out}(dBm)	ACPR1(dBc) Max	ACPR2(dBc) Max	PAE(%) Max	P_{gain}(dB) Max
GaInNAs	94	28	45.4	61.2	47.2	25.8
Control	38	28	50.5	60.8	47.8	26.1

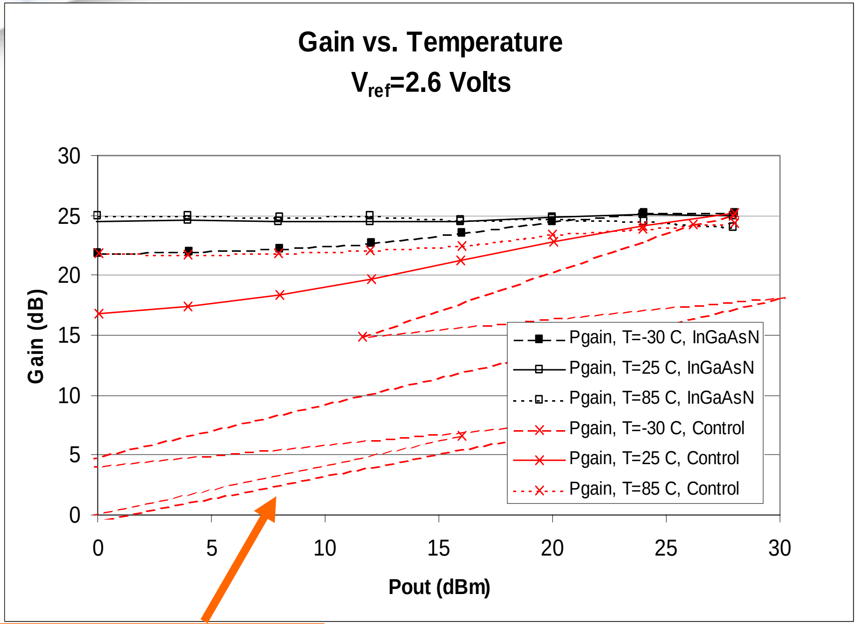
LoadPull (I_{CQ}=95mA, P_{OUT}=28.0dBm)

Vcc=3.4V, I_{CQ}=95mA, T=25°C, f_0=1.88GHz, IS-95 modulation

ACPR1 Offset=1.25MHz, ACPR2 Offset =2.25MHz,
Main Channel bandwidth=1.23MHz, Adjacent / Alternate channel bandwidth=30kHz

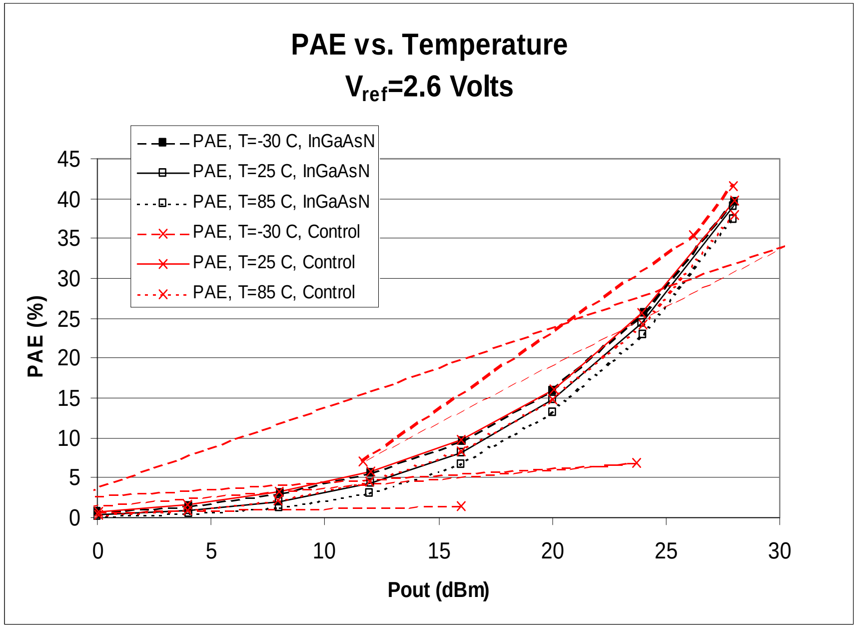
Type	I_{cq}(mA)	P_{out}(dBm)	ACPR1(dBc)	ACPR2(dBc)	PAE(%)	P_{gain}(dB)
Control	95	28	49	58.9	39.8	27.1
Type	I_{cq}(mA)	P_{out}(dBm)	ACPR1(dBc) Max	ACPR2(dBc) Max	PAE(%) Max	P_{gain}(dB) Max
GaInNAs	95	28	45.4	61.2	47.2	25.8
Control	95	28	52.3	63.2	46.6	27.3

V_{ref}=2.6 Volts, P_{gain} and PAE



Gain vs. Temperature

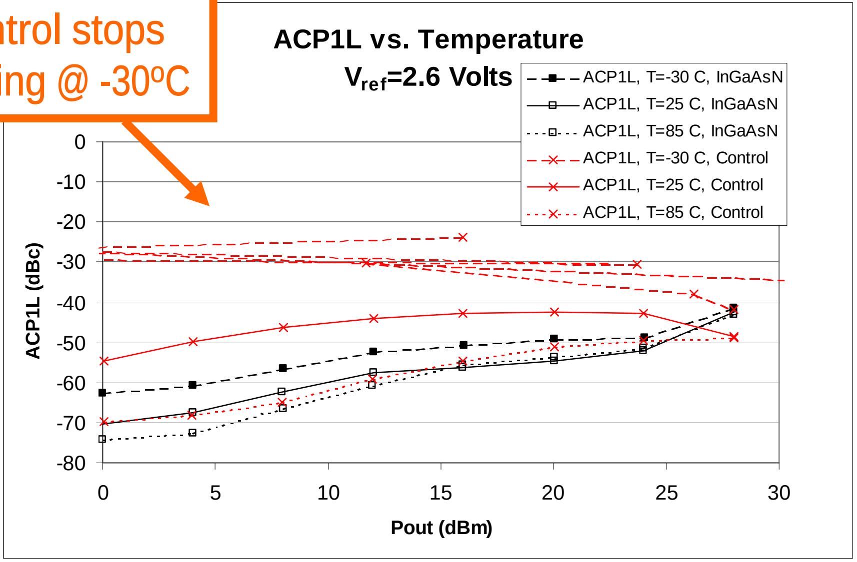
V_{ref}=2.6 Volts



PAE vs. Temperature

V_{ref}=2.6 Volts

Control stops working @ -30ºC

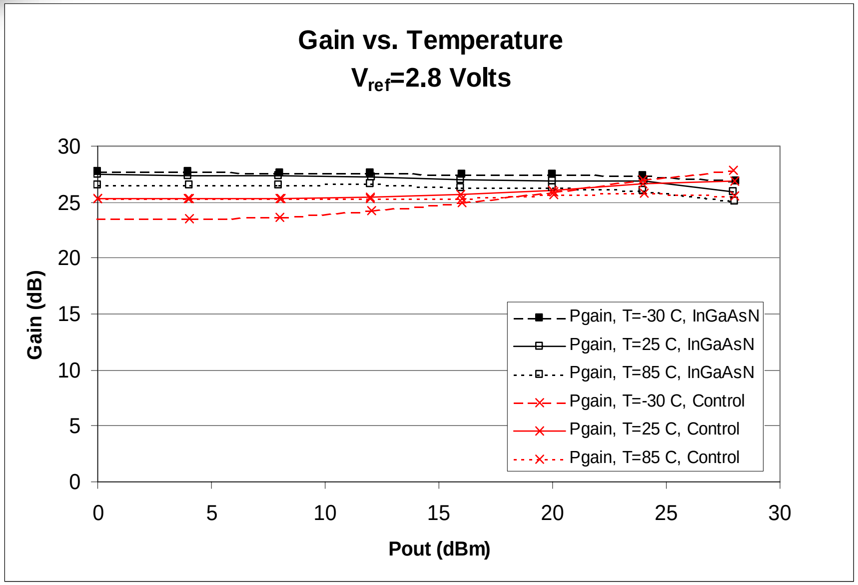


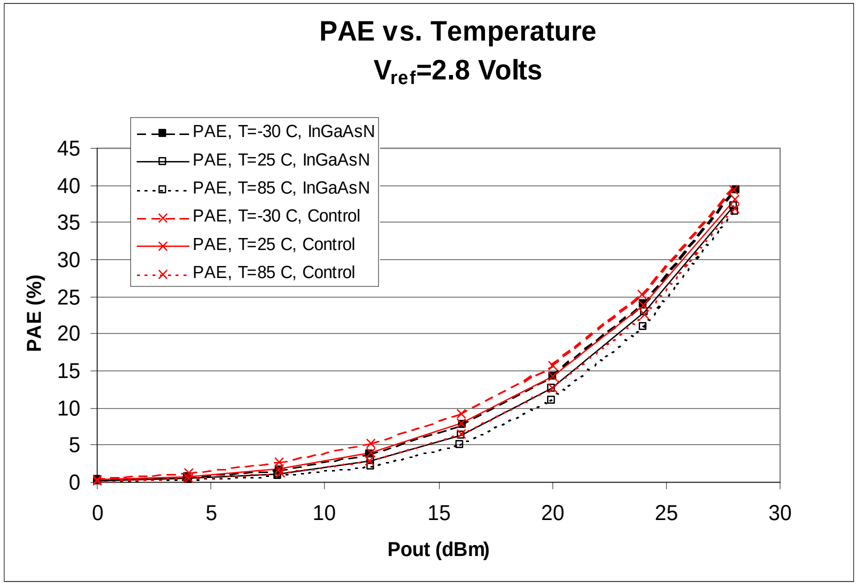
ACP1L vs. Temperature

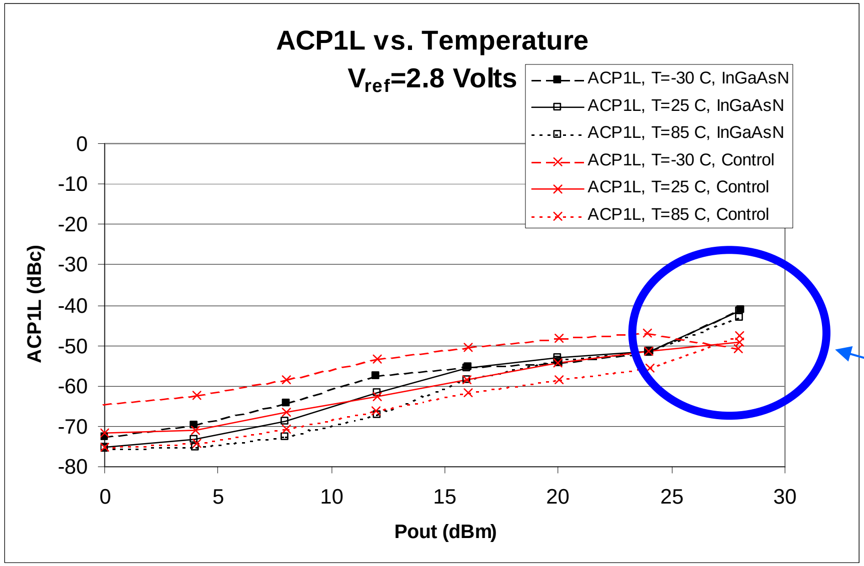
V_{ref}=2.6 Volts

InGaAsN Part Functions at 2.6 V_{ref}, Cold!

V_{ref}=2.8 Volts, P_{gain} and PAE



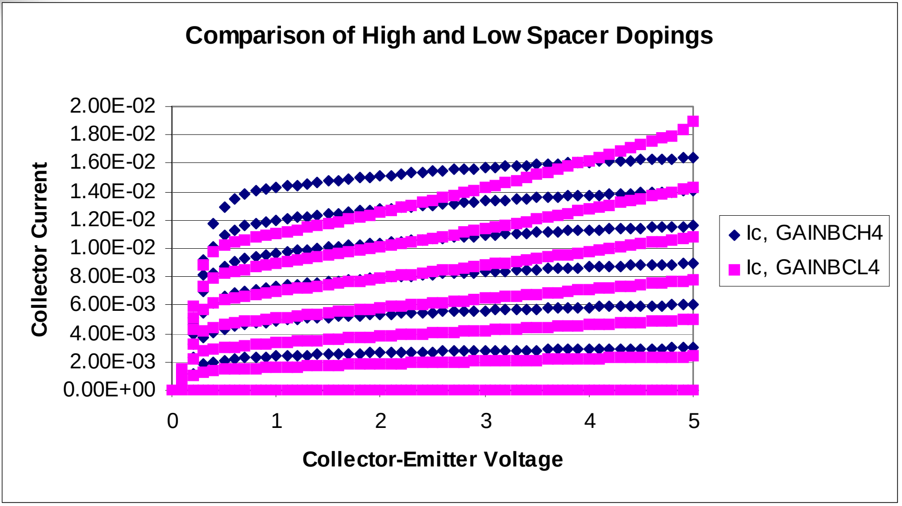


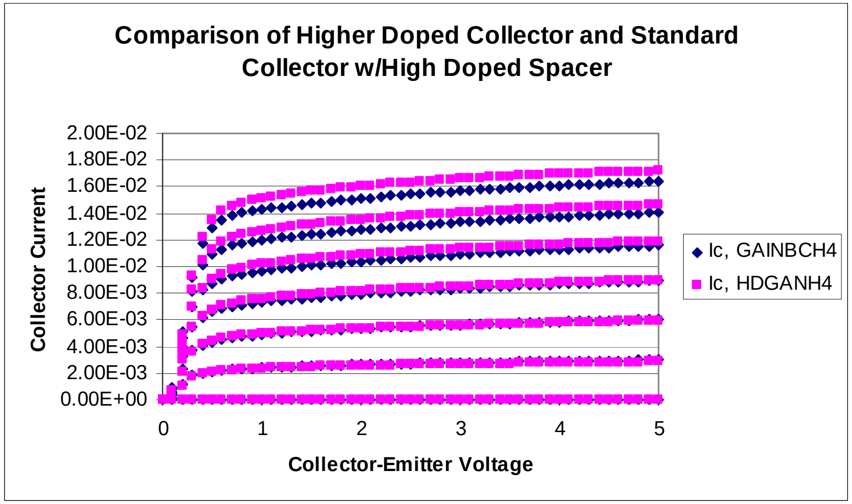


InGaAsN and control comparable 2.8 V_{ref}

This is bad

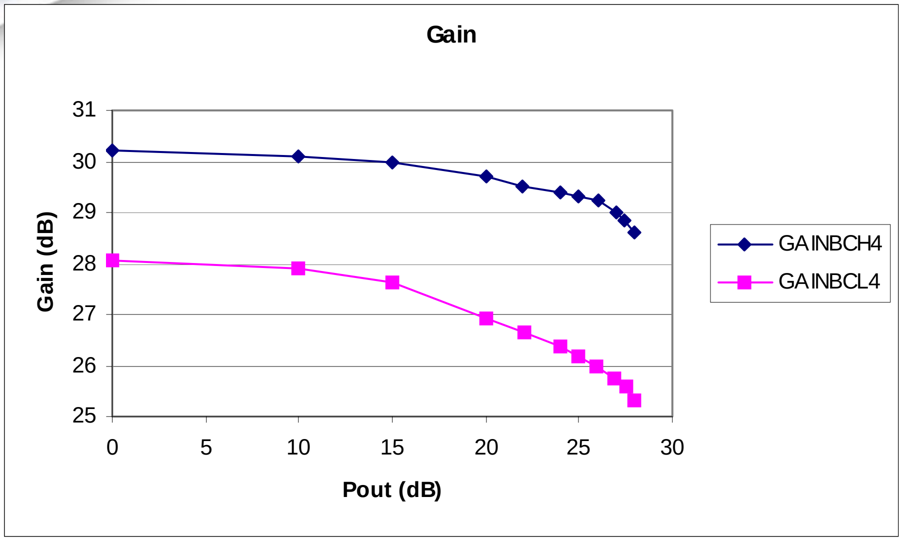
Device Level Experimental Results
2nd Generation Material

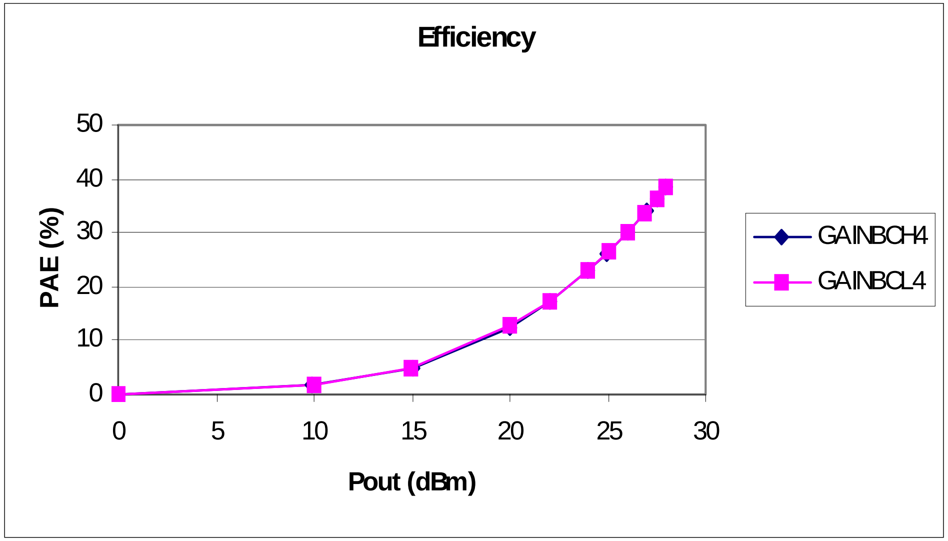

Comparison of High and Low Spacer Dopings


Comparison of Higher Doped Collector and Standard Collector w/High Doped Spacer

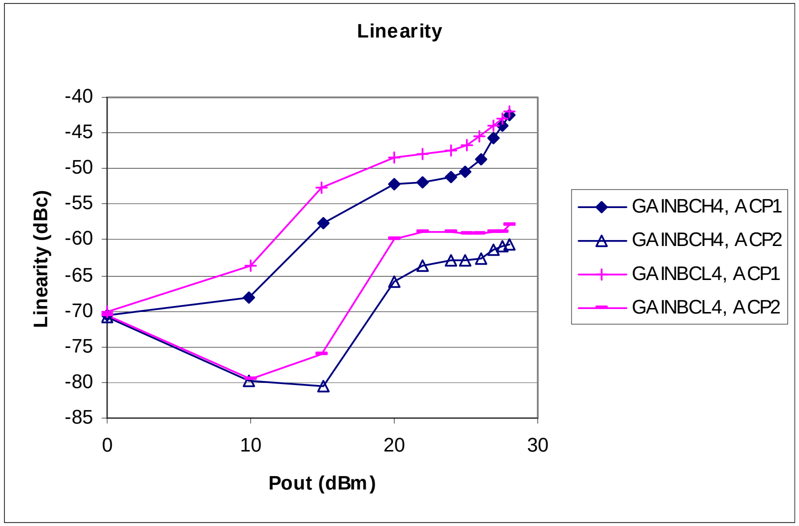
- Higher BC spacer doping improves knee voltage characteristics
- Results confirm performance degradation is due to low-doped spacer
- This has SIGNIFICANT impact on PA!

Effect of BC "Fix" on PA Performance, Different Part





GAINBCH4=high doped spacer
GAINBCL4=low doped spacer



As expected, higher doped spacer improved both Gain and Linearity

Summary and Status

- We have demonstrated a fully integrated PA that functions at a low V_{ref} (2.6 volts) at cold temperatures (-30 C)
  - 100 mV reduction is good enough for some applications
  - Some device level improvements did not translate to circuit level
- Second iteration material provided significant improvements
  - High doped spacer improves device level characteristics – observed effect was Early voltage, not barrier
  - High doped p+ spacer also improves gain and linearity over low-doped spacer
  - Some slight retuning was required (identical die) to implement in InGaAsN
- *GAIN material is being used in high volume commercial PAs!*

GAIN – It’s not just for laundry anymore!

*** Pick your acronyms carefully!**