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Advanced LIGO Photodiode Development

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Solid State Research Lab, Stanford University

LSC Meeting – LLO

March 22nd, 2005

LIGO-G050116-00-Z

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Outline

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- AdLIGO Photodiode Specifications
- Device Results
- Damage Threshold
- AdLIGO Devices
- Future Directions

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Advanced LIGO Schematic

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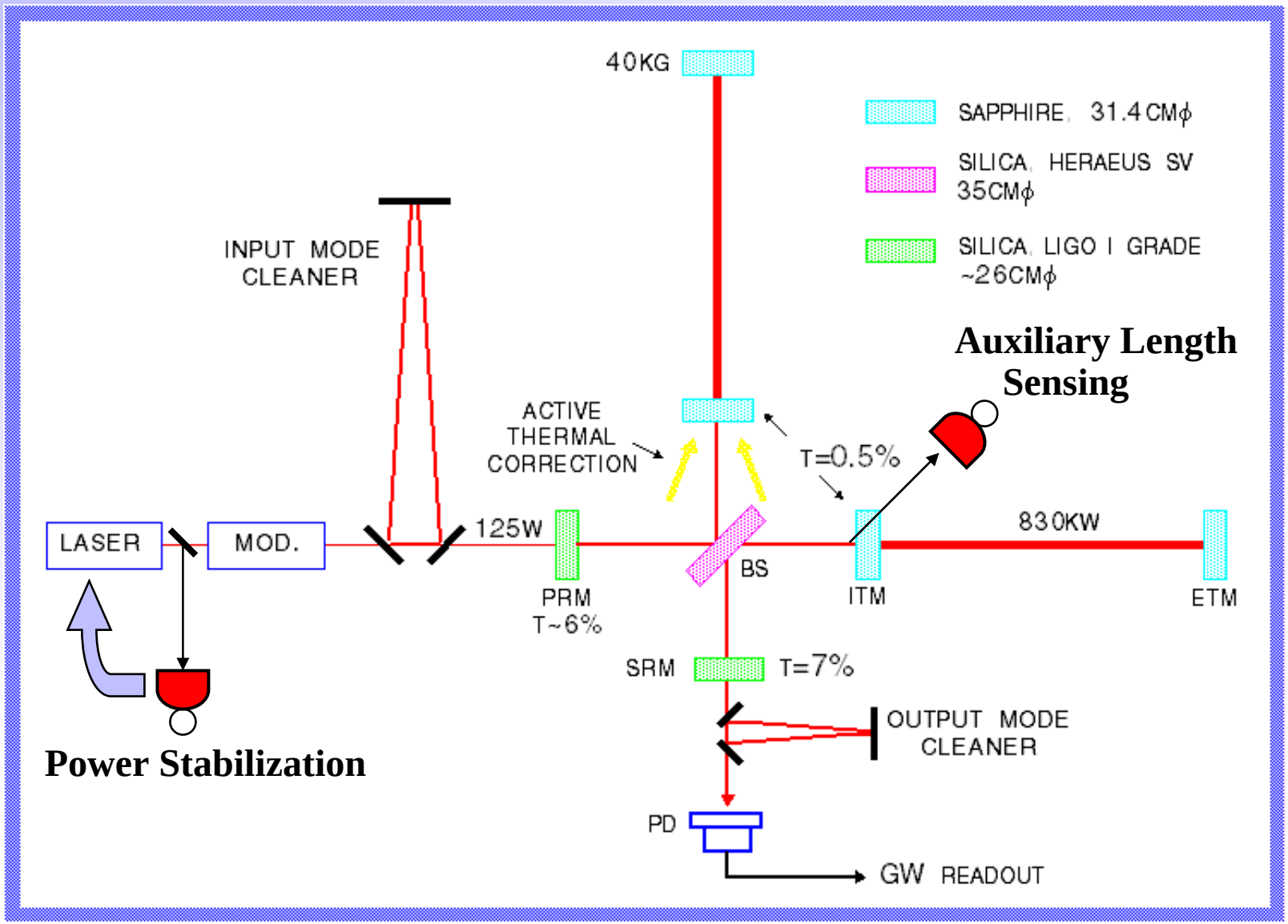


Photodiode Specifications

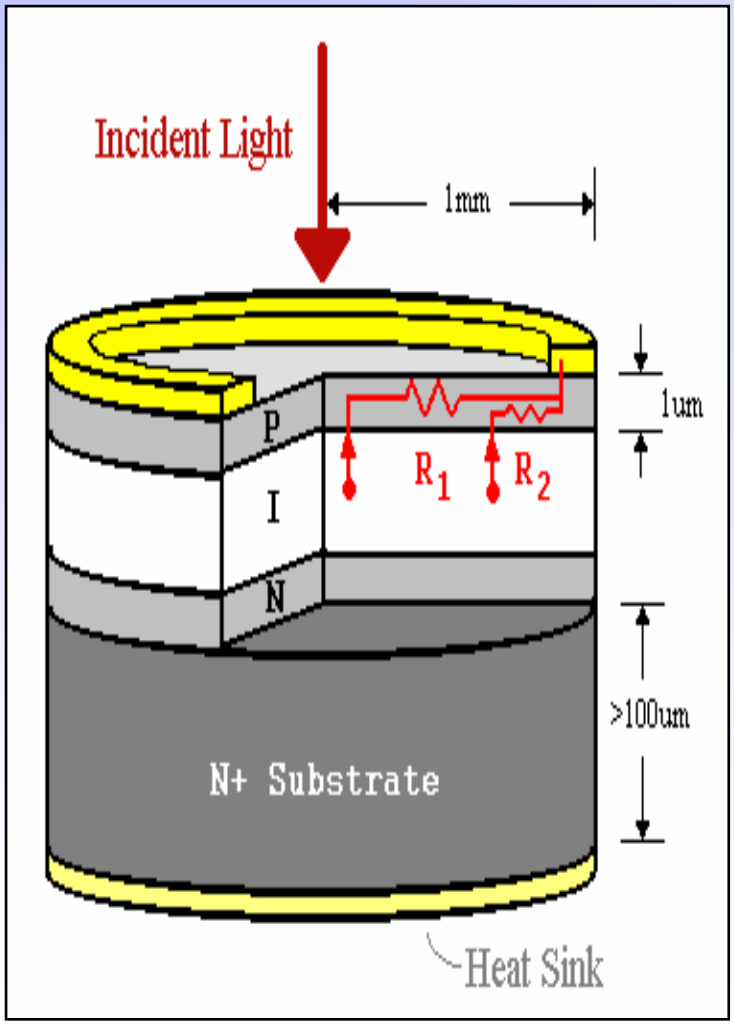
	LIGO I		Advanced LIGO	
Detector	**Bank of 6PDs**	**Power Stabilization**	**Aux. Length (RF) Detection**	**DC - GW Channel**
Steady-State "Power"	0.6 W	200 ~ 300 mA	10 – 100 mW	30 mW
Operating Frequency	~29 MHz	100 kHz	200 MHz	100 kHz
Quantum Efficiency	> 80%	η	> 80%	> 90%

(300mA)/(0.868A/W * 0.90 QE) = 385mW

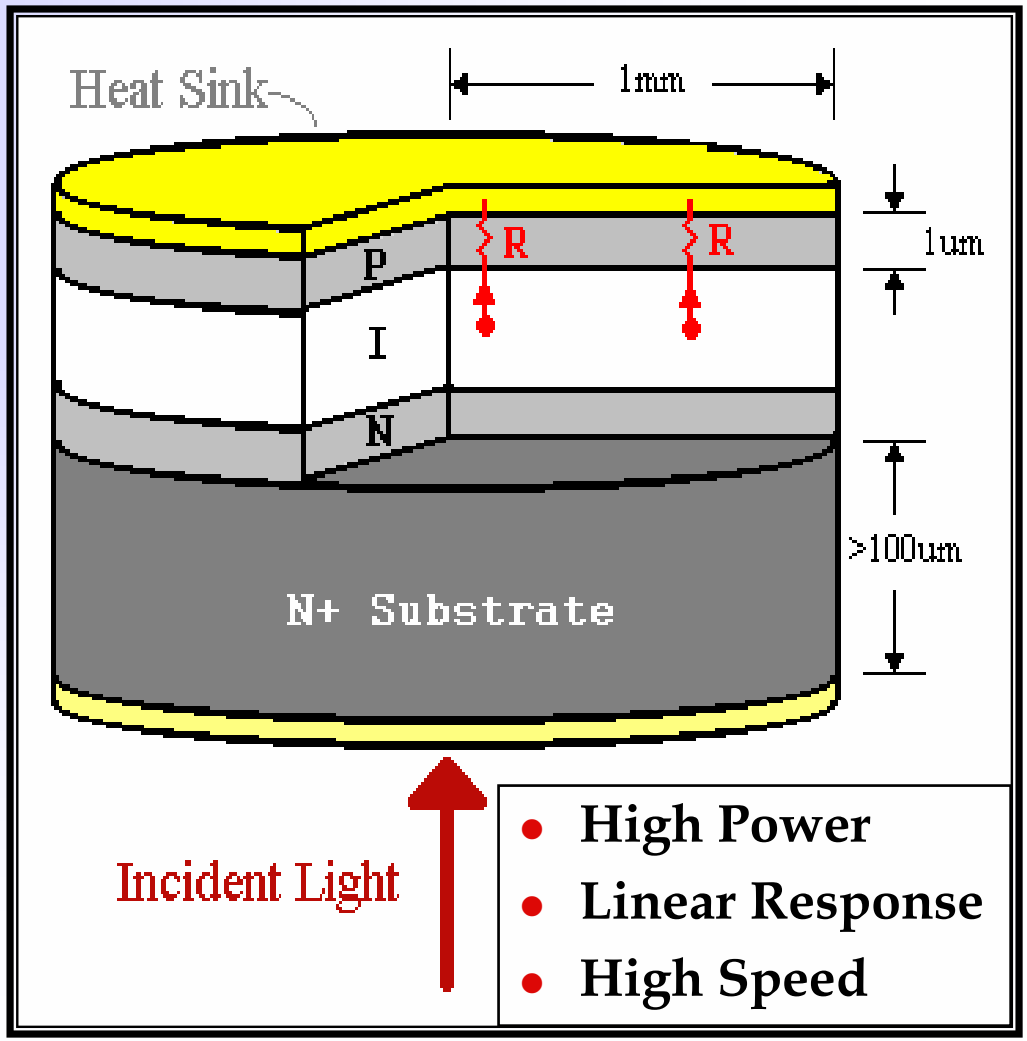
Resonating Tank Circuit

Trades w/ Sensitivity

Rear-Illuminated PD Advantages



Conventional PD



Adv. LIGO Rear-Illuminated PD

Materials Analysis – InGaAs/GaAs vs. GaInNAs/GaAs

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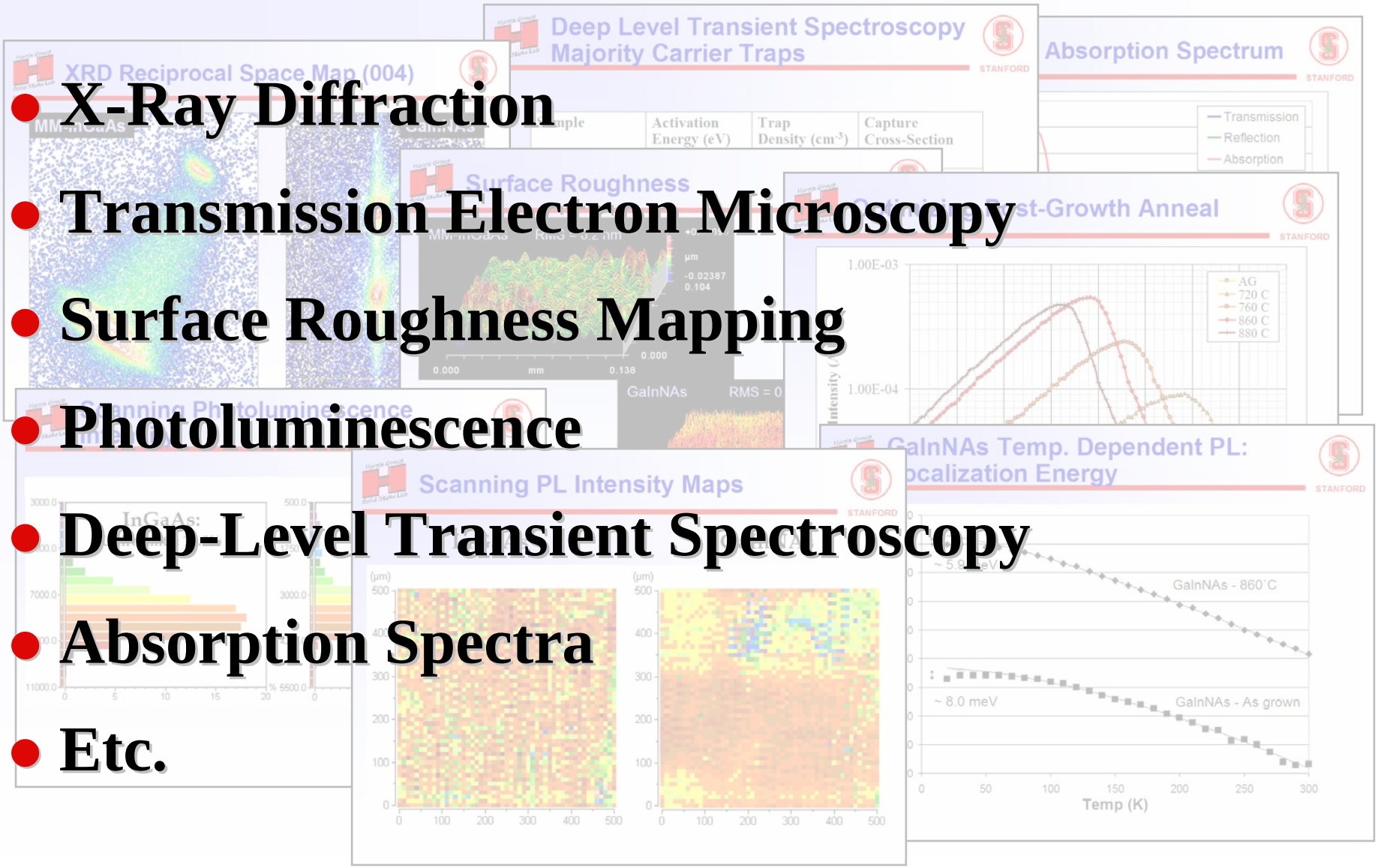
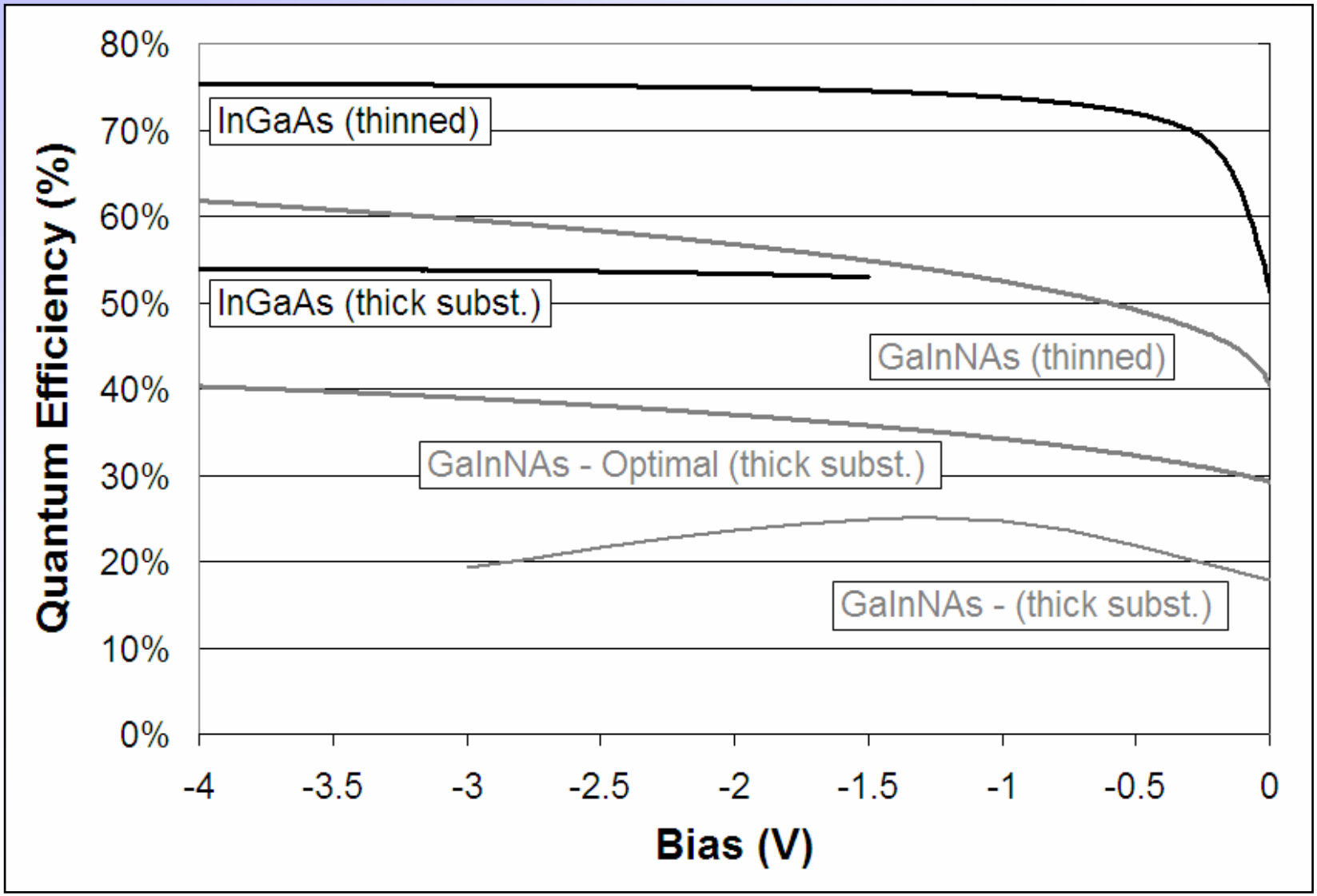
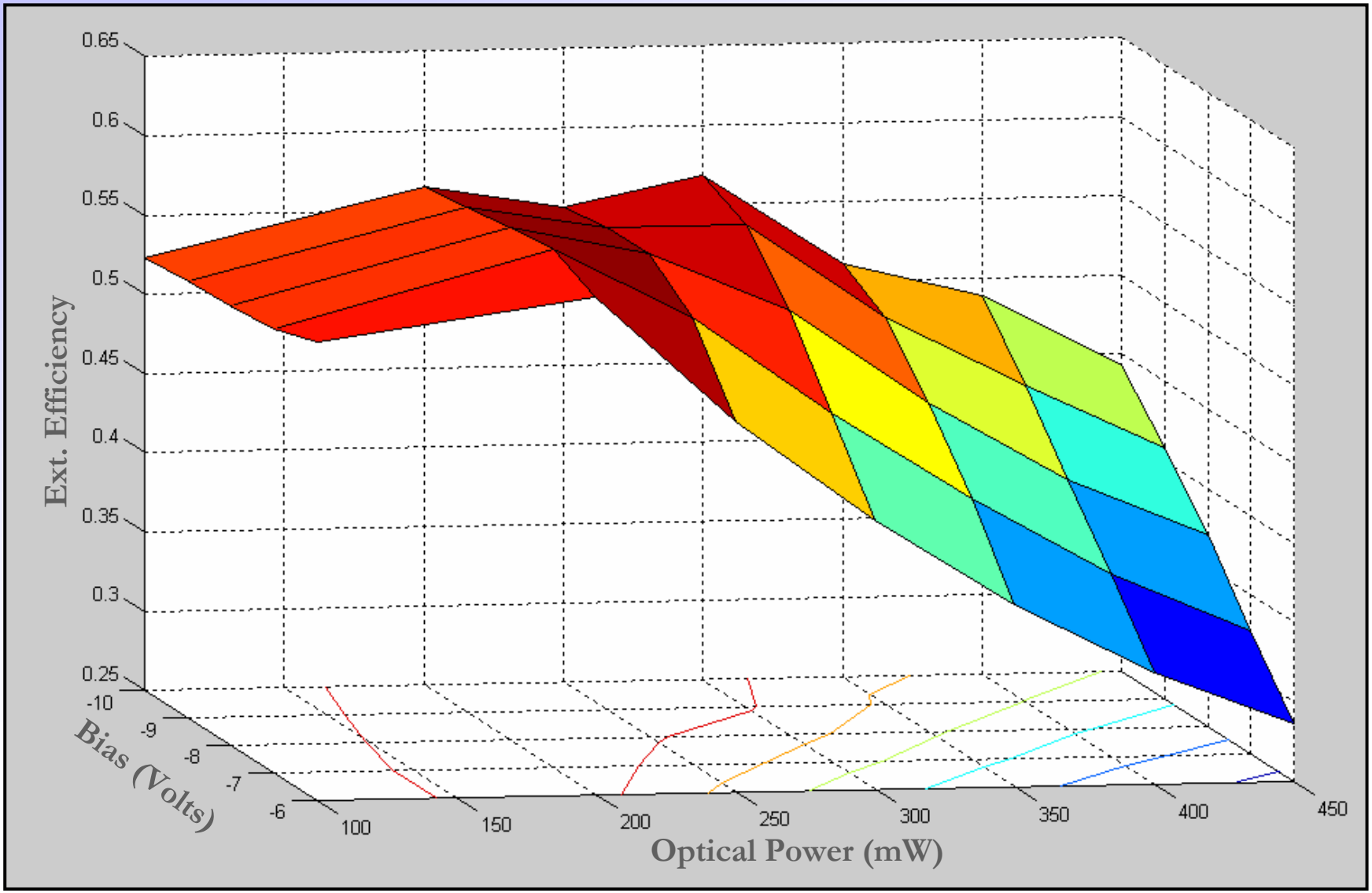
- X-Ray Diffraction
- Transmission Electron Microscopy
- Surface Roughness Mapping
- Photoluminescence
- Deep-Level Transient Spectroscopy
- Absorption Spectra
- Etc.



Device Internal Quantum Efficiency (Low Power ~ 50 mW)



External Quantum Efficiency – Thick Substrate



Damage Threshold – LLO Devices (9/23/03)

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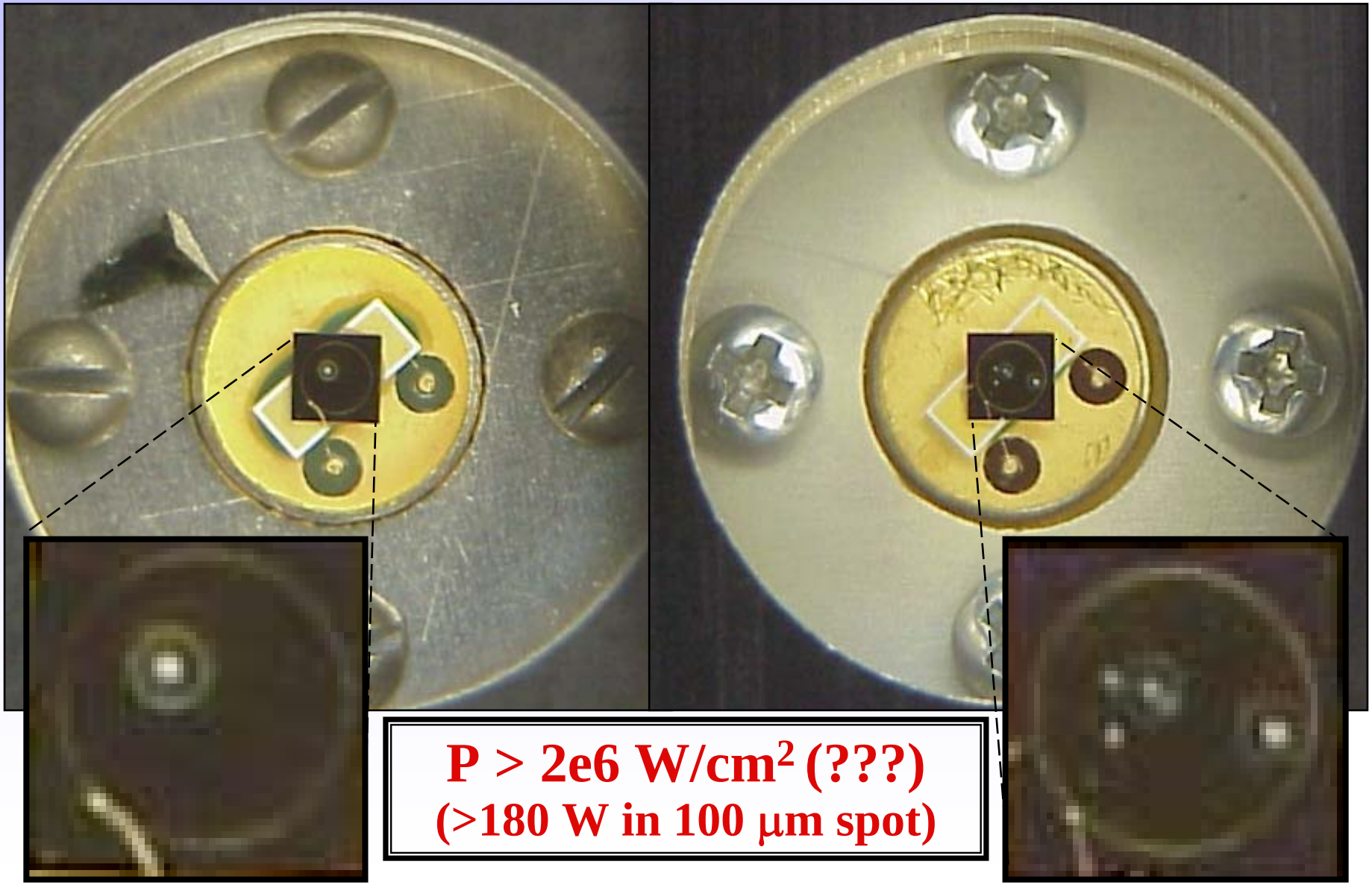
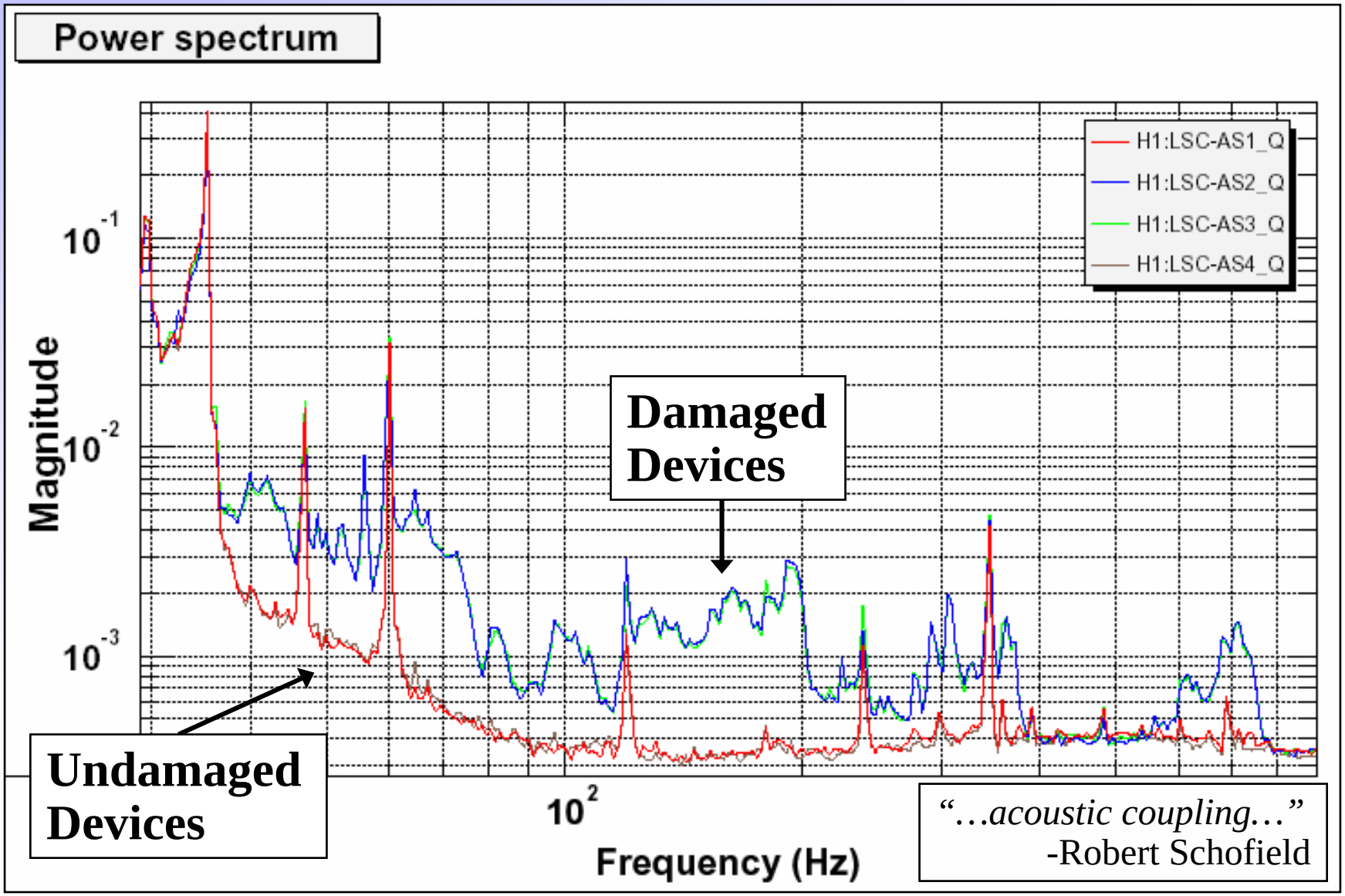
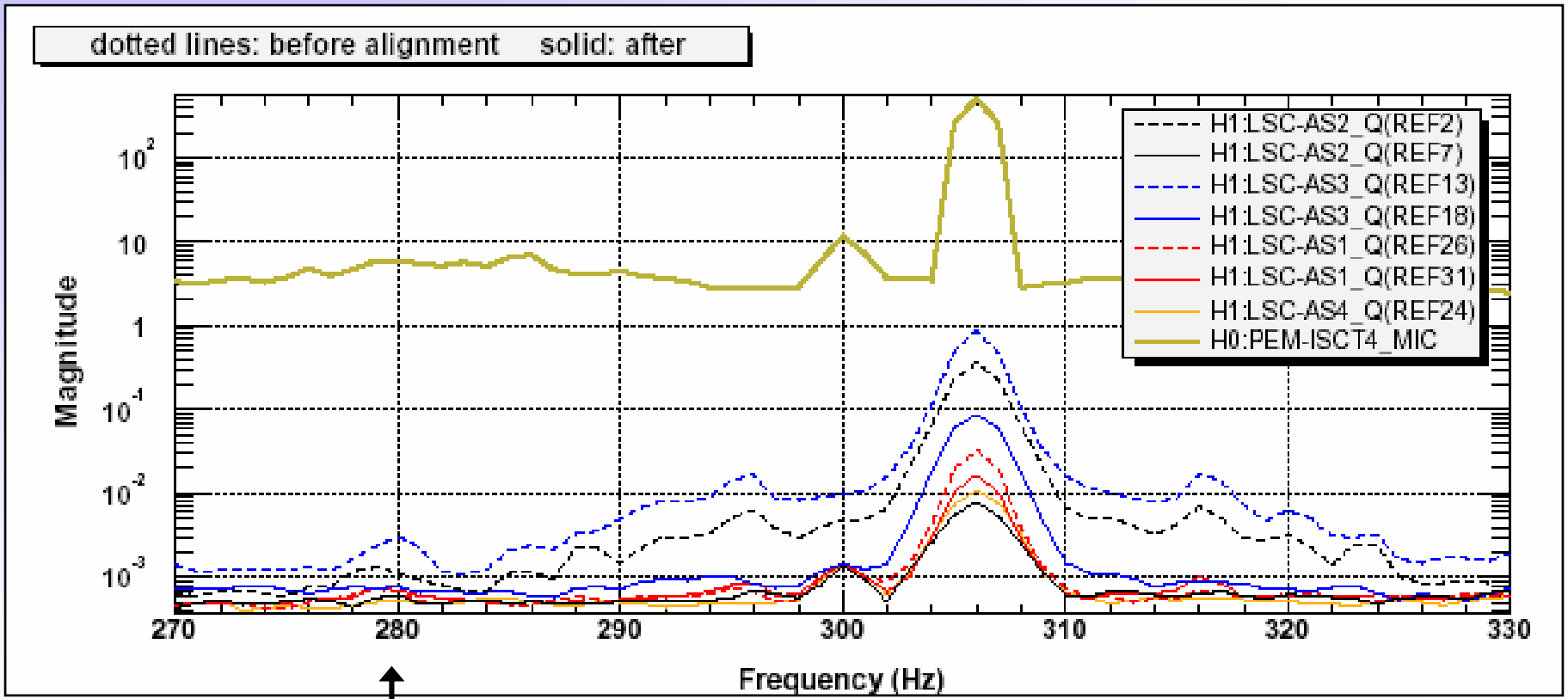


P > 2e6 W/cm^2 (???)
(>180 W in 100 μm spot)

LHO Damaged PDs – Shutter Problems (2/22/05)

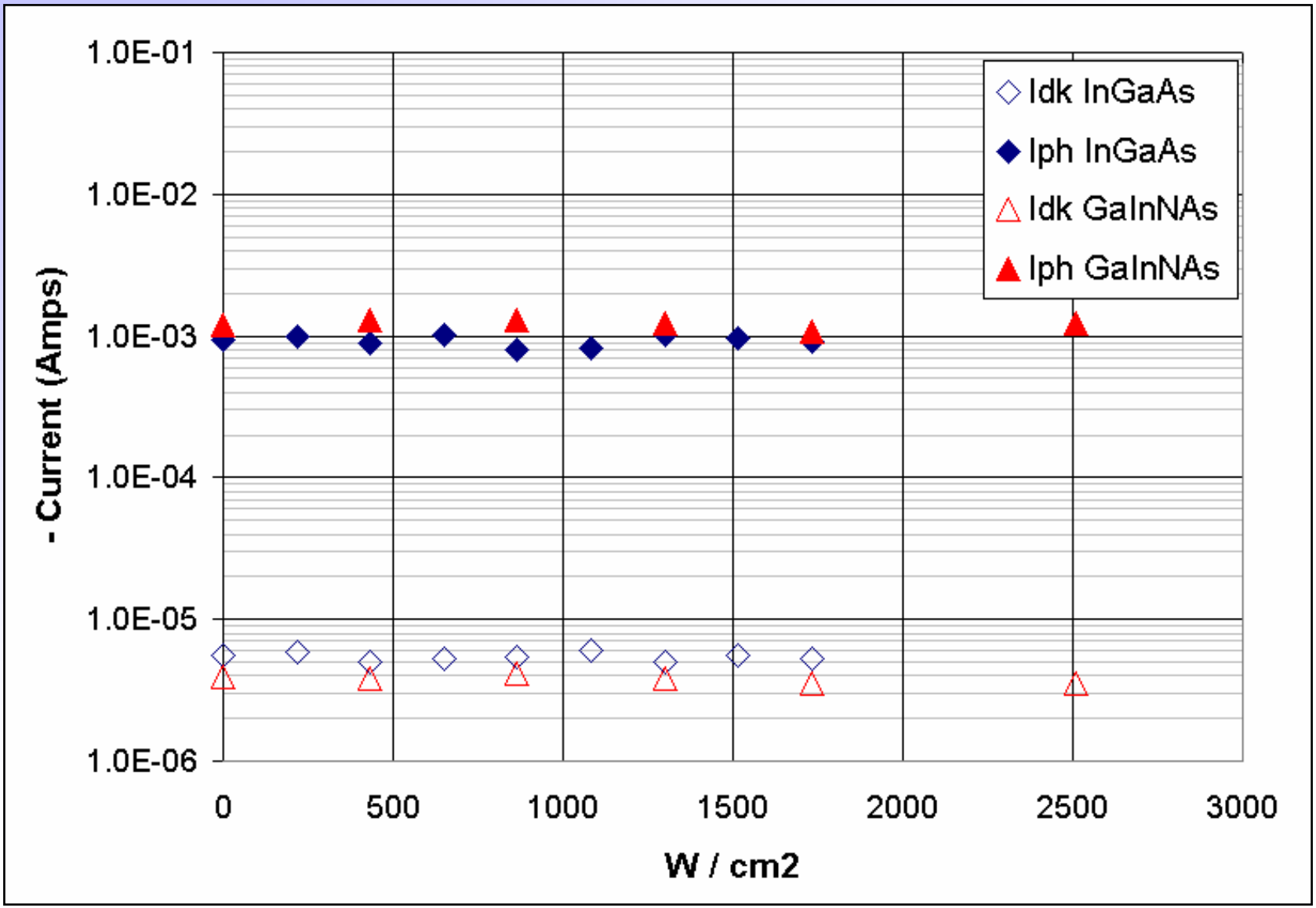


LHO Damaged PDs – Shutter Problems (2/18/05)

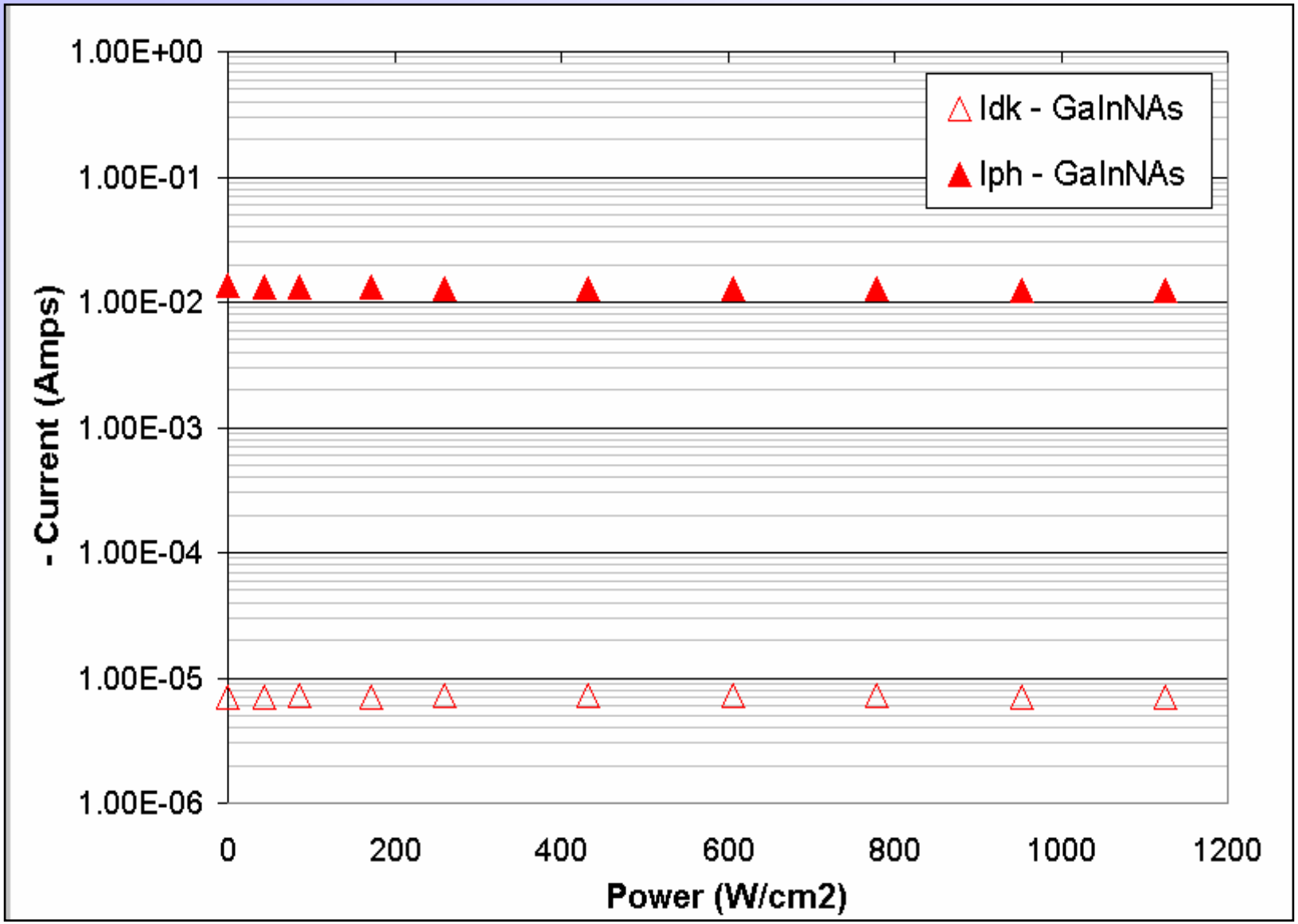


No injected Peak at 280 Hz

Rear-Illuminated Damage-Threshold Test



Front-Illuminated Damage-Threshold Test



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AdLIGO Devices

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Detector	Power Stabilization	Aux. Length Sensing	GW Channel
Diameter	3 mm	1.5 mm	1 mm (or larger?)
Steady-State Power	300 mW	100 mW	50 mW
3-dB 1/RC Bandwidth	5 MHz	30 MHz (→ 180 MHz?)	60 MHz
Quantum Efficiency	–	> 80 %	80 ~ 90 %
Damage Threshold	–	*?*	*Important?!*

AdLIGO Devices: Commercial Vendors

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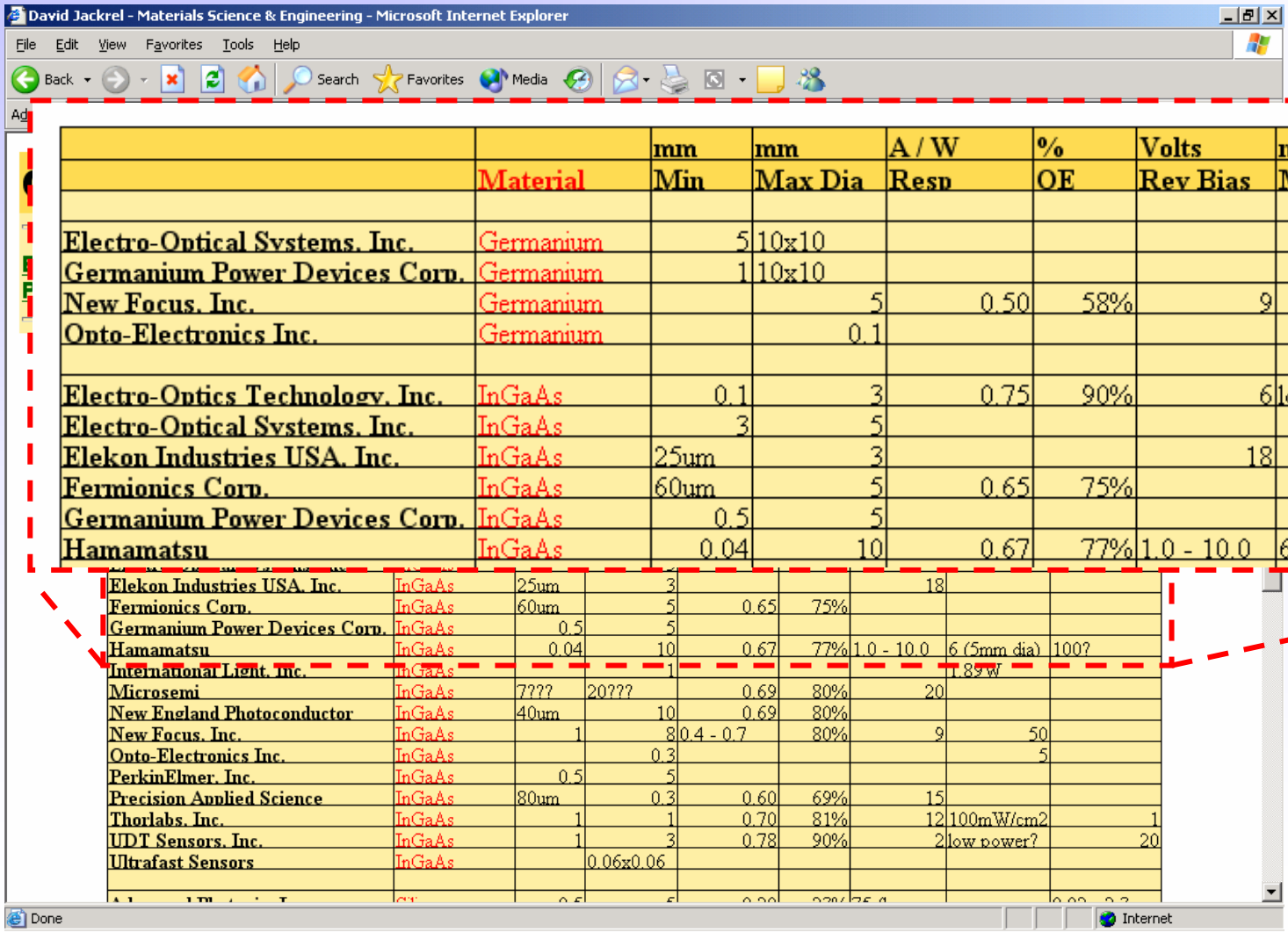
http://www.stanford.edu/~djackrel



	Material	mm Min	mm Max Dia	A / W Resp	% QE	Volts Rev Bias	mW Max Power	mA Max Linear
Electro-Optical Systems, Inc.	Germanium	5	10x10					
Germanium Power Devices Corp.	Germanium	1	10x10					
New Focus, Inc.	Germanium		5	0.50	58%	9	3	
Opto-Electronics Inc.	Germanium		0.1				0.5	
Electro-Optics Technology, Inc.	InGaAs	0.1	3	0.75	90%	6	low power	
Electro-Optical Systems, Inc.	InGaAs	3	5					
Elekon Industries USA, Inc.	InGaAs	25um	3			18		
Fermionics Corp.	InGaAs	60um	5	0.65	75%			
Germanium Power Devices Corp.	InGaAs	0.5	5					
Hamamatsu	InGaAs	0.04	10	0.67	77%	1.0 - 10.0	6 (5mm dia)	100?
International Light, Inc.	InGaAs		1				1.89W	
Microsemi	InGaAs	7???	20???	0.69	80%	20		
New England Photoconductor	InGaAs	40um	10	0.69	80%			
New Focus, Inc.	InGaAs	1	8	0.4 - 0.7	80%	9	50	
Opto-Electronics Inc.	InGaAs		0.3				5	
PerkinElmer, Inc.	InGaAs	0.5	5					
Precision Applied Science	InGaAs	80um	0.3	0.60	69%	15		
Thorlabs, Inc.	InGaAs	1	1	0.70	81%	12	100mW/cm2	1
UDT Sensors, Inc.	InGaAs	1	3	0.78	90%	2	low power?	20
Ultrafast Sensors	InGaAs		0.06x0.06					

In Progress / Future Directions

- Substrate removal
- GaInNAs(Sb) growth (w/ upgraded system)
- ARC
- 1/f noise experiments

Successor - Zhilong Rao

- Packaging devices / Testing components
- Higher saturation power? (→ RF detection?)
- Surface uniformity?, Backscatter?, etc.

Future Directions – What types of diodes are needed?

- Quantum Efficiency?
- Damage Threshold?
- Saturation Power?
  - RF detection
  - AdLIGO laser stabilization
- Electronic Noise?
  - DC
  - RF? (180 MHz)
- Frequency Response?
  - Commercially available?
- Other???

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XRD Reciprocal Space Map (004)

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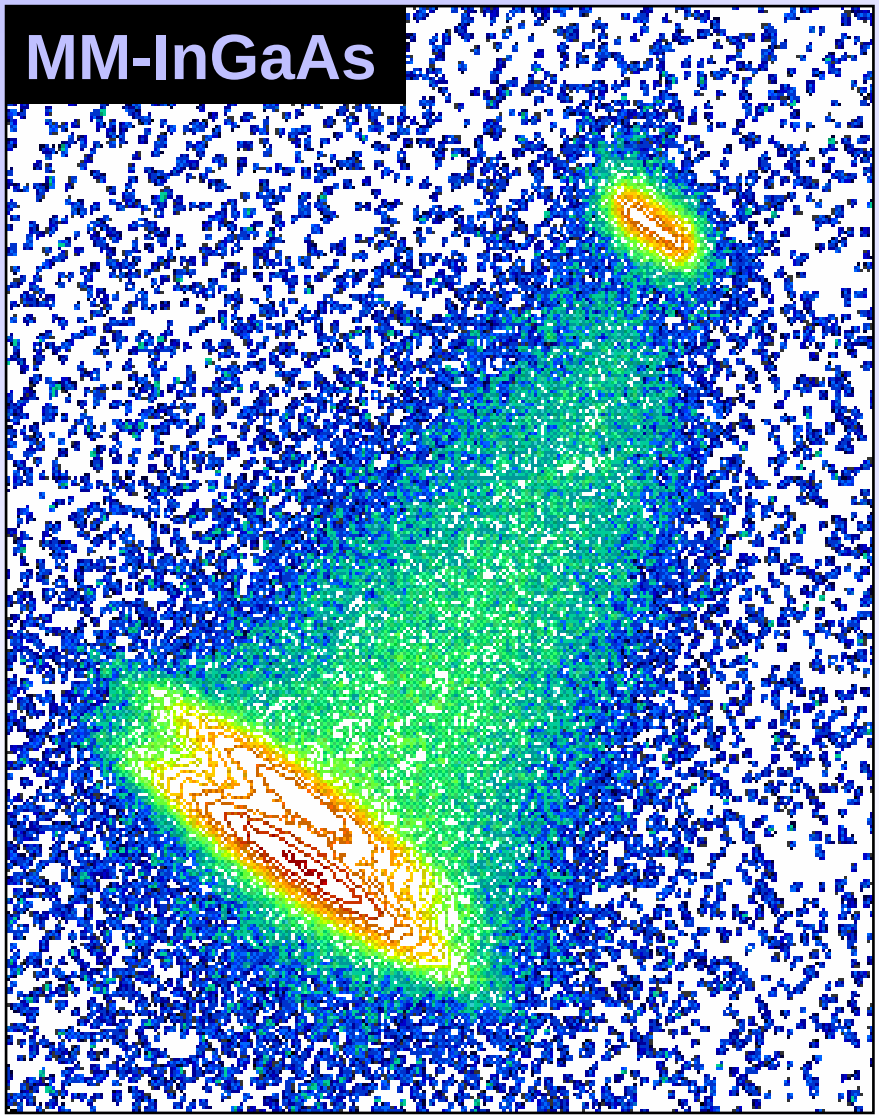
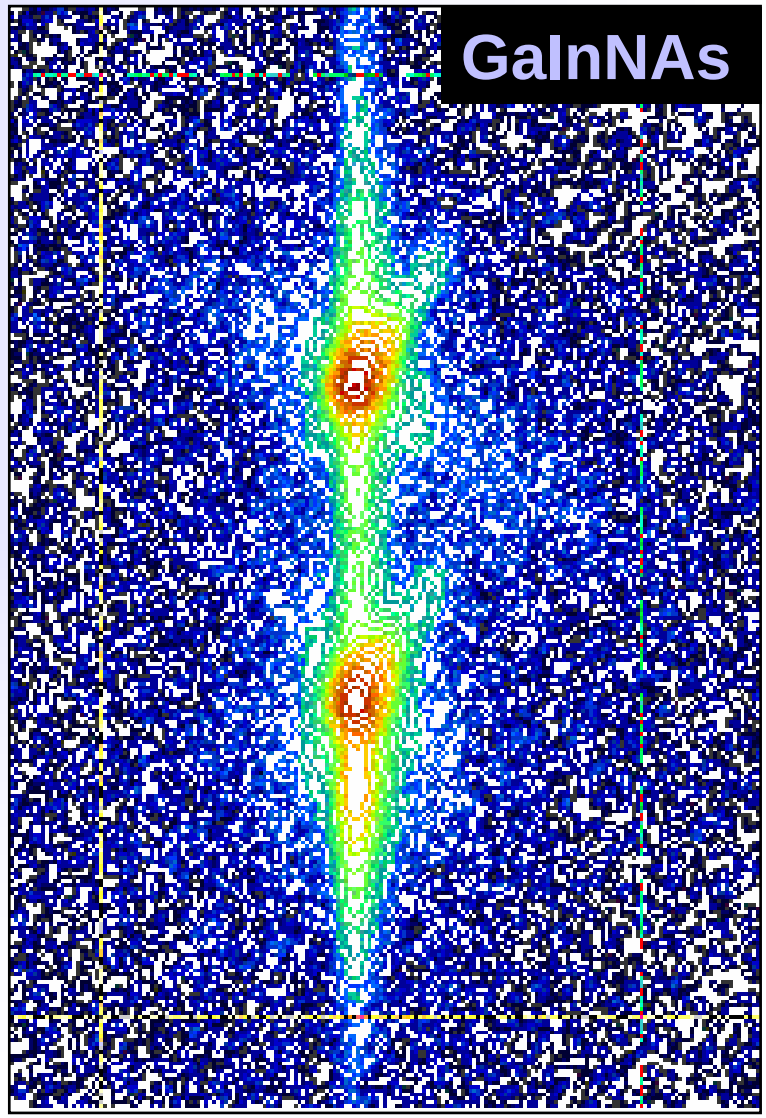
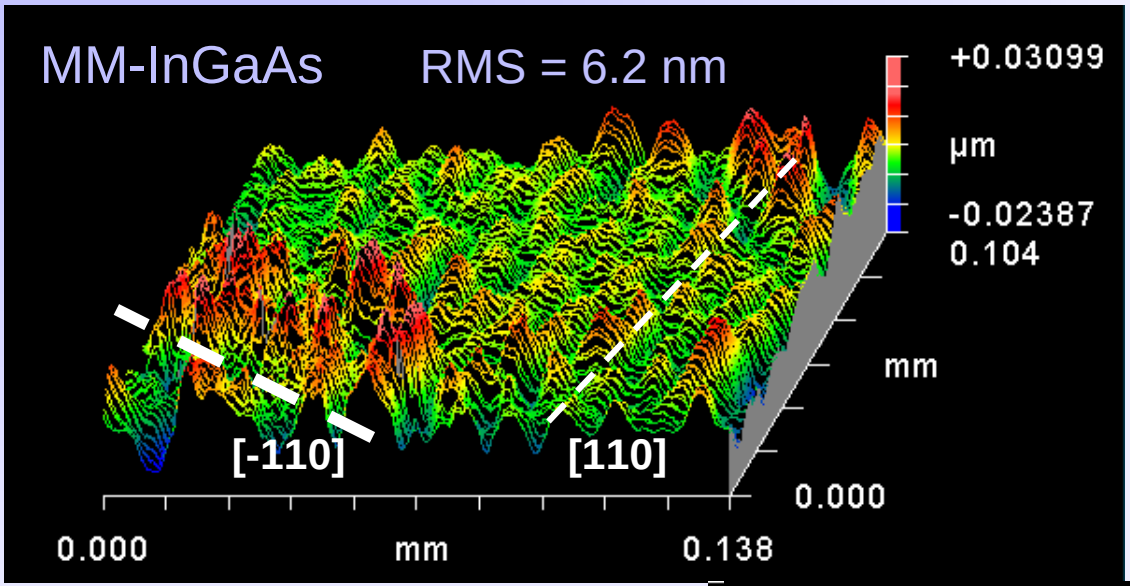
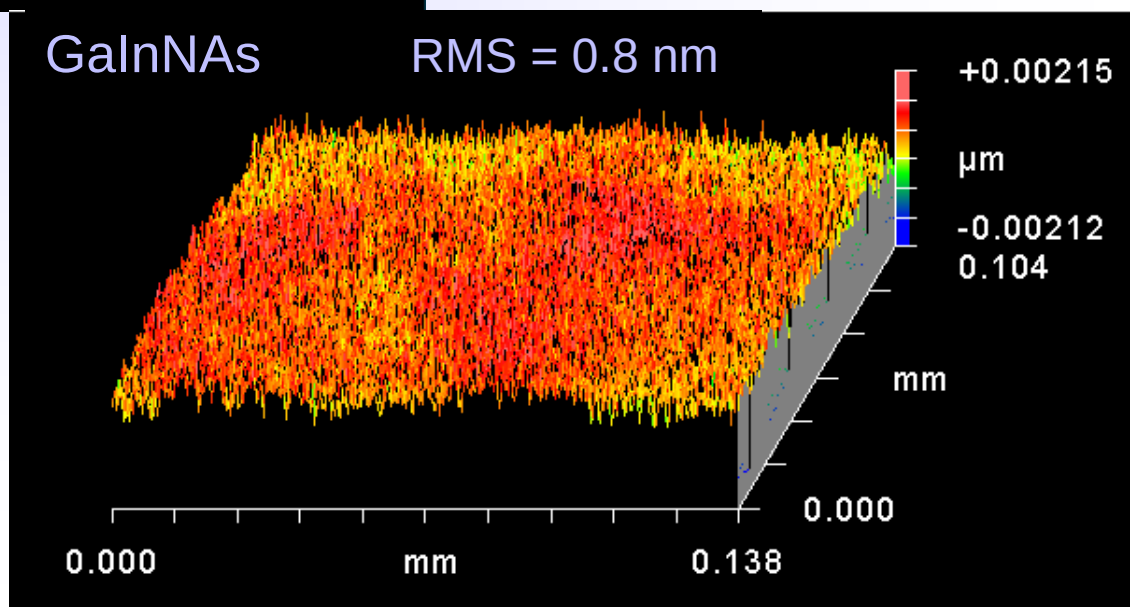


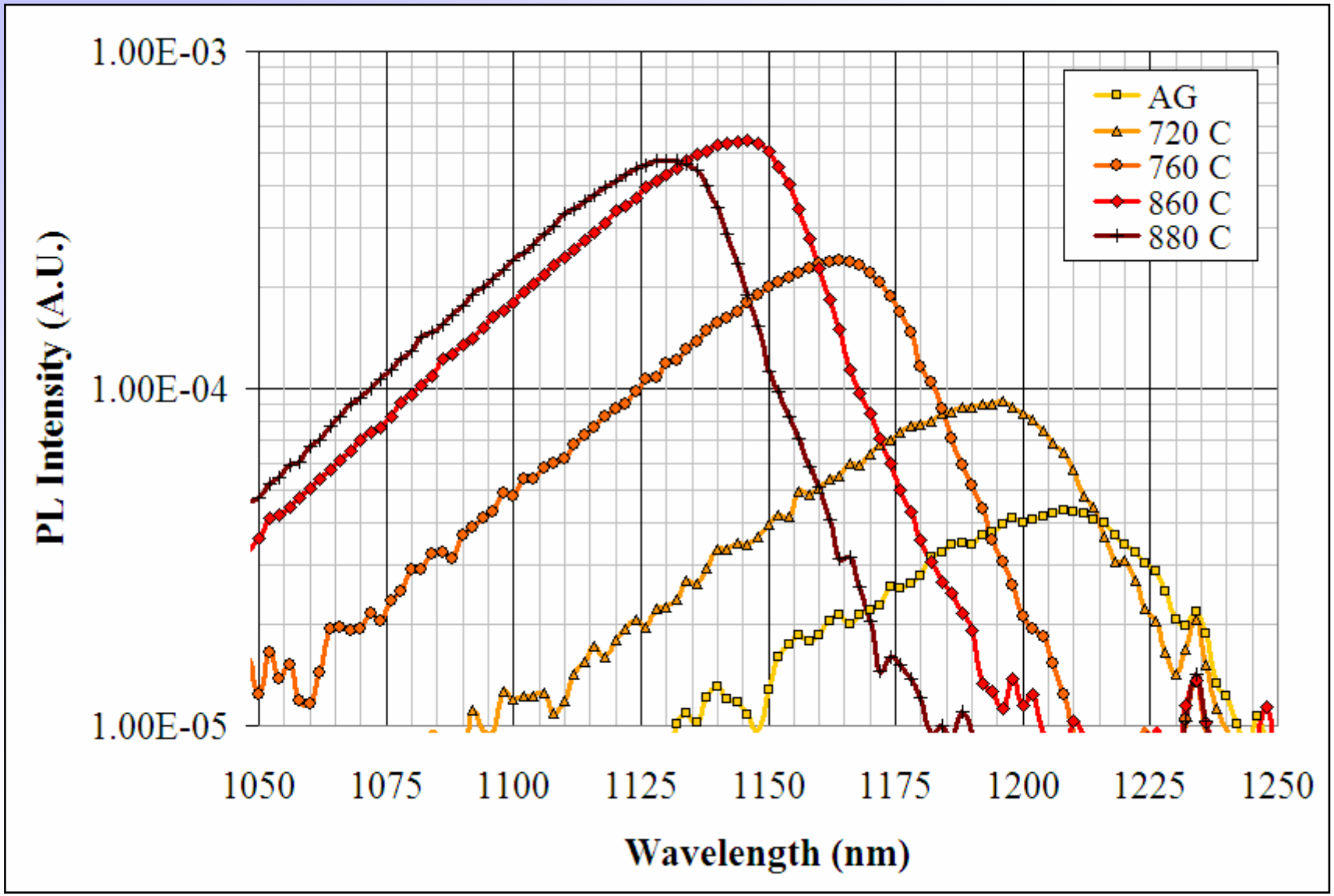


Surface Roughness





Optimizing Post-Growth Anneal



Scanning Photoluminescence Intensity

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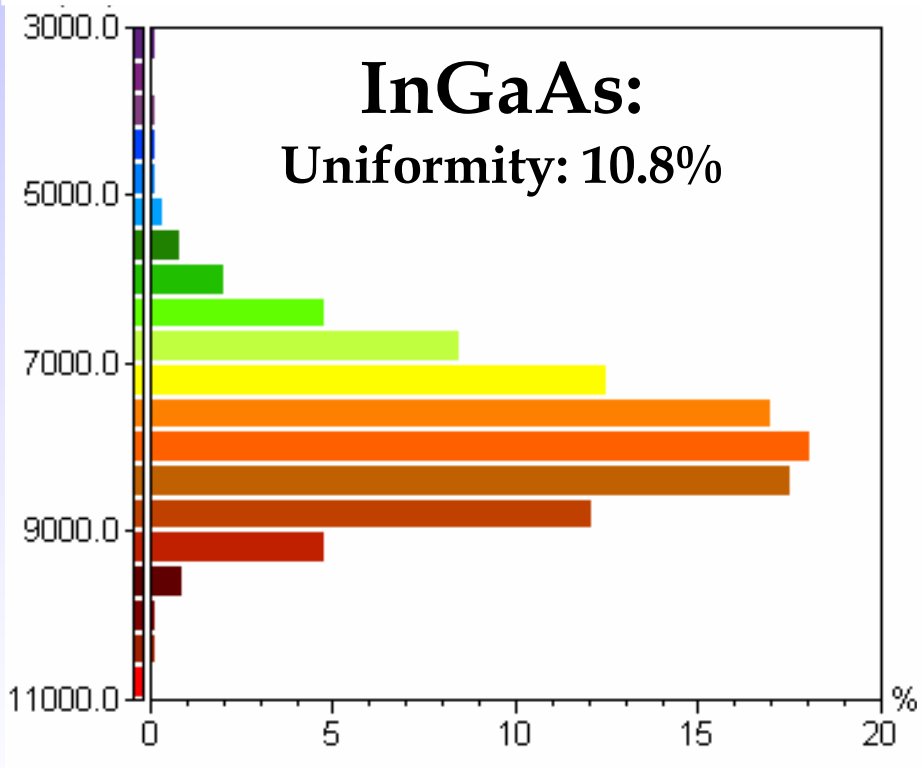

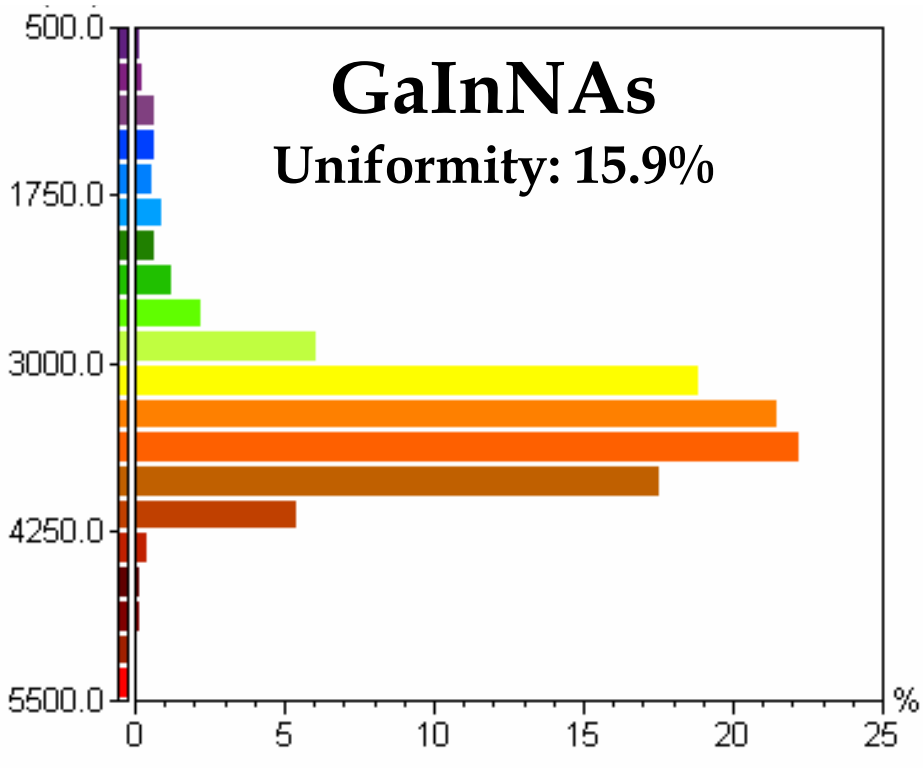

Scanning PL Intensity Maps

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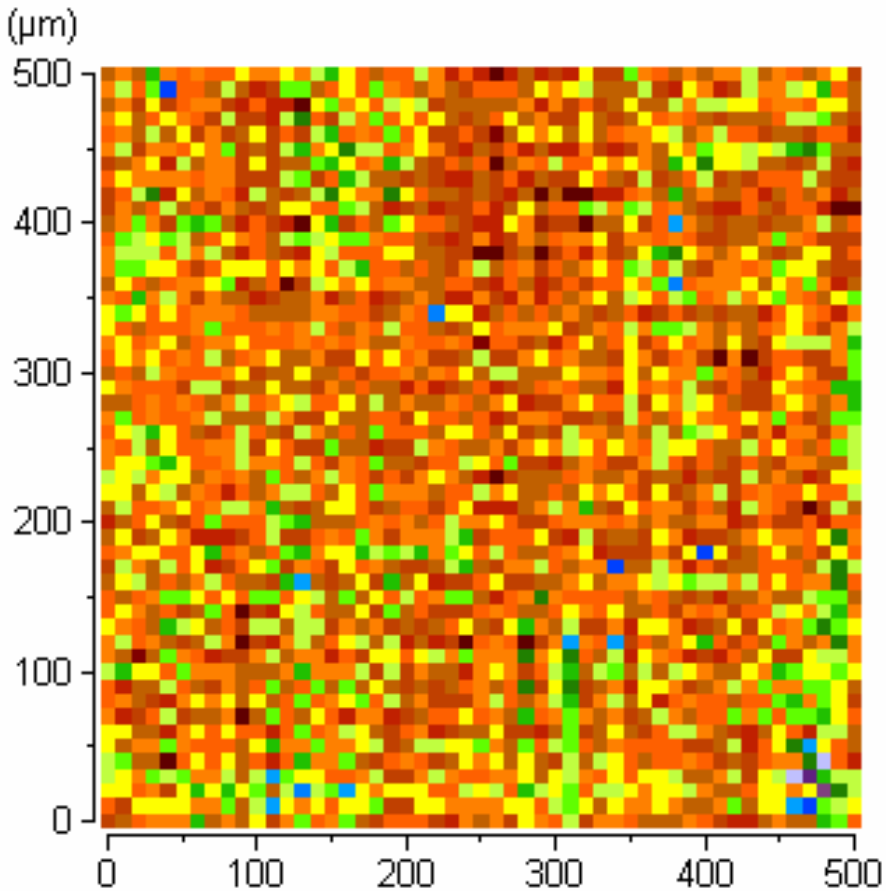
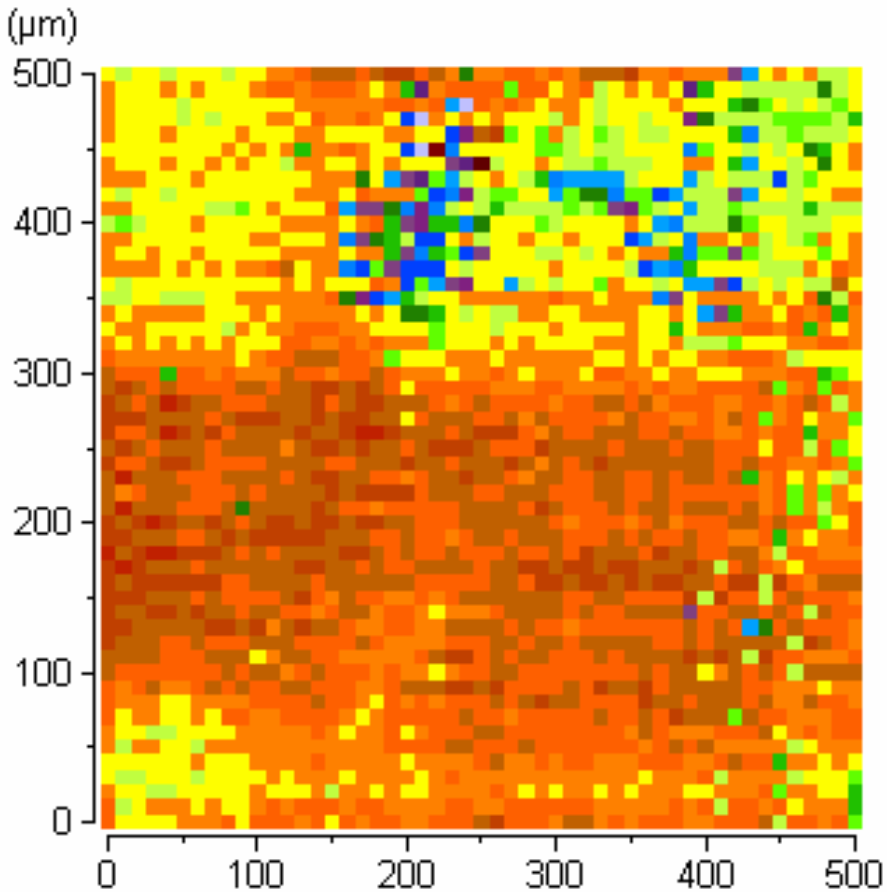
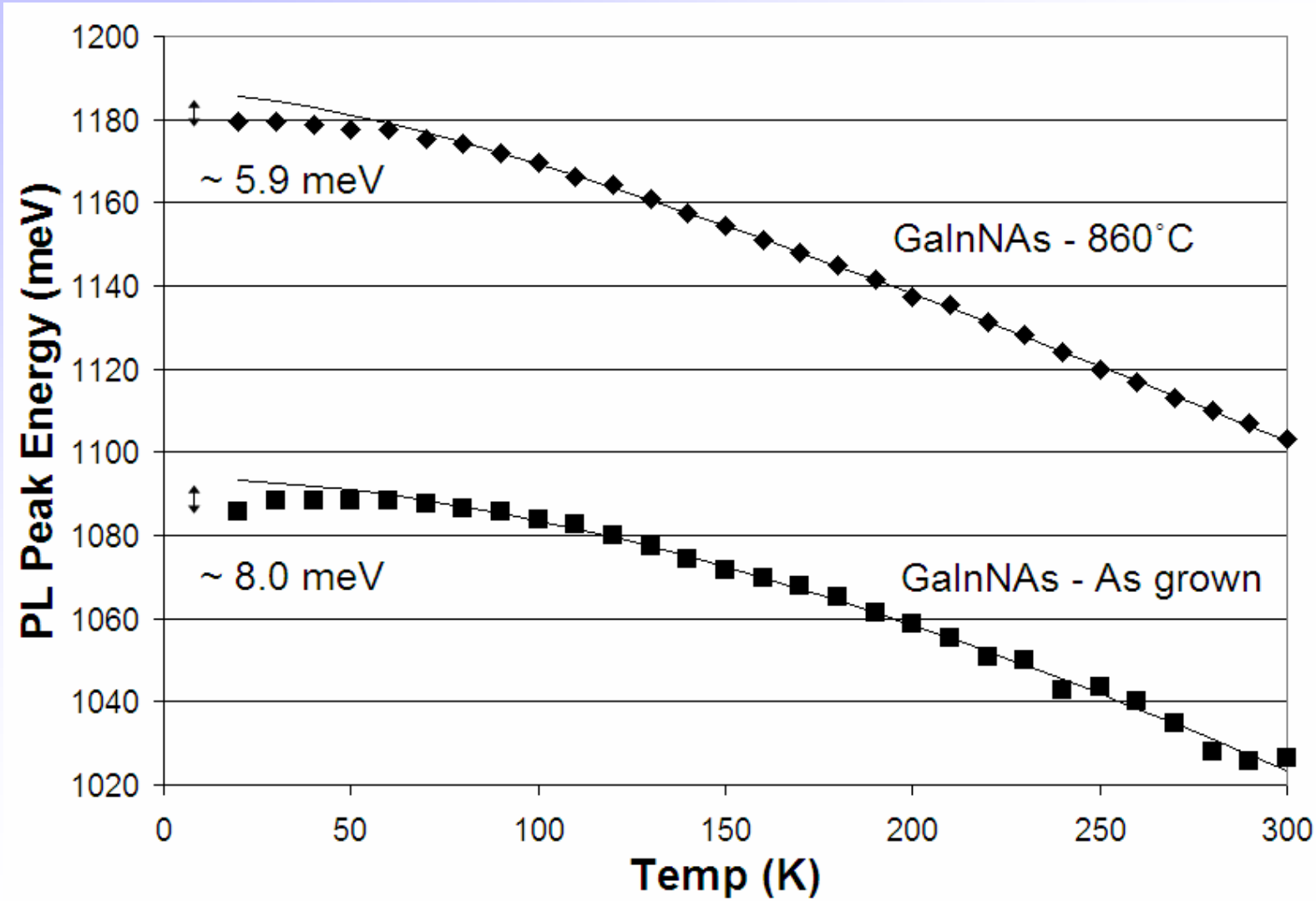
InGaAs



GaInNAs



GaInNAs Temp. Dependent PL: Localization Energy



Deep Level Transient Spectroscopy Majority Carrier Traps

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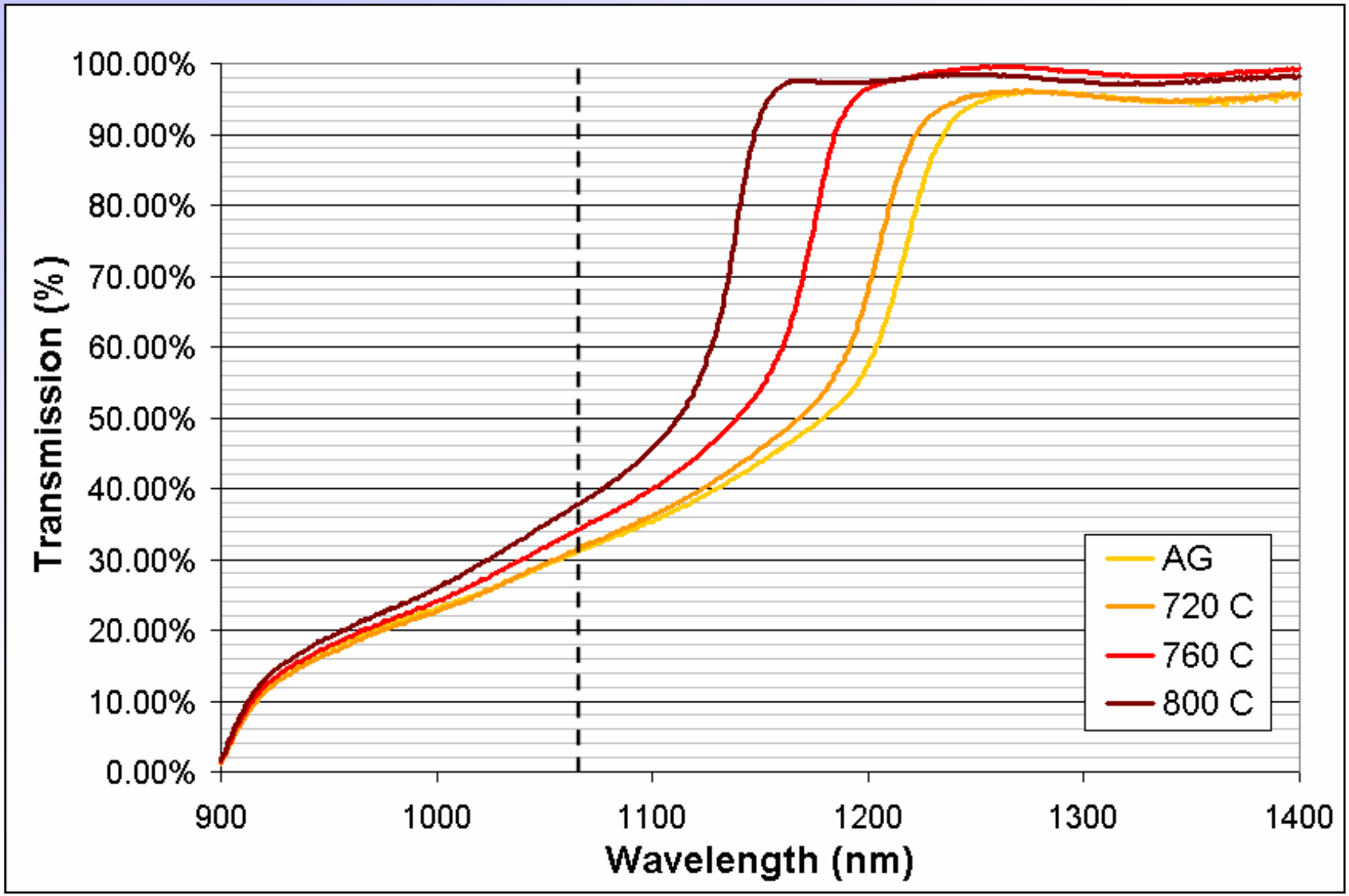
Sample	Activation Energy (eV)	Trap Density (cm^{-3})	Capture Cross-Section (cm^2)
LM - GaInNAs	0.63	1.1×10^{14}	9.0×10^{-15}
	0.27	3.9×10^{13}	2.5×10^{-16}
	0.22	7.5×10^{13}	3.2×10^{-15}
	0.15	1.7×10^{13}	5.2×10^{-18}
MM - InGaAs	0.47	2.0×10^{13}	4.9×10^{-15}
	0.12	3.1×10^{12}	3.2×10^{-12}

1 μm GaInNAs Film Transmission



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2 μm InGaAs Absorption Spectrum

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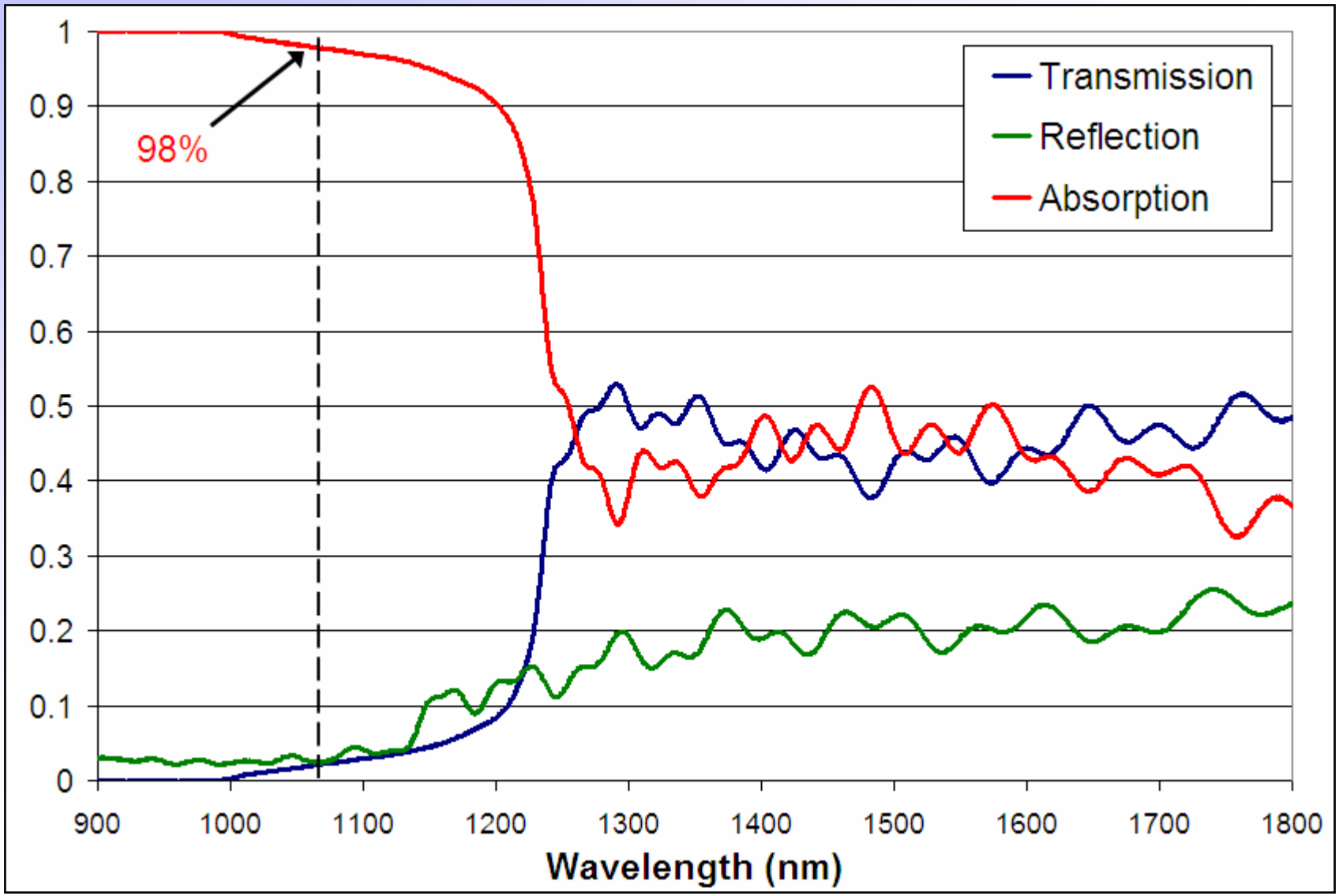

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InGaAs vs. GaInNAs Dark I Density

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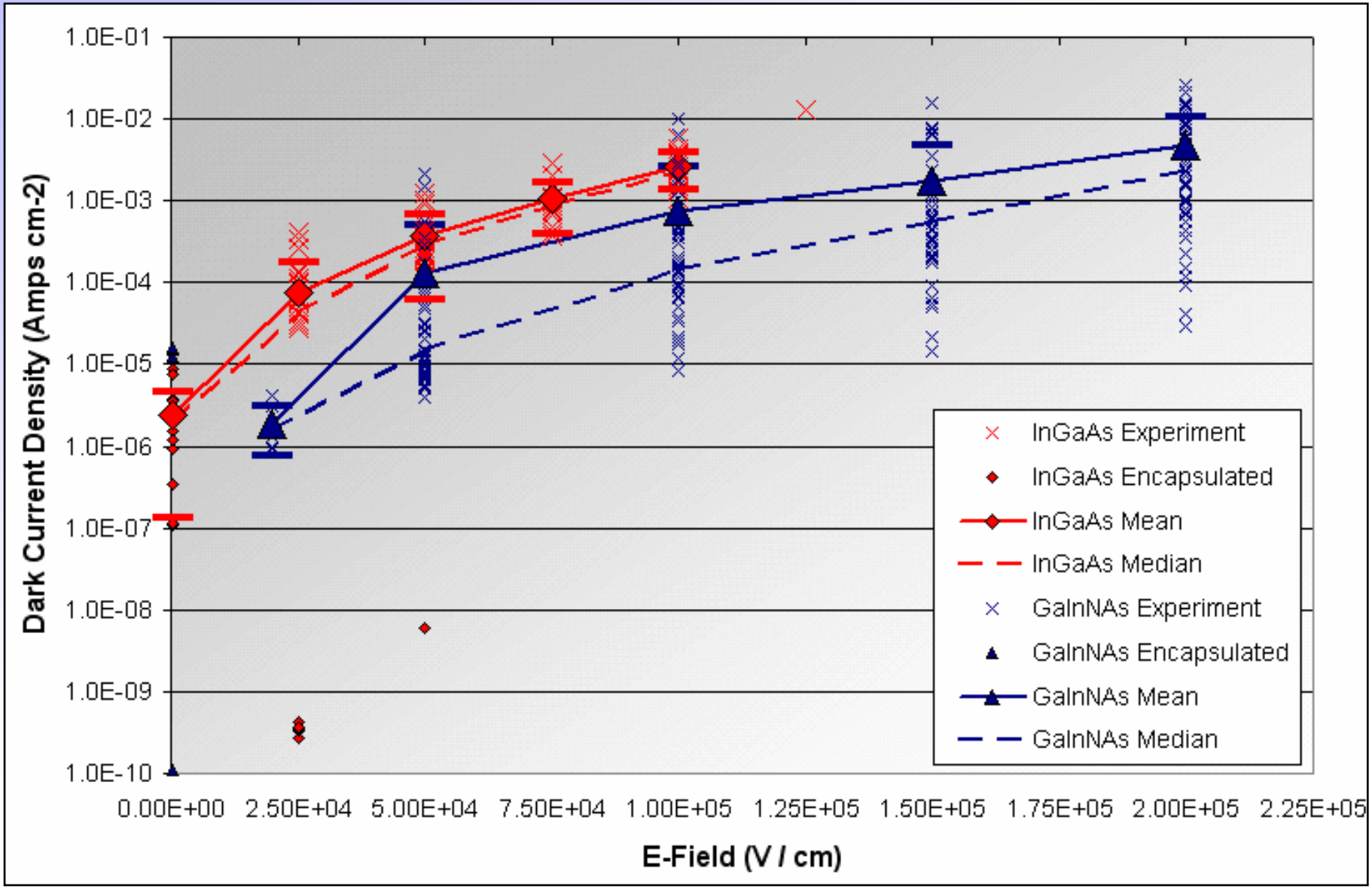
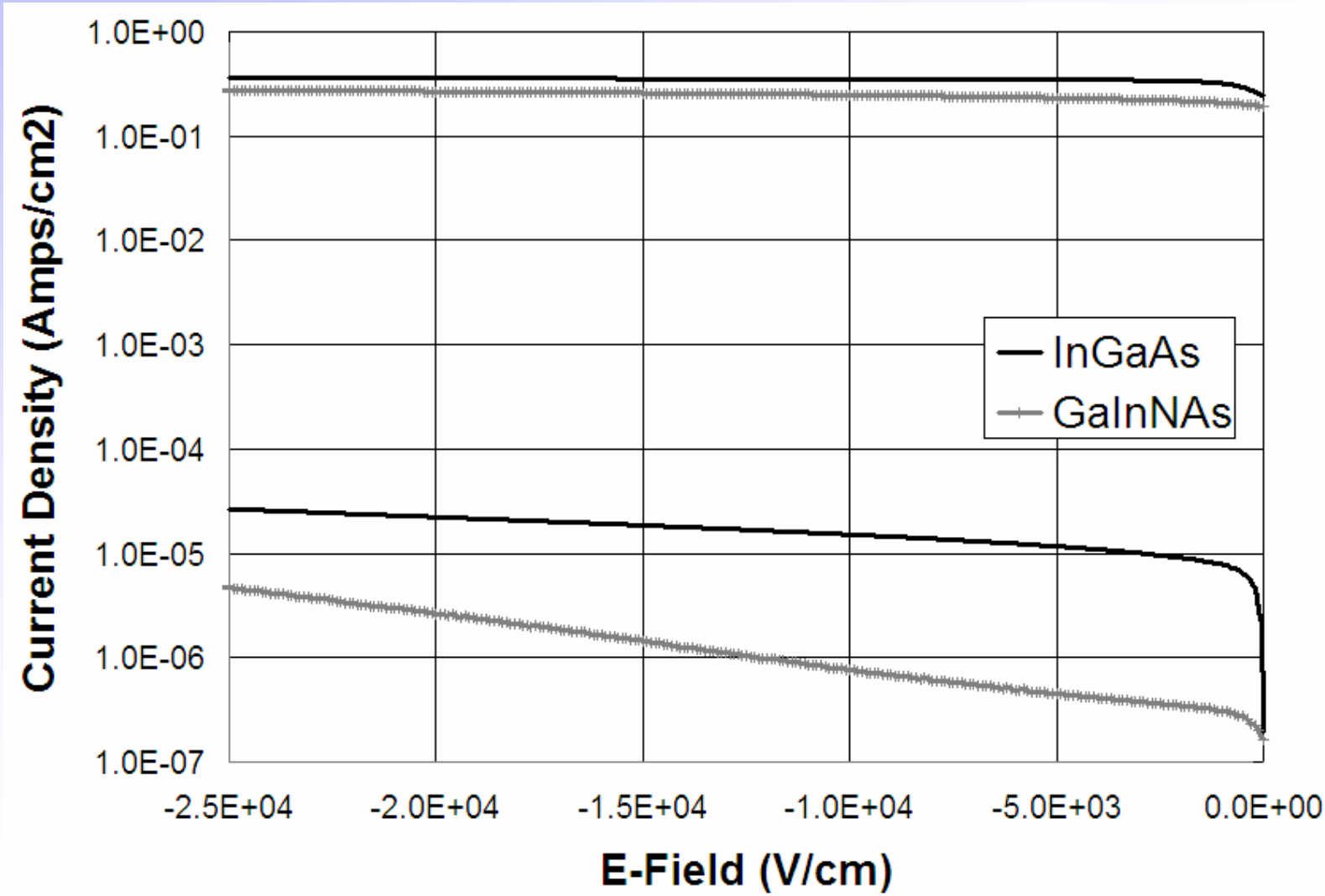


Dark and Photocurrent (SNR)



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Photovoltaic Response

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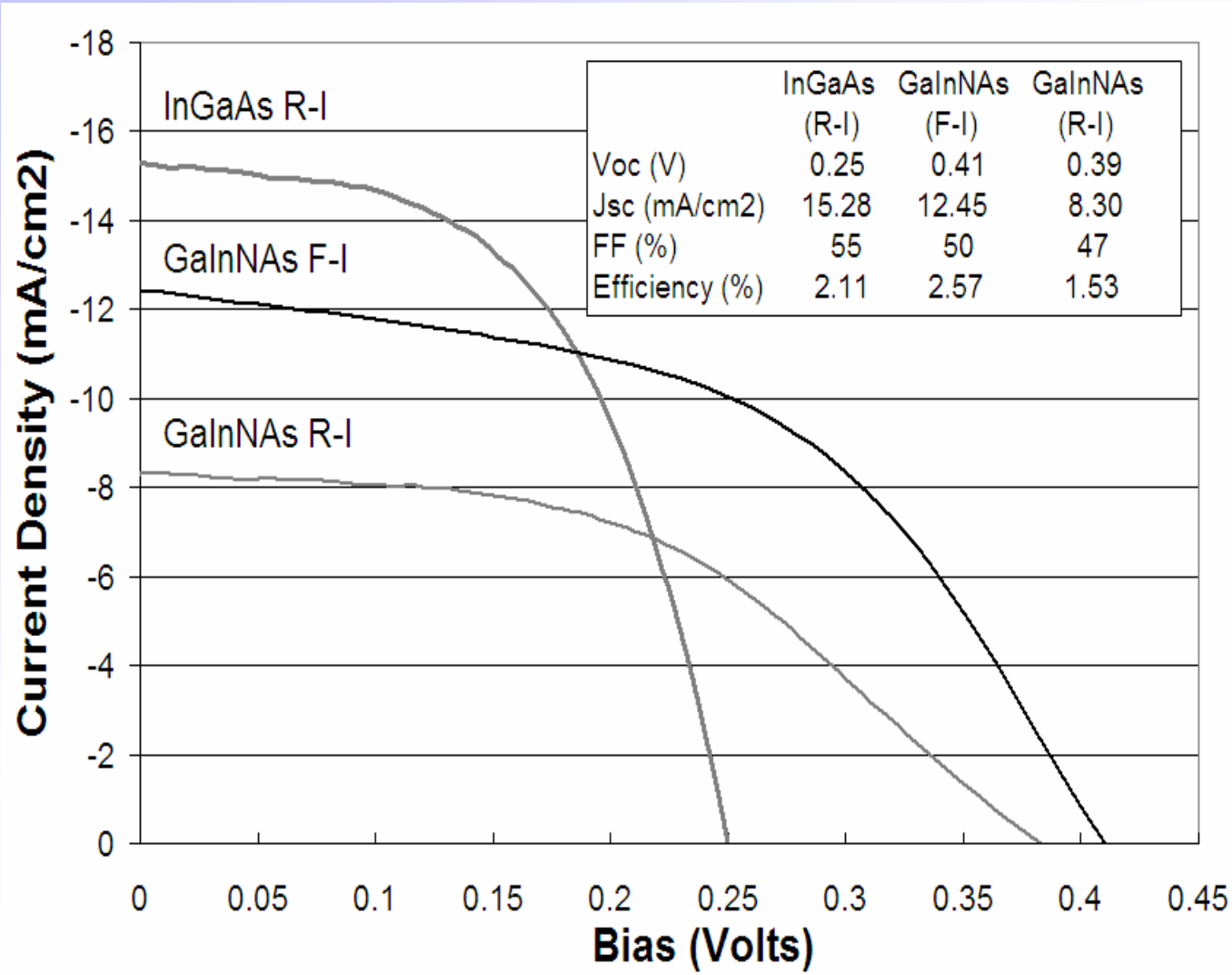

	InGaAs (R-I)	GaInNAs (F-I)	GaInNAs (R-I)
Voc (V)	0.25	0.41	0.39
Jsc (mA/cm2)	15.28	12.45	8.30
FF (%)	55	50	47
Efficiency (%)	2.11	2.57	1.53

C-V Curves

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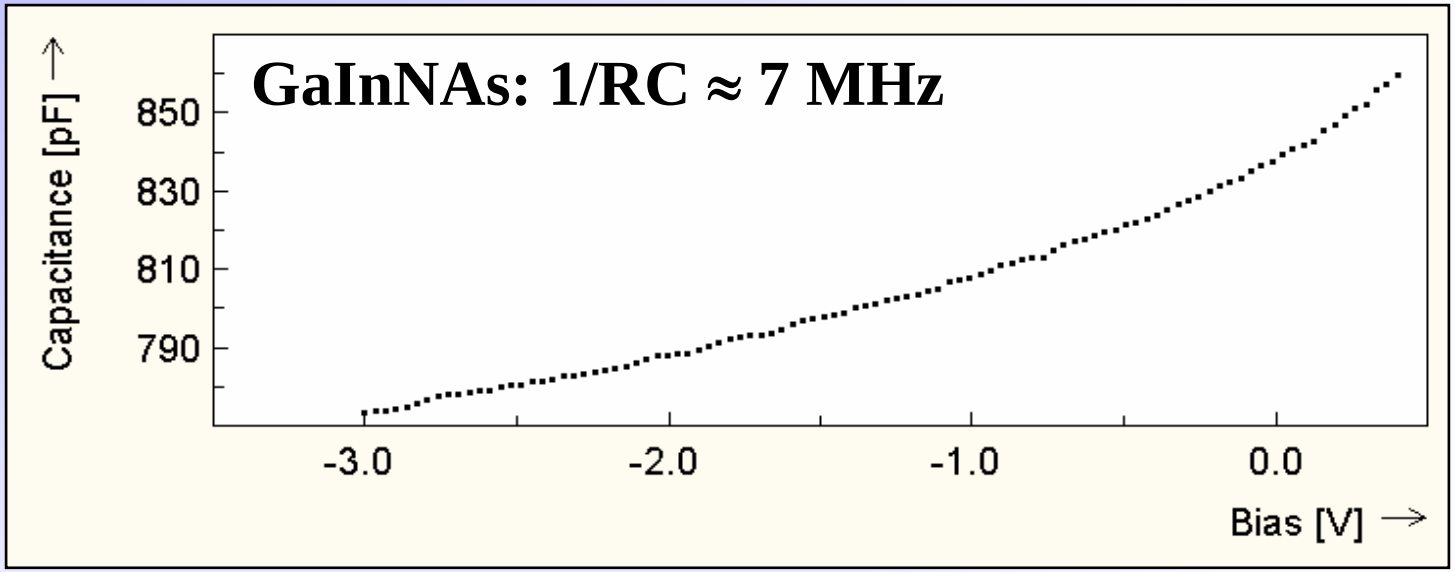

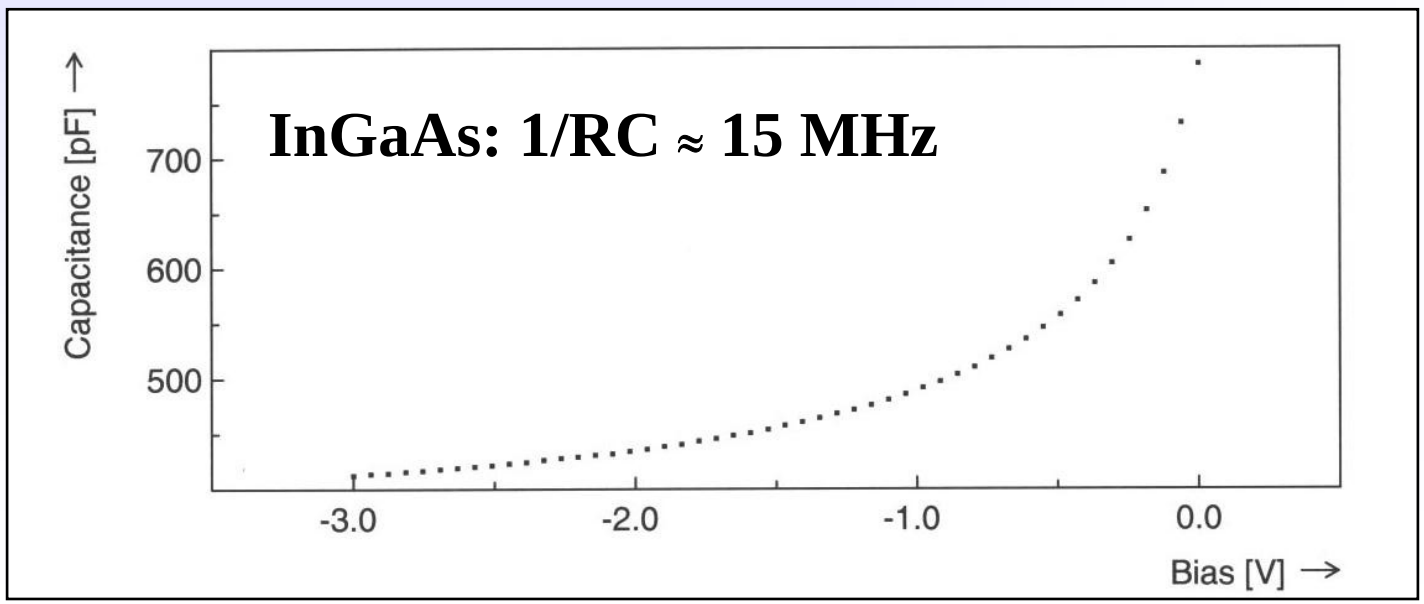

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LCR Resonant Circuit Modeling

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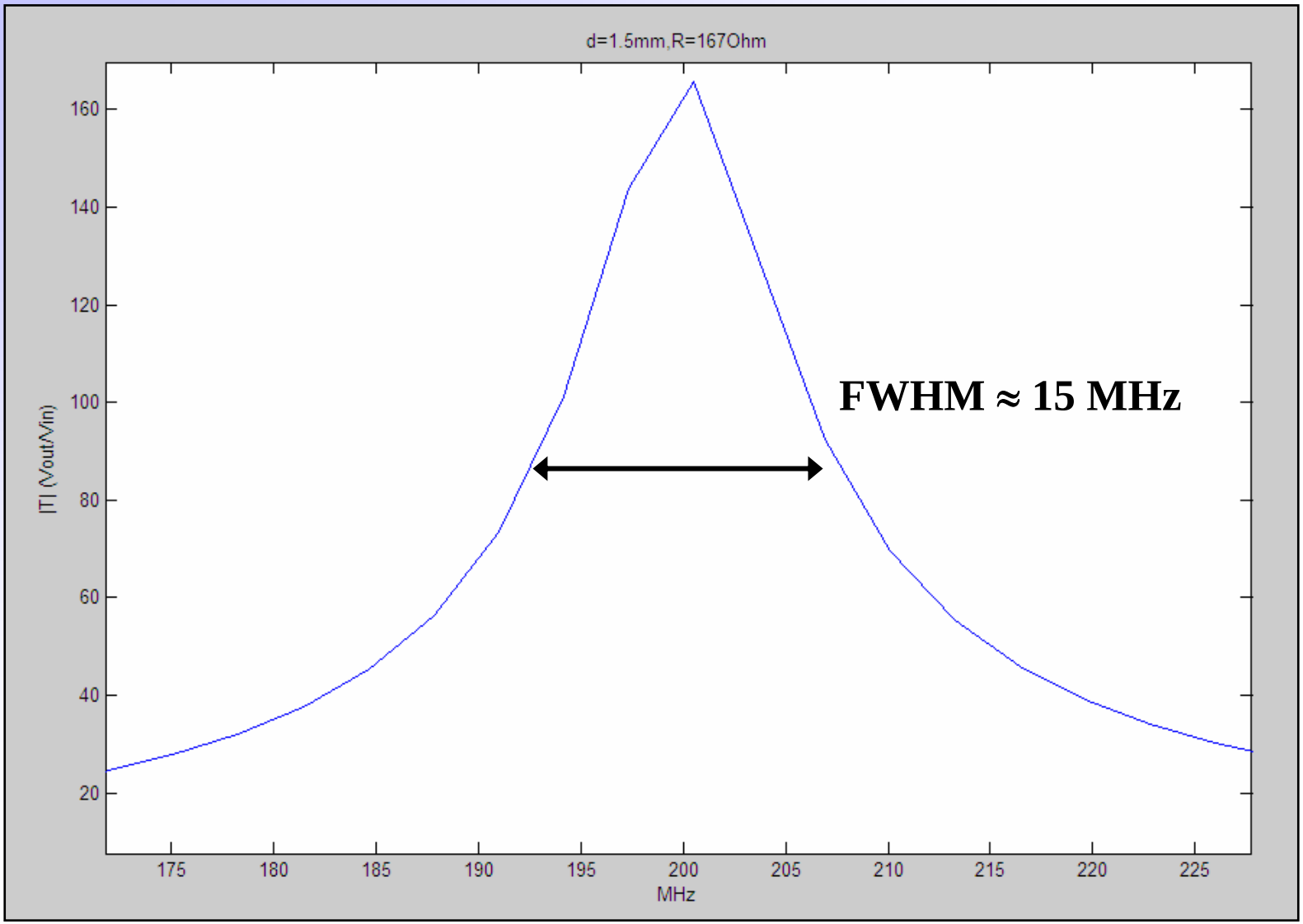

Damage Threshold Tests

LIGO 1

power in each arm (W)	ITM transmission	Total Power on AS-PD	Spot Radius (um)	Area (cm2)	Power Density (W/cm2)
6000	0.03	360	5.00E+01	7.85398E-05	4.58E+06
6000	0.03	180	5.00E+01	7.85398E-05	2.29E+06
		20	1.178511302	4.36E-06	4.58E+06
		20	1.666666667	8.73E-06	2.29E+06

AdLIGO

power in each arm (W)	ITM transmission	Total Power on AS-PD	Spot Radius (um)	Area (cm2)	Power Density (W/cm2)
8.30E+05	0.03	4.98E+04	5.00E+01	7.85398E-05	6.34E+08
		20	0.100200602	3.15E-08	6.34E+08