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# High-Power High-Efficiency Photodiode for Advanced LIGO

LIGO-G010359-00-Z

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# Outline



- Introduction
  - Photodiode Specifications
  - Device Structure & Materials
- Experimental Results
  - DC Response
  - RF Response
- Development Plan
  - InGaAs
  - GaInNAs

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# Photodiode Specifications?

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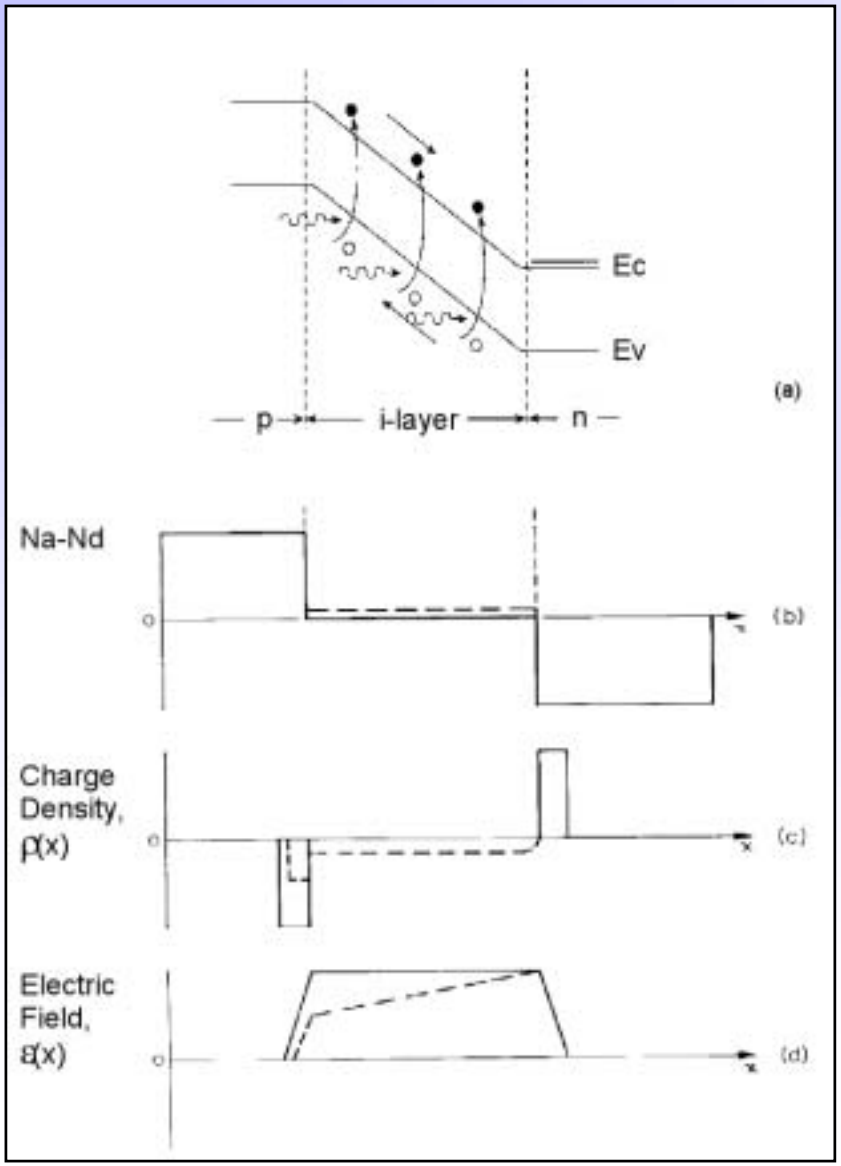
| Parameter | LIGO I | Advanced LIGO |
|---|---|---|
| **Steady-State Power** | 0.6 W | 1~10 W |
| **Operating Frequency** | < 29 MHz | 100 kHz ~ 180 MHz |
| **Quantum Efficiency** | > 80% | > 90% |
| **Detector Design** | Bank of 6(+) PDs | 1 PD |

# P-I-N Device Characteristics




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

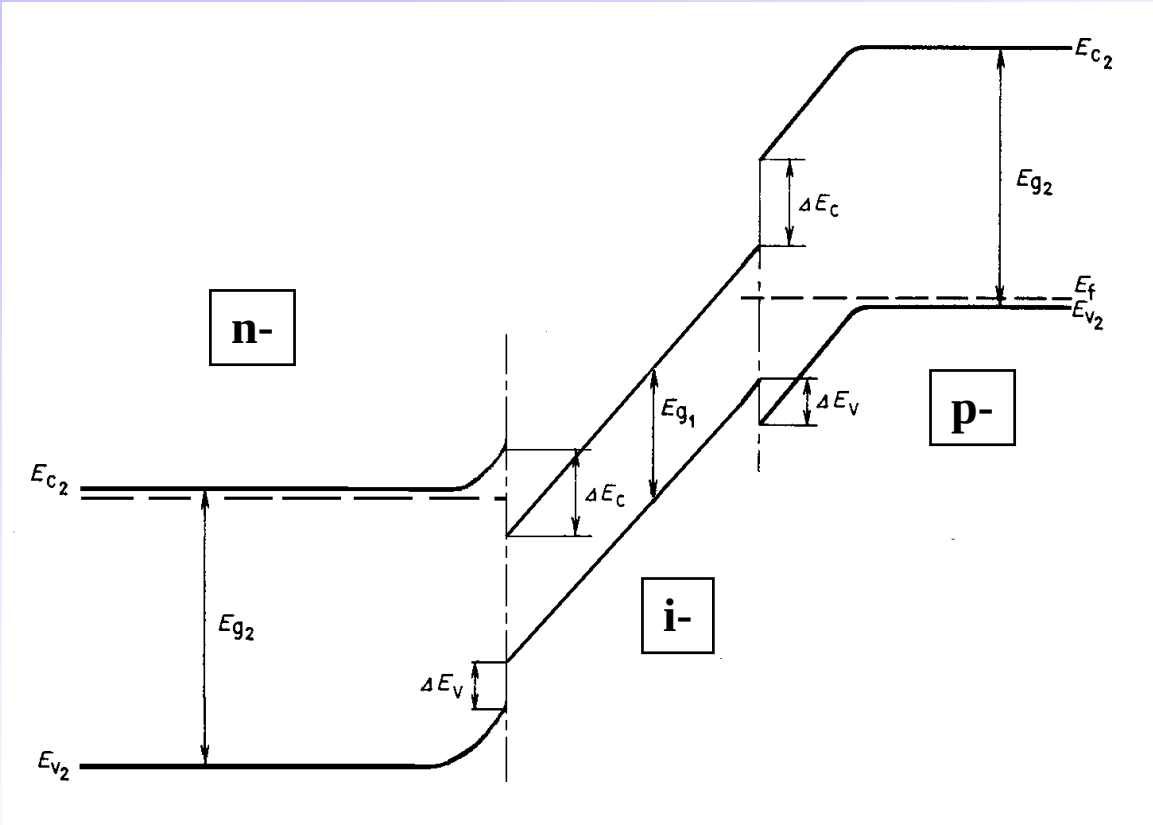
$$\approx R_s C_J$$

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

  - **Tuned to a specific λ**

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

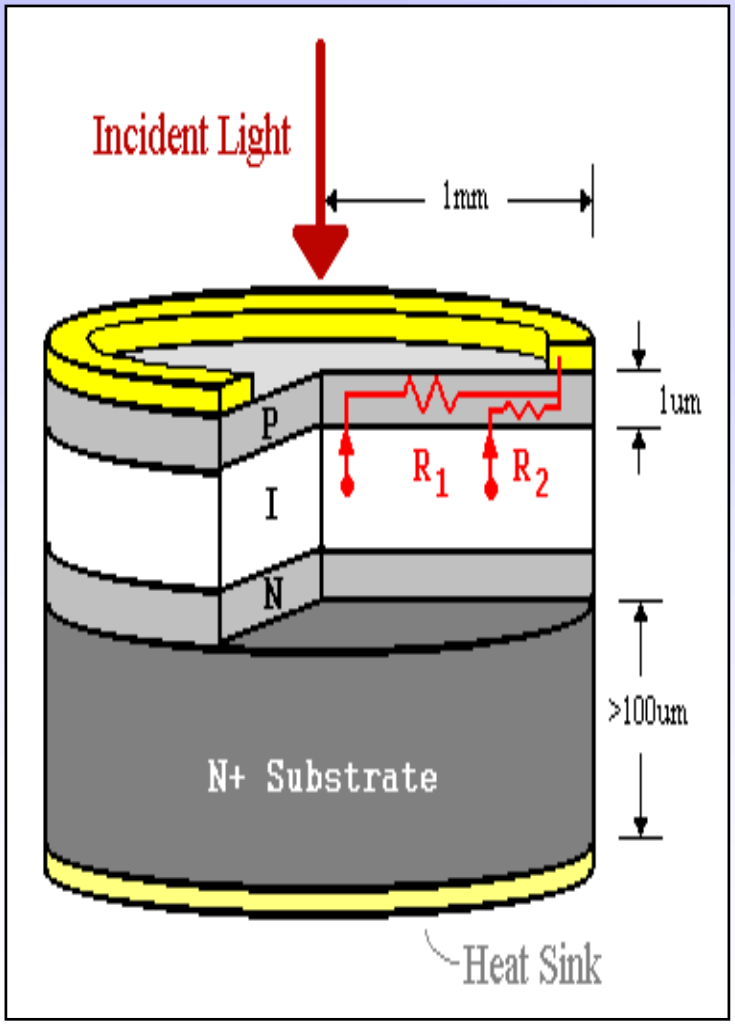
# Heterojunction Band Gap Diagram

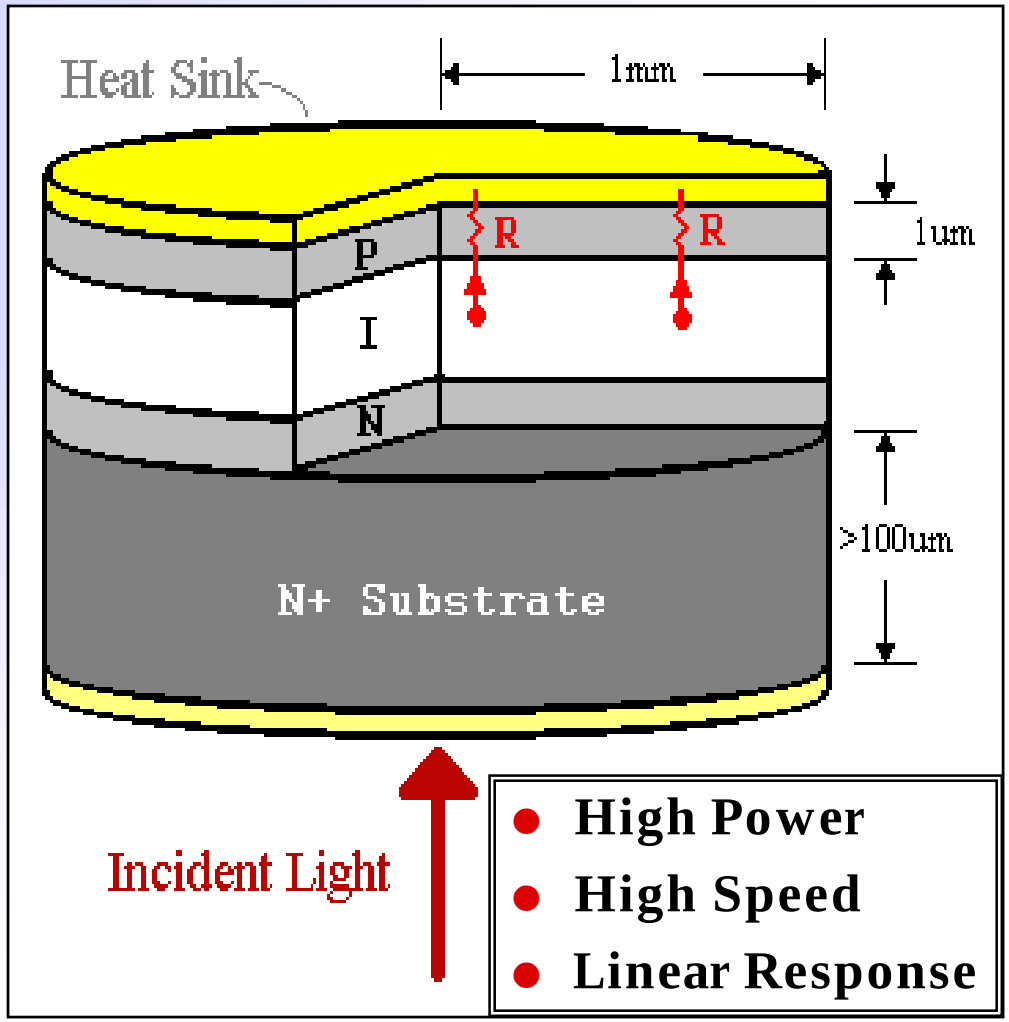



- $\lambda = 1.064\mu m$
  $\Rightarrow h\nu = 1.17eV$
- Absorption occurs in i-region
- InAlAs Optically transparent to 1.06μm radiation

| N-layer: | I-layer: | P-layer: |
|---|---|---|
| $In_{.22}Al_{.78}As$ | $In_{.22}Ga_{.78}As$ | $In_{.22}Al_{.78}As$ |
| $E_{g2} = 1.8eV$ | $E_{g1} = 1.1eV$ | $E_{g2} = 1.8eV$ |

# Rear-Illuminated PD Advantages

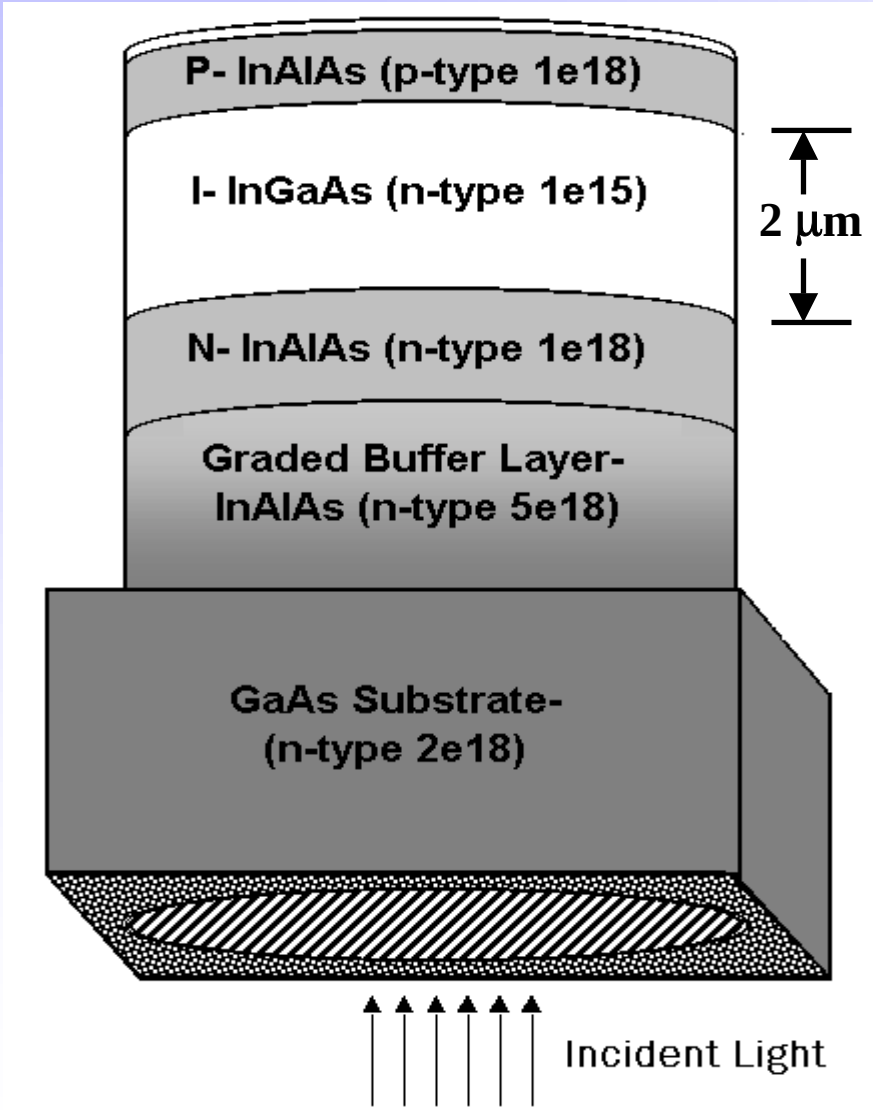



**Conventional PD**

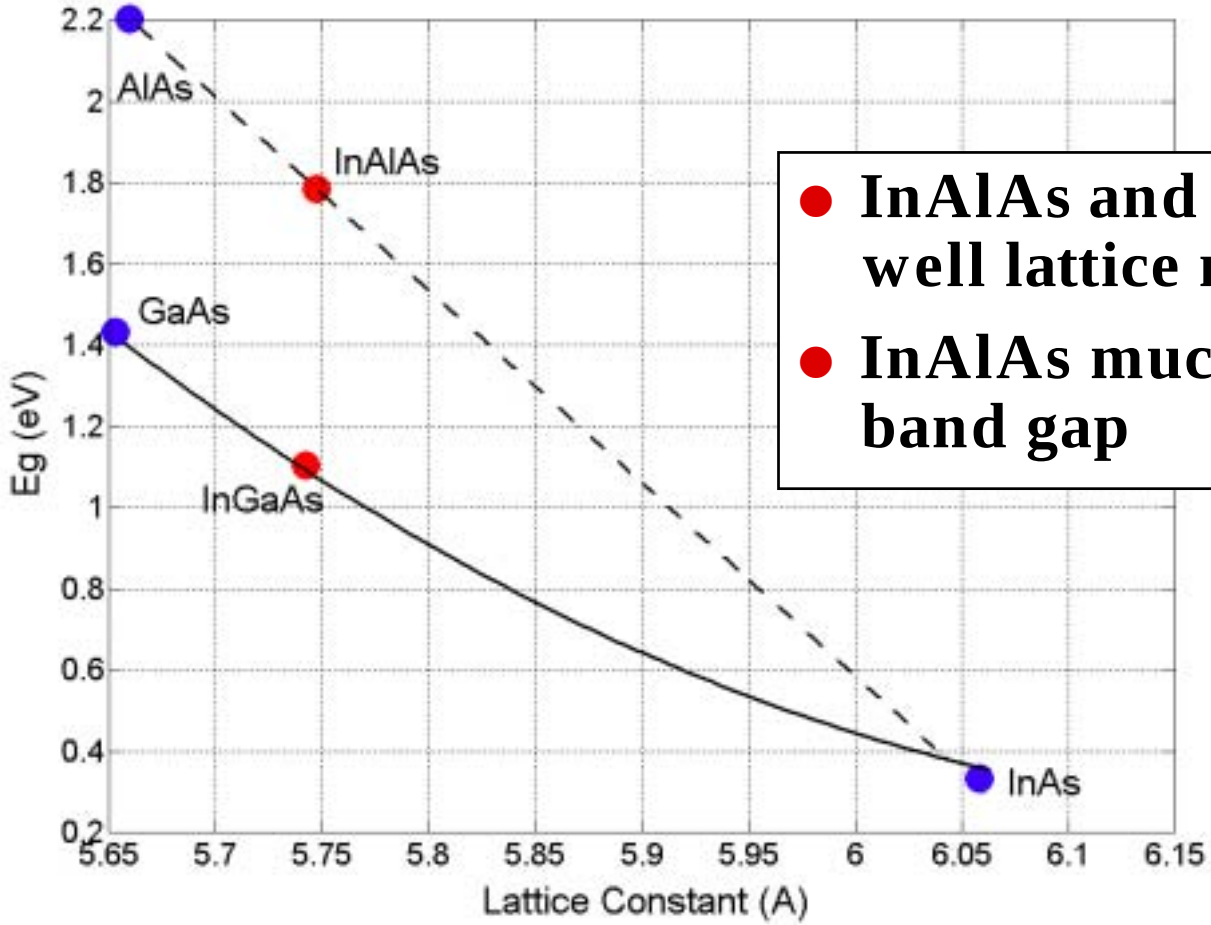
**Adv. LIGO Rear-Illuminated PD**

# InGaAs/GaAs PD Structure



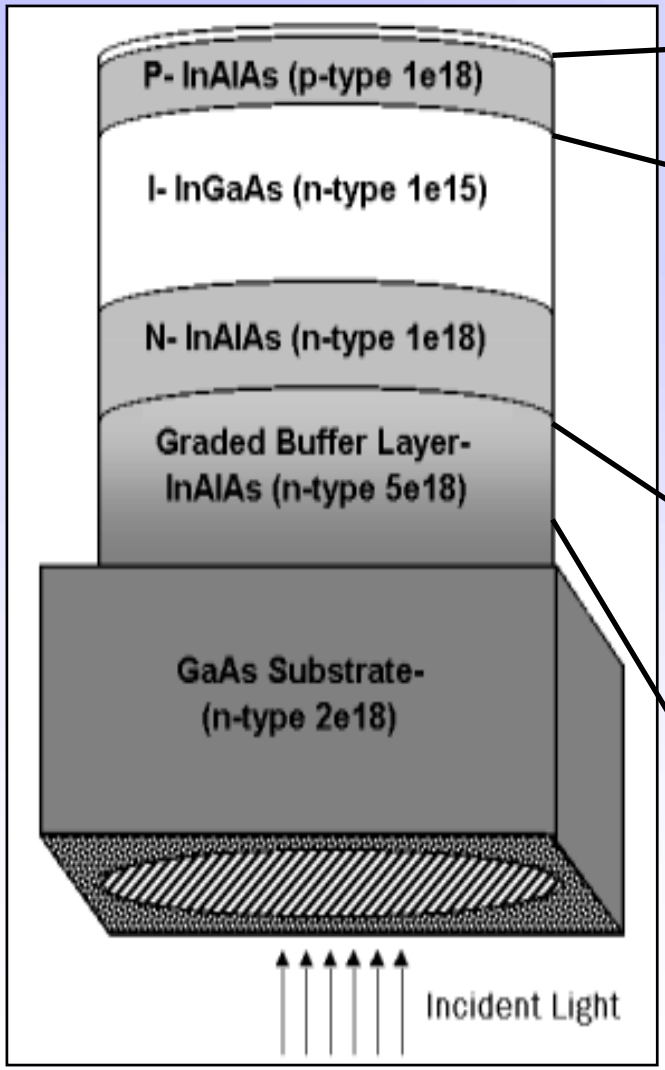

- MBE
- GaAs Substrate
- InGaAs for i-layer
- InAlAs for the n- and p- layers
- Graded Buffer layer
- AR coating & Au/Pt contacts

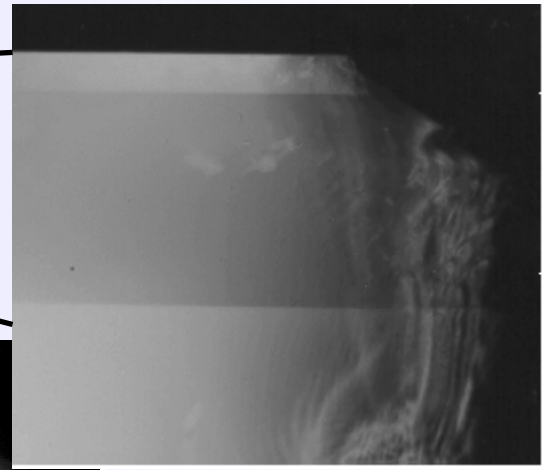
# III-V Lattice Constants and Band Gaps

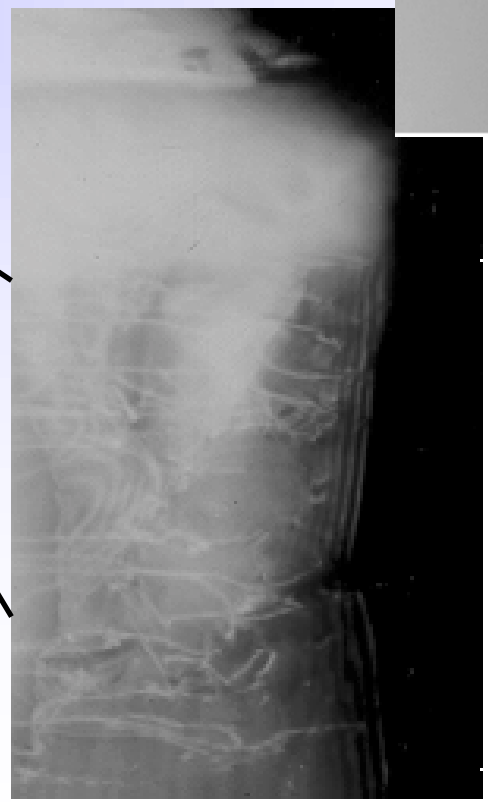



- **InAlAs and InGaAs well lattice matched**
- **InAlAs much wider band gap**

# TEM Images of Confined Dislocations

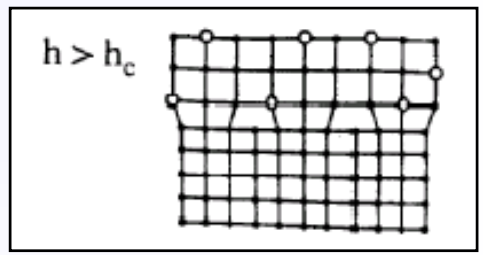




**Device Layers:**

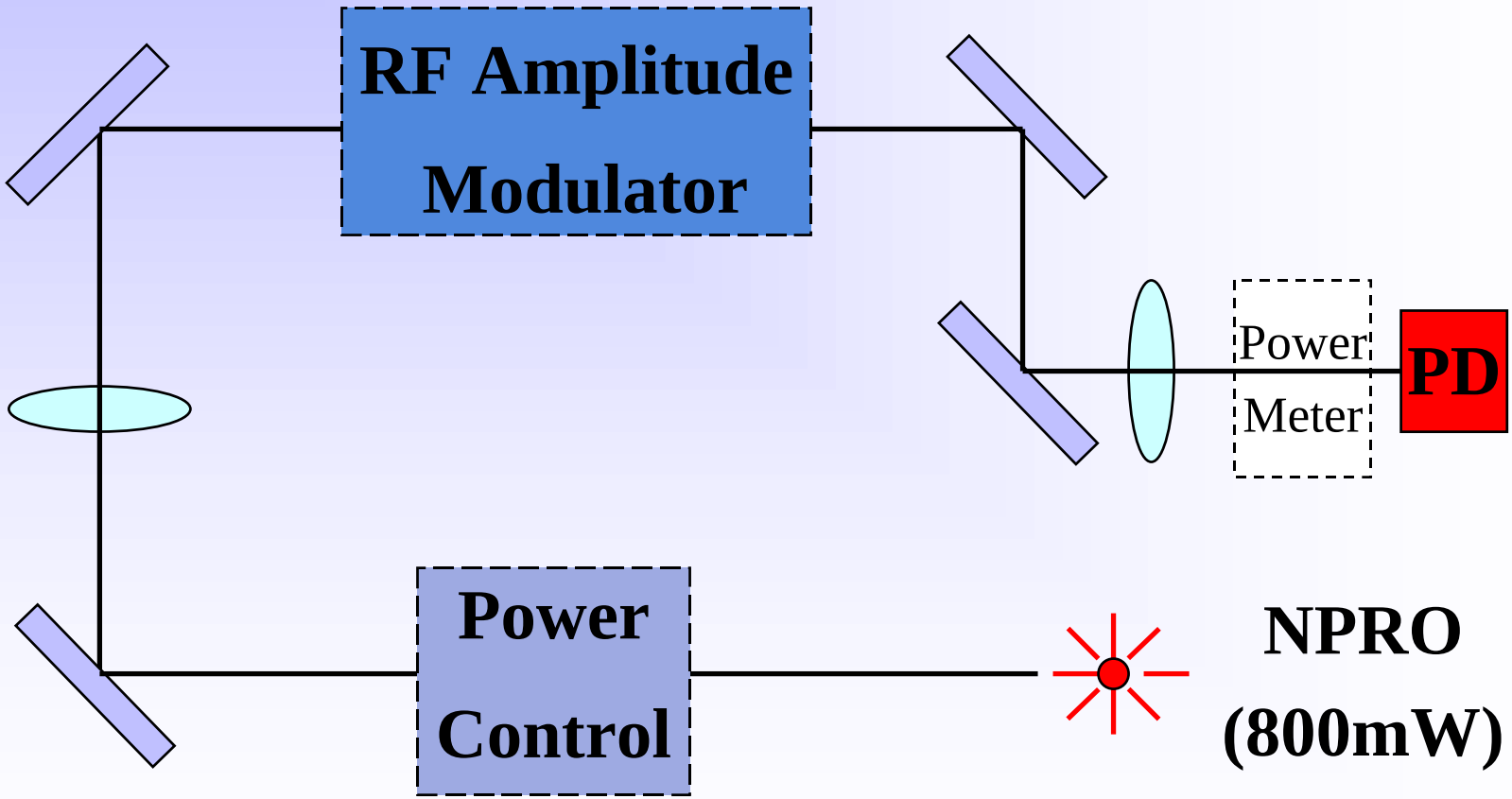
**-few dislocations**



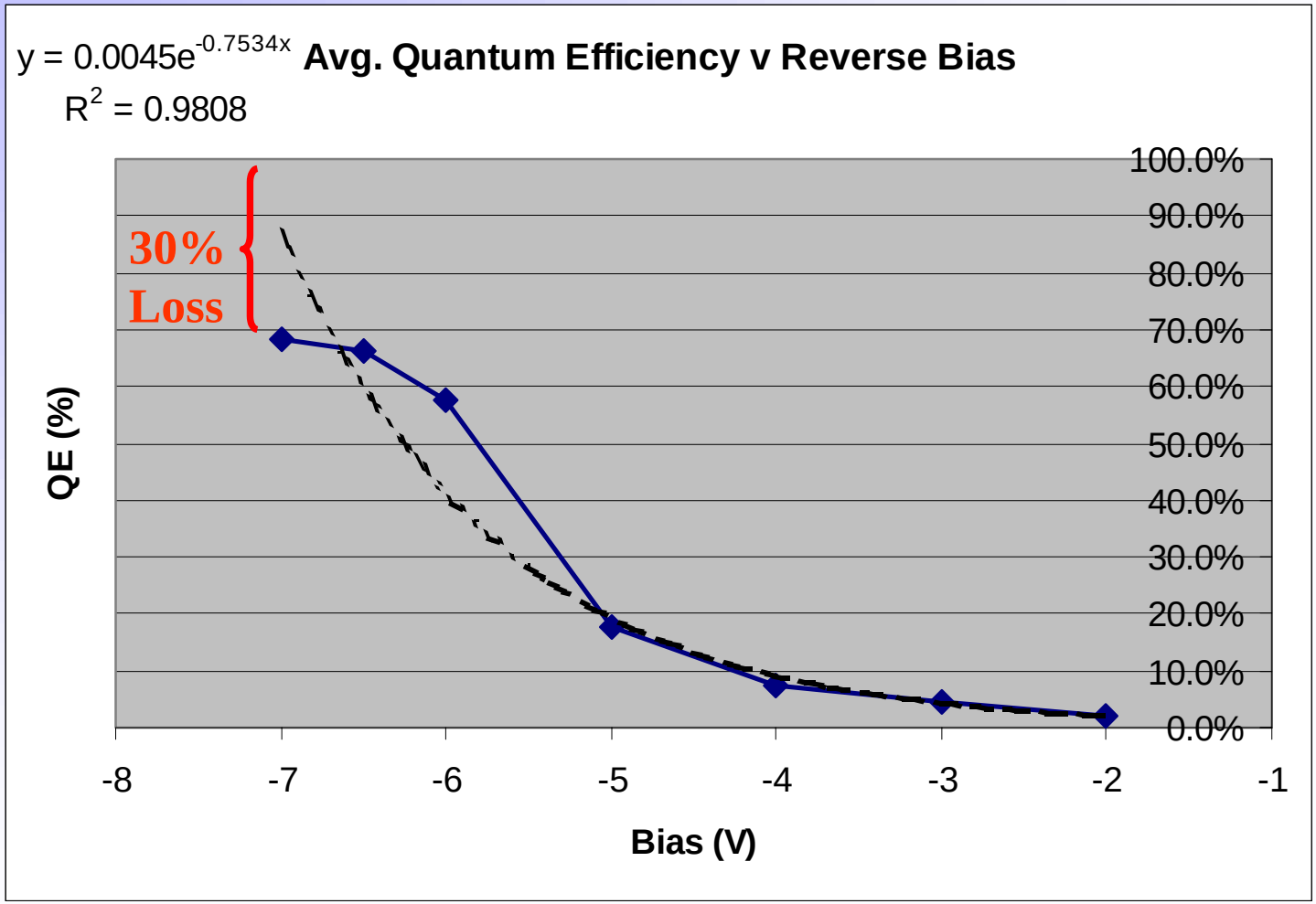

**Graded Buffer:**

**-many dislocations**

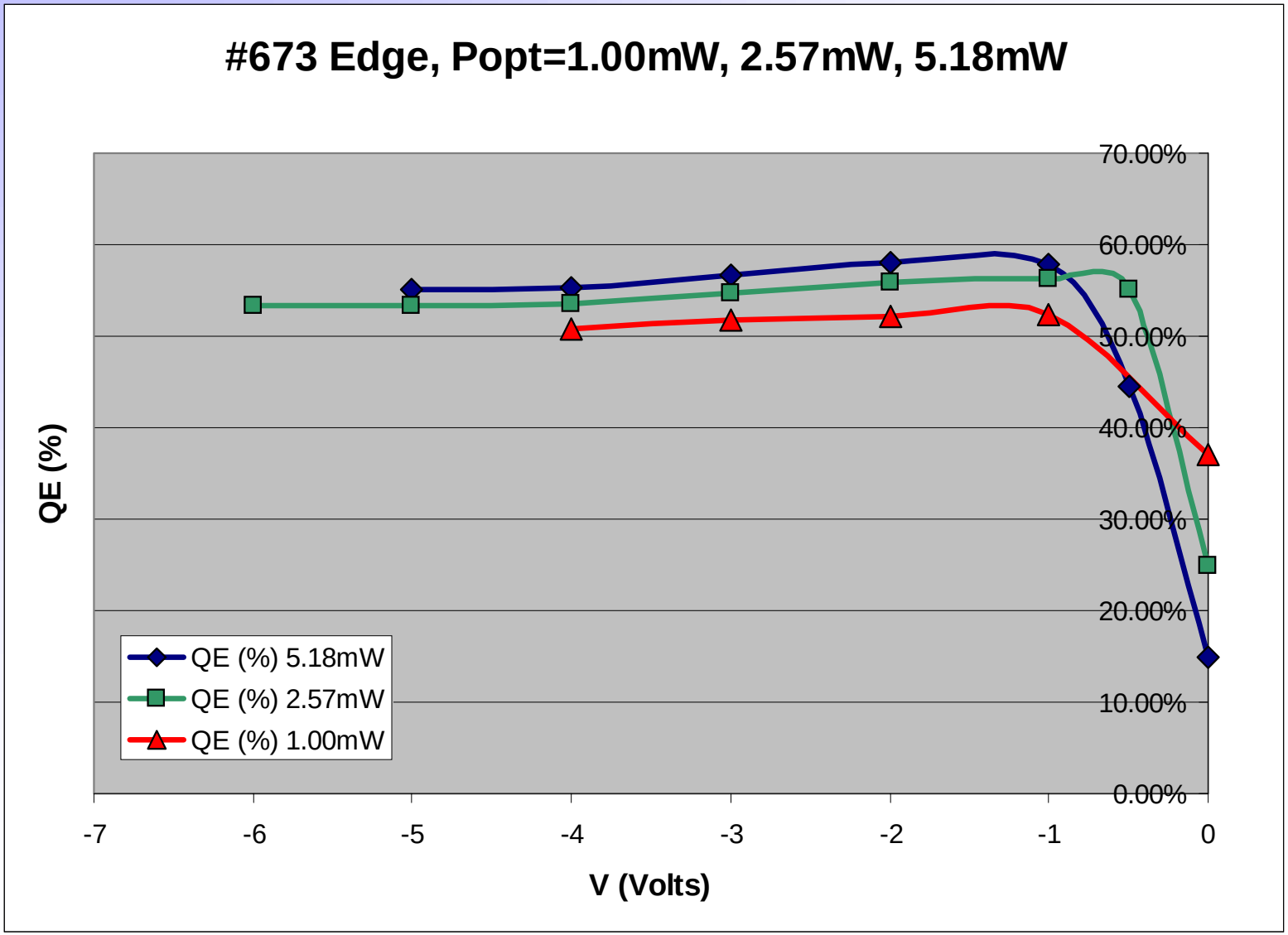
# Nd:YAG (NPRO) PD Test Setup



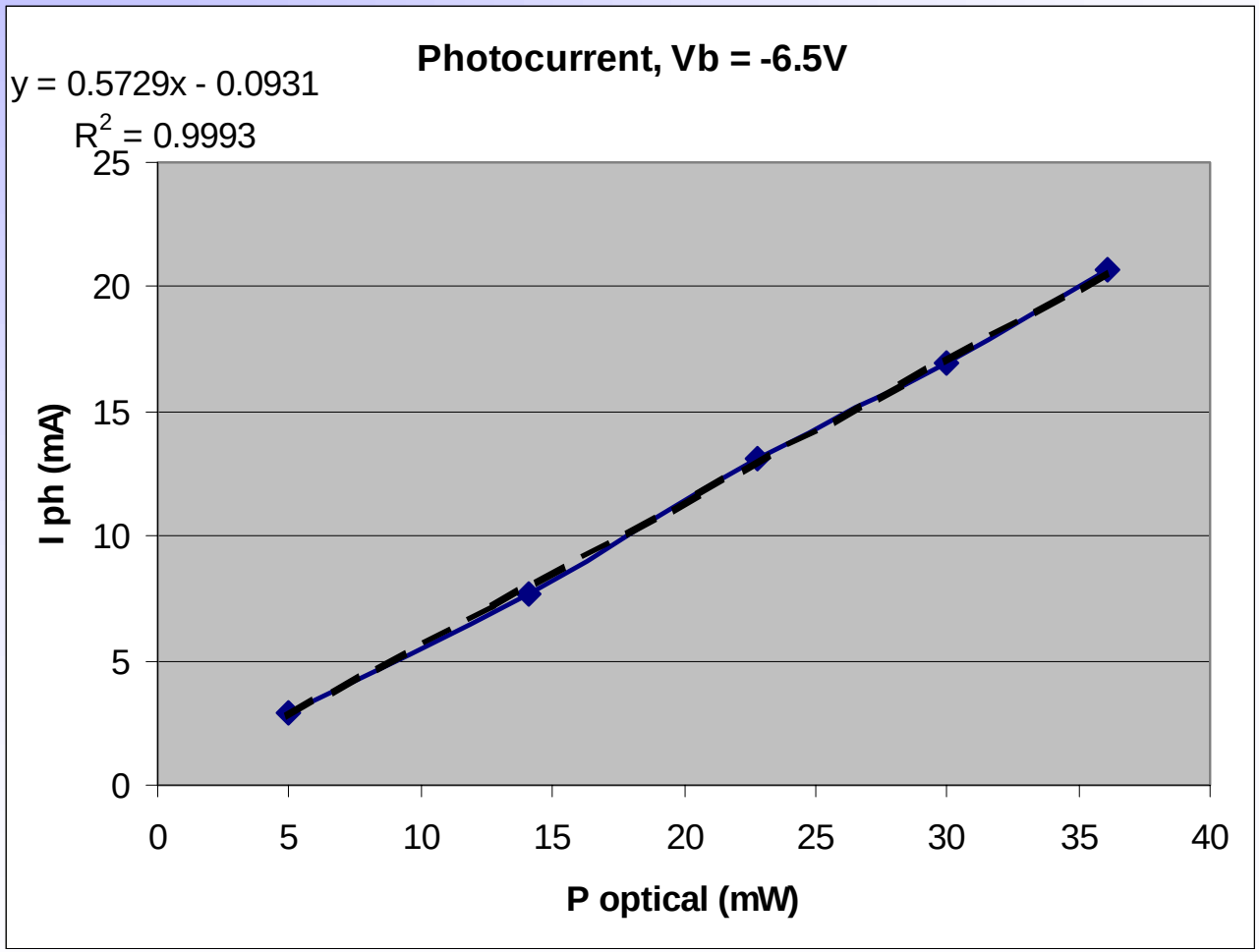
# Quantum Efficiency: #673



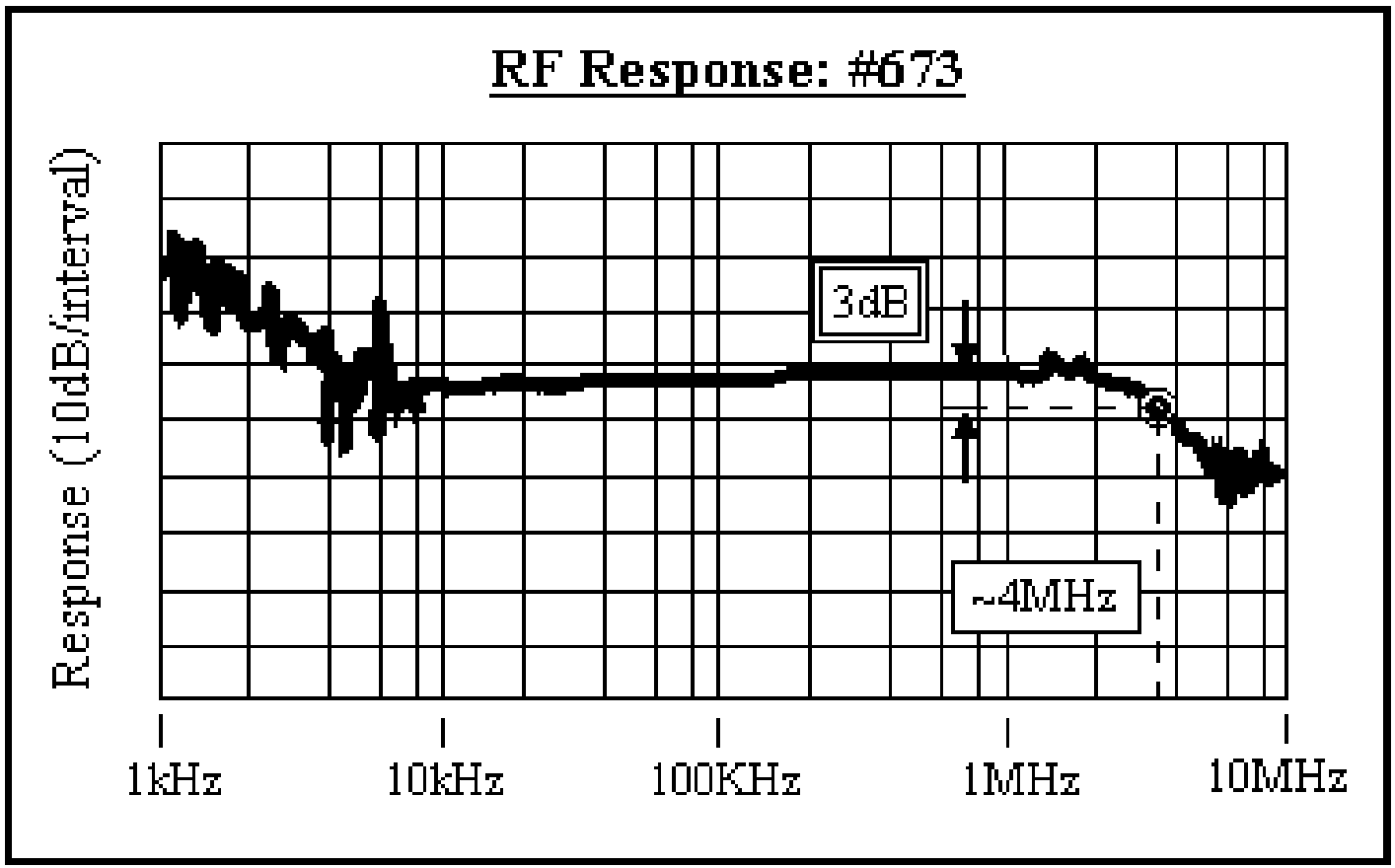
# QE: Power & Bias Effects



# DC Response Linearity: #673



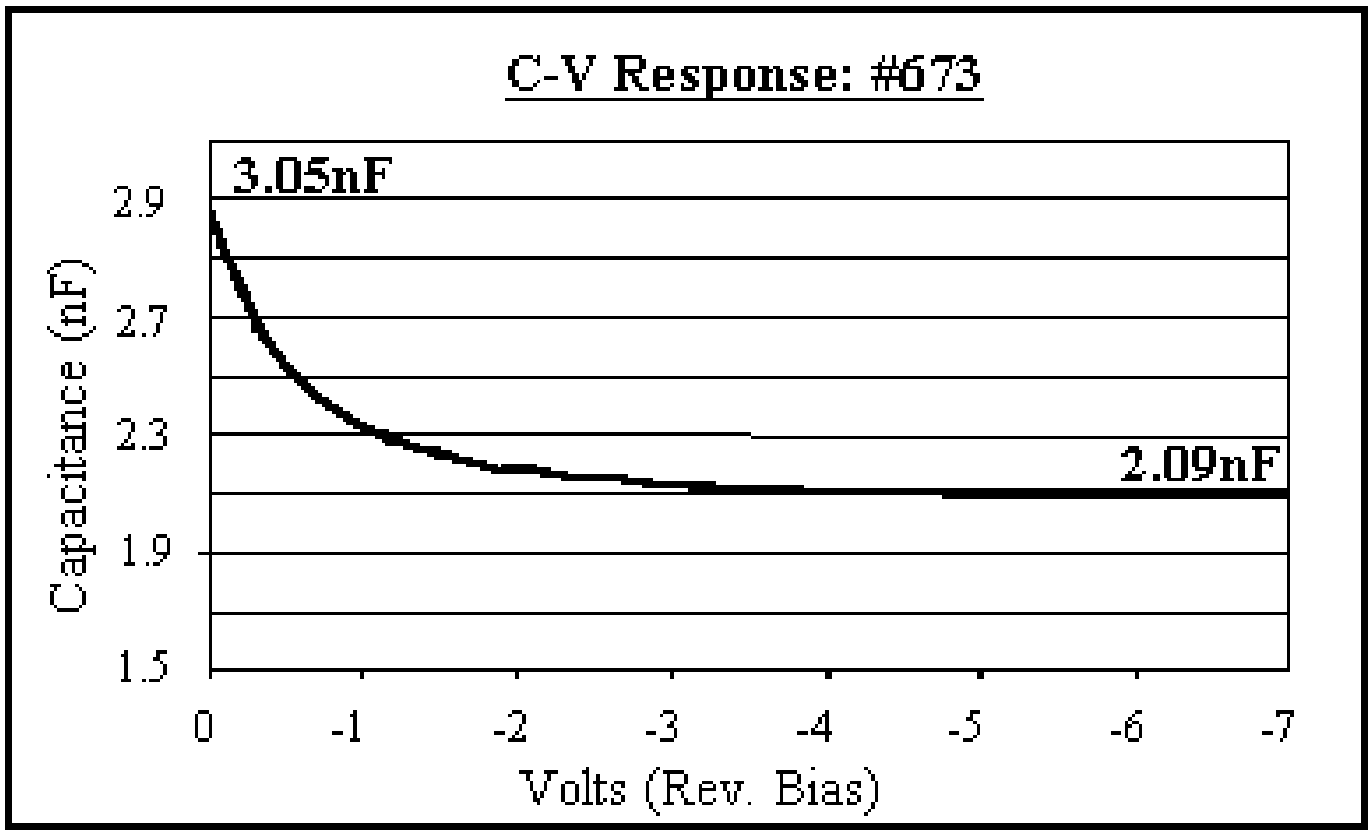
# RF Response: 3dB Bandwidth




**~4MHz, 3dB-Bandwidth**

**→ ~5nF Capacitance**

# C-V Characteristics (#673)




→ depletion width 1.44 μm ~2.16μm

# InGaAs Development Plan

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**<u>Goals:</u> by Sept. 2002…**

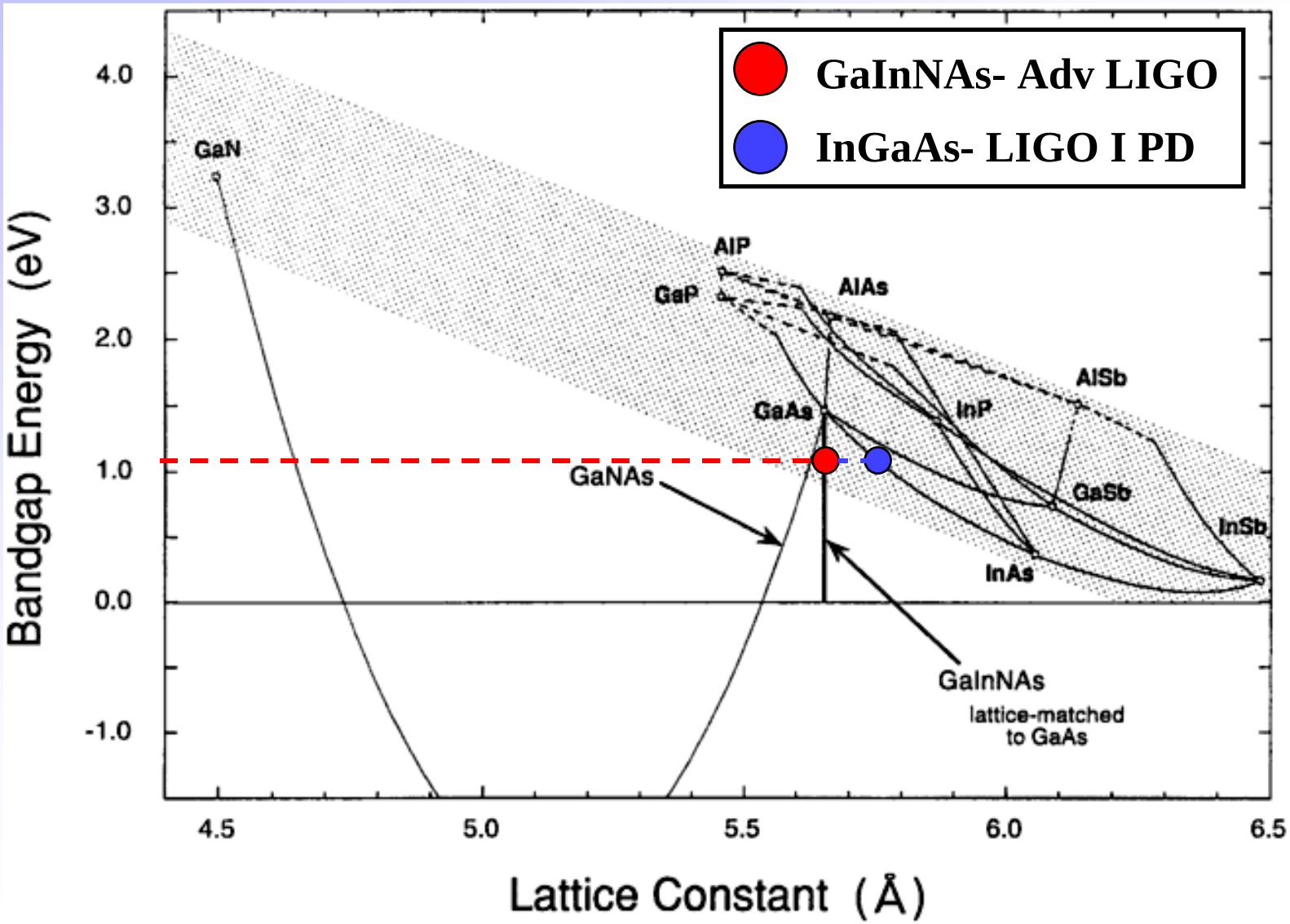
**∗90% QE**

**→Thin substrates to 50μm-100μm**

**∗Maximize Bandwidth**

**→Optimize illuminated area**

# GaInNAs Lattice-Matched to GaAs



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# Conclusion

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- Introduction
  - Photodiode Specifications
  - Device Structure & Materials
    - → InGaAs RI PIN PD
- Experimental Results
  - DC Response
    - → 70% QE
  - RF Response
    - → 4MHz 3-dB Bandwidth
- Development Plan
  - InGaAs
  - GaInNAs