Intelligent Epitaxy Technology, Inc.

Company Information

IntelliEPI

1250 E. Collins Blvd.

Richardson, TX 75081

USA

E-mail: info@IntelliEPI.com

Web Site: www.IntelliEPI.com

Japanese Agent: ATN Japan

E-mail: sales@ATNJapan.com

Web Site: www.ATNJapan.com

ISO 9001:2000
FM 511967

Intelli*EPI*: Outline

Company Information Update

- *Facility and Products*
- *Capabilities and in-situ monitoring technology*

Selected Product Highlights

- *pHEMT, iHEMT, and mHEMT*
- *HBT Activities (InP-based HBT, HBT w/ GaAaSb base)*
- *PIN, QWIP, and Sb-based SLS*

Quality Management System

Summary

***IntelliEPI*: The Company**

- *A Texas semiconductor manufacturing company located in Richardson, TX, since January 1999.*
- *Founded by Dr. Yung-Chung Kao (TI), Dr. Paul Pinsukanjana (UCSB/JPL), Randy Thomason (TI), and Kevin Vargason (TI), combining experiences in electronics and optoelectronics. In 2001, Dr. J.M. Kuo (Lucent) and Dr. H.J. Zhu (Paul Drude Inst) joined.*
- *A venture capital funded company*
- *ISO 9001: 2000 certified since March 2007 (current ISO9001:2008)*

IntelliEPI provides GaAs (up to 6in) and InP (up to 4in) MBE PHEMT and HBT epitaxial wafers to RF MMIC and wireless wafer fabs for communications applications. We also provide optoelectronics products (PIN, QWIPs, and lasers) and various III-V based industrial and energy-related products

Intelli*EPI*: Technical Experience

Technical team has combined experience over 100 years in industrial III-V MBE operation (GaAs and InP)

Yung-Chung Kao, Ph.D.EE, UCLA, '87; Texas Instrument, '87-'98; IET, '99-date

- *27 years in III-V related business. 25 years in MBE. Head of TI's MBE Lab. 89-96.*
- *12 US patents and over 100 technical publications related to III-V materials, devices.*

Paul Pinsukanjana, Ph.D.Phys., UCSB, '94; EPI (Veeco), '96-'97; JPL, '97-'99; IET, '99-

- *15 years in III-V electronics and optoelectronics: MBE growth, processing, and characterization. Hold 3 patents on in-situ real-time sensor technology for MBE.*

Jenn-Ming Kuo, Ph.D.EE, Rutgers U., '87; AT&T/Lucent Bell Labs, '86-'01; IET, '01-

- *27 Years in III-V epitaxial growth by MBE and gas source MBE. 22 years experience in R&D of III-V electronic and opto-electronic device, MBE growth, and device processing.*
- *9 US patents and 128 technical publications related to MBE growth and III-V devices.*

Randy Thomason, Texas Instrument, '82-'96; TriQuint Semi., '96-'98; IET, '99-

- *25 years in MBE operation, modification, facility maintenance, and construction*

Kevin Vargason, Texas Instrument, '90-'98; IET, '99-

- *17 years in semiconductor characterization, MBE production, and failure analysis*

H.J. Zhu, Ph.D. Phys., Fudan U., China, '96; Paul Drude Institute '98-'01; IET,'01-

- *16 years in III-V electronics and opto-based MBE growth, 10 years in production MBE*

Intelli*EPI*: Facility at Richardson, Texas

Current facility since January 2002: 1250 E. Collins, Richardson, TX (Dallas suburb)

- *23,000 ft2 (production: 13,000 ft2; Office: 10,000 ft2)*
- *Set up to host 8 production MBE systems*
- *Clean room for post growth testing and LAD processing*
- *30 full time employees*

MBE Facility at Intelli*EPI's* Facility in Richardson, Texas

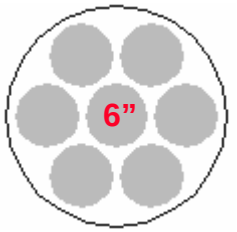
- *8 MBE reactors:*
  - **1 Riber 7000 (7x6”, 14x4”)**
  - **3 Riber 6000 (4x6”, 9x4”, 15x3”)**
  - **3 Riber 49, 1 VG V100 (4x4”, 5x3”)**
- *Dedicated operation and cleaning facilities designed to handle phosphorous for all MBE systems*

Riber 7000

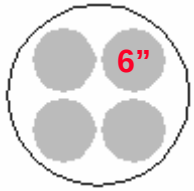
***IntelliEPI*: Multi-Wafer Production MBE Platen Design**

Capacity for production reactors

Riber7000: **7x6”**
14x4”
25x3”



Riber6000: **4x6”**
9x4”
15x3”



Riber 49: **4x4”**
3x5”
11x2”

Riber7000: 7x6” MBE reactor

Experienced with product transition:

- *Development to production on multi-wafer MBE systems*
- *Reactor & substrate size scaling: mainly support from 2” to 6” size substrates (1” and 8” are also supported)*

Post-growth Characterization Capability

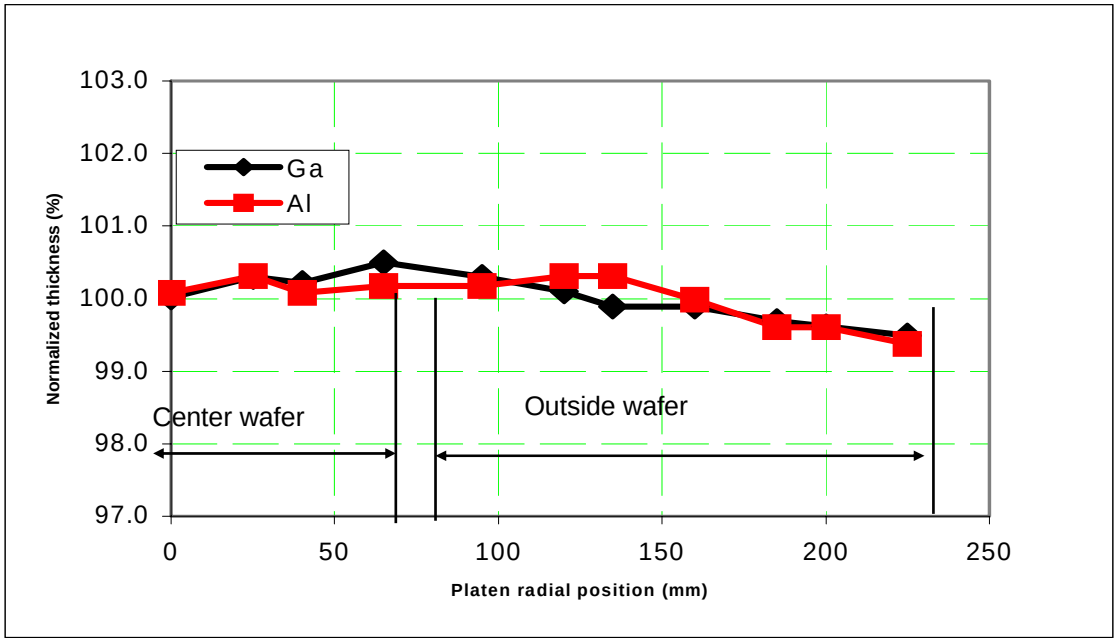
- *Class 100 clean room: (2000 ft^2)*
- *Characterization tools:*
  - **X-ray diffraction**
  - **PL mapping**
  - **Surface particle scan**
  - **Hall measurement**
  - **Contactless resistivity mapping**
  - **Electro-chemical CV profiling**
  - **White light reflection spectrometer**
  - **Electrical CV profiling**
  - **Mercury probe CV**

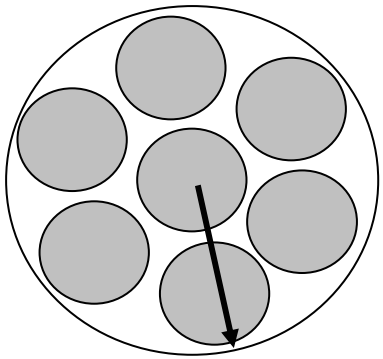
Intelli*EPI*: III-V Compound Semiconductor Product Matrix

	RF and microwave	High Speed Digital	Optoelectronics
Applications	• RF components in handsets • Automotive radar • Defense related	• OC768- 40Gbps network • OC192-10Gbps network	• Fiber optic network light sources and Photo-detectors
Device Structure (Red in Production mode)	• GaAs pHEMT • GaAs mHEMT • InP HEMT • InP HBT	• InP SHBT/DHBT • InP HEMT • GaAs mHEMT • GaAsSb DHBT	• GaAs PIN/APD • InP PIN/APD • QWIP • Diode laser • Modulator

IntelliEPI: Thickness Uniformity Across Platen for 7x6” MBE

Riber 7000 thickness uniformity measured by white light reflection



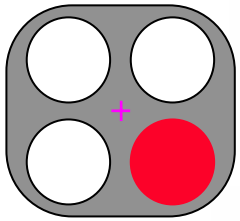


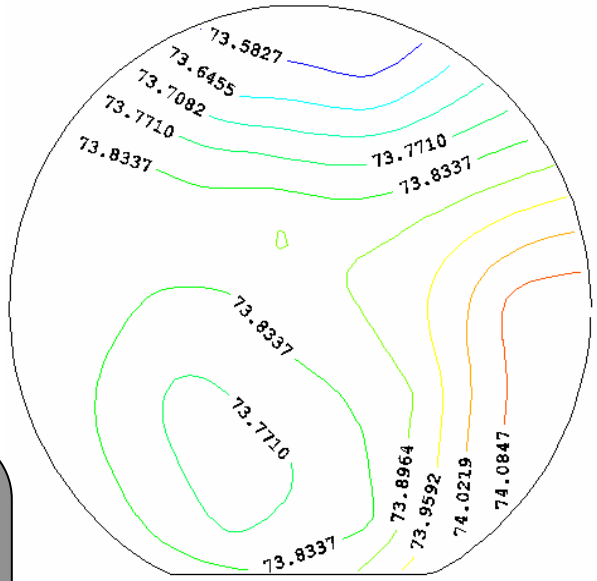
7X6” platen

2,500Å GaAs
2,000Å AlAs
GaAs substrate

- *Thickness variation across platen < 1% across 7X6” platen configuration*
- *Si doping GaAs layer uniformity by contactless resistivity mapping:*
  - *6” wafer doping variation < 1%*
  - *Difference from center wafer to outside wafer < 0.5%*

CBr4 Carbon Doping of P-type InGaAs

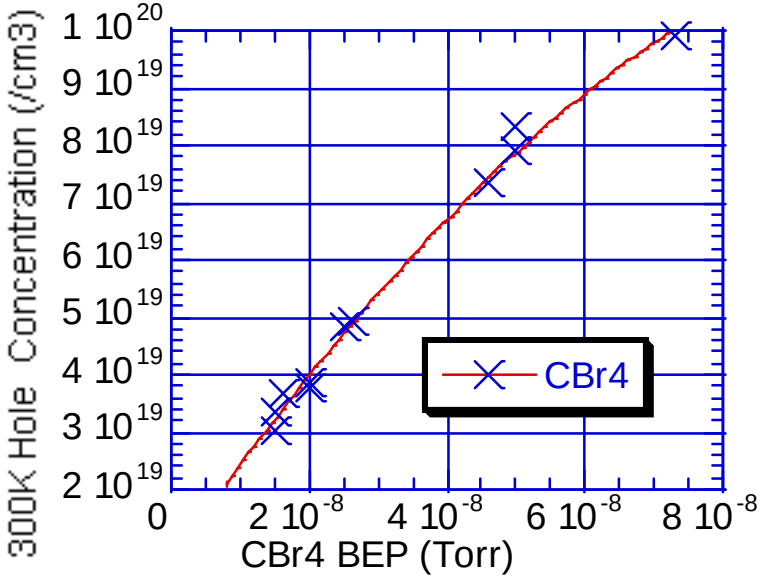


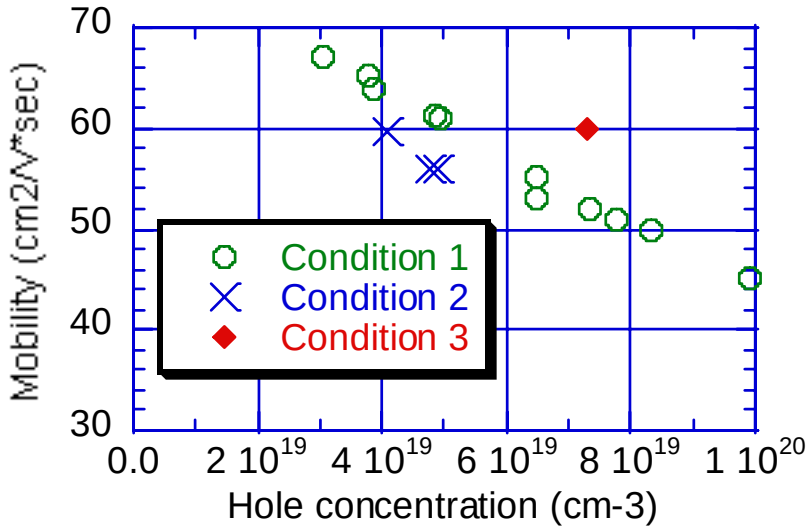


Statistical Summary

Number of Test Points	36
Average Value	73.8482
Maximum Value	74.1416
Minimum Value	73.521
Sample Spread (%)	0.84
Std Dev Value	0.1379
Wafer Uniformity Value (%)	0.19

Sheet resistance measurement using Lehighton shows the resistivity across 4" wafer grown from a 4x4 MBE system. The epi layer is a 350 nm thick InGaAs doped at 4e19 cm-3.



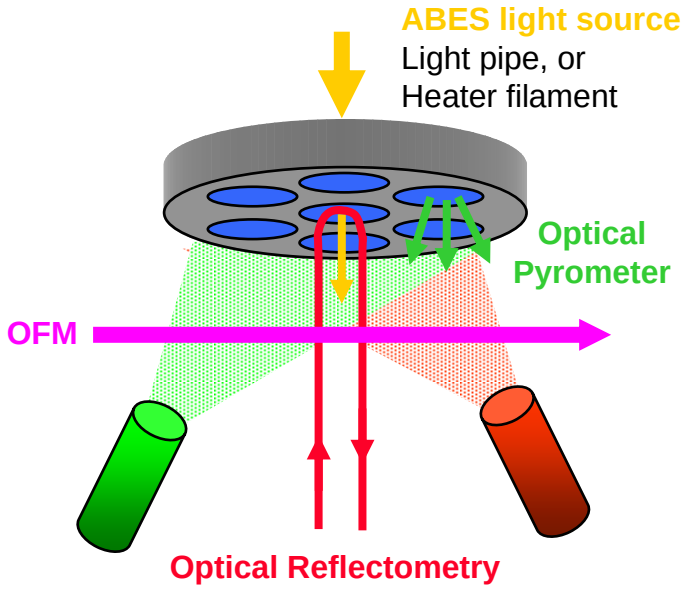


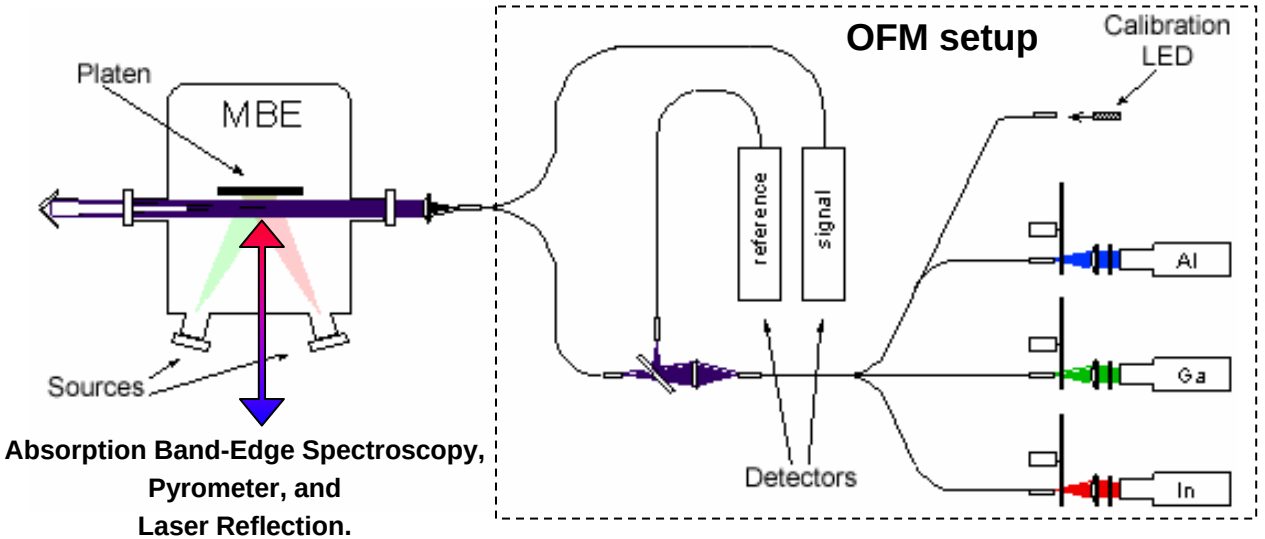
Production MBE Operation Improvement by *In Situ* Sensors

- *Run-to-run reproducibility:*
  - **Maintaining critical specification ranges**
  - **Verification of growth process details (condition and layers)**
- *Limitations of ex-situ characterization:*
  - **Slow post-growth feedback**
  - **Additional wafer handling and cost**
  - **Limited information about growth condition profile vs. epi-depth**
- *New product development:*
  - **Faster development cycle time**
  - **Improved performance for more demanding specifications**
- *Bad run detection/correction/termination:*
  - **Loss of wafers: very expensive for larger systems and for InP**
  - **Wasted machine time, materials, & operating expenses**

Overview of IntelliEPI in-situ Sensor Technologies

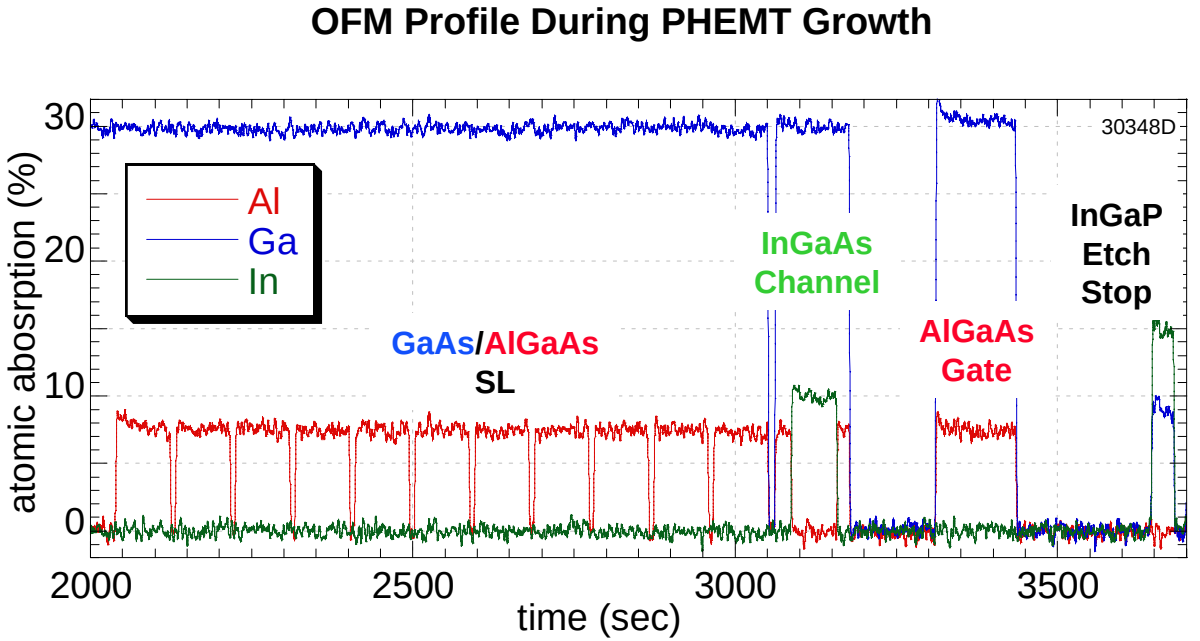
- *Substrate temperature*
  - **Pyrometry**
  - **Absorption Band-Edge Spectroscopy (ABES): band-gap dependence on temp**
- *Materials composition*
  - **Optical-based Flux Monitor (OFM): atomic absorption of group III fluxes**
- *Growth rate*
  - **Optical Reflectometry**
  - **Pyrometric Interferometry**

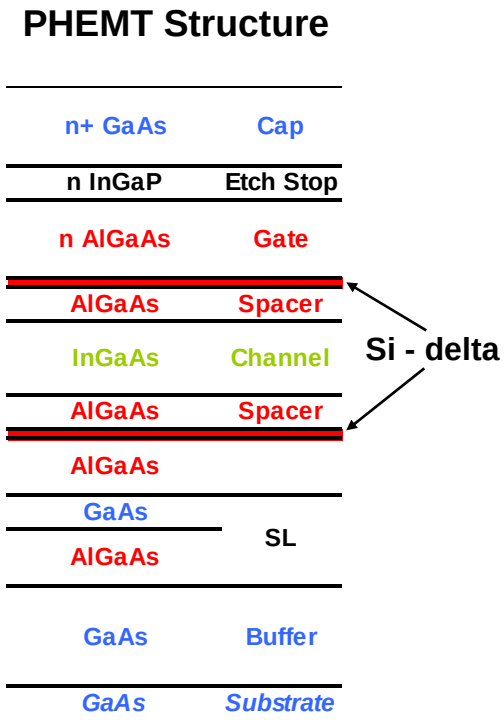




Absorption Band-Edge Spectroscopy, Pyrometer, and Laser Reflection.

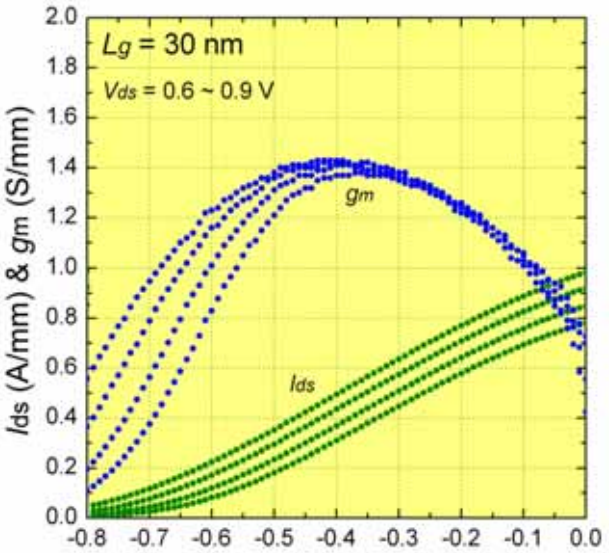
PHEMT In-situ Composition Monitoring with OFM

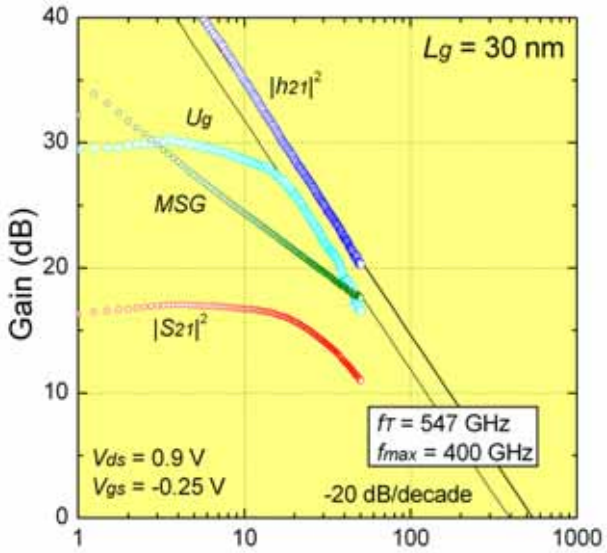


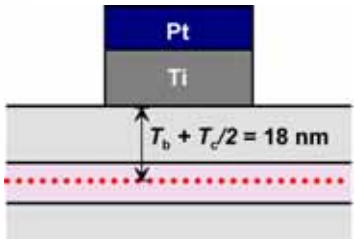


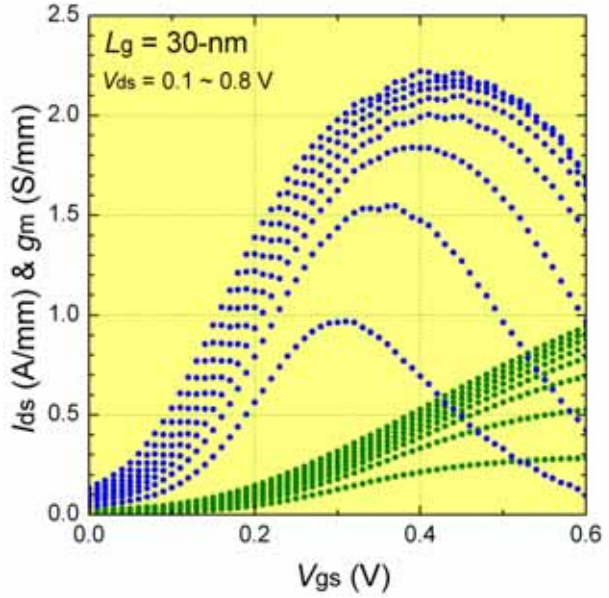
- *Direct composition monitoring for each critical layer*
- *In-situ composition monitoring for key layers:*
  - **InGaAs Channel: Accurate x-ray measurement**
  - **AlGaAs Gate: X-ray represents average of SL and Gate**
  - **InGaP Etch Stop: Very thin layer limits x-ray accuracy**

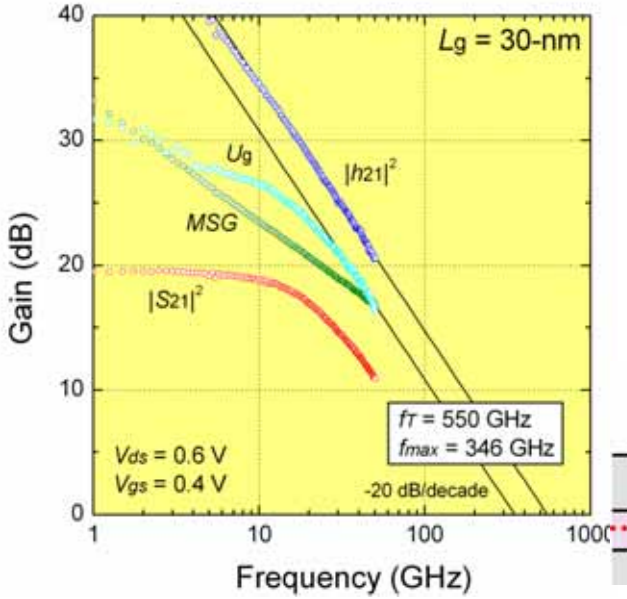
30-nm D-Mode & E-Mode $In_{0.7}Ga_{0.3}As$/InP HEMT









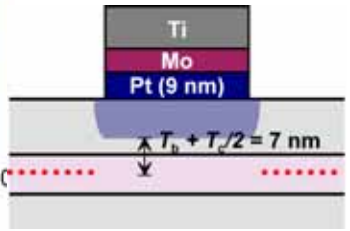


D-mode InP HEMT on InP

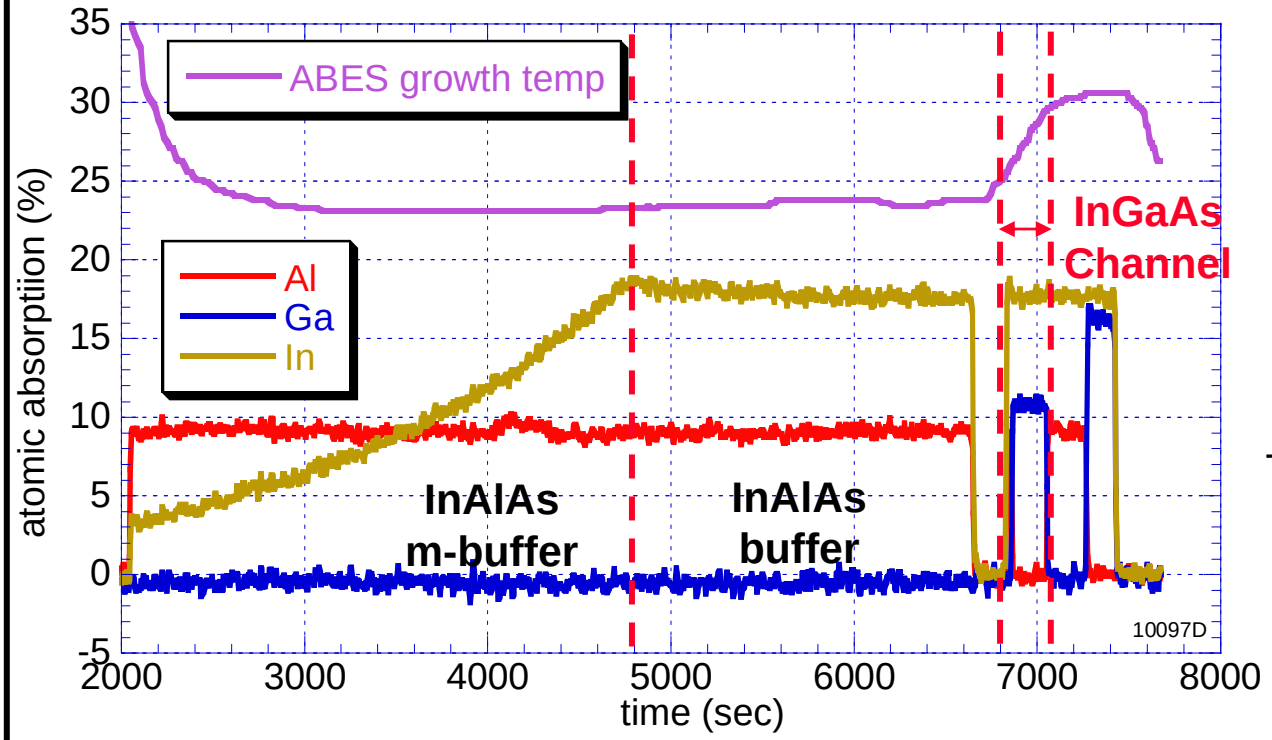
- *Gm = 1.4 S/mm*
- *fT = 547 GHz*
- *fmax = 400 GHz*

E-mode InP HEMT on InP

- *Gm = 2.2 S/mm*
- *fT = 550 GHz*
- *fmax = 350 GHz*



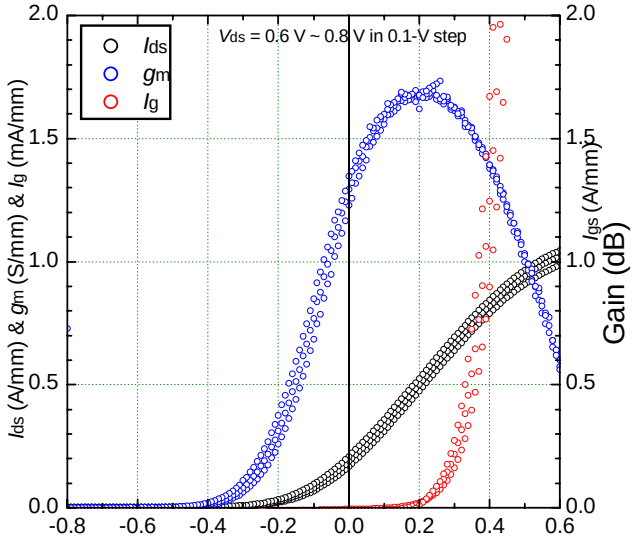
MHEMT: Temperature and Group III flux control

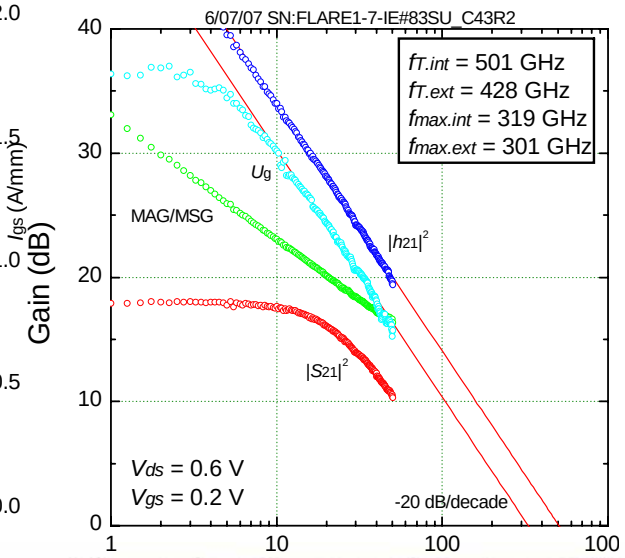


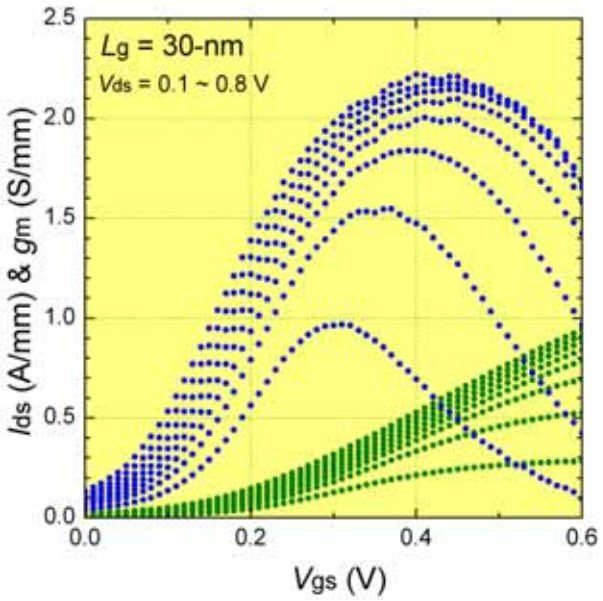
Contact (InGaAs)
Gate (InAlAs)
Channel (InGaAs)
buffer (InAlAs)
m-buffer (InAlAs)
GaAs substrate

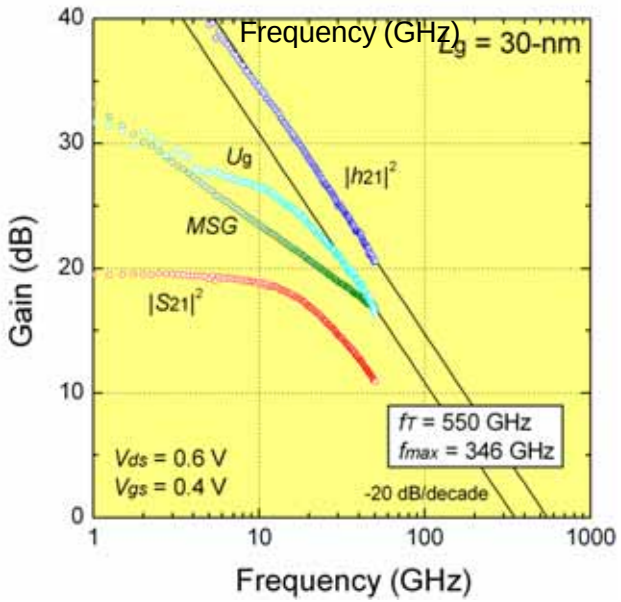
- *MHEMT: InP-performance on GaAs substrate.*
- *Critical growth parameters: substrate temperature, and growth rates.*
- *Room temp mobility 11,000 cm2/V*sec, ns~3.9e12 cm-2.*

E-Mode $In_{0.7}Ga_{0.3}As$/InP HEMT and mHEMT on GaAs









Strain-relaxed InP mHEMT on GaAs

- *Gm = 1.7 S/mm*
- *f_T = 500 GHz*
- *f_{max} = 320 GHz*

InP HEMT on InP

- *Gm = 2.2 S/mm*
- *f_T = 550 GHz*
- *f_{max} = 350 GHz*

TELEDYNE SCIENTIFIC COMPANY
A Teledyne Technologies Company

Intelli*EPI*: InP SHBT/DHBT Status

Strong Customer Base Facilitates Fast Structure Optimization

- *US and Japan foundries and companies*
- *Both C and Be doped SHBTs and DHBTs*
- *HBT-PIN and HBT-Opto structure integration*

In-House Large Area Device (LAD) Fabrication Capability

- *Fast turn around (~8 hours)*
- *Correlation with customers device characteristics*
- *CV measurements for device fine tune*
- *Correlation with in-house in situ growth database*

Developed GaAsSb-base HBT under DARPA TFAST Program

- *GaAsSb-base up to 1e20 cm-3 carbon doping*

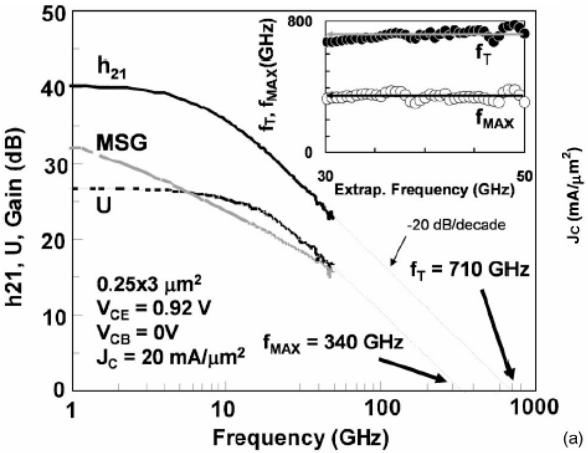
IntelliEPI: InP-HBT Experience Highlights

Pohang University of Science and Technology (POSTECH): InP-HBT results

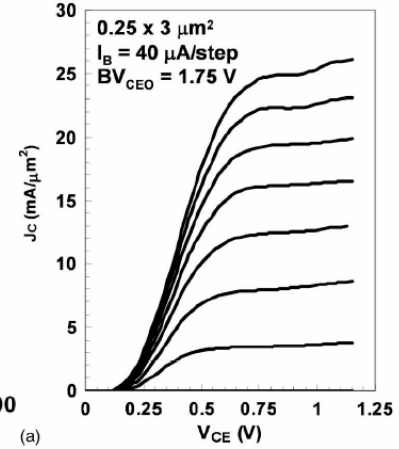
- *F_{max} = 689 GHz (Postech/IntelliEPI, IEDM, San Francisco, December 2004)*

University of Illinois, Urbana Champaign: InP-HBT results

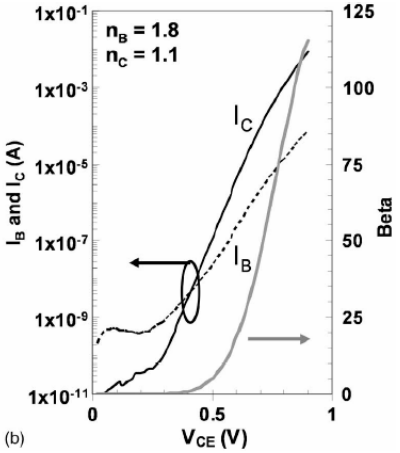
- *Most recent data: F_t = 710 GHz (Hafez et al. Appl. Phys. Lett., 87, 2005)*

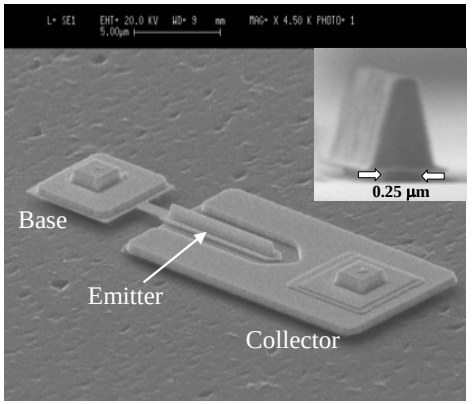


(a)



(b)





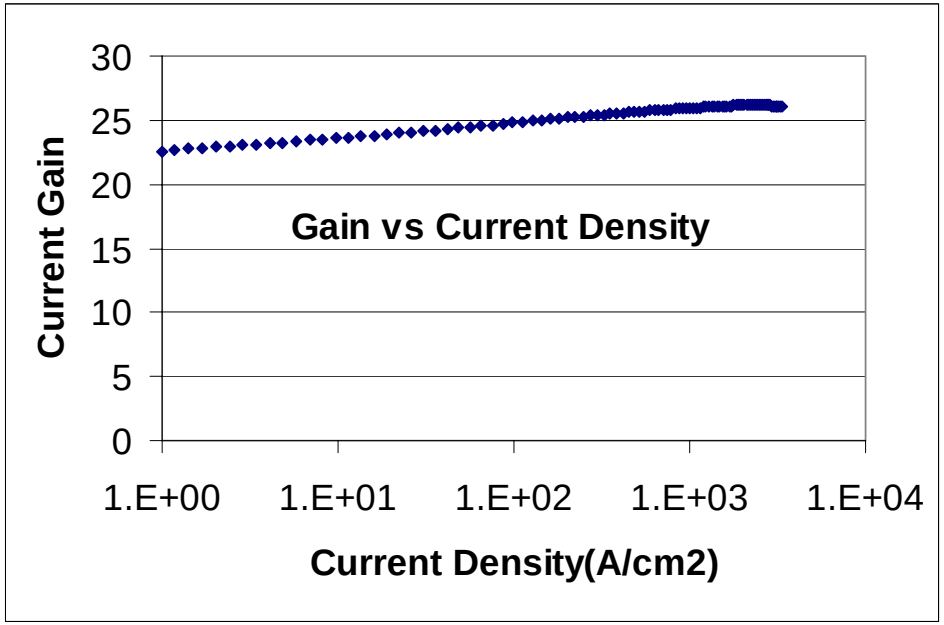
IntelliEPI *provides volume InP-based HBTs to US and Japan InP IC foundries*

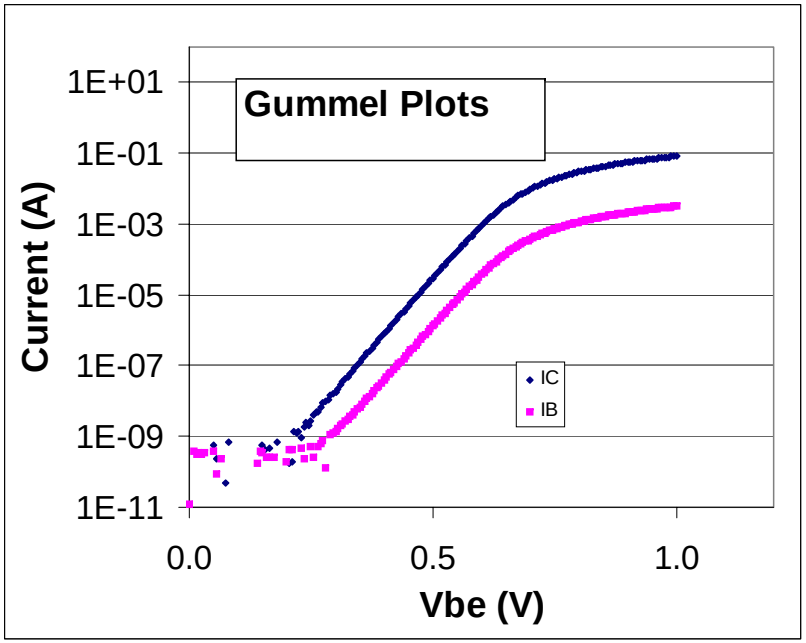
- *High level of integration VIP-1 SHBT: ~5000 transistors inside 3 mm square die*
- *100% transistor yield for VIP-2 DHBT: over 450 GHz F_t and F_{max} (DARPA – TFAST)*

InP/InGaAs SHBT with High Base doping DC Characteristics

Layer	comment	Material	Thickness (Å)	Dopant	Level (/cm³)
7	InGaAs:Si	In(x)Ga(1-x)As	500	Si	2.00E+19
6	InP :Si	InP	500	Si	1.0E+19
5	InP :Si	InP	500	Si	5.0E+17
4	InGaAs :C	In(x)Ga(1-x)As	400	C	8.0E+19
3	InGaAs :Si	In(x)Ga(1-x)As	2,000	Si	2.0E+16
2	InP :Si	InP	100	Si	2.00E+19
1	InGaAs :Si	In(x)Ga(1-x)As	4,000	Si	2.00E+19
	Substrate	InP			

- *Current Gain*
  24 @ 10A/cm2,
  25 @ 100A/cm2,
  26 @ 1kA/cm2
- *Base Rbs (TLM)*
  406 Ohm/sq
- *Current cross-over*
  < 1.0E-9 A
- *Von @ 5A/cm2*
  542 mV

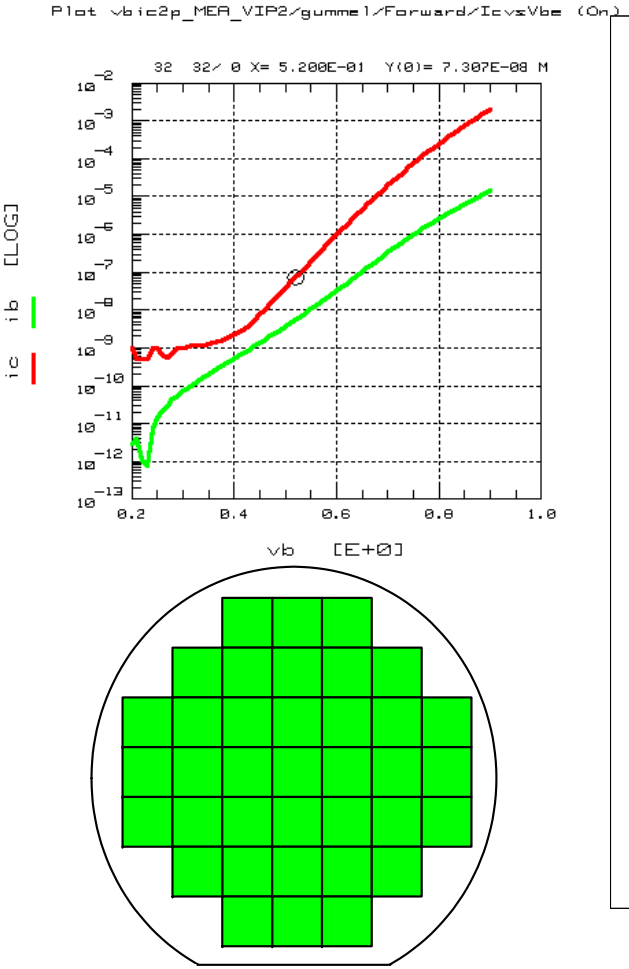


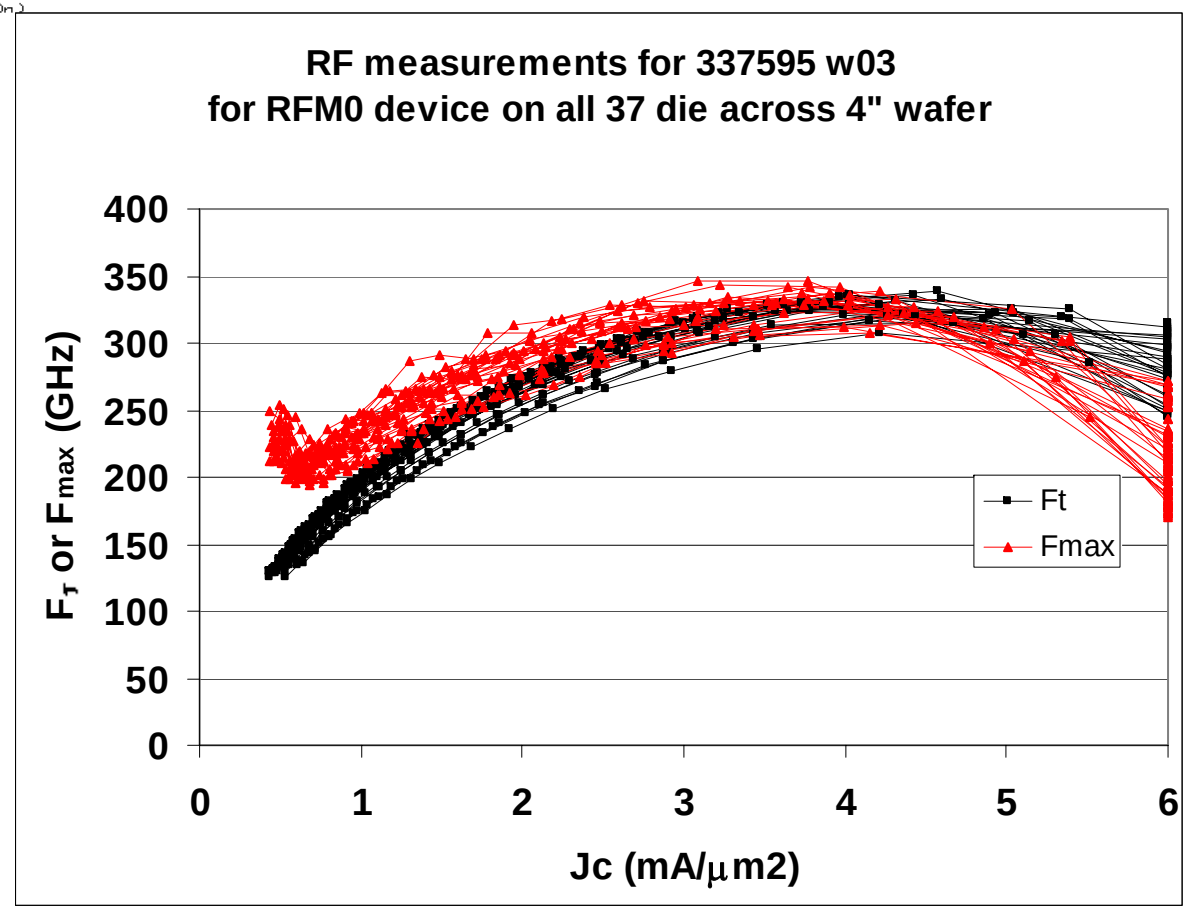


100% Transistor Yield attained!

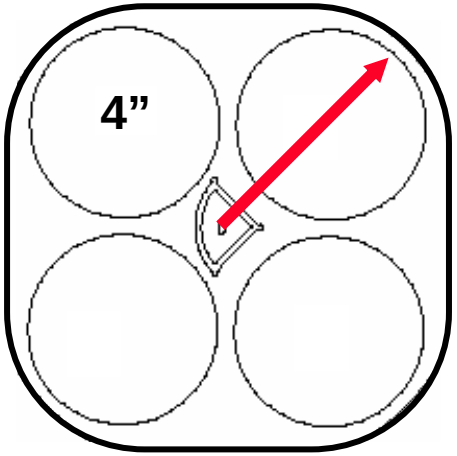
All sites over 300 GHz Ft and Fmax (DHBT)

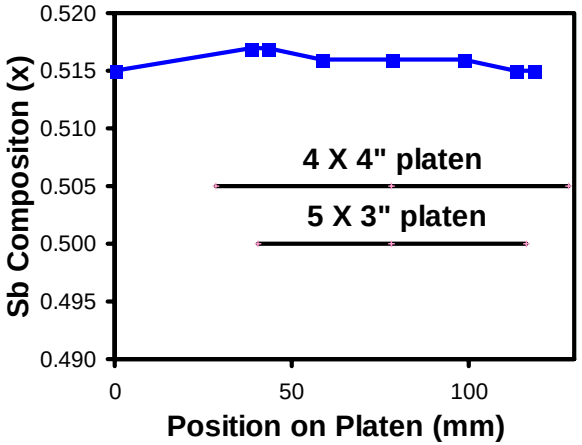
All sites functional and operational at high speed

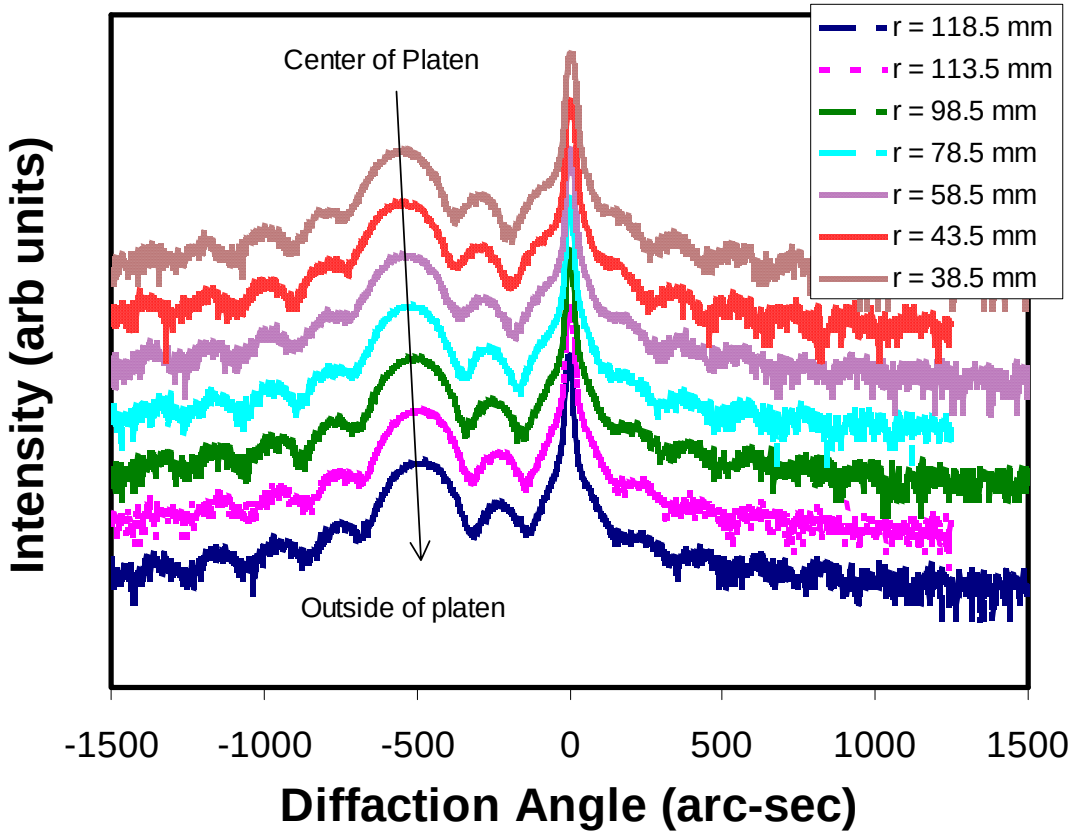




X-ray data of GaAsSb uniformity across 4x4” platen







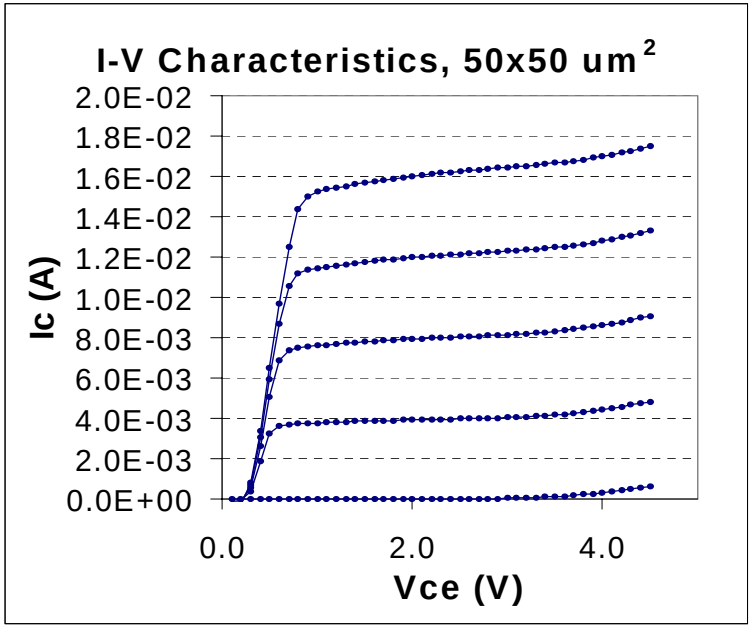
- *GaAsSb composition uniformity is within ±0.1 atomic percent across 4x4” platen*

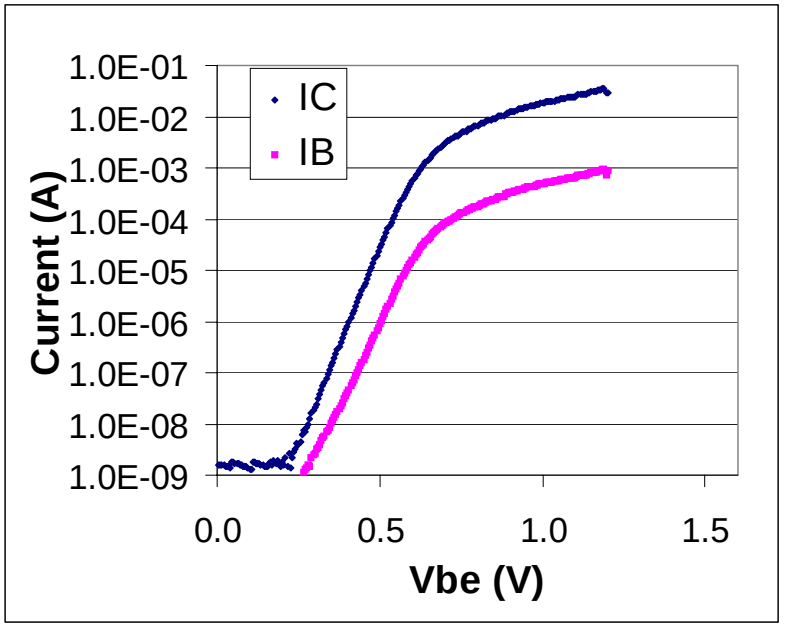
InAlAs/GaAsSb/InP DHBT DC characteristics

InAlAs emitter GaAsSb DHBT (Improved E-B junction)

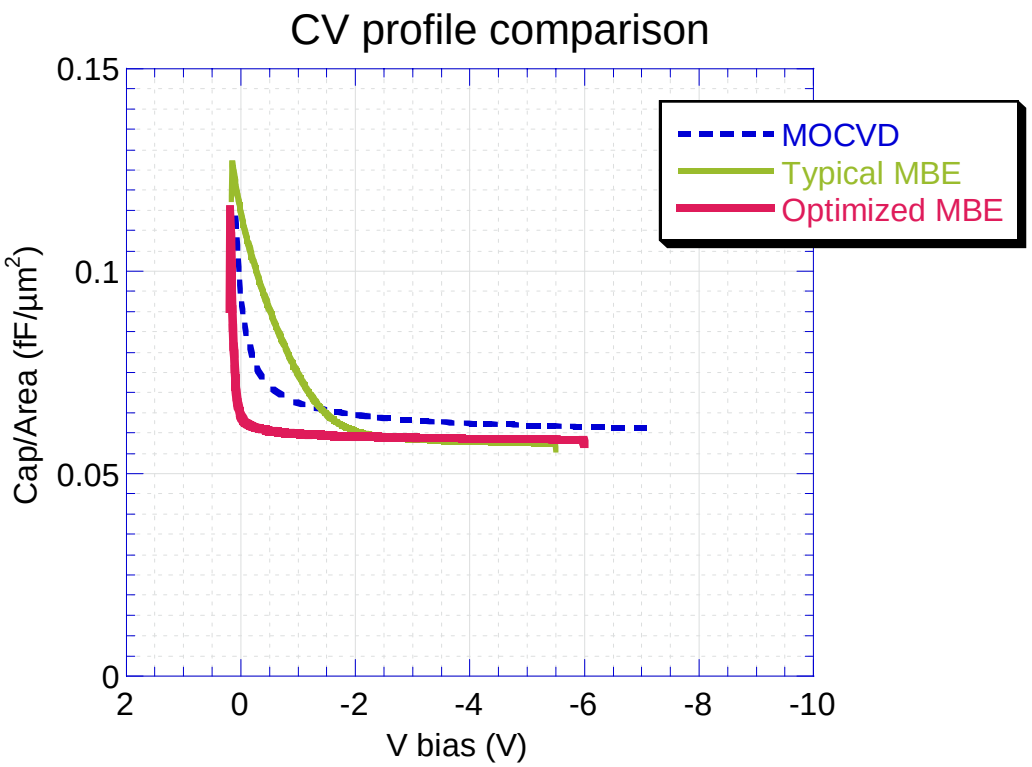
Layer	Comment	Material	x	Thick. (Å)	Dop.	Level (/cm^3)	Type
8	Emitter cap	In(x)Ga(1-x)As	0.532	1,000	Si	3.0E+19	N+
7	Emitter cap	InP		300	Si	5.0E+18	N+
6	Emitter	InP		300	Si	5.0E+17	N
5	Emitter	In(x)Al(1-x)As	0.522	150	Si	5.0E+17	N
4	Base	GaAs(1-x)Sb(x)	0.513	400	C	4.5E+19	P+
3	Collector	InP		2,000	Si	3.0E+16	N
2	Subcollector 1	InP		500	Si	5.0E+18	N
1	Etch stop	In(x)Ga(1-x)As	0.532	2,000	Si	3.0E+19	N+
	Substrate						

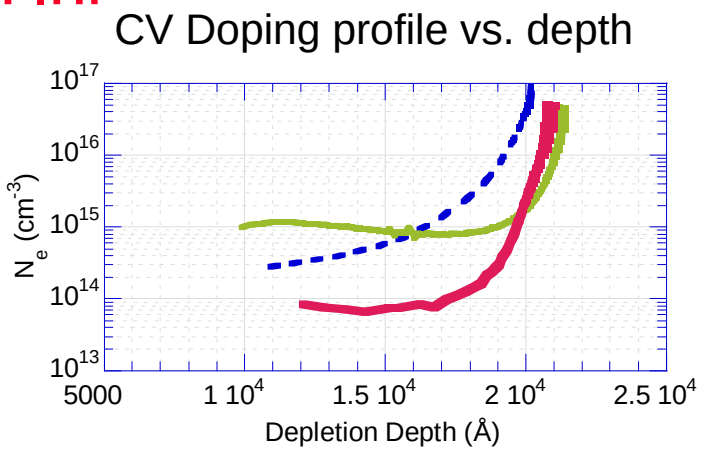
- *Current Gain*
  34.3 @ 10A/cm2,
  36.6 @ 100A/cm2,
  38.1 @ 1kA/cm2
- *Base Rbs (TLM)*
  885.9 Ohm/sq
- *Current cross-over*
  < 1.0E-9 A
- *nc = 1.10; nb = 1.29*





Low Intrinsic Background InGaAs on InP





P+ layer (InP)

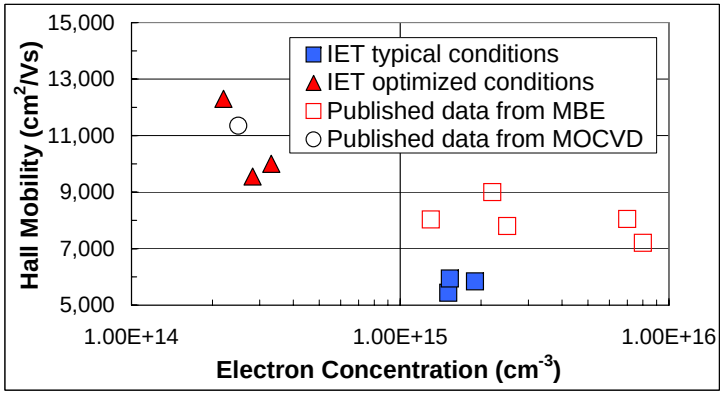
i-layer (2um InGaAs)

N+ layer (InP)

InP substrate

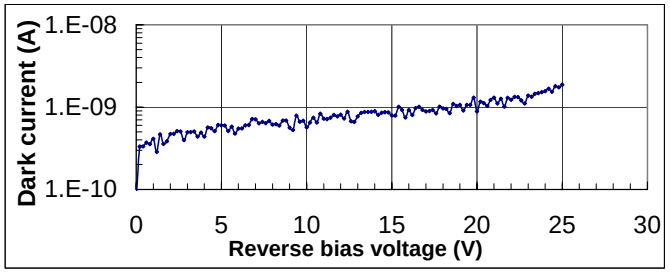
Intelli*EPI's optimized MBE PIN advantages:*

- *Nearly depleted at 0V bias*
- *Background doping level better than MOCVD*
- *Intrinsic InGaAs mobility from 10 – 12x10³ cm²/V·sec*



High Speed InGaAs/InP PIN Photodetector from MBE

Dark Current



3 dB Bandwidth @ 1550 nm

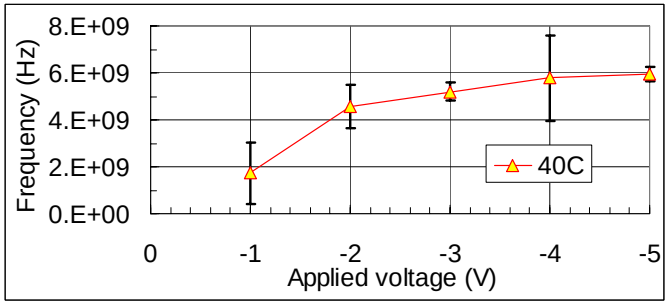
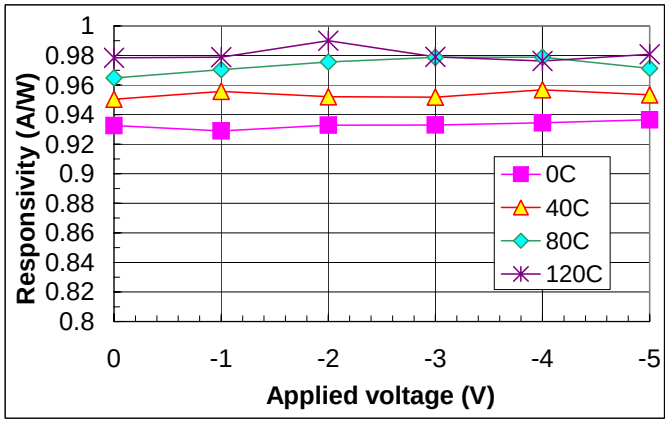
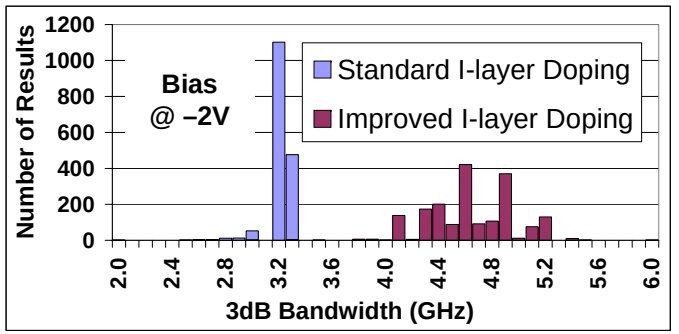


Photo response @ 1550 nm

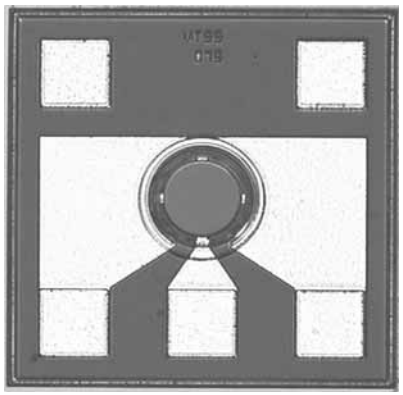


Data Courtesy of *VITESSE*

3 dB Bandwidth Histogram Across 4" Wafer

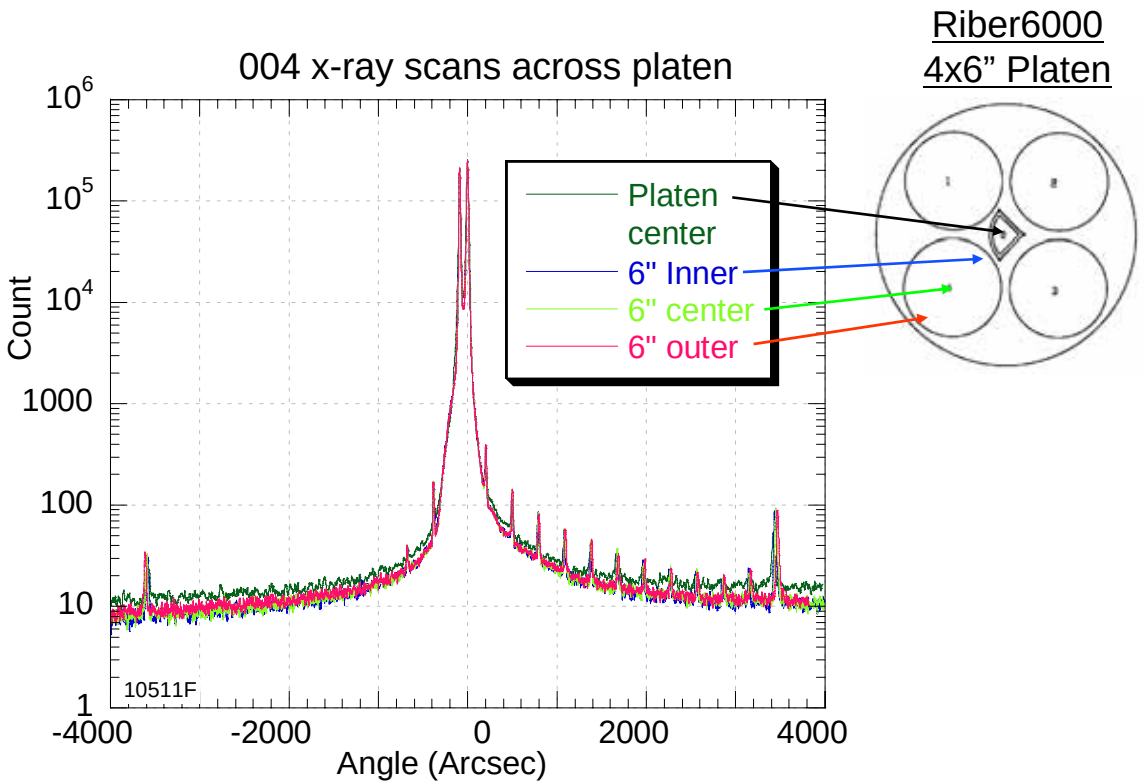


75 µm Diameter Active Area



- *Average 3 dB bandwidth of ~ 4.6 GHz @ –2V*
- *Dark current well below 1 nA @ –2V*

IntelliEPI: QWIP Production Experience

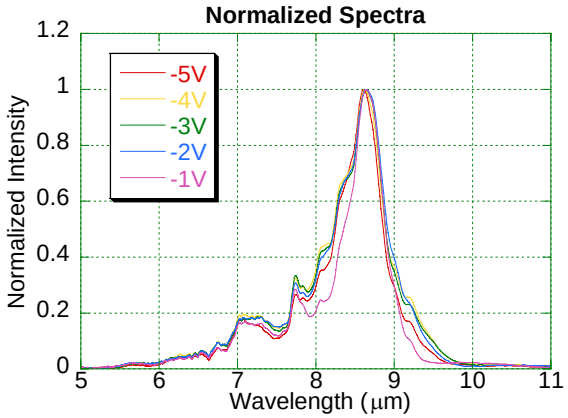


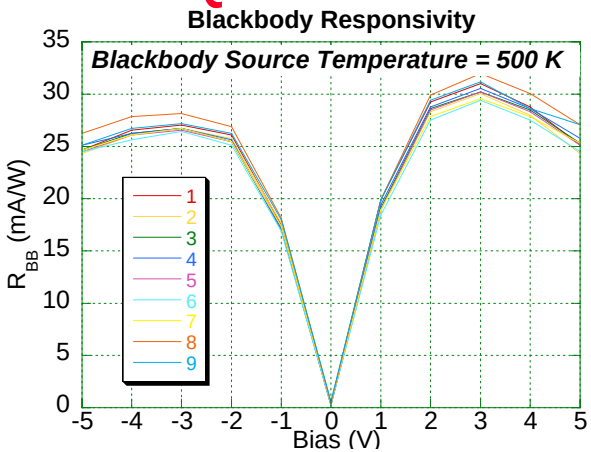
Courtesy of QmagiQ

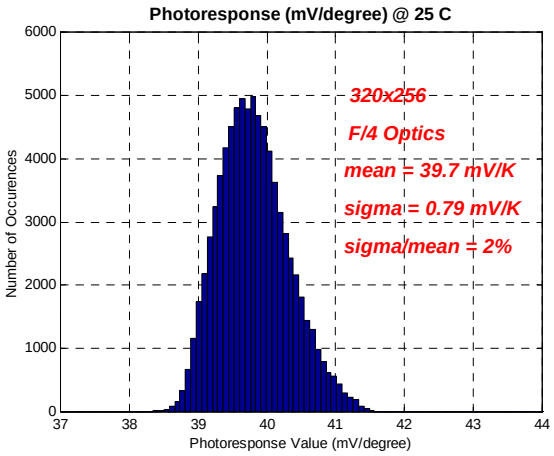
8.6 µm thermal image taken with large format 640x512 QWIP FPA IntelliEPI. Die size ~16x13 mm^2.

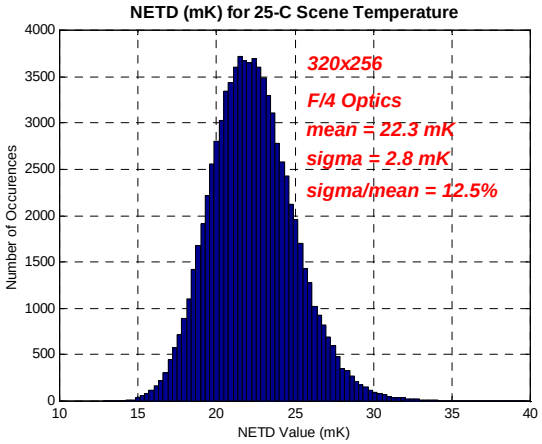
- *Stability of growth rate during long repeated structure as indicated by narrow x-ray peaks*
- *Excellent interface and materials quality as indicated by sharp x-ray peaks*
- *±0.5% thickness uniformity across 6 inch diameter wafer based on x-ray*
- *Achieved 100% pixel yield with 320x256 format FPA*

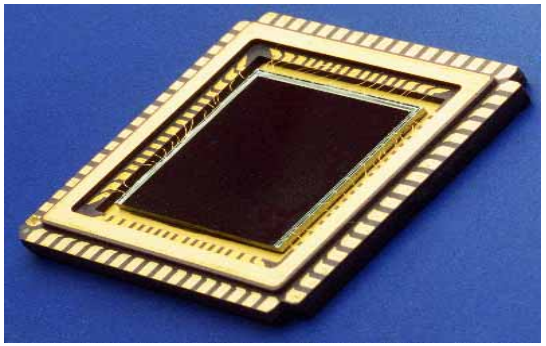
IntelliEPI: Device Data for QWIP FPA











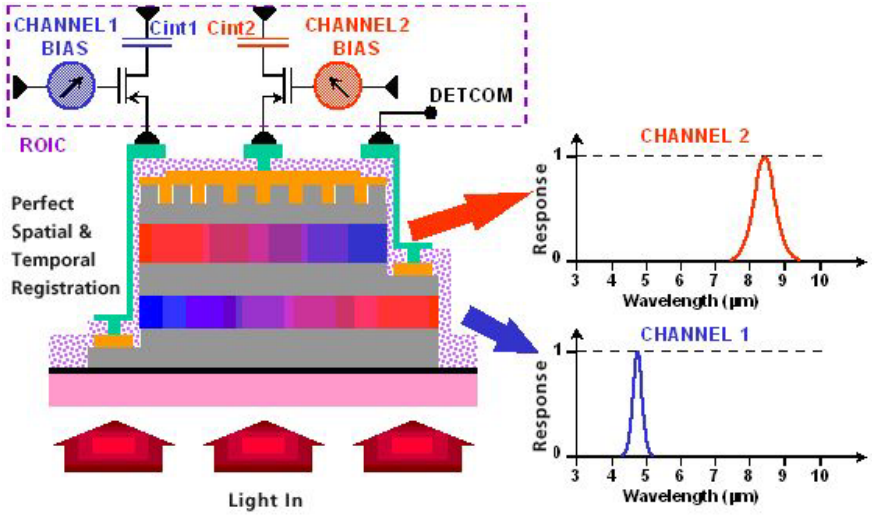
- *320x256 and 640x512 formats*
- *LWIR band, 8.6-mm peak wavelength*
- *Optical response uniformity ≈2%*
- *Average NEDT less than 25 mK at F/4*
- *Operability greater than 99.8%*

Data Courtesy of QmagiQ

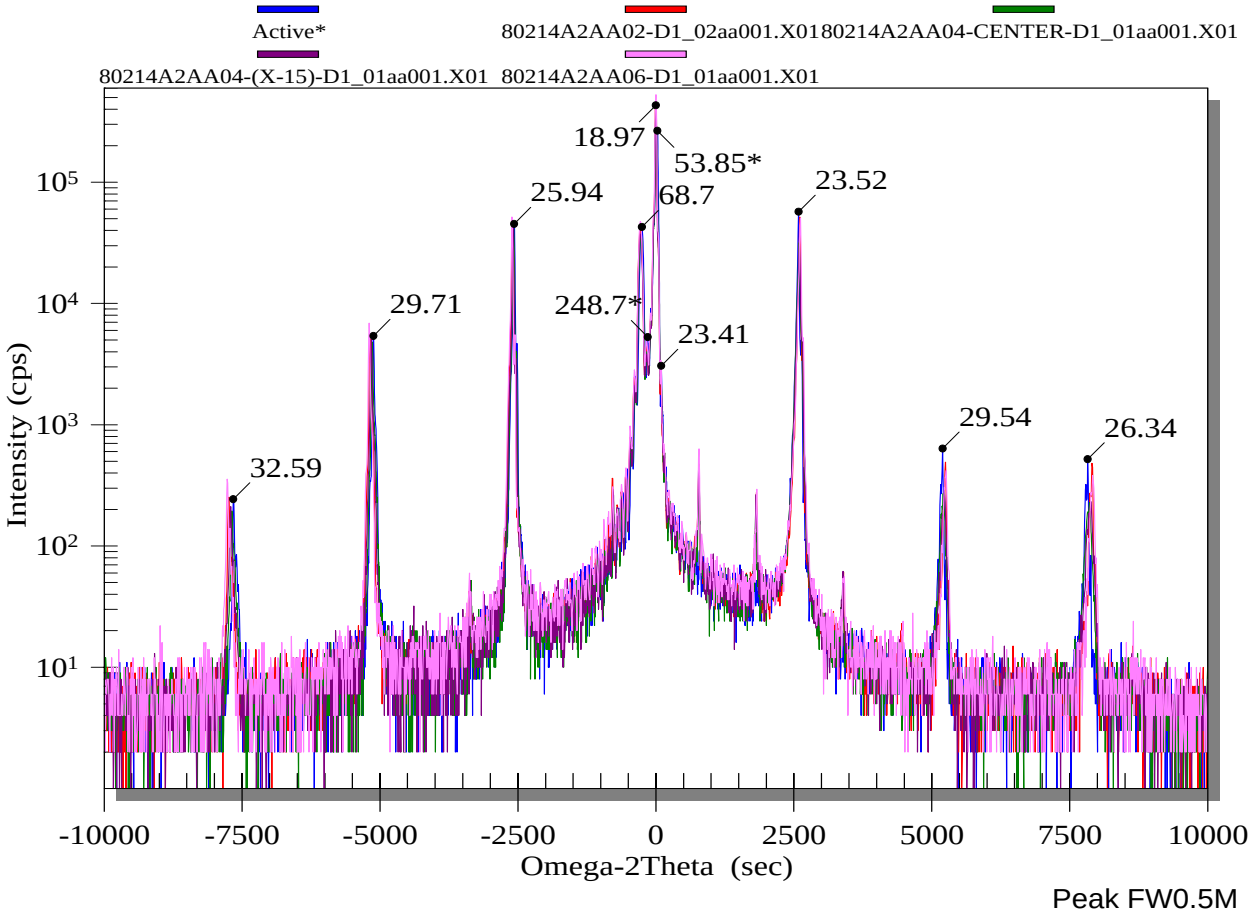
Intelli*EPI*: Dual-color QWIP

Data Courtesy of QmagiQ

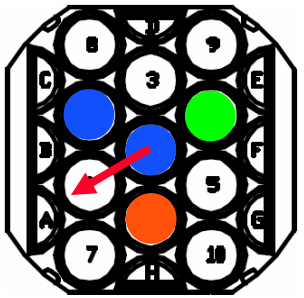
- *2-color per pixel in 320x256 format*
- *Dual-band for MWIR and LWIR*
- *Epi materials on 6" GaAs*



Intelli*EPI:* InAs/GaSb SLS Growth for LWIR Applications



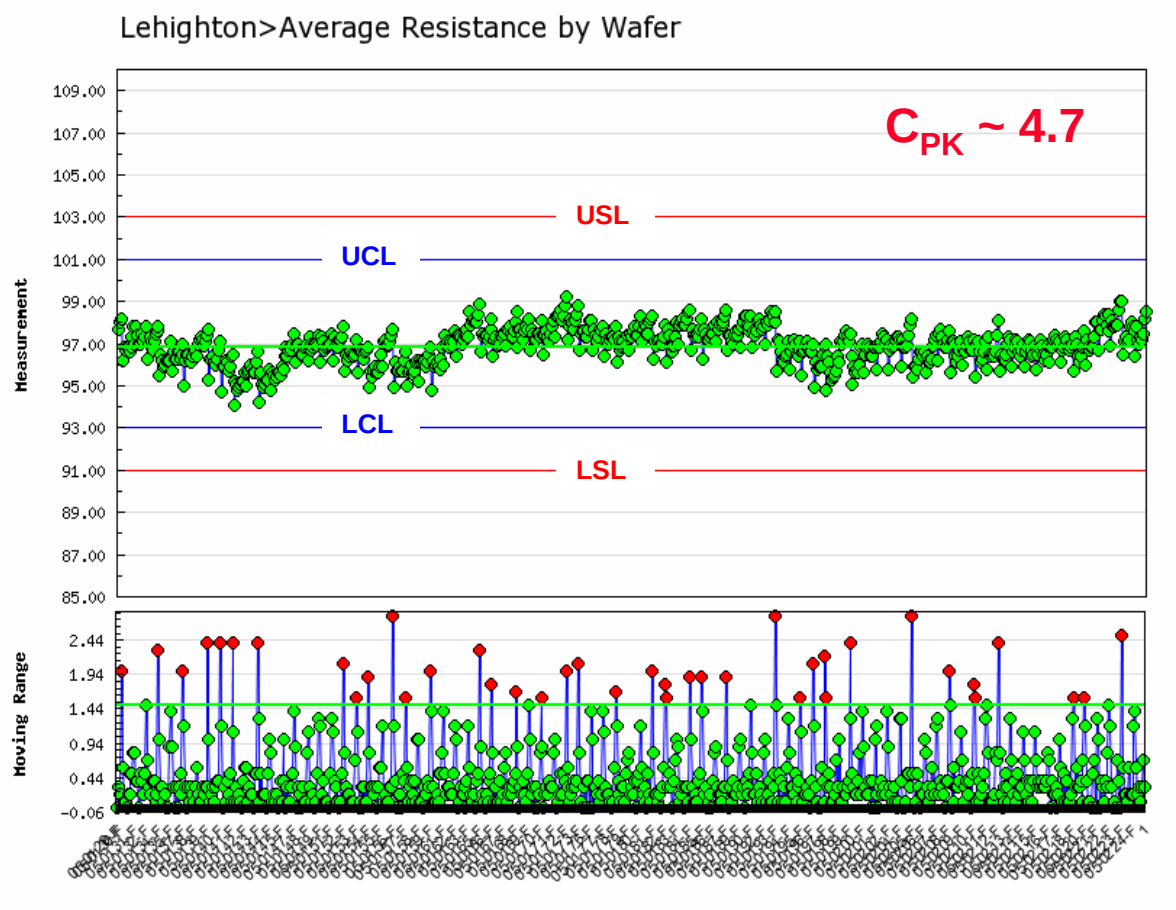
X-ray data across 2” Platen



- **Wafer Tech**
- **IntelliEPI polished**
- **Galaxy**

- *QmagiQ design InAs / binary GaSb SL for long wavelength (LW) IR detection*
- *SL FWHM < 30 arc sec, SL0 peak mismatch < 16 arc sec*
- *Thickness uniformity from center to inner ring within ± 1%*

IntelliEPI: Quality Management System



SPC chart of contactless sheet resistivity mapping during PHEMT production

- *ISO9001:2000 certified since March 2007*
- *Utilize SPC for volume production tracking/control*

IntelliEPI: Summary

IntelliEPI's real-time sensors monitor growth and maintain reproducible conditions

- Non-invasive; early identification of problems during run: immediate feedback
- Yield improvement, fast product development and delivery

IntelliEPI developed advanced MBE growth technology and materials

- High volume GaAs product such as PHEMTs for handset switch applications
- High performance InP based HBTs and PINs for fiber optical applications

IntelliEPI provides 100% customer satisfaction guaranty