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Advanced LIGO High-Power Photodiodes

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LSC Conference, LLO

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LIGO-G030069-00-Z

Harris Group Solid State Lab

Outline

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- Introduction
- High-Power Results
- High Efficiency Process
- Predictions

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Photodiode Specifications

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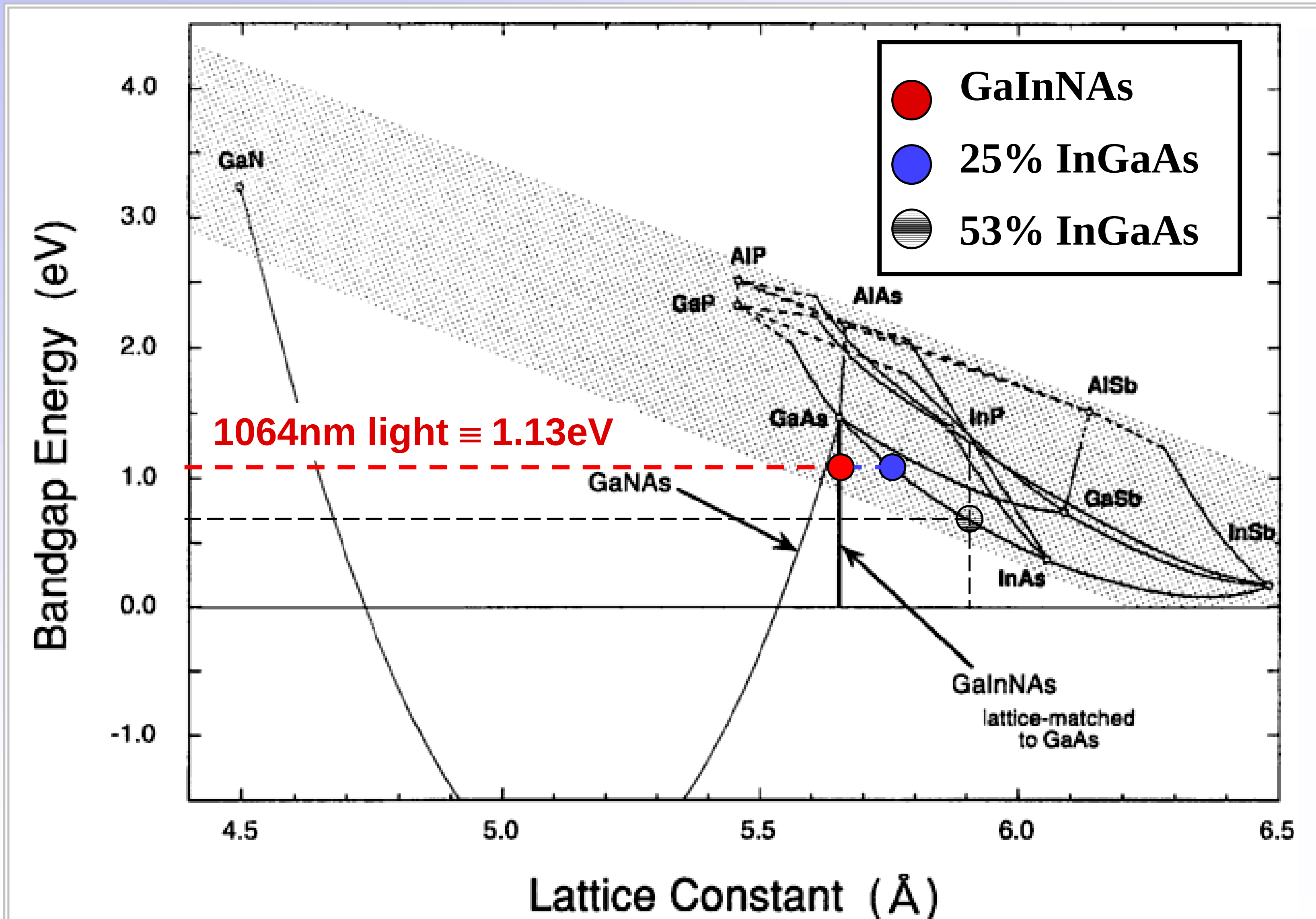
Parameter	LIGO I	Advanced LIGO
Steady-State Power	0.6 W	~1 W
Operating Frequency	< 29 MHz	100 kHz ~ 180 MHz
Quantum Efficiency	> 80%	> 90%
Detector Design	Bank of 6(+) PDs	1 PD

GaInNAs vs. InGaAs



InGaAs vs. GaInNAs PD Designs

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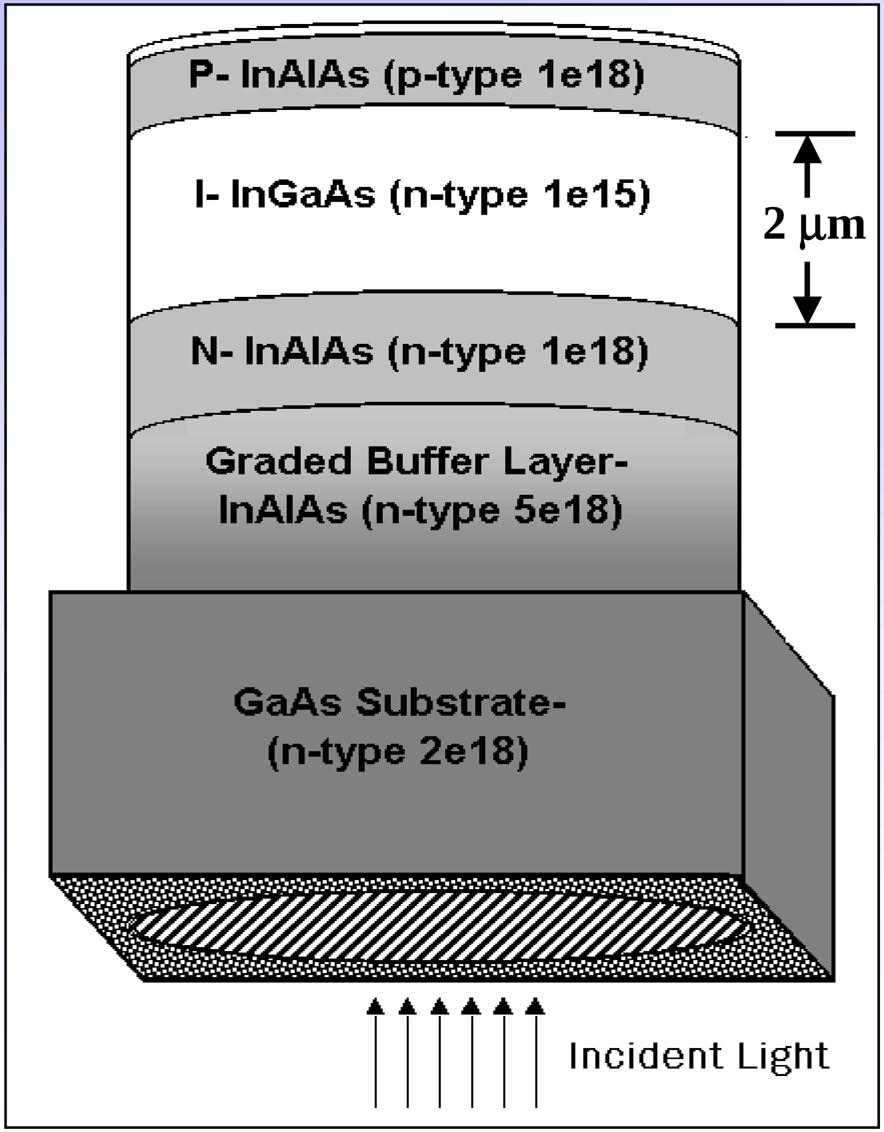

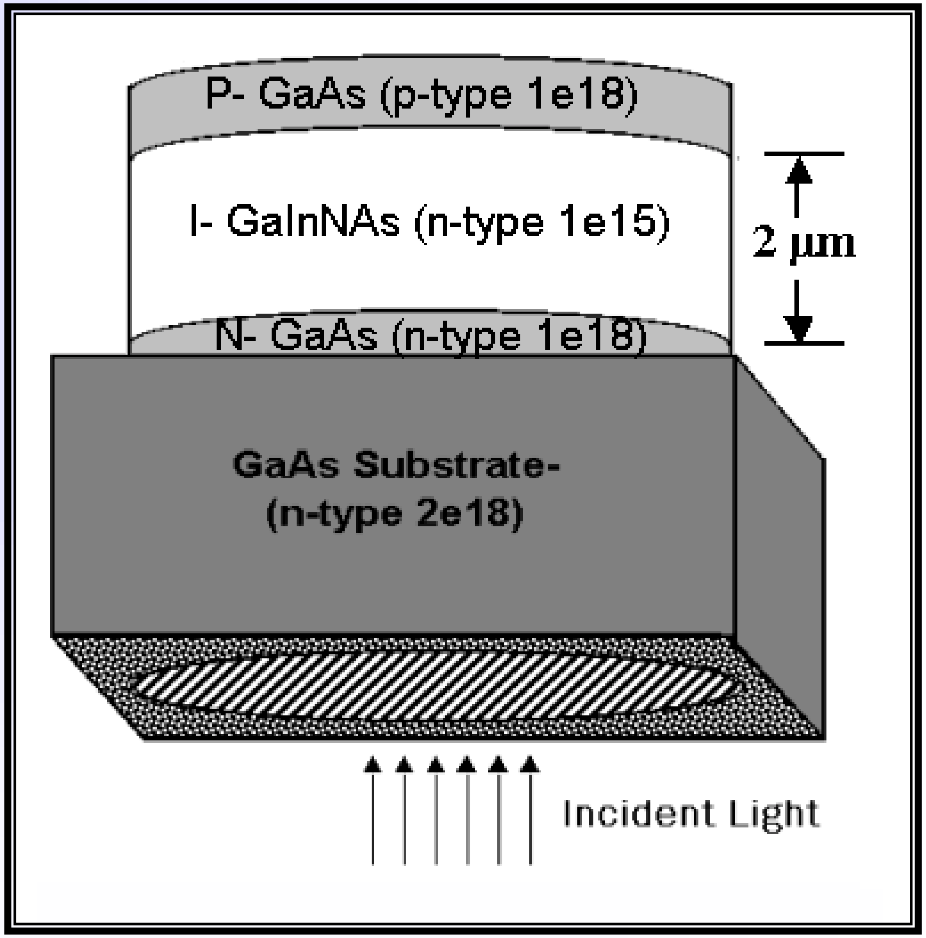

GaInNAs lattice-matched to GaAs!

Heterojunction Band Gap Diagram

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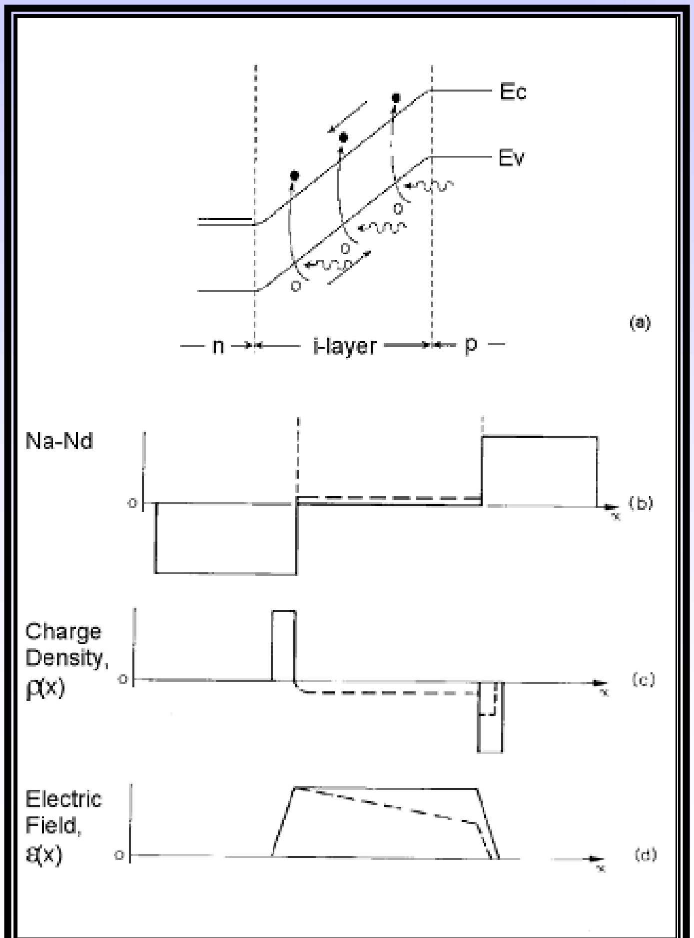
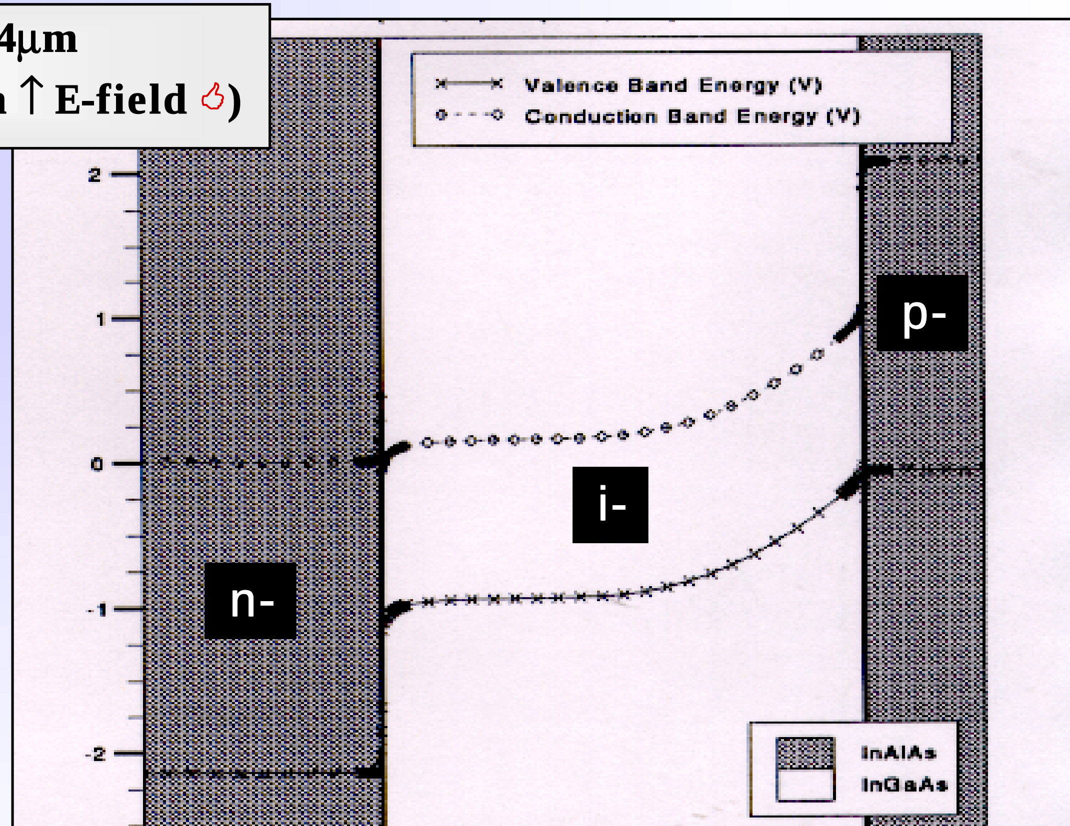
InAlAs and GaAs transparent at 1.064µm
→ Absorption occurs in I-region (in ↑ E-field ☝)





N-layer:

$In_{.22}Al_{.78}As$ or GaAs

$E_{g2} = 2.0 - 1.4eV$

I-layer:

$In_{.22}Ga_{.78}As$, or $Ga_{.88}In_{.12}N_{.01}As_{.99}$

$E_{g1} = 1.1eV$

P-layer:

$In_{.22}Al_{.78}As$ or GaAs

$E_{g2} = 2.0 - 1.4eV$

Rear-Illuminated PD Advantages

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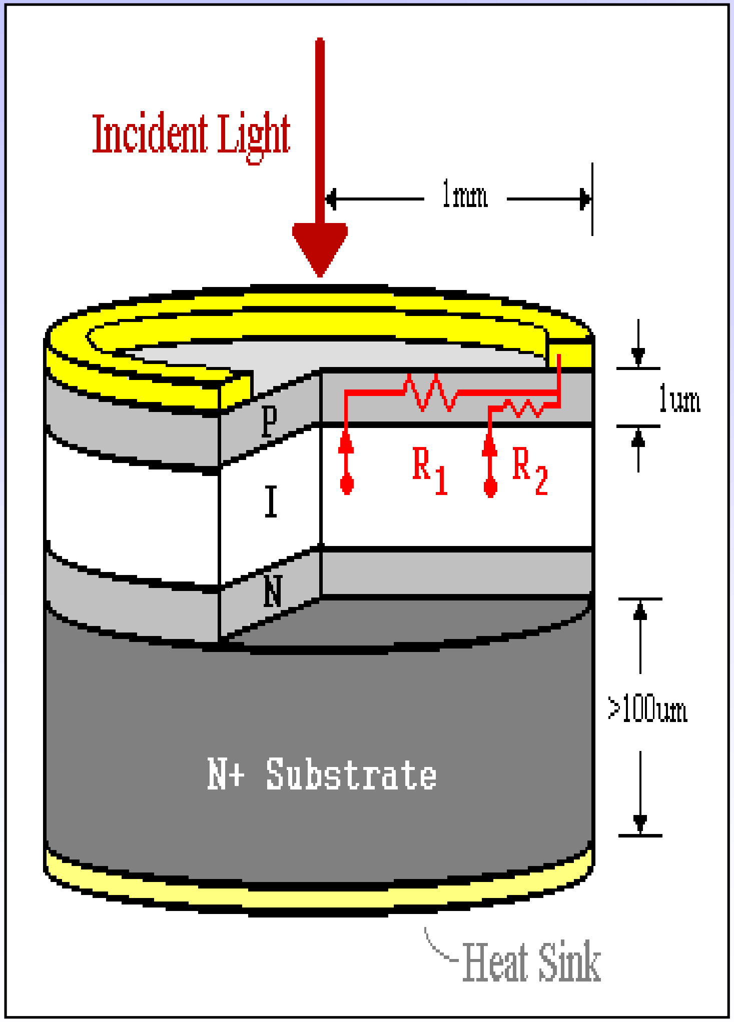
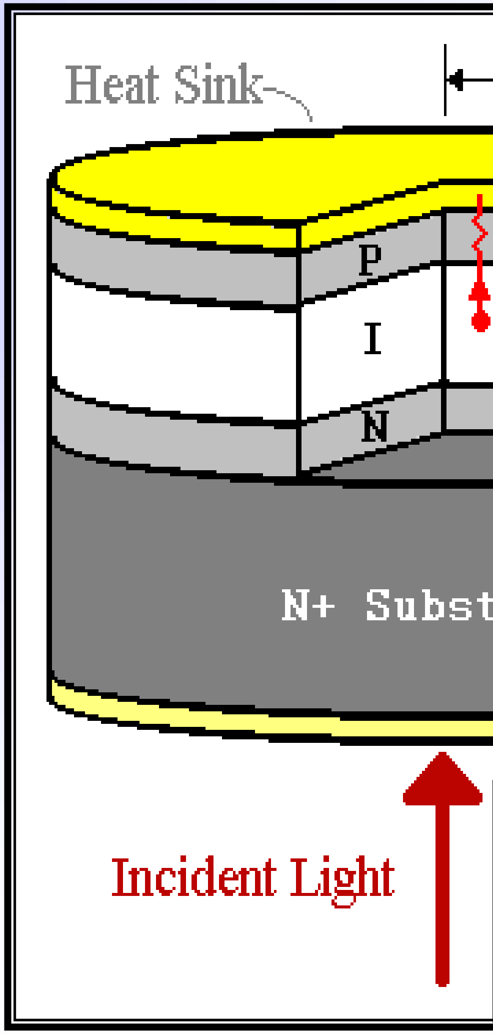


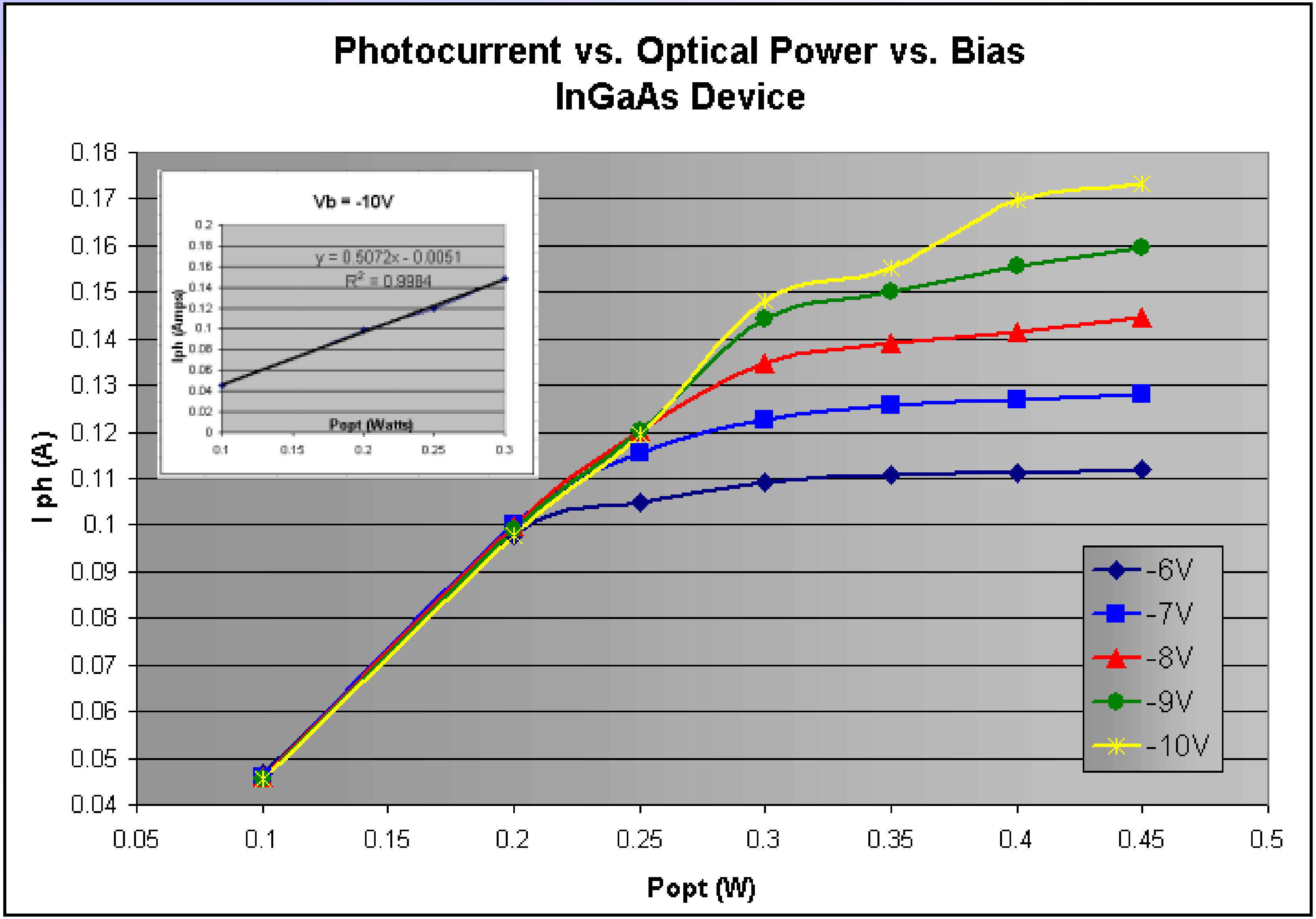


- High Power
- Linear Response
- High Speed

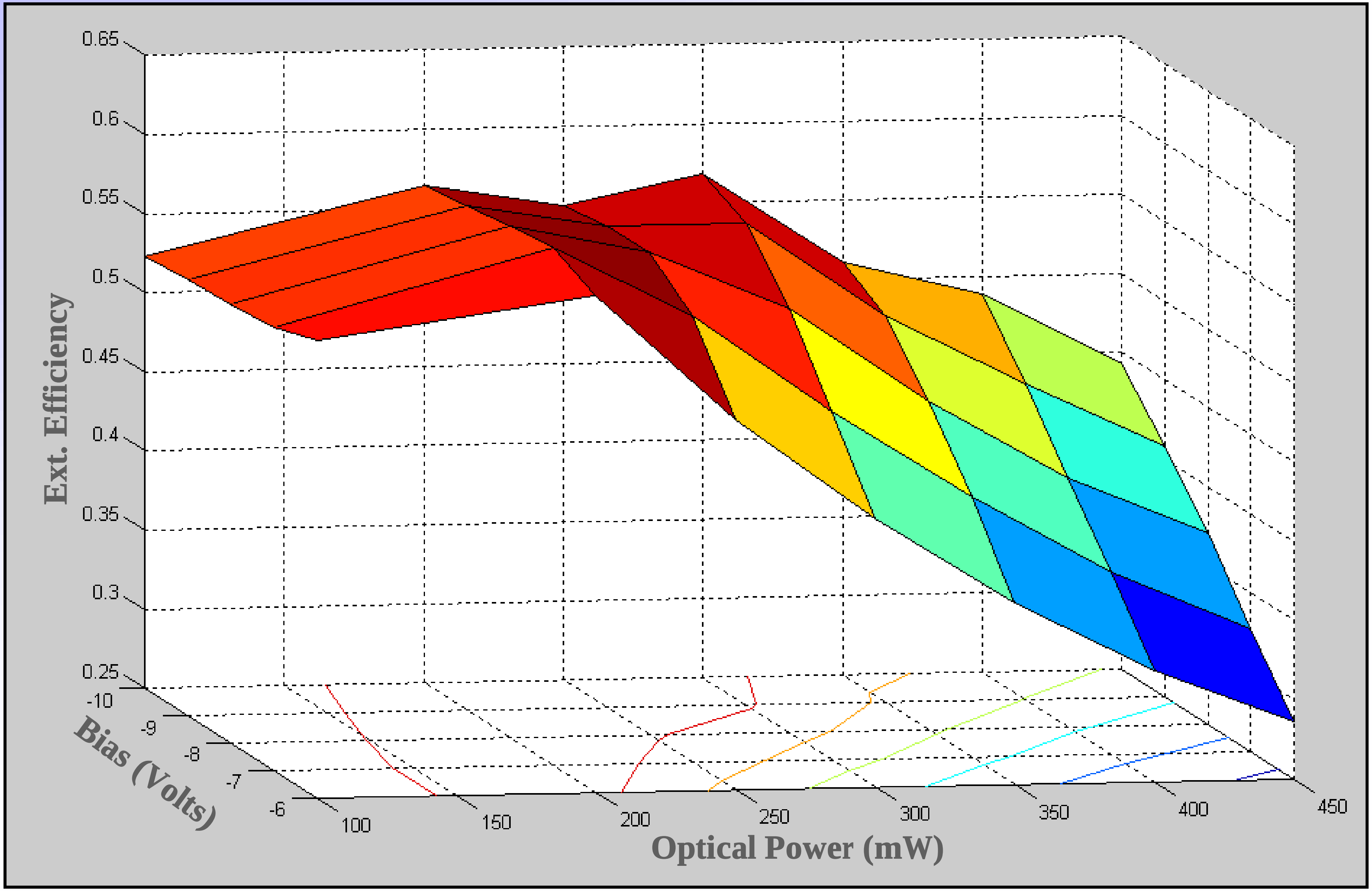
Conventional PD

Adv. LIGO Rear-Illuminated PD

DC Device Response



DC Device Efficiency



High Efficiency Detector Process (1)

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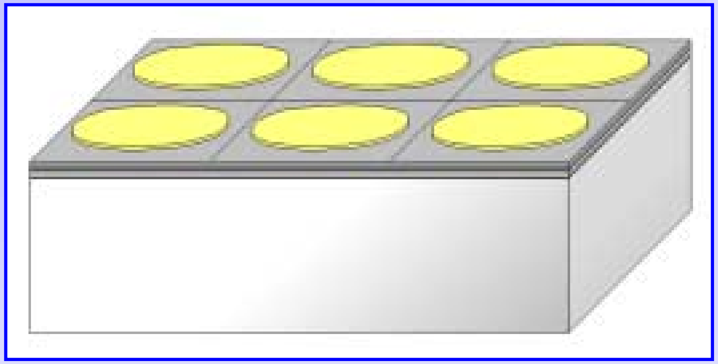
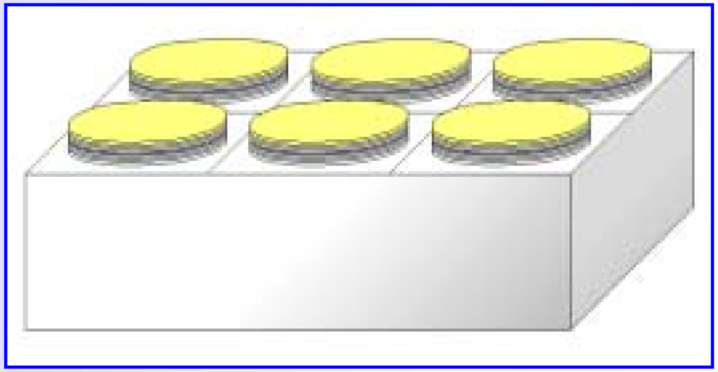
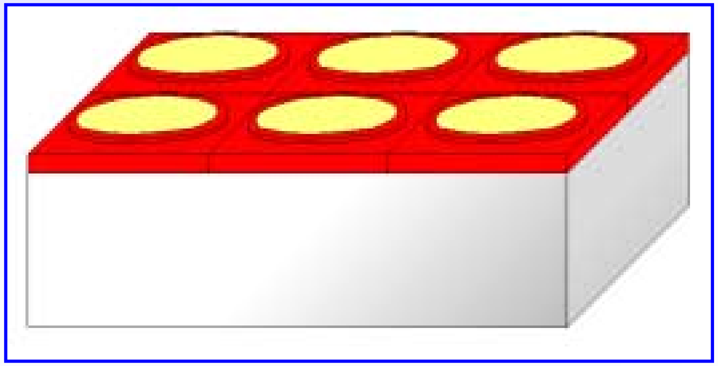
1. Deposit and Pattern P-Contact



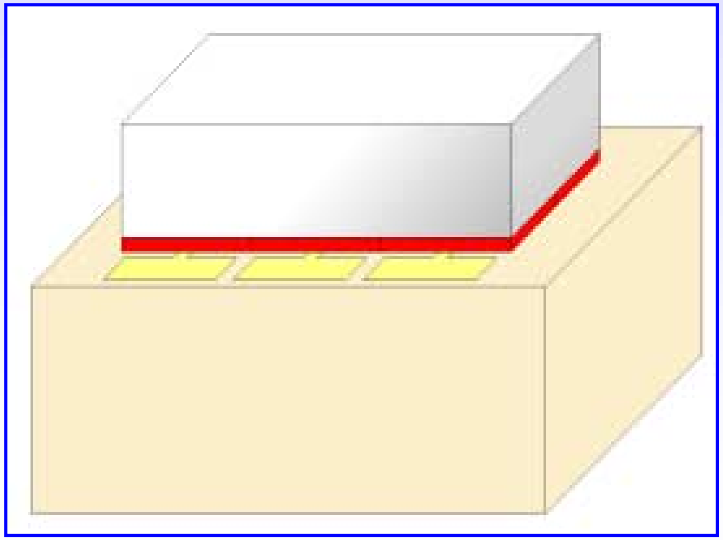
2. Etch Mesa – $H_2SO_4:H_2O_2:H_20$ and Passivate in $(NH_4)_2S+$



3. Encapsulate Exposed Junction



4. Flip-Chip Bond



- N+ GaAs Substrate
- Epitaxial Layers
- Au Contacts
- Polyimide Insulator
- SiN_x AR Coating
- AlN Ceramic

High Efficiency Detector Process (2)

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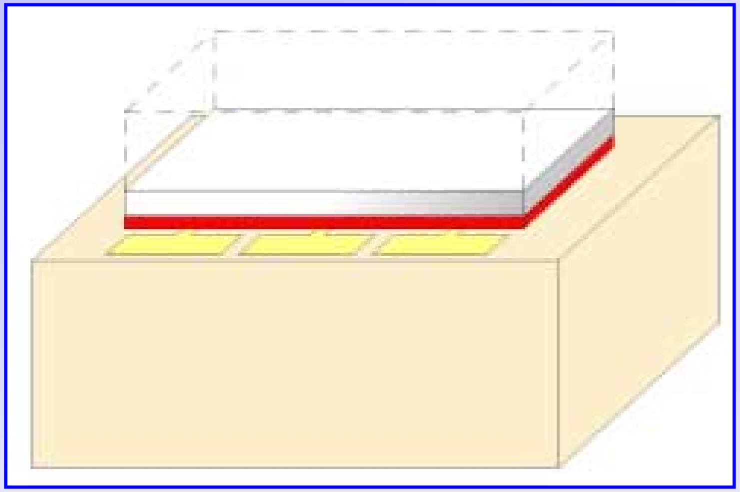
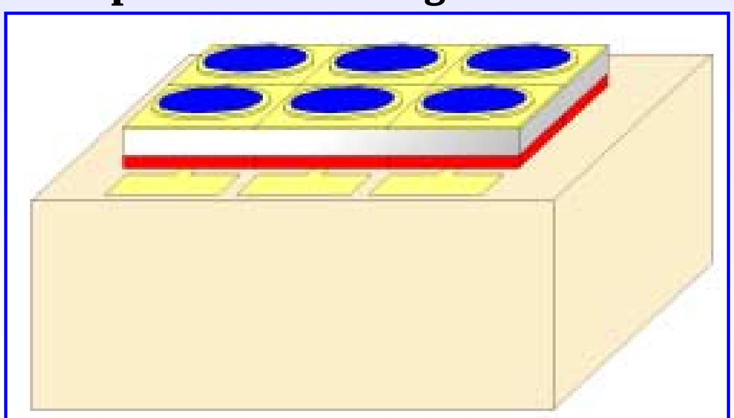
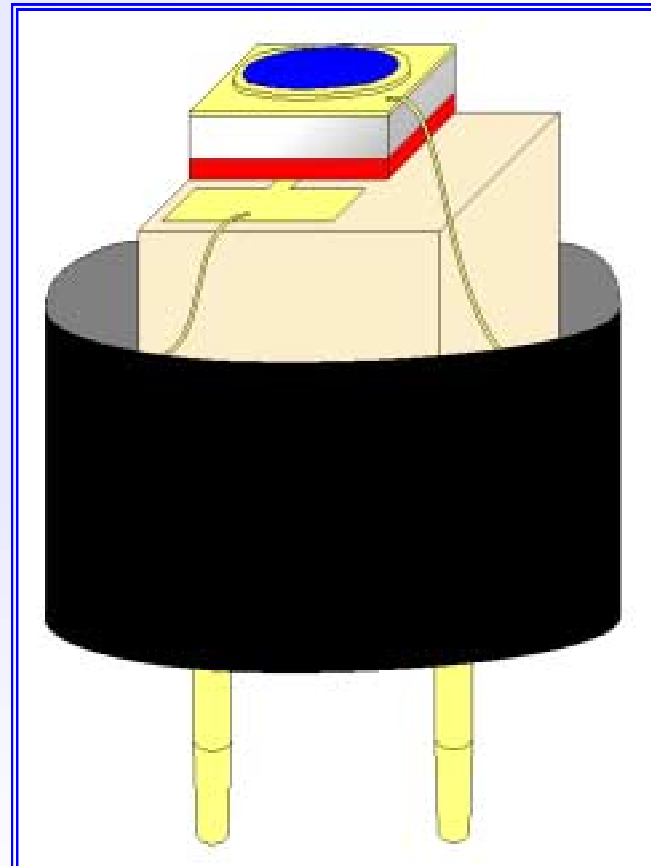
5. Thin N+ GaAs Substrate



6. Deposit AR Coating & N-Contact

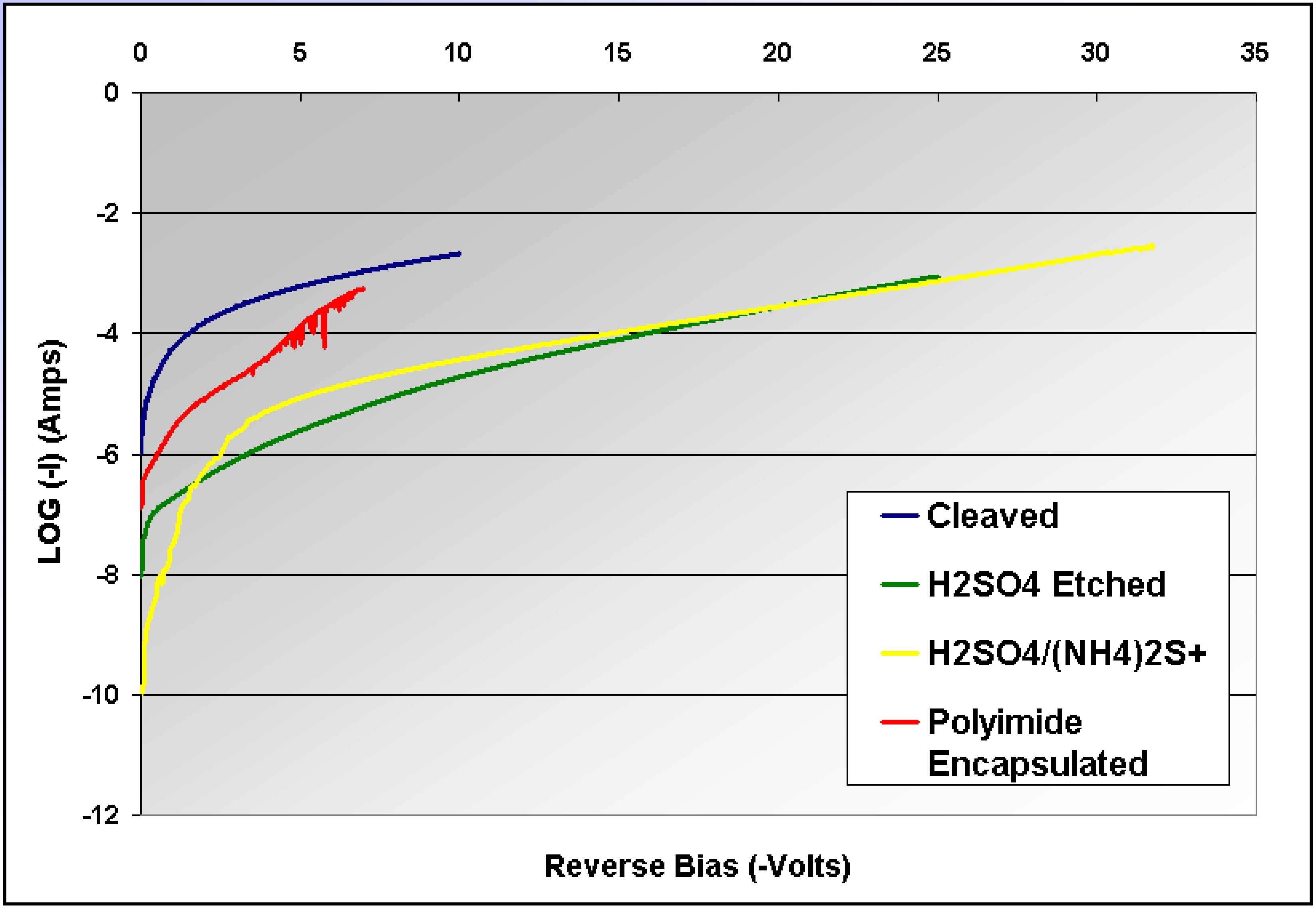


7. Saw, Package and Wire-Bond



- N+ GaAs Substrate
- Epitaxial Layers
- Au Contacts
- Polyimide Insulator
- SiN_x AR Coating
- AlN Ceramic

Surface Passivation Results



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Predictions

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Diameters	3mm	4.5mm	150um
Saturation Power			
Devices	Old	New	New
	300mW	~1W	~2mW
Bandwidth			
Devices	Old	New	New
	3MHz	~1MHz	~1GHz

Conclusion

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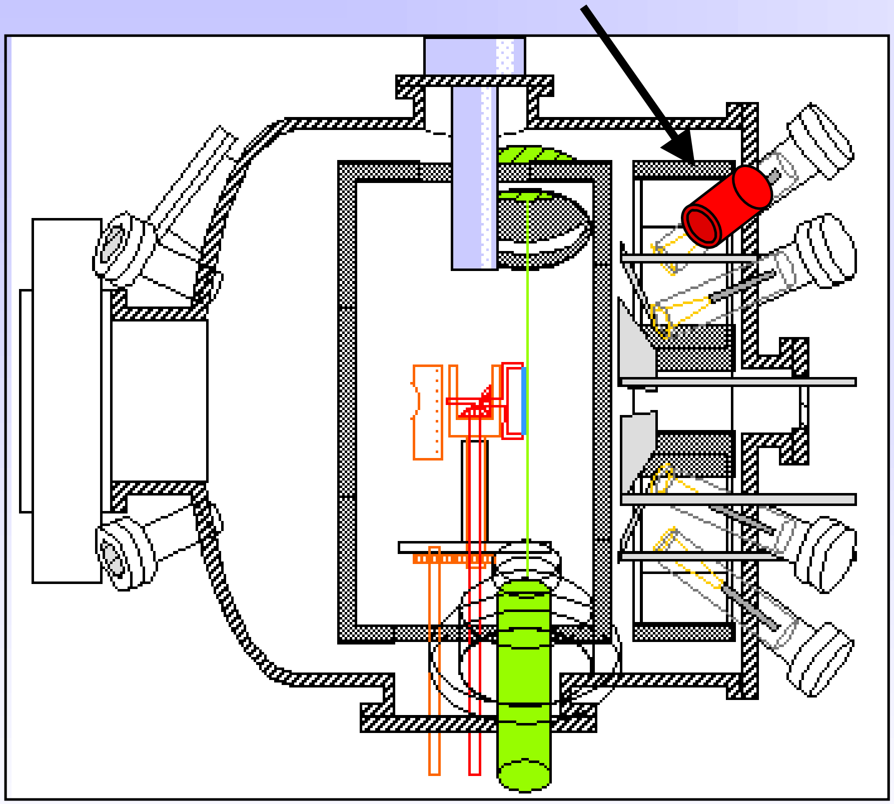
- High-Power Results
  - 300mW (@ 3MHz B.W.)
  - 60% External Efficiency
- High-Efficiency Process
  - < -30 Volts realized (on un-mounted devices)
  - Working out processing
- Predictions (by Next LSC…)
  - 1 Watt (@ 1MHz B.W.)
  - 90% External Efficiency

MBE Crystal Growth

N Plasma Source



Atomic source of nitrogen needed

$\rightarrow$ Plasma Source!

- **Effusion cells for In, Ga, Al**
- **Cracking cell for As**
- **Abrupt interfaces**
- **Chamber is under UHV conditions to avoid incorporating contaminants**
- **RHEED can be used to analyze crystal growth** *in situ* **due to UHV environment**
- **T=450-600°C**

P-I-N Device Characteristics

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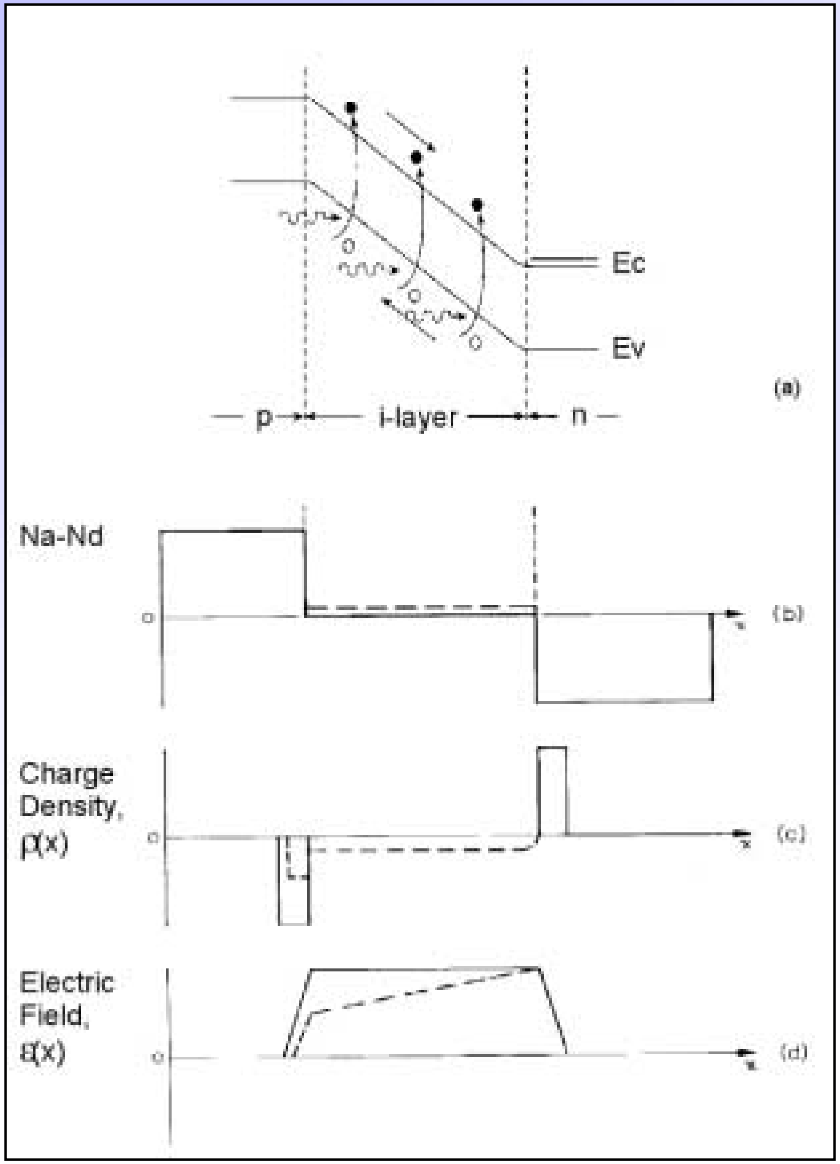


- **Large E-field in I-region**
- **Depletion Width ≈ Width of I- region**
  - **RC time constant**

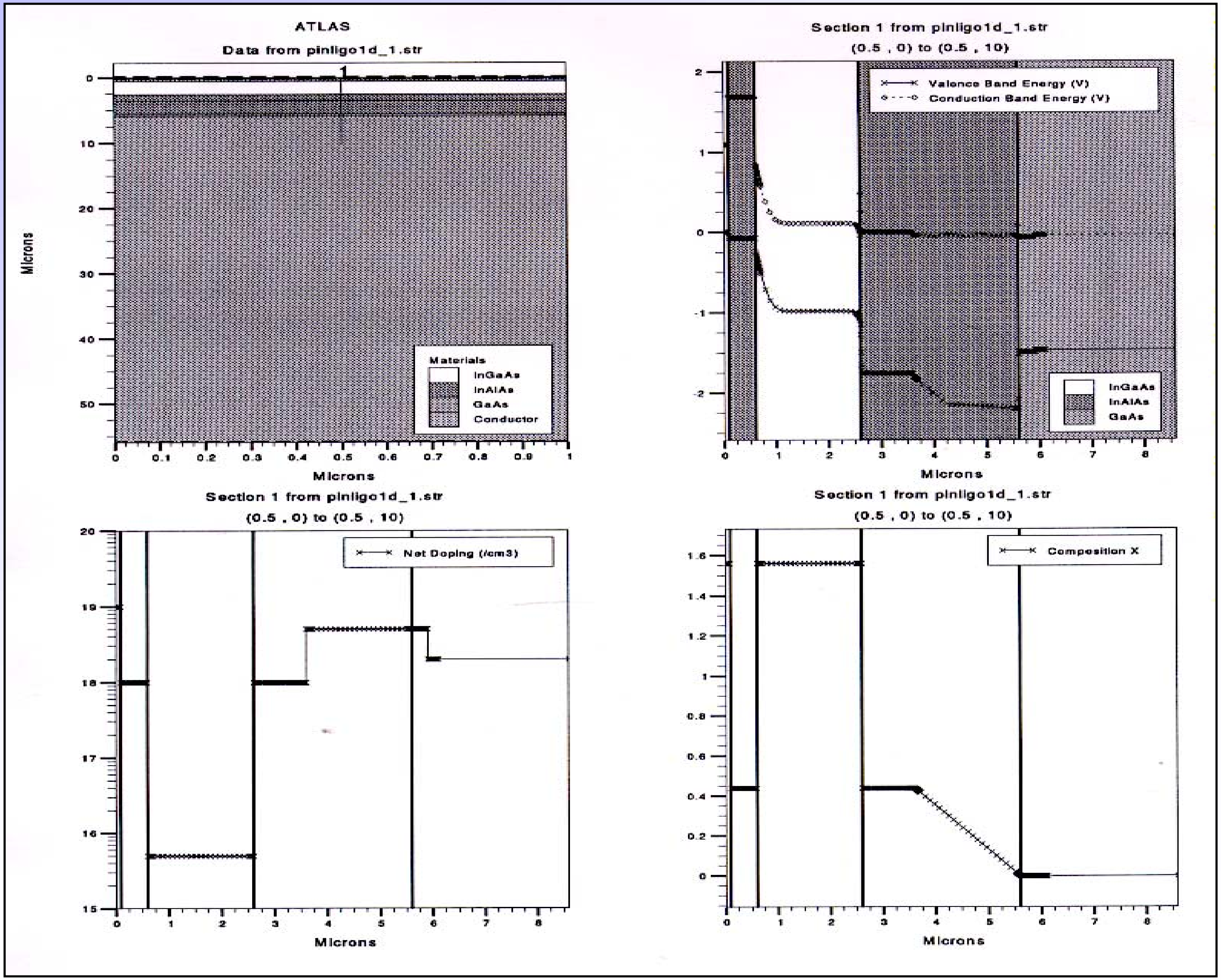
$$\approx R_s C_J$$

$$C_J = K_s \varepsilon_0 A / W_I$$

  - **Absorbs a specific λ**

$$W_I >> \frac{1}{\alpha}$$

Full Structure Simulated by ATLAS



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DC Device Efficiency

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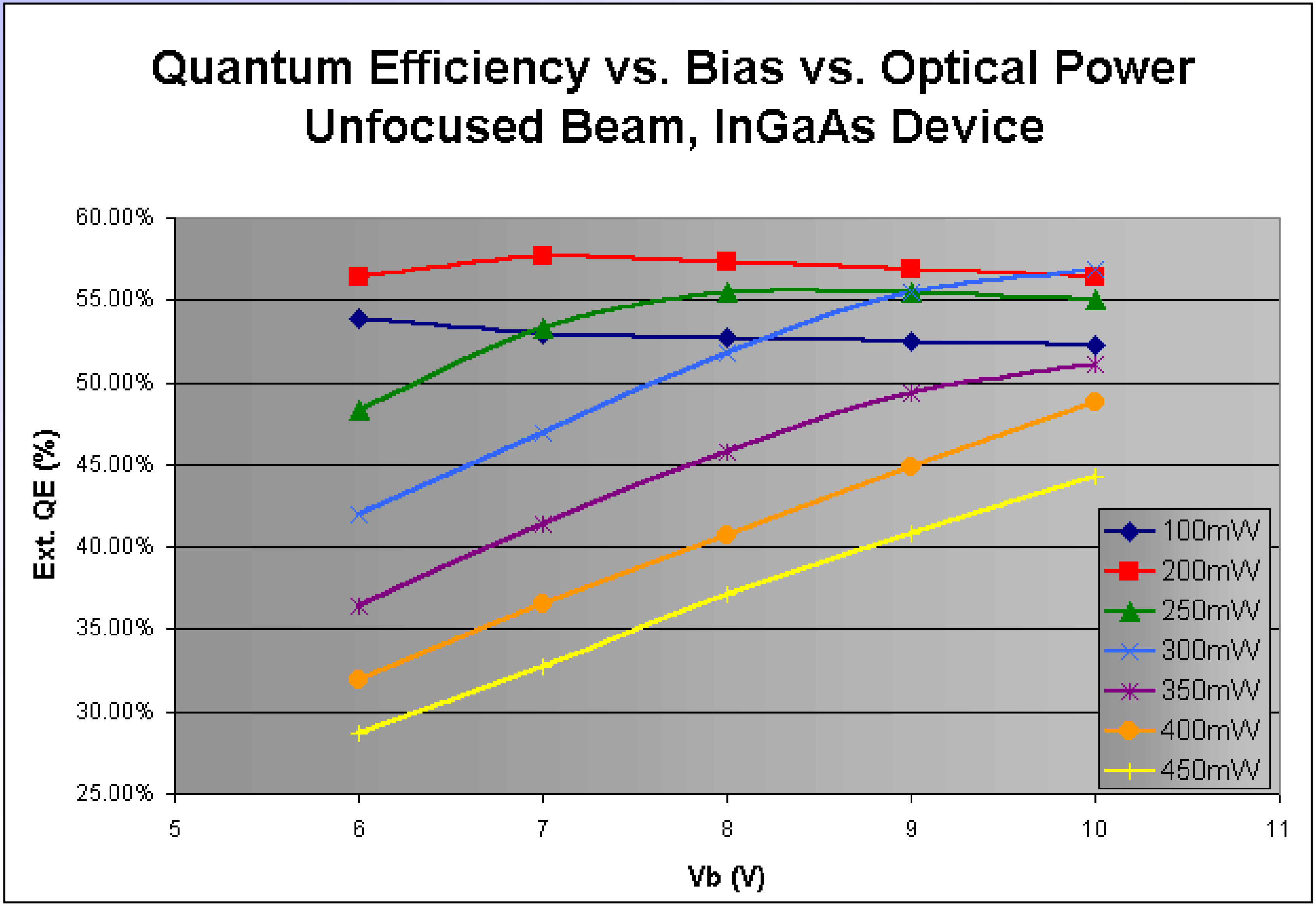
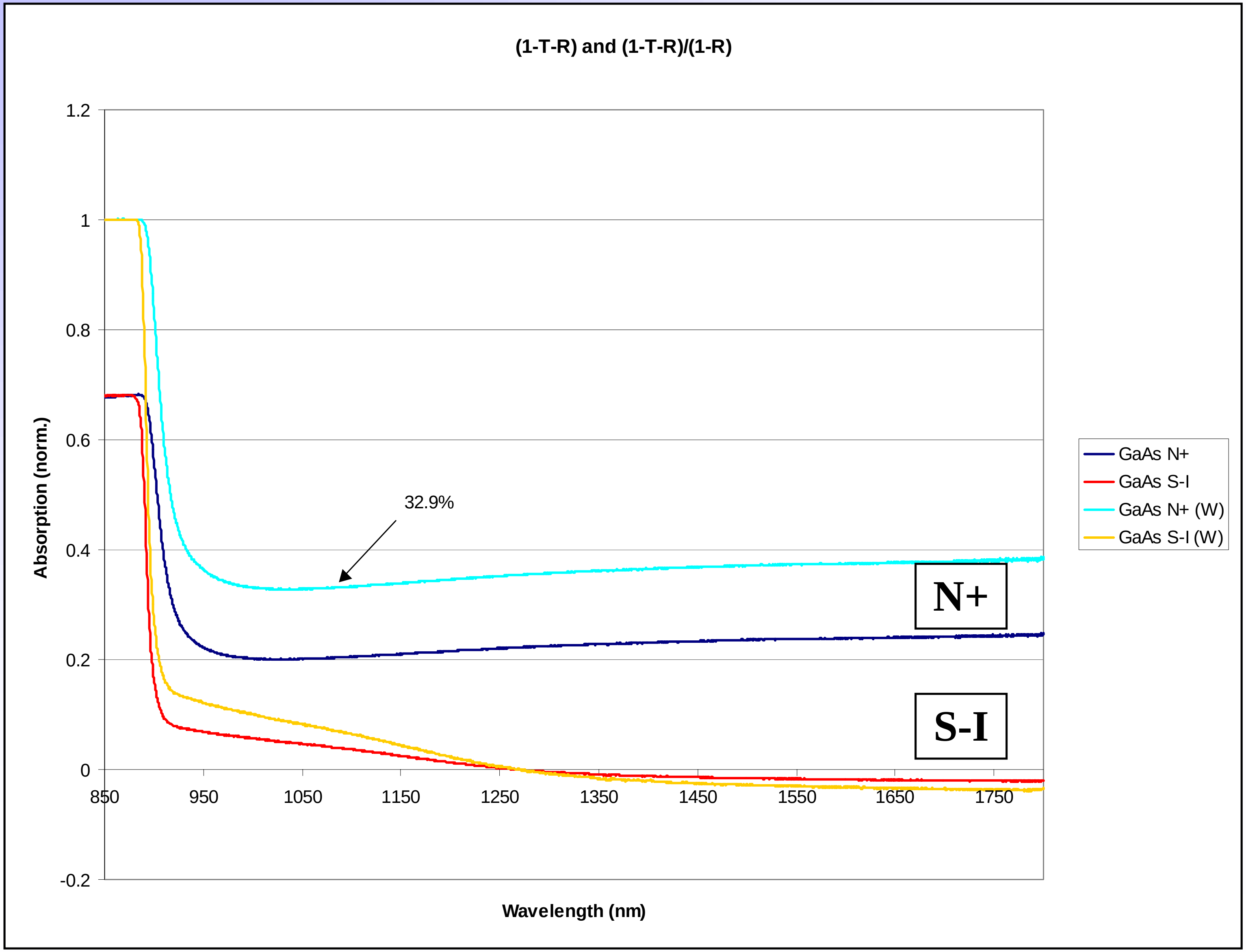
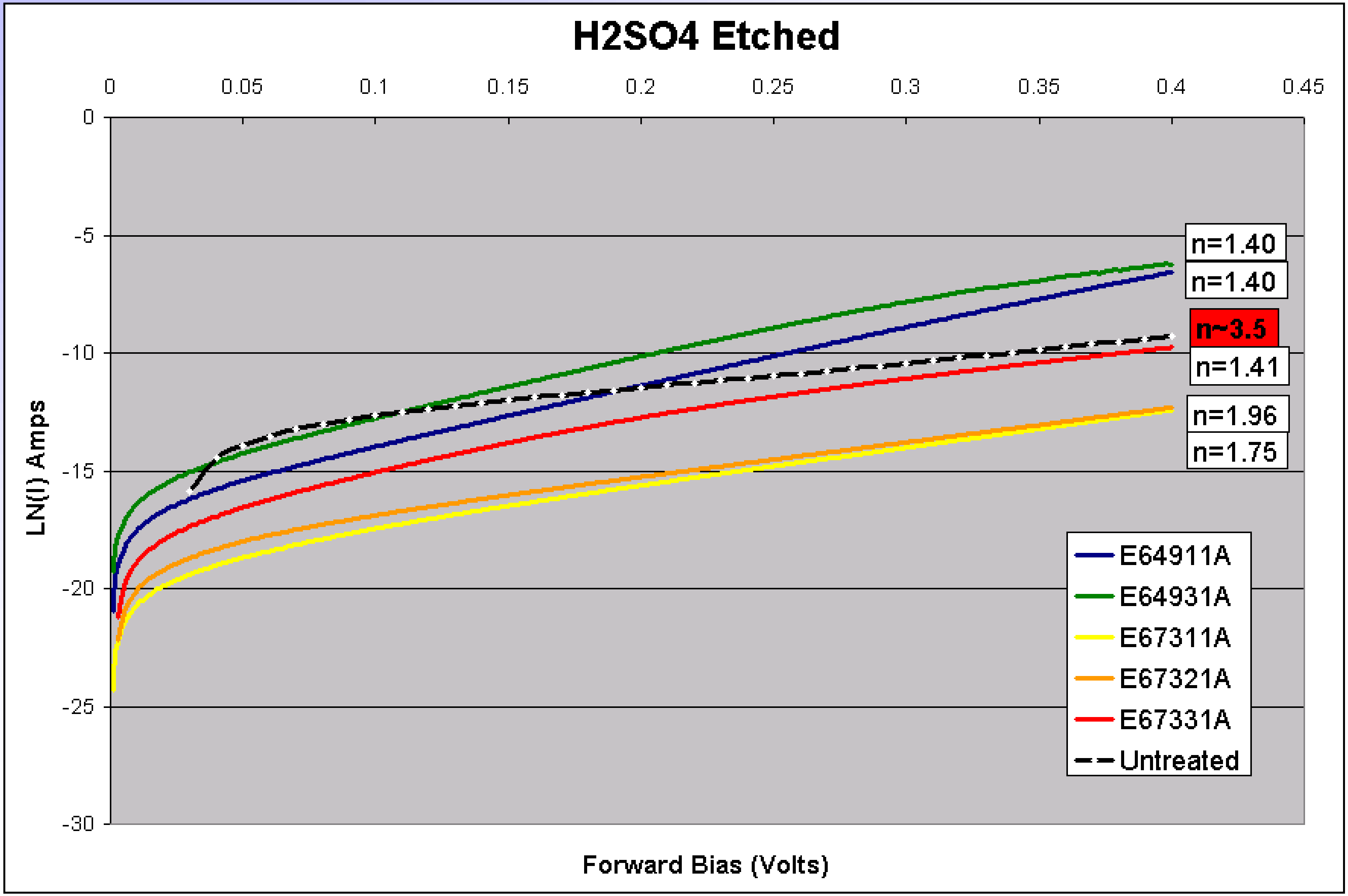


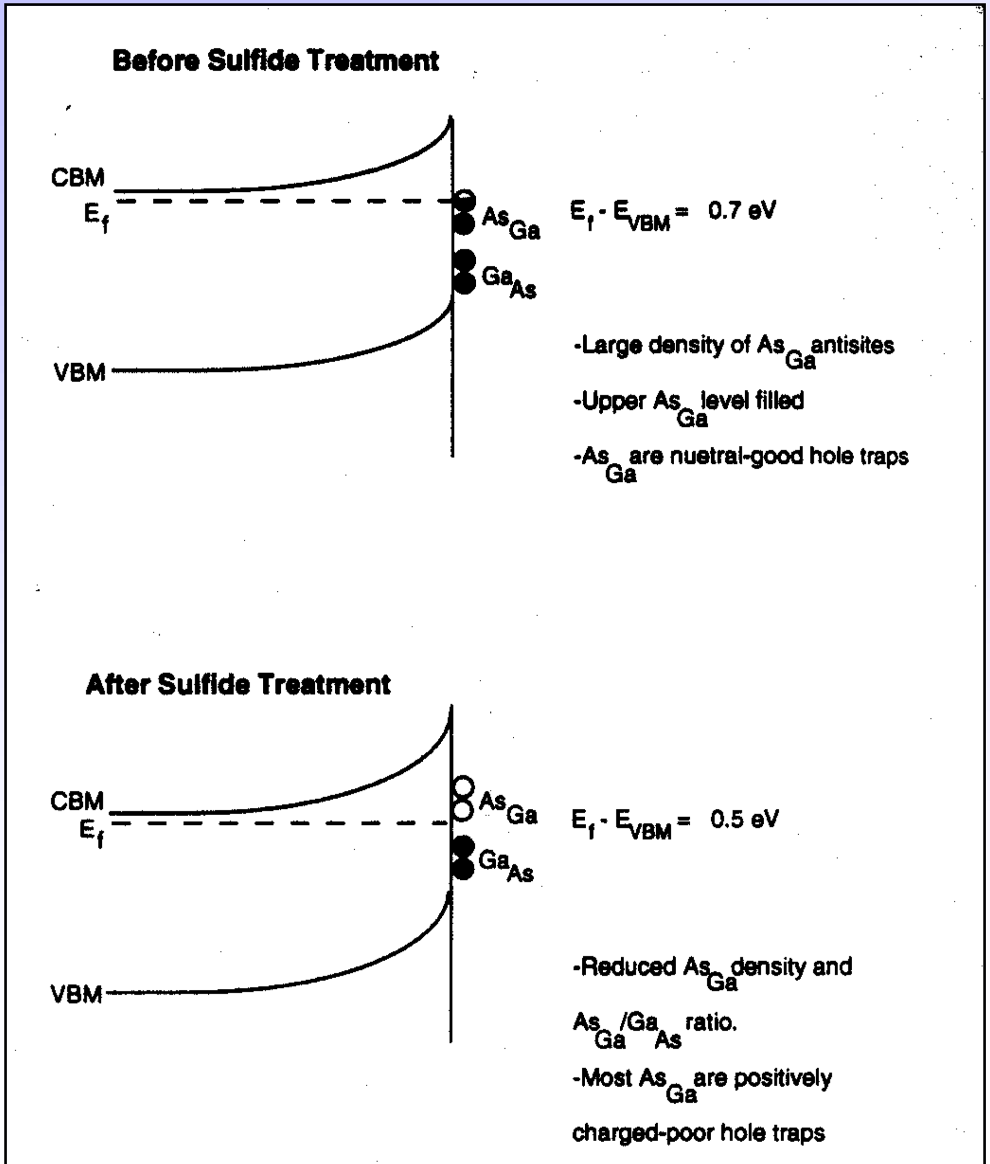
Free-Carrier Absorption

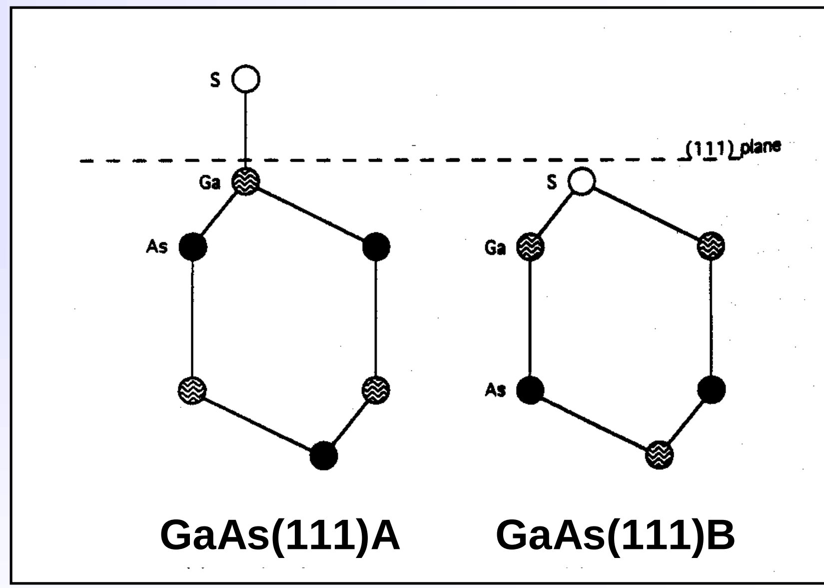


Surface Passivation Results (2)



$(NH_4)_2S$+ Surface States





(Green and Spicer, 1993)