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InGaAs and GaInNAs(Sb) Advanced LIGO Photodiodes

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Solid State Research Lab, Stanford University

LSC Meeting – LHO

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LIGO-G050435-00-Z

Outline

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- Introduction
  - AdLIGO Photodiode Specifications
  - Device Materials
  - Device Design
- GaIn(N)As(Sb) Materials & Device Results
- Conclusion

Advanced LIGO Schematic

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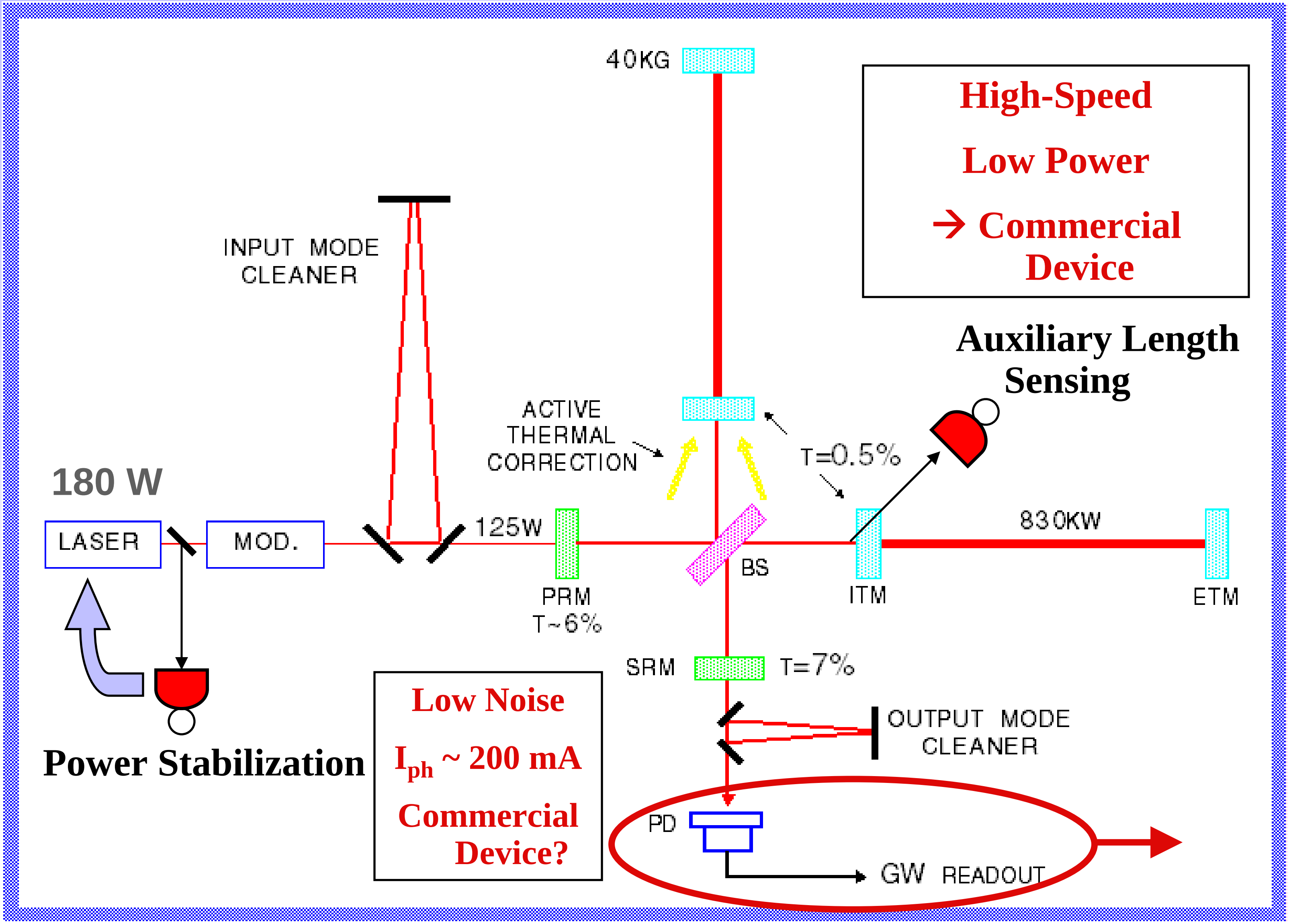

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LIGO AS-Photodiode Specifications

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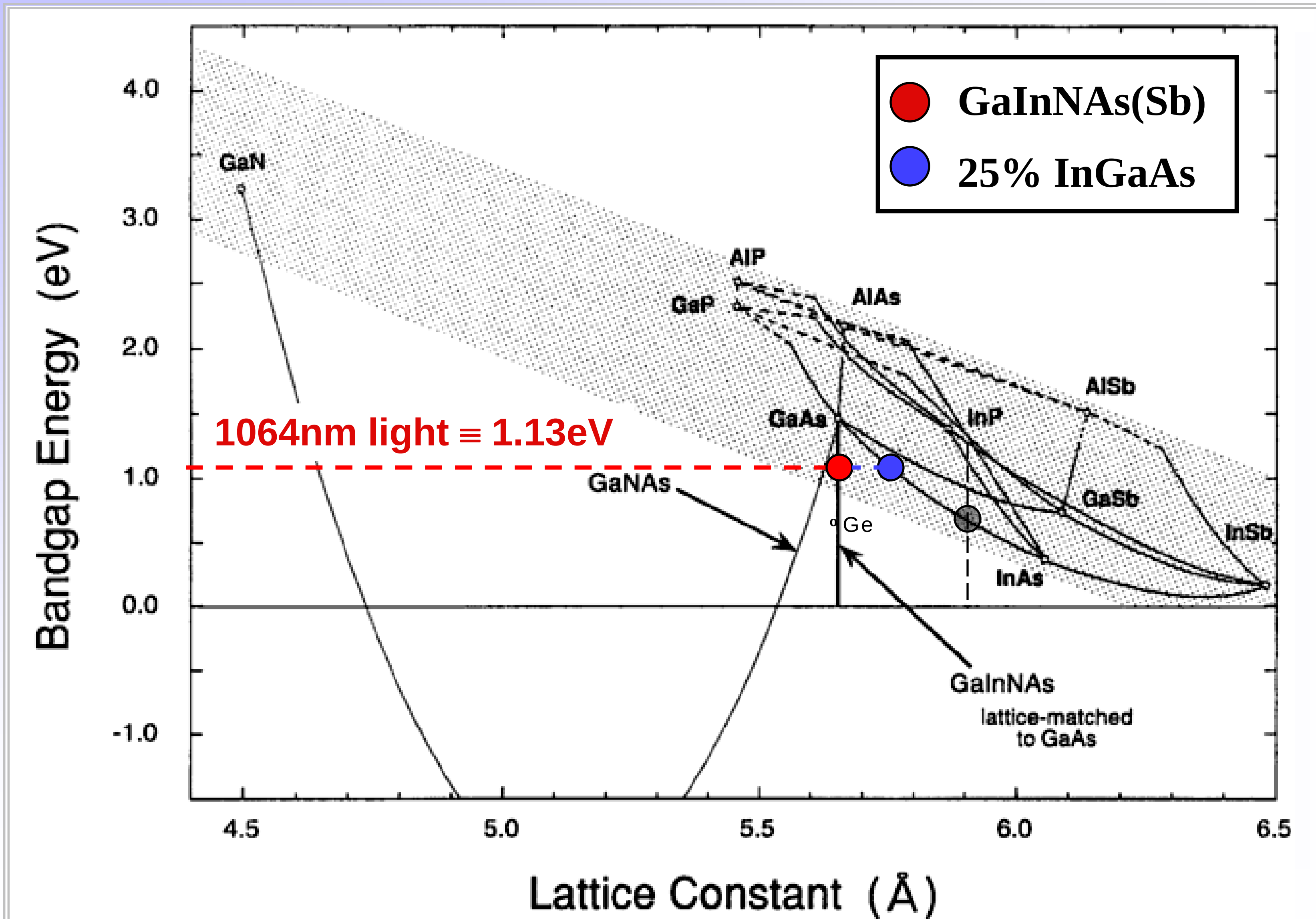
	I-LIGO	Advanced LIGO	
Detector	Bank of 6PDs	DC - Readout	RF – Readout
Steady-State "Power" (mW)	600	30 – 100	← *(same as DC)*
Operating Frequency	30 Mhz	100 kHz	200 MHz
Quantum Efficiency	> 80%	> 90%	← *(same as DC)*
Damage Threshold (MW/cm^2)	< 5	< 50	← *(same as DC)*

1 eV Materials: InGaAs & GaInNAs



Metamorphic-InGaAs vs. GaInNAs Double Heterostructres

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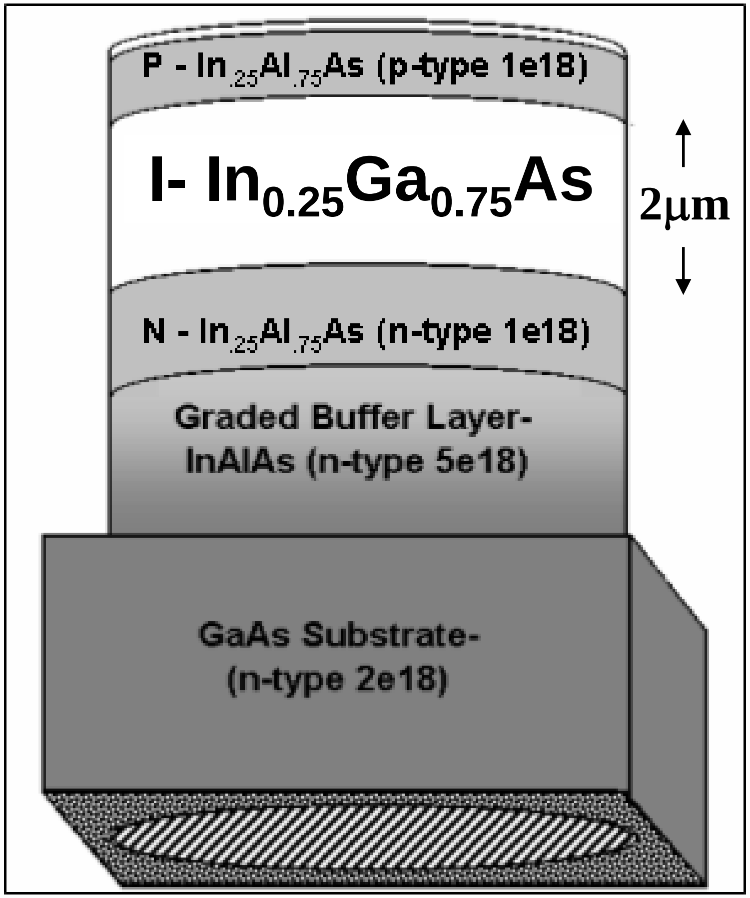

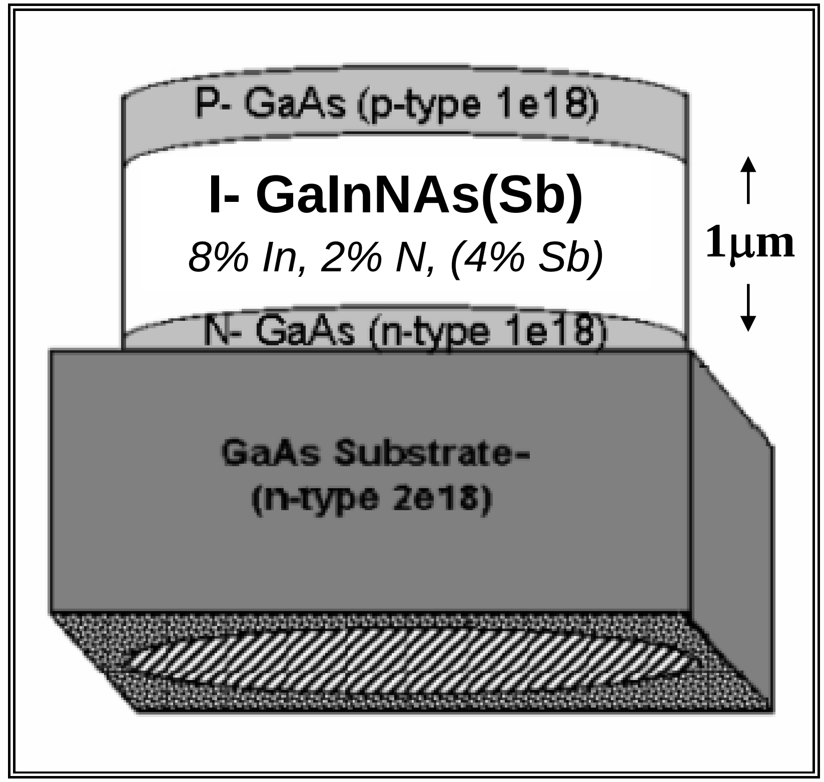

- GaInNAs(Sb) MBE growth with RF-Plasma source for N
- Sb surfactant effects improve thin strained nitride films

Back-Illuminated Photodiodes

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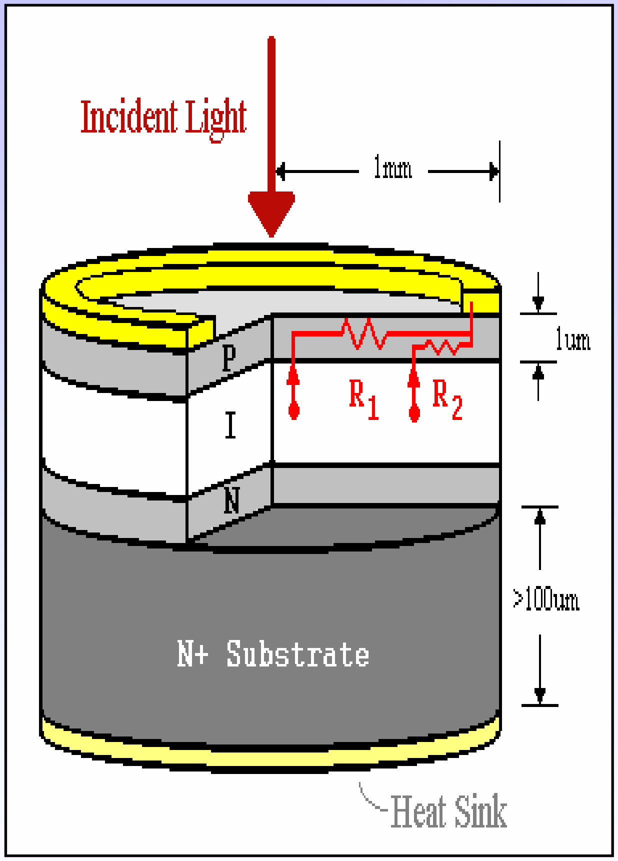
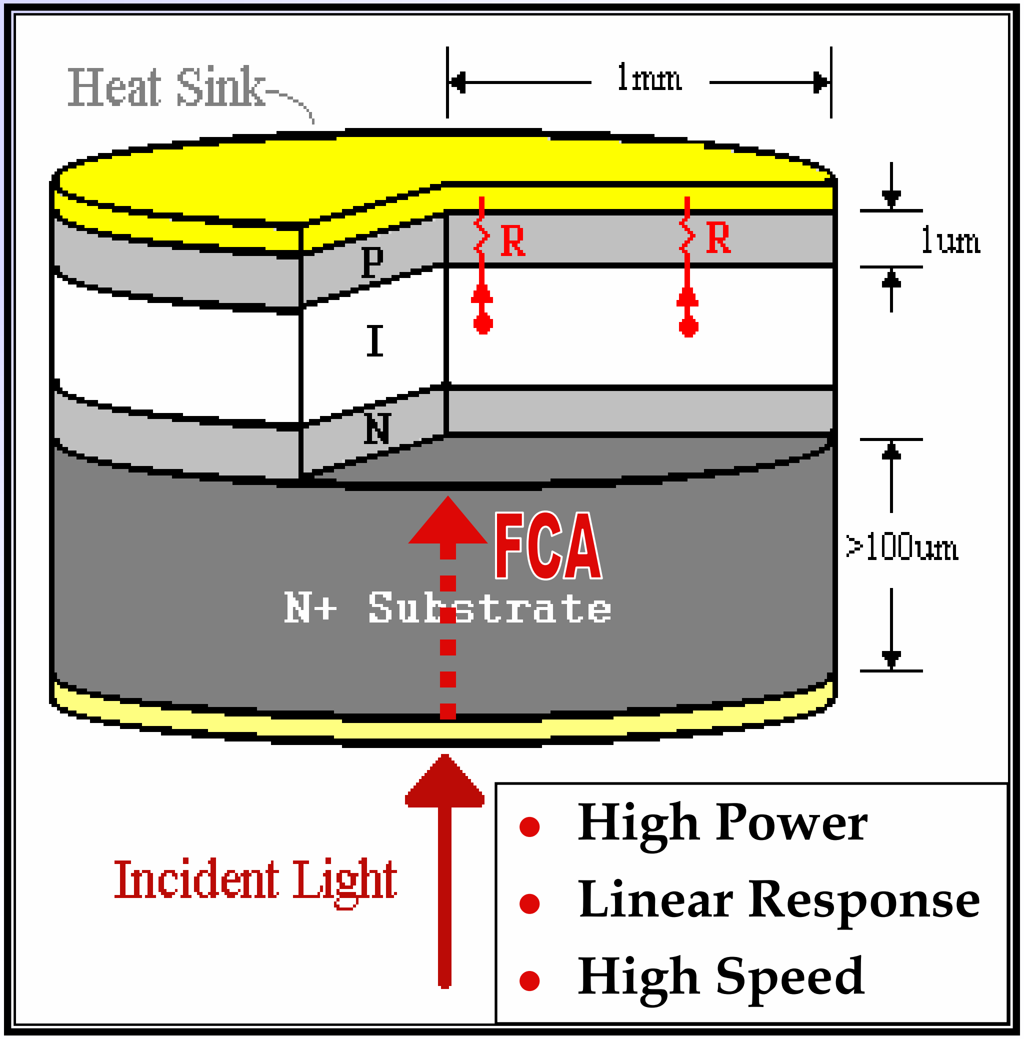


Conventional PD

Adv. LIGO Back-Illuminated PD



- High Power
- Linear Response
- High Speed

Outline

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- Introduction
- GaIn(N)As(Sb) Materials and Device Results
  - Materials Characterization Summary
  - Dark Current
  - Bandwidth
  - Quantum Efficiency
  - Saturation Power Level
- Conclusion & Future Work

Materials Characterization Summary

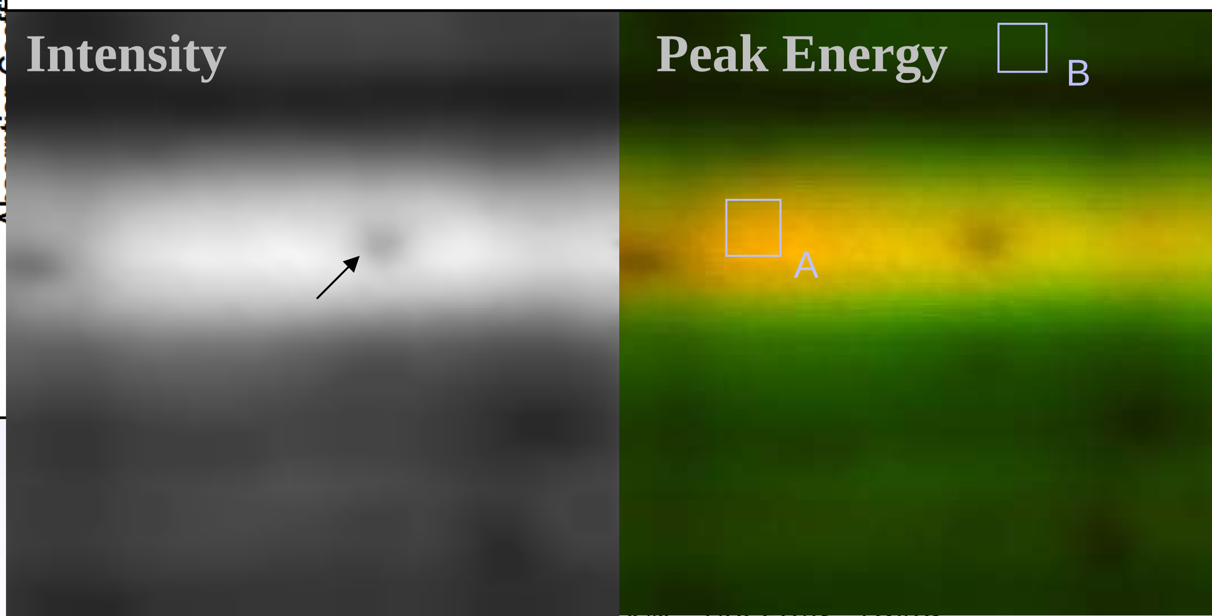
Absorption

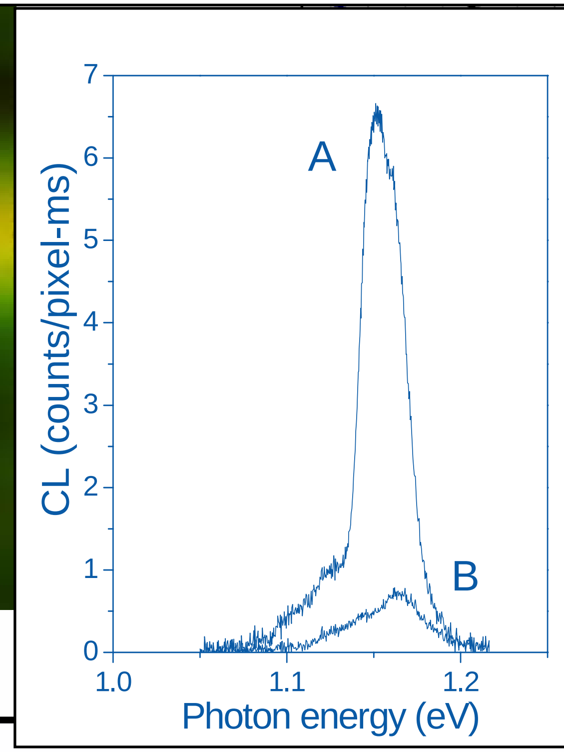
Deep-Level Transient Spectroscopy (DLTS)

pectra

Spectral Cathodoluminescence (CL) Imaging

to determine Threading Dislocation Density (TDD)

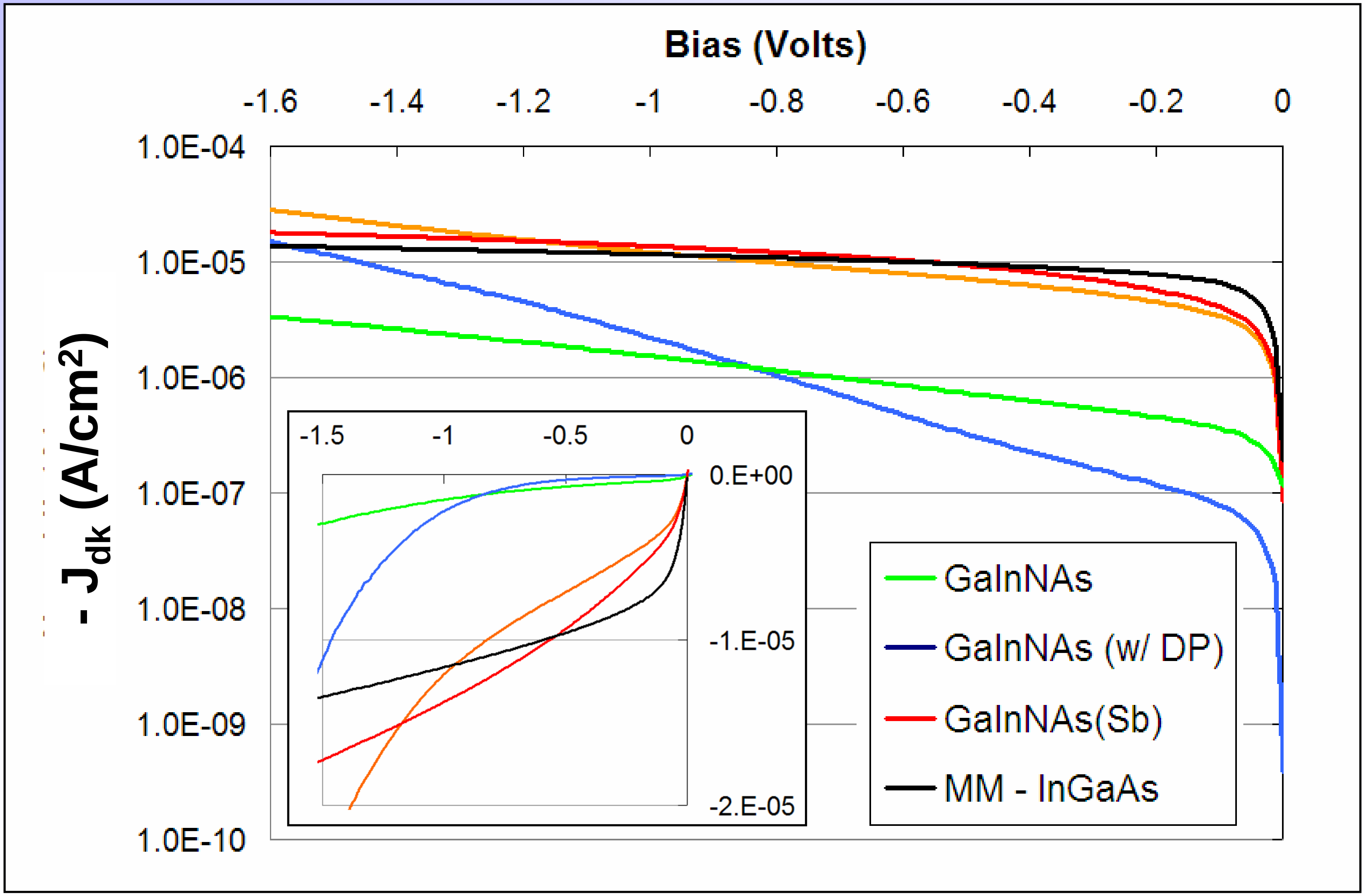




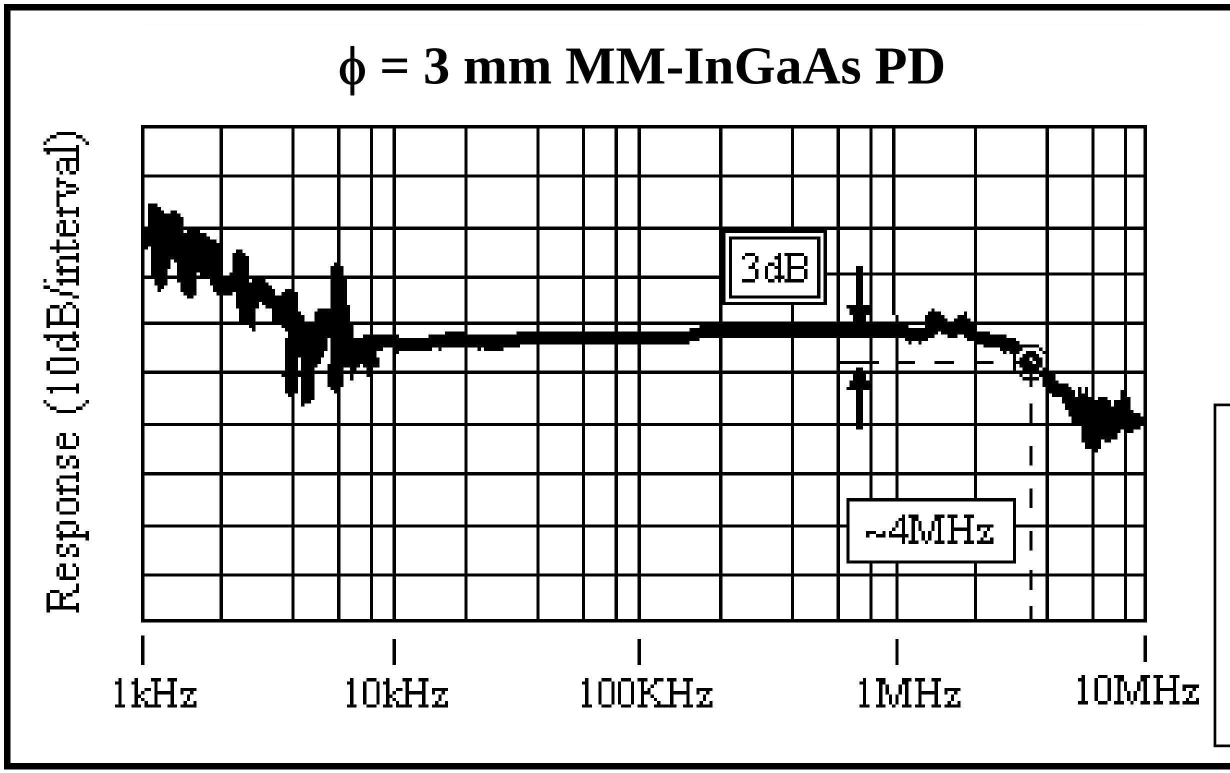
GaInNAsSb (w/ D.P.)

OBSERVE TRAPS IN THIS REGION

Dark Current Density: GaIn(N)As(Sb) Devices



MM-InGaAs: 3dB Bandwidth



BW ~ 1/RC

BW > 200 MHz

ϕ = 400 μm

P_{sat} ~ 10 mW

AdLIGO PD Specifications:

3-dB Bandwidth	***Sat. Power***
DC-Scheme: 100 kHz	***30 – 100 mW***
RF-Scheme: 200 MHz	

AdLIGO RF-Readout Challenging for PDs!

InGaAs & GaInNAs PDs – IQE (w/ FCA & Incomplete Absorption)

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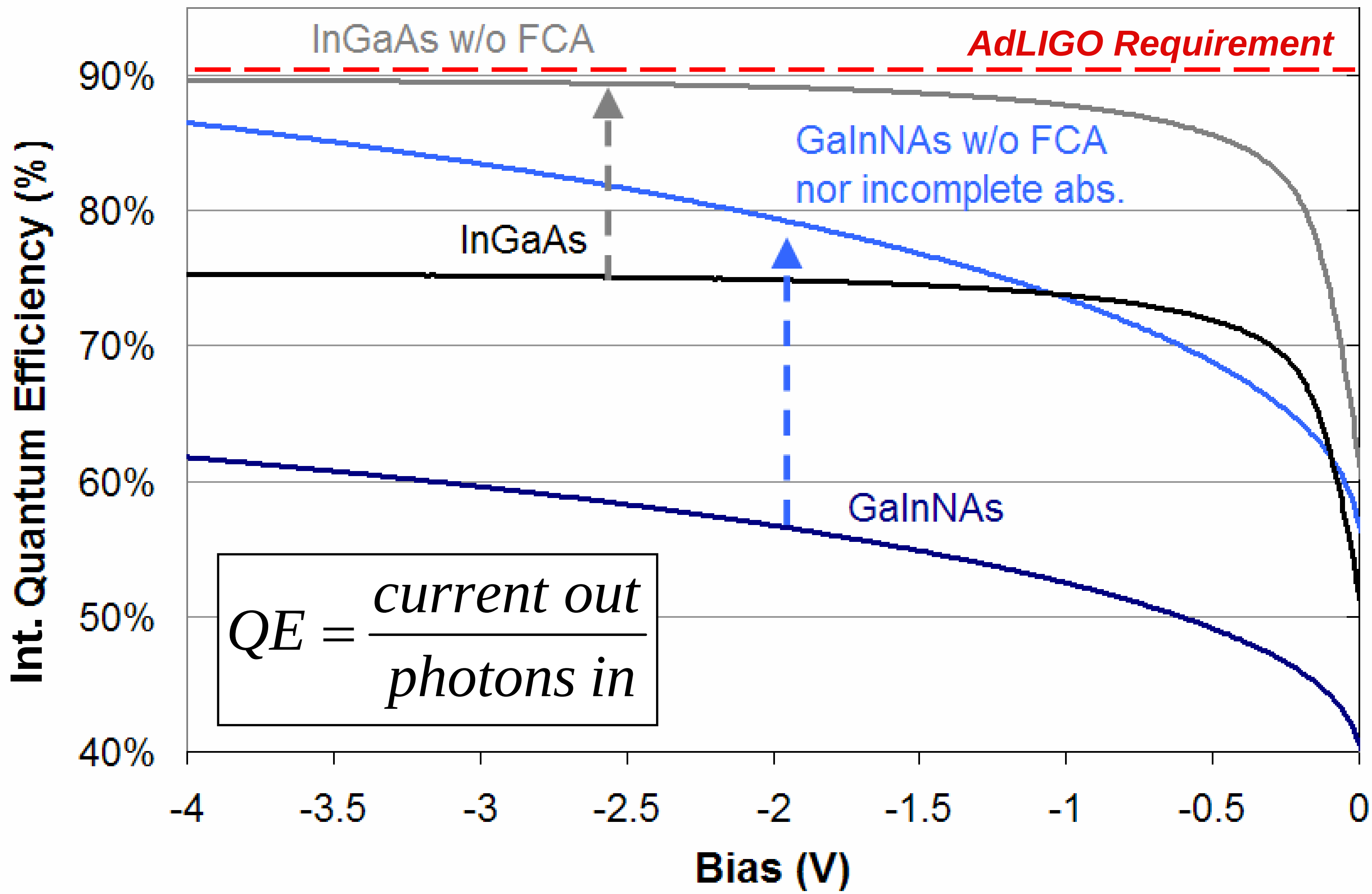
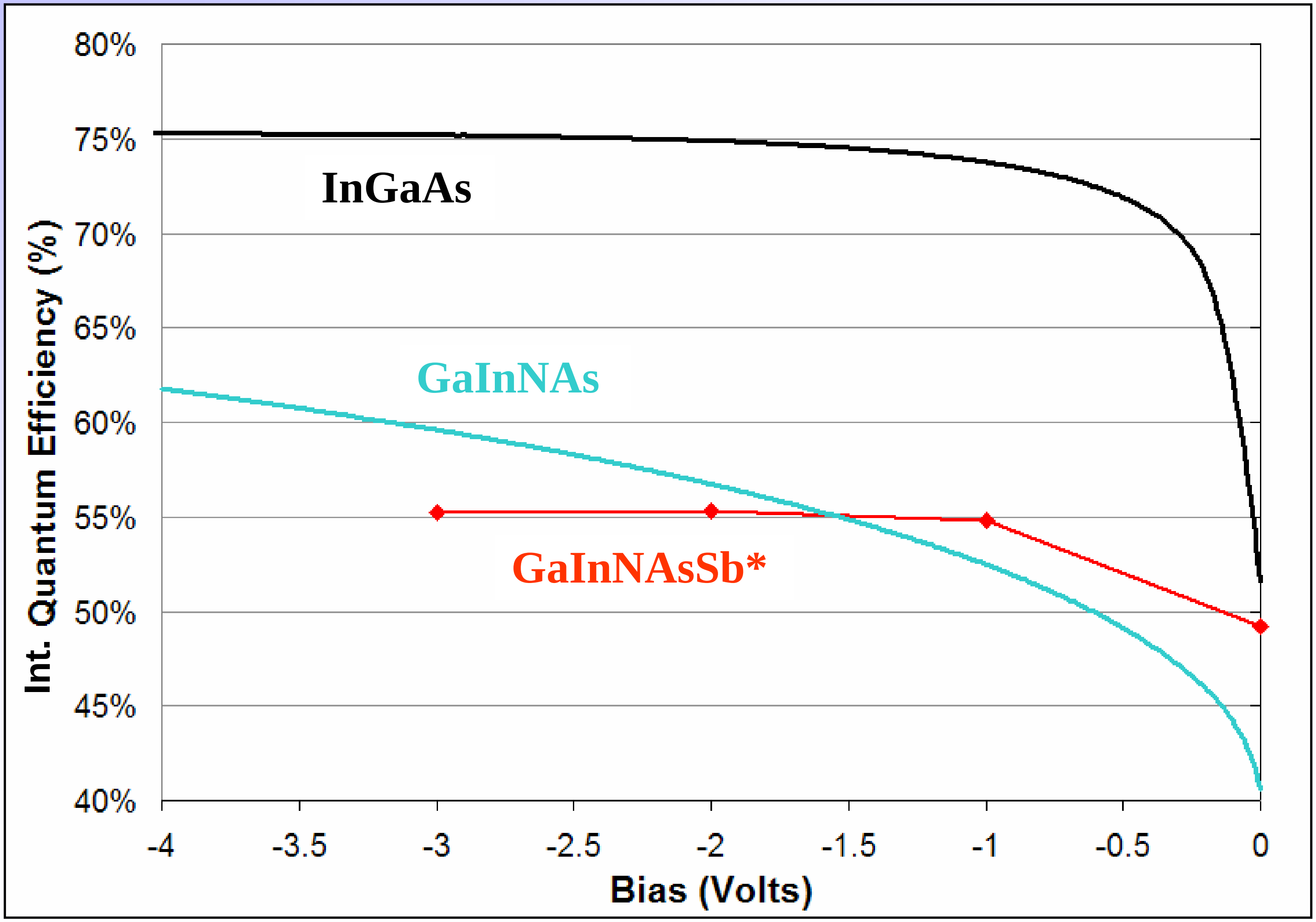


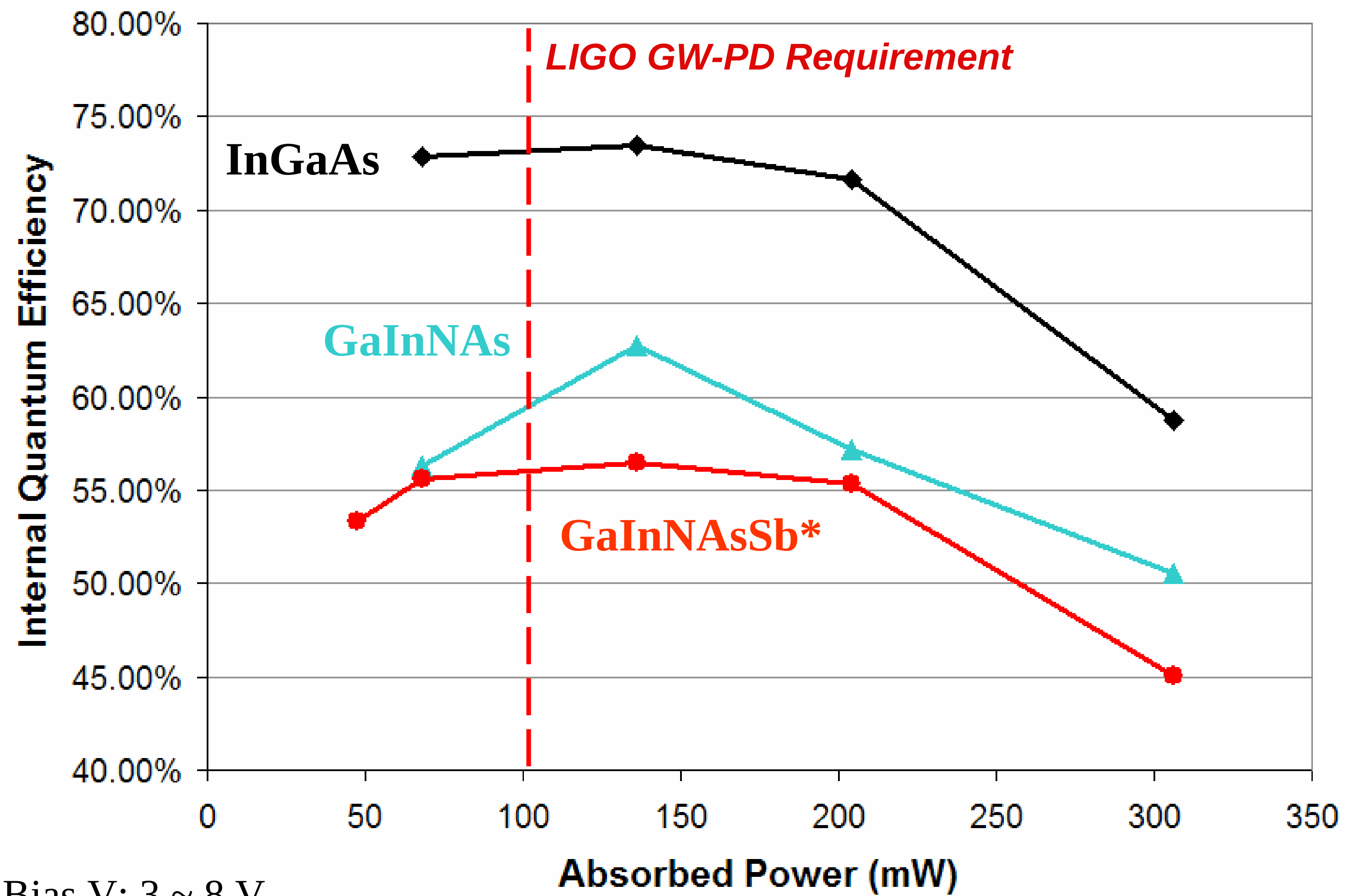
$$QE = \frac{current\ out}{photons\ in}$$

GaIn(N)As(Sb) PD QE



(* scaled to account for FCA in thick substrates)

Photodiode Saturation Power



Bias V: 3 ~ 8 V

(* scaled to account for FCA in thick substrates)

Photodiode Results Summary

	Materials Parameters				Photodetectors	
	Abs. (%)	Relax. (%)	TDD (cm^{-2})	Trap Density (cm^{-3})	IQE (%)	J_{dk} ($\mu A/cm^2$)
MM- InGaAs	96%	88.9	1e7	2.0e13	75%	~ 10
GaInNAs	60%	4.3	~1e5	1.1e14	62%	~ 0.1
GaInNAsSb	80%	44.6	< 1e5	-	56% *(scaled)*	~ 1

Conclusion

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	AdLIGO AS-PD Specification	B-I PDs *Developed at Stanford*	F-I PDs *Commercial devices*
Saturation Power (mW)	30 - 100	~ 150	100 ~ 200
Quantum Efficiency	90 %	75 % *(→ 90 % w/ substrate removal)*	~ 90 %
Bandwidth (MHz)	100 kHz *(→ 200 MHz RF-scheme)*	4	1 ~ 10
Damage Threshold (MW / cm^2)	< 5 *(w/ 1 μs shutter & 1 mm spot)*	Modeling ~ 3 *(w/ 1 mm spot)*	Modeling ~ 0.4 *(w/ 1 mm spot)*

AdLIGO Photodiode Development: Future Work

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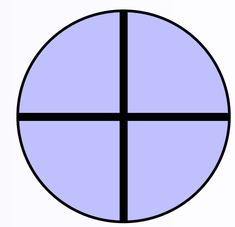
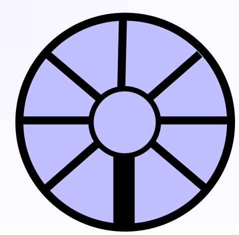
- **Substrate removal**
  - **→ 90 % QE**
- **High-Temperature Packaging**
  - **LLO or LHO Damage Threshold Tests?**
  - **Compatible with other experiments (GEO-600, MIT?)**
- **Surface Uniformity & Noise Characterization**
  - **GEO-600**
- **Multi-Element Sensors?**
  - **Additional pointing information**
  - **Spatial mode information**





- **Fabricate AdLIGO Photodiodes**

Acknowledgements

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- National Science Foundation (NSF); this material is based on work supported by the NSF under grants 9900793 and 0140297.
- Aaron Ptak, Manuel Romero and Wyatt Metzger at National Renewable Energy Labortatory (NREL) in Golden, CO
- Gyles Webster at Accent Optical in San Jose, CA

- Thank You

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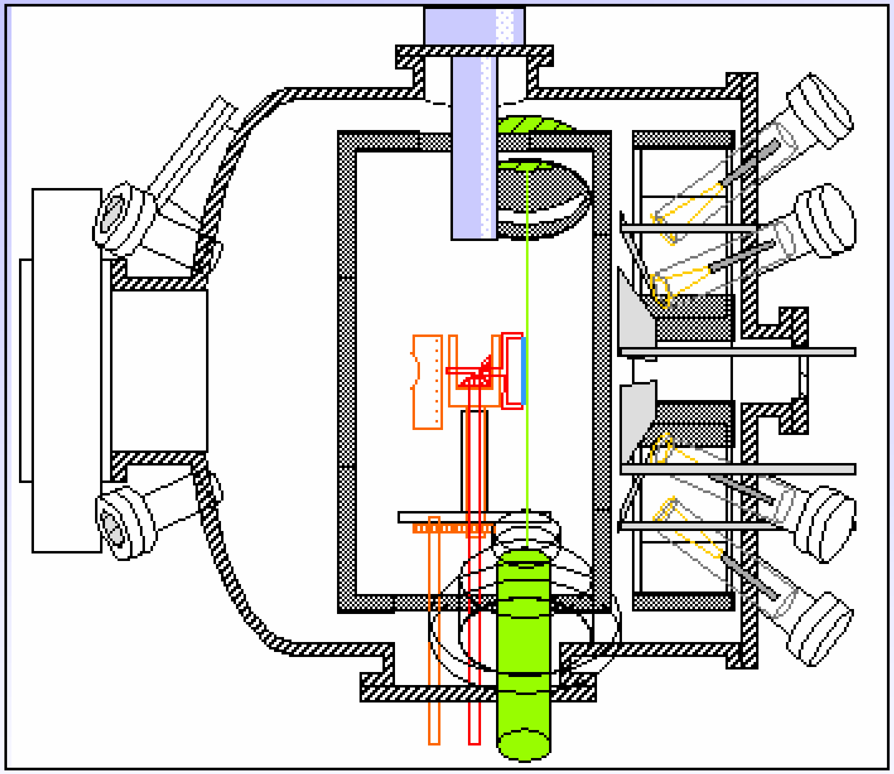
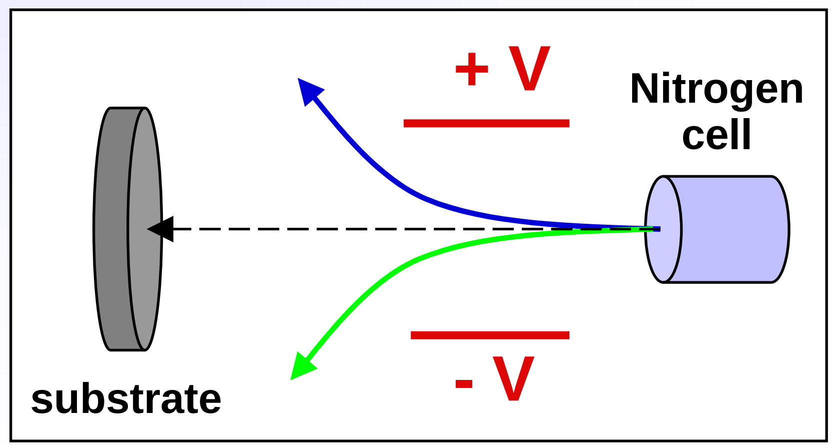
Extra slides

Molecular Beam Epitaxy (MBE)



- Effusion cells for In, Ga and Al
- Cracking cell for As and Sb
- RF-Plasma N cell



Deflection Plates (DP) on Plasma Source
→ protect growth surface from ion damage

Double-Heterostructure PIN Photodiodes

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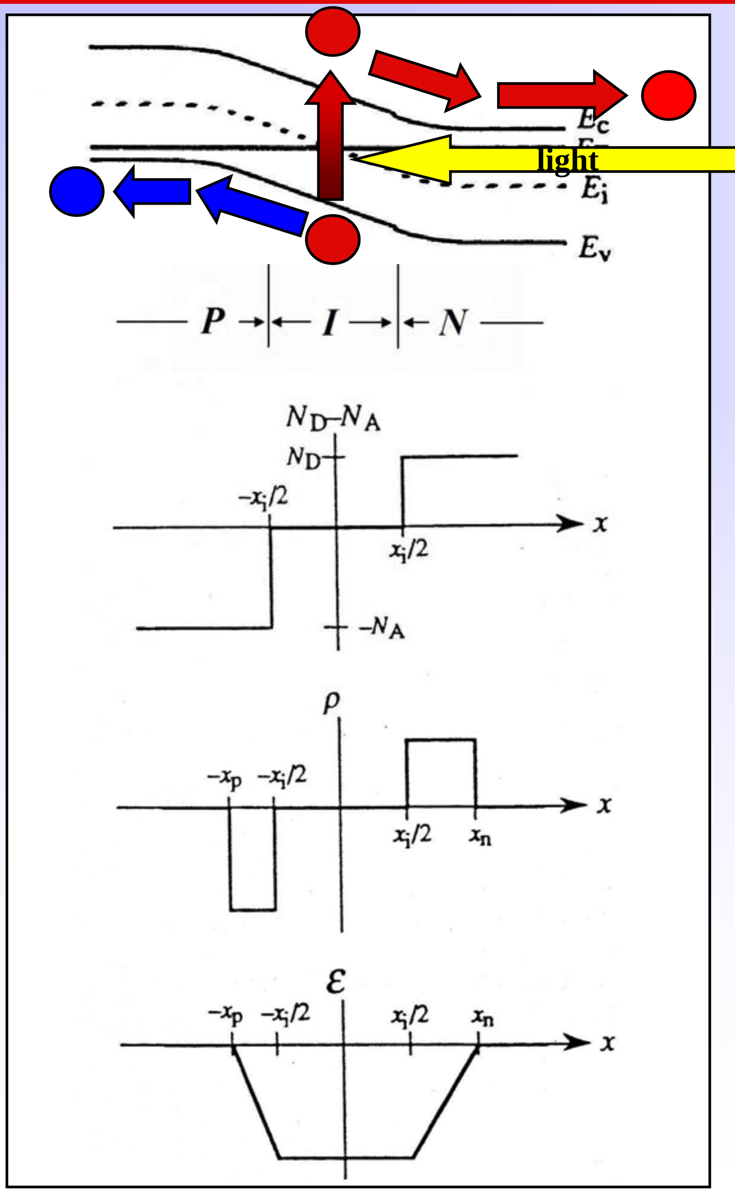
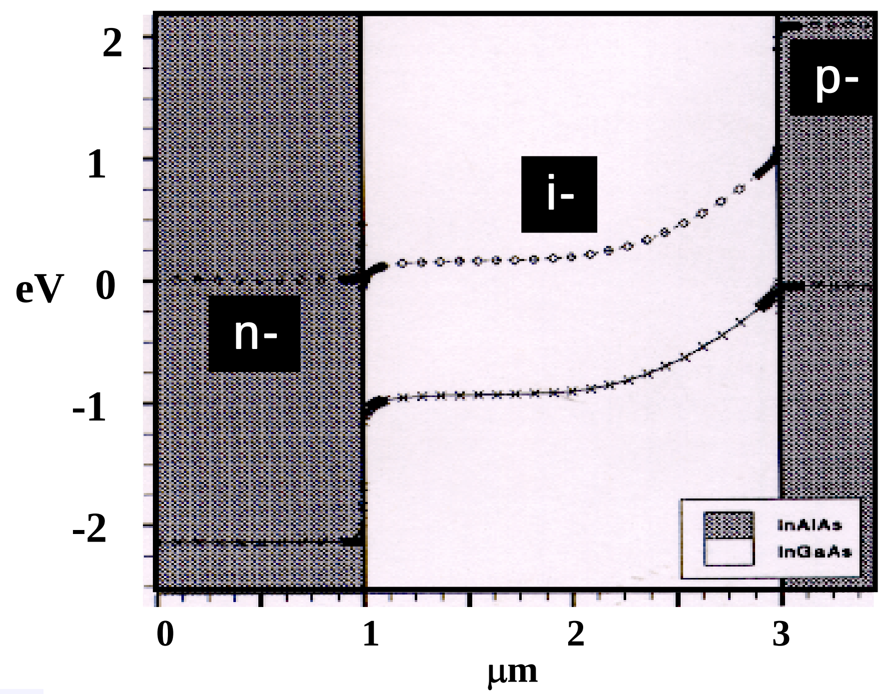
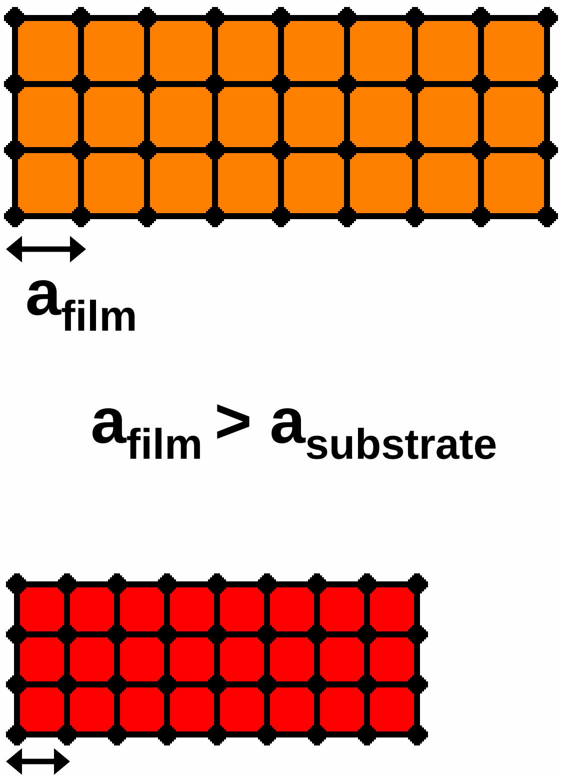




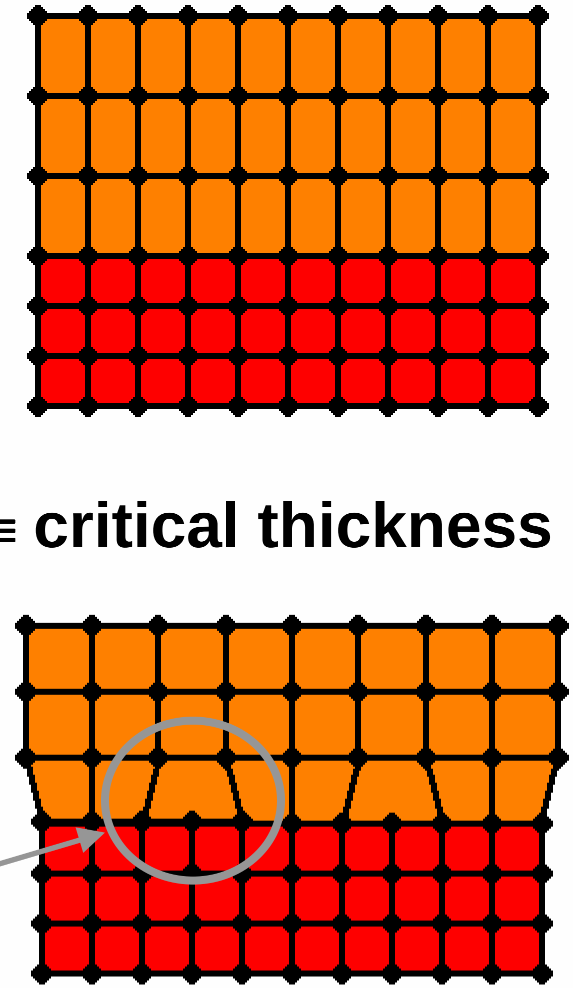
N- and P- transparent
→ Absorption occurs in I-region where E-field is large

InGaAs DH-PIN device simulated by ATLAS (Silvaco)

Lattice-Mismatched Epitaxy



$a_{film} > a_{substrate}$



$h_c \equiv$ critical thickness

misfit dislocation

Materials Results Summary

	PL Intensity (A.U.)	Relaxation (%)	Absorption (%)	TDD (cm^{-2})	Trap Density (cm^{-3})
MM- InGaAs	24.1	88.9	96%	1e7	2.0e13
GaInNAs	2.2	4.3	60%	~1e5	1.1e14
GaInNAs (DP)	8.5	-	70%	~3e5	-
GaInNAsSb	1.1	44.6	80%	< 1e5	-