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Characteristics of AlGaAs/GaAs Multiple Quantum Well Infrared Detectors

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We have fabricated and characterized several AlGaAs/GaAs multiple quantum well infrared detectors to evaluate the ultimate performance of these devices for low infrared background applications. The detectors were designed to have a single bound state in the quantum well and the first excited state in the continuum above the AlGaAs conduction band edge. The difference in energy between the two levels, as determined by the quantum well width and aluminum mole fraction in the barrier, was chosen such that peak absorption would occur near 8 µm. The initial structures studied comprised 50 periods with 40 Å well widths and 300 Å $Al_{0.28}Ga_{0.72}As$ barriers. The performance of these detectors can be summarized as follows:

1). Low dark current densities at 6K which are very sensitive to the device peak absorption wavelength (8.9 µm ⇒ 1E-06 A/cm^2 ; 7.5 µm ⇒ 3E-08 A/cm^2).

2). Dark current activation energies (135-150 meV) in good agreement with the predicted quantum well transition energies.

3). Measured noise which is less than the predicted shot noise on the device dark current.

4). The absence of 1/f noise at frequencies down to 20 Hz.

5). Peak responsivities of approximately 0.3 A/W (uncorrected for reflection losses).

6). Peak detectivities in excess of 10^{12} cm√Hz/W at 6K.

7). Constant detectivity over the temperature range from 6K to approximately 50K.

To better interpret these results and design optimized detectors, we have modeled both the detector noise and tunneling currents. The noise model correctly predicts that multiple quantum well detectors will, indeed, exhibit noise lower than full shot noise. The tunneling current model predicts the dark current versus bias for any choice of design parameters in a multiple quantum well detector. This model predicts a substantially reduced dark current (x 10^{-4}) for samples with 400 Å barriers.

To evaluate structures with thicker barriers, we have fabricated and characterized detectors with 400 Å and 500 Å barriers; a comparison of detector dark currents is shown in Fig. 1. These results are consistent with the predictions of our dark current model. Since the responsivity for these samples (0.3 A/W) is not compromised by the additional barrier width, these new devices have a significantly higher detectivity, as shown in Fig. 2 for the 400 Å barrier sample where detectivities in excess of 10^{13} cm√Hz/W have been measured at temperatures above 30K. The behavior of this device as a function of temperature indicates that tunneling currents are no longer limiting the low-temperature performance of this device.

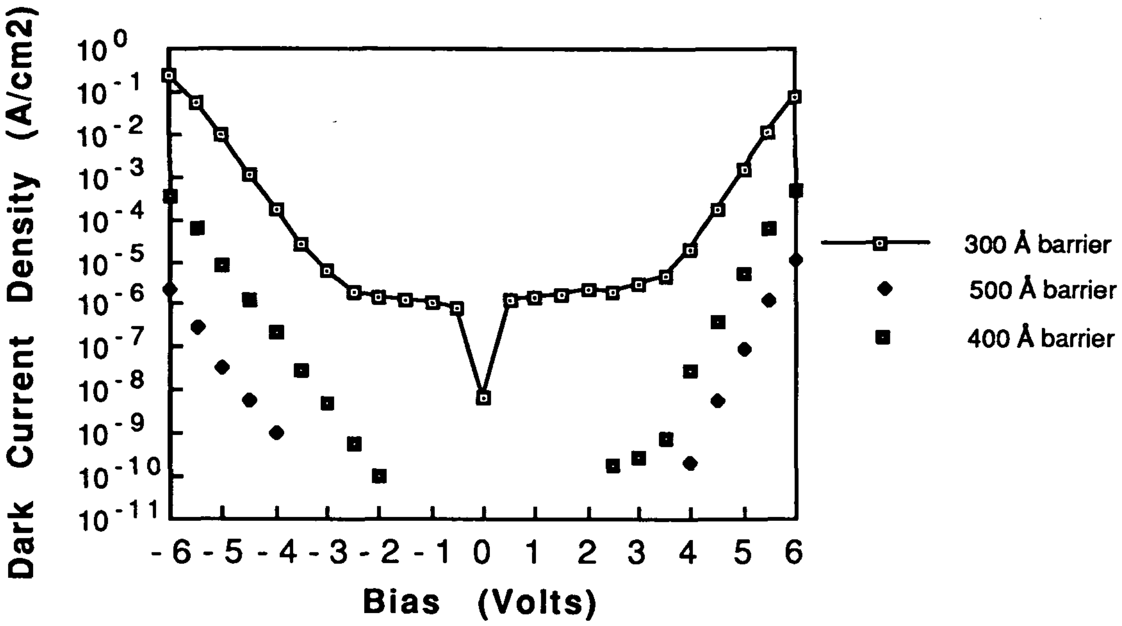

Fig. 1. Dark current density vs. bias at 6K for samples with 300Å, 400Å, and 500Å barriers.

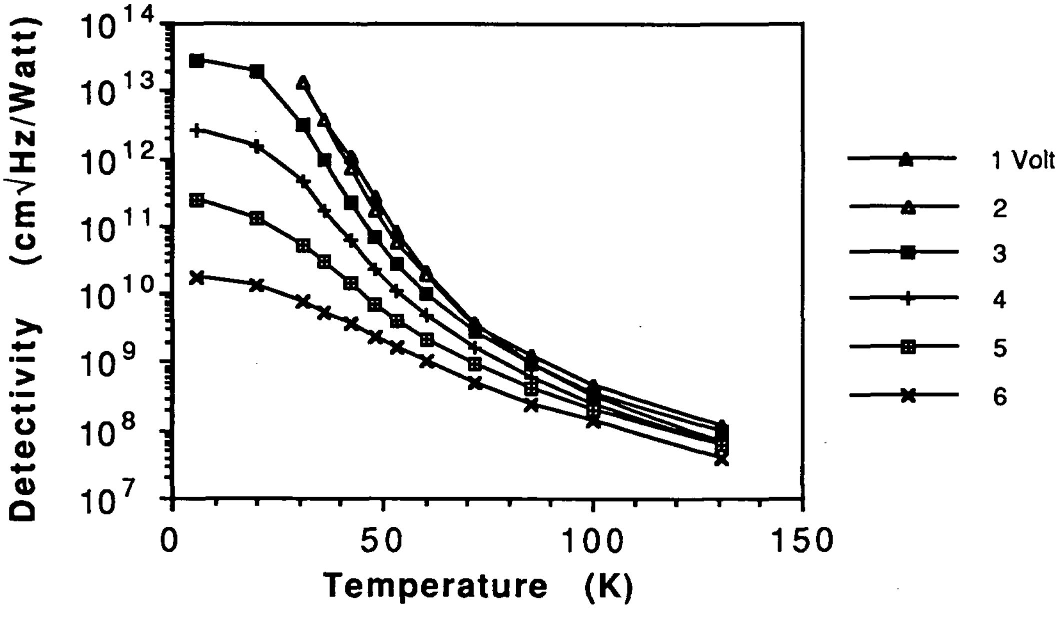

Fig. 2. Detectivity vs. temperature for 400Å barrier sample.

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<u>Outline:</u>

- Motivation
- Materials Preparation/Characterization
- Device Fabrication
- Detector Performance/Modeling Results
  - Noise, dark current models
  - Performance <u>vs.</u> barrier width
- Summary/Conclusions

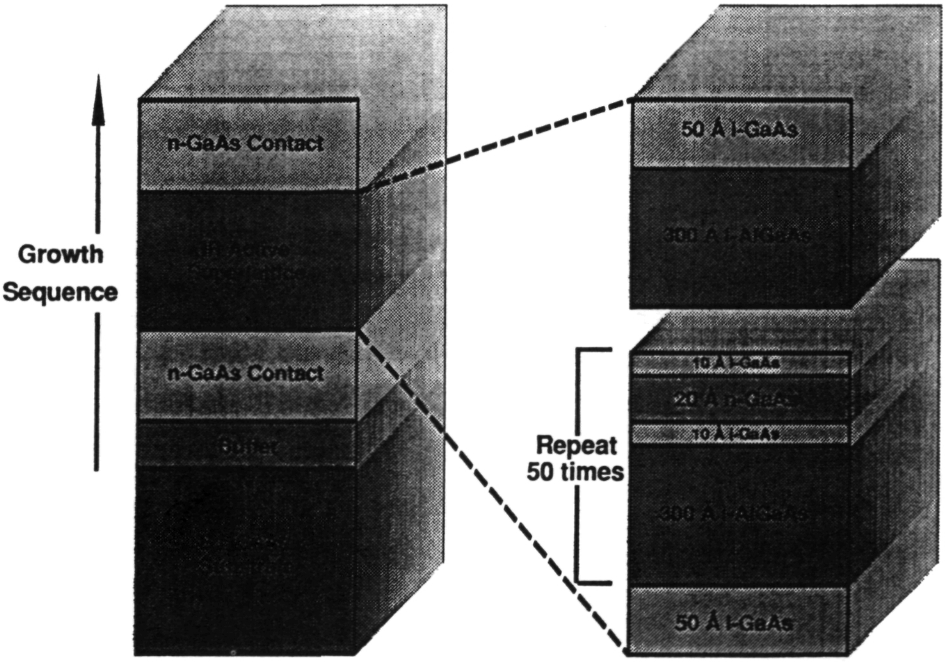
Background/Motivation

- Aerospace role in IR detector development
- VG Semicon MBE machine operational January, 1989
- Are AlGaAs/GaAs quantum well IR detectors appropriate for low infrared background applications?
- What is the ultimate performance of these devices?

Approach

- Two wafers comprise the initial focus of this study:
  - Nominal structure: 40Å GaAs wells/300Å AlGaAs barriers (x=0.28) - 50 periods
  - Excited state in continuum above AlGaAs conduction band edge.
  - Predict ~ 8μm peak responsivity
    - Reproduce AT&T results?
    - Low-background, low temperature performance?
    - Noise sources?
- Additional structures grown to suppress device tunneling currents
  - 300Å, 400Å, 500Å barrier samples

Quantum Well Detector Growth



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FTIR Absorption Spectra of IR Quantum Well Samples

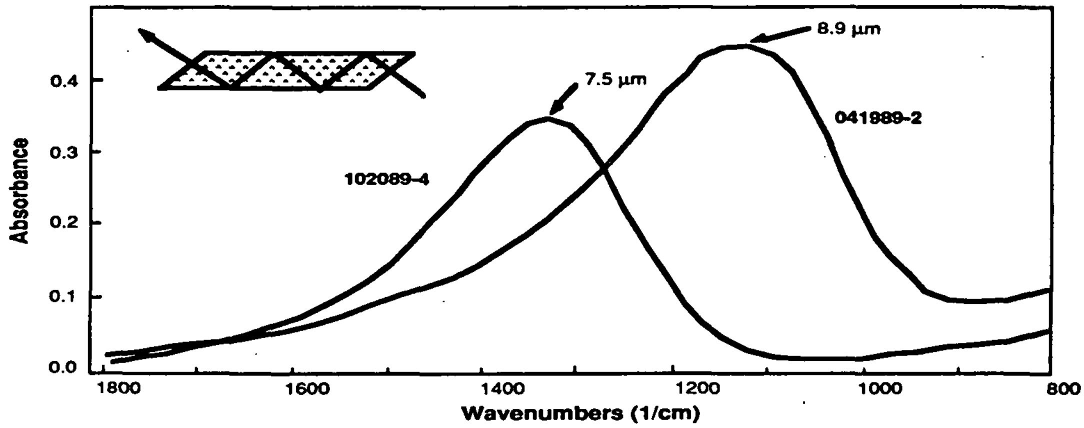
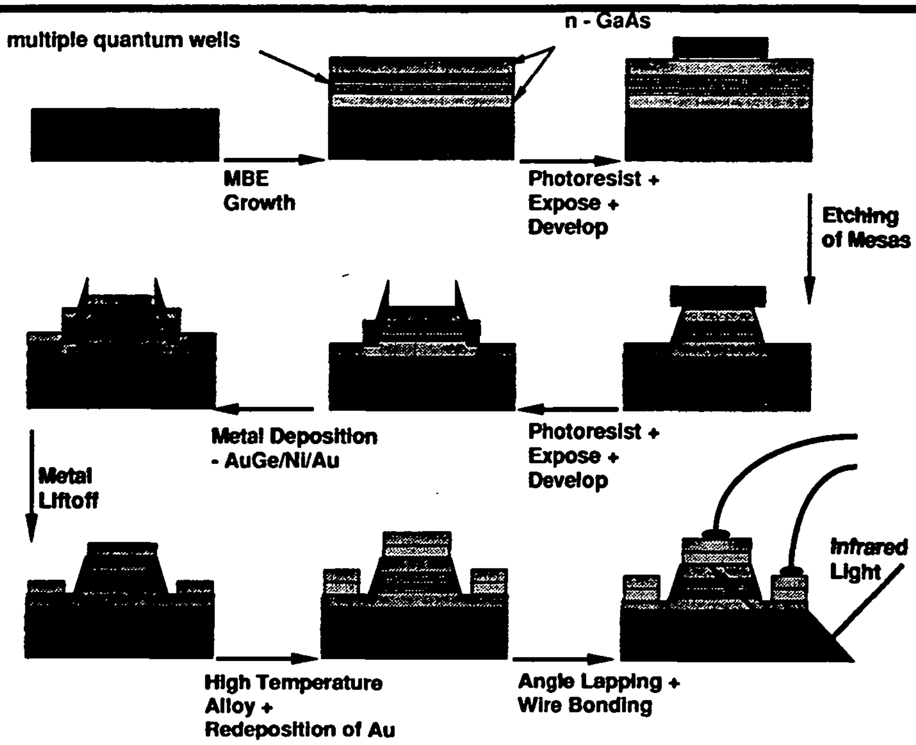


Table of Measured Material Parameters

	041989-2	102089-4	010890-2	010890-4
Peak Wavelength (FTIR)	8.9μm	7.5μm	8.5μm	8.3μm
Superlattice Period (x-ray)		346Å	528Å	432Å
Superlattice Period (TEM)	320Å			
Al Mole Fraction (x-ray)		.35	.31	.31
Al Mole Fraction (Modulation Spectroscopy)	.29	.33		

IR Detector Fabrication



multiple quantum wells

n - GaAs

MBE Growth

Photoresist + Expose + Develop

Etching of Mesas

Photoresist + Expose + Develop

Metal Deposition - AuGe/Ni/Au

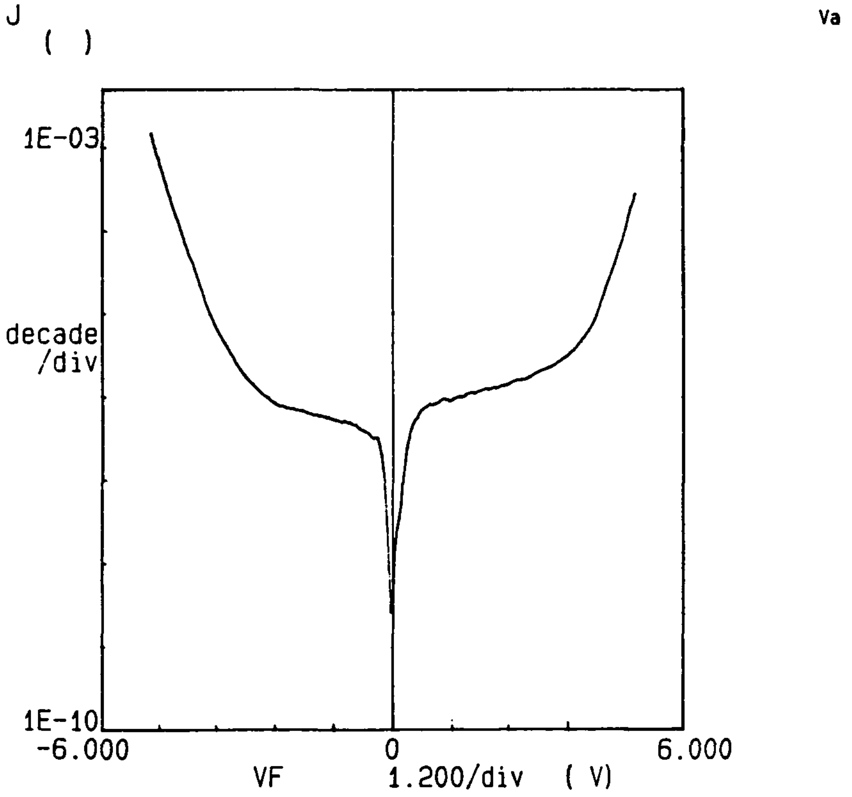
Metal Liftoff

High Temperature Alloy + Redeposition of Au

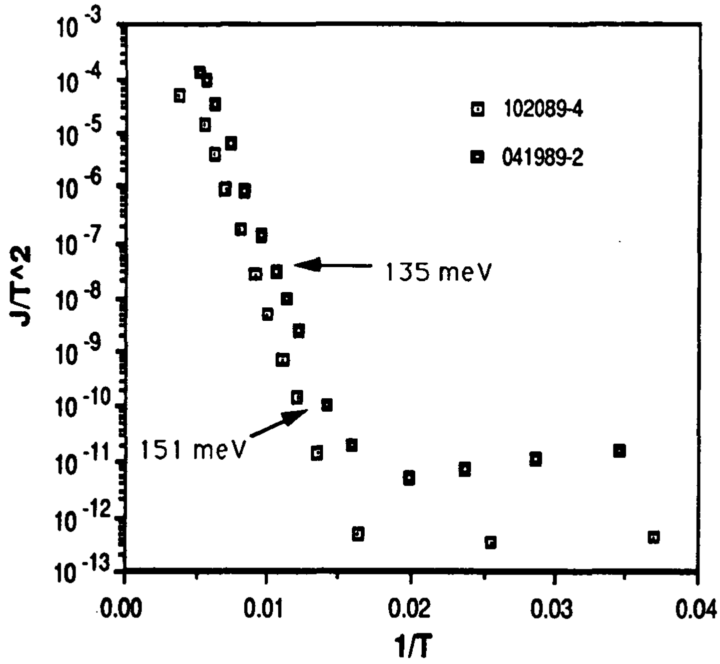
Angle Lapping + Wire Bonding

Infrared Light

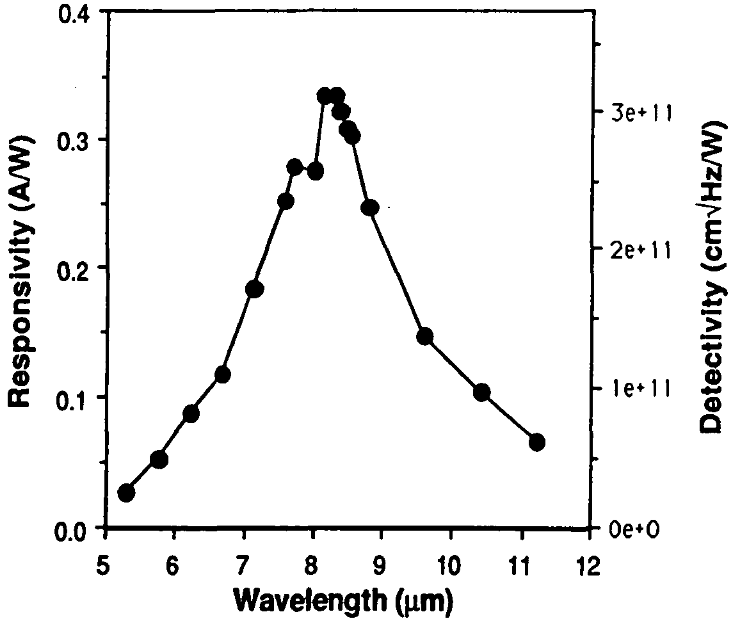
****** GRAPHICS PLOT ******
041989-2 5K



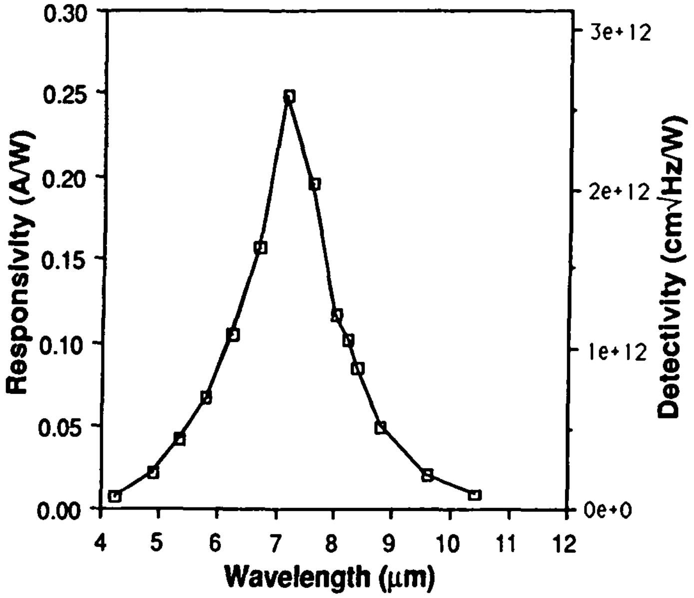
Arrhenius Plots of Detector Dark Current



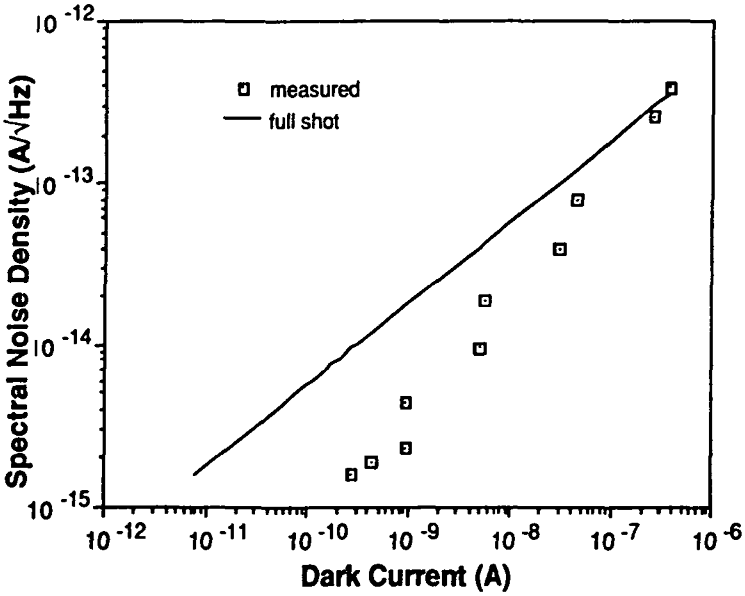
R and D* vs. Wavelength (6K) - Sample 041989-2



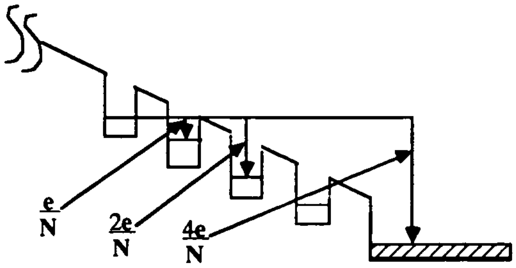
R and D* vs. Wavelength (6K) - Sample 102089-4



Spectral Noise Density vs. Dark Current (7K) - Sample 041989-2



Noise Model

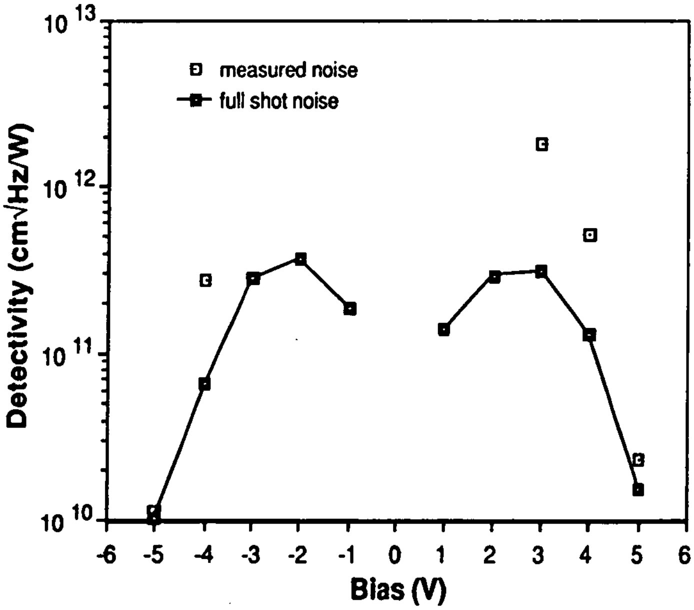


- tunneling events are independent
- governed by Poisson statistics

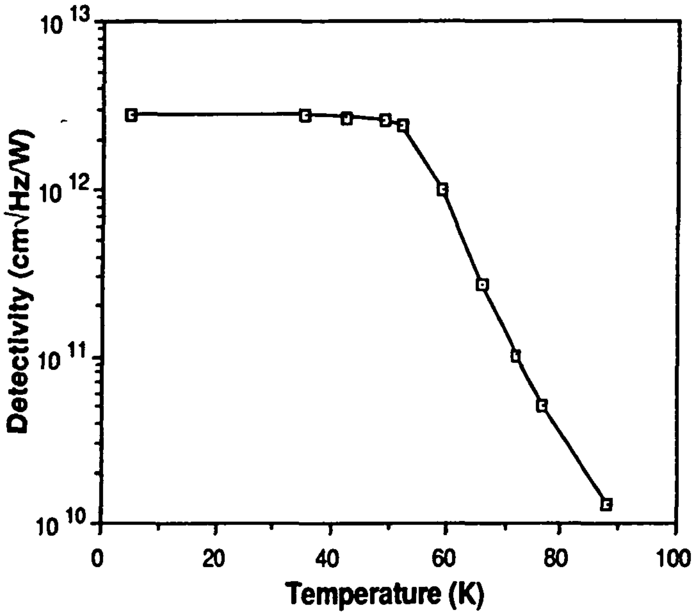
- Input parameters:
  - Fraction of total tunneling current from an internal well that is emitted to the continuum
  - Hot electron mean free path
  - Number of periods

- Key Results:
  - Quantum well detectors are predicted to exhibit noise lower than full shot noise.

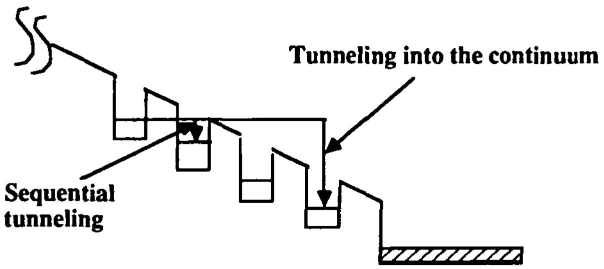
IR Quantum Well Detectivity (7K) - Sample 041989-2



Detectivity vs. Temperature - Sample 102089-4

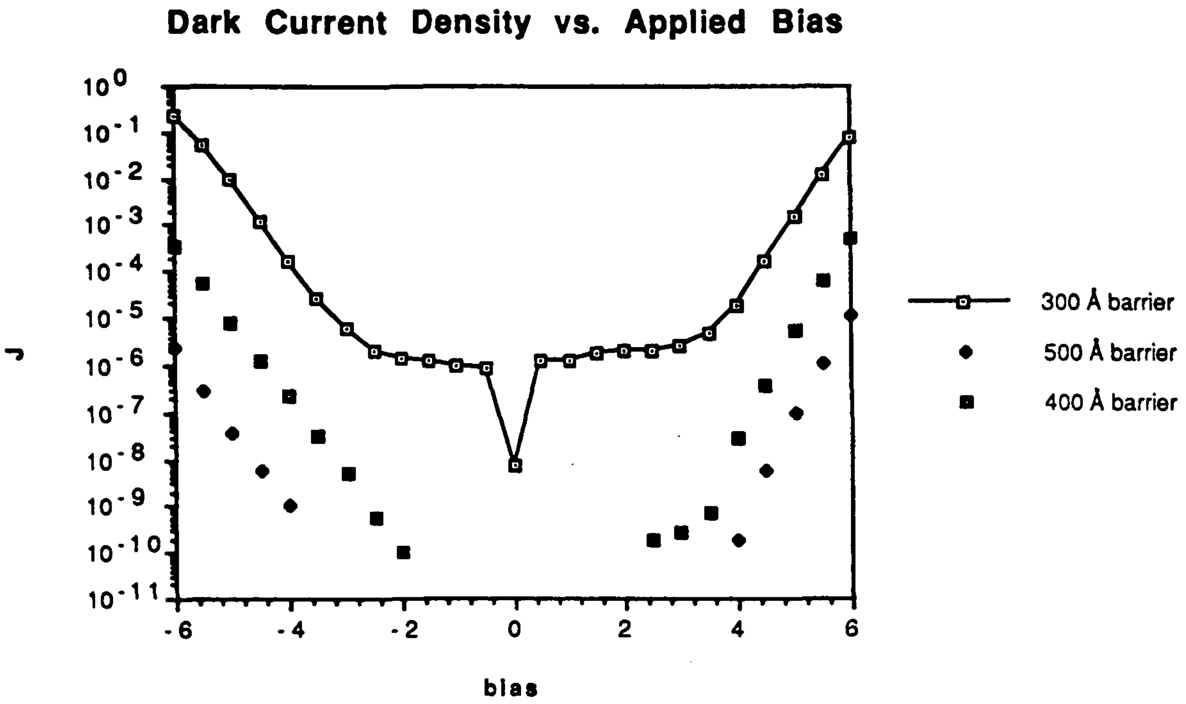


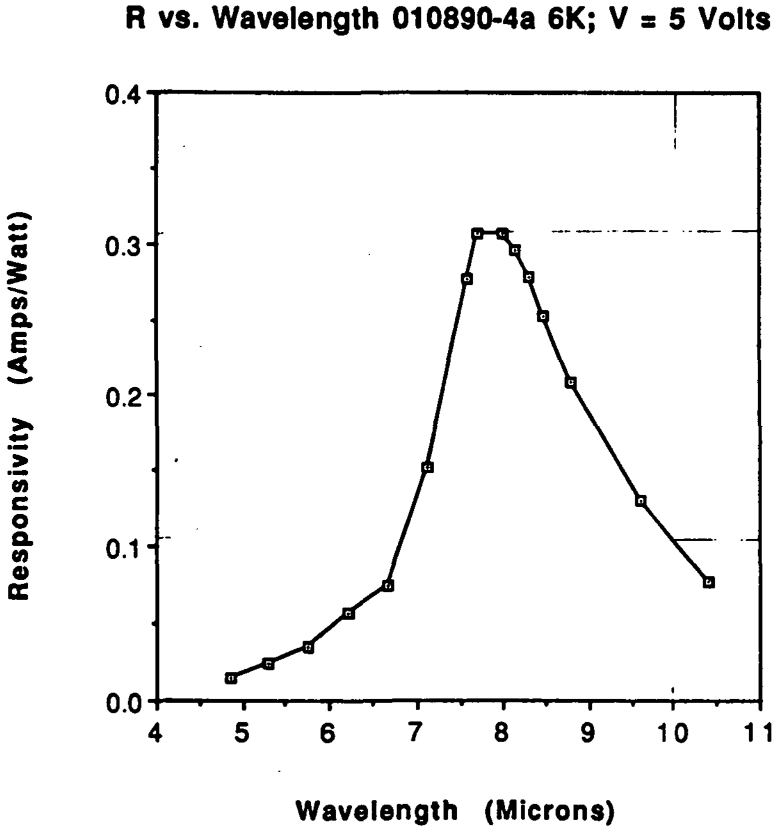
Tunneling Dark Current Model



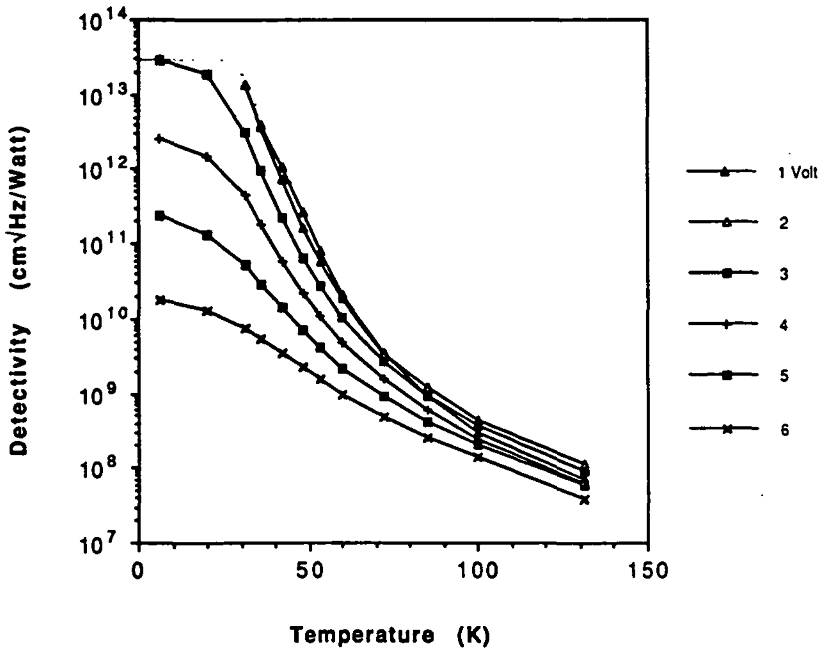
- Dark current vs. bias for any choice of detector design parameters.

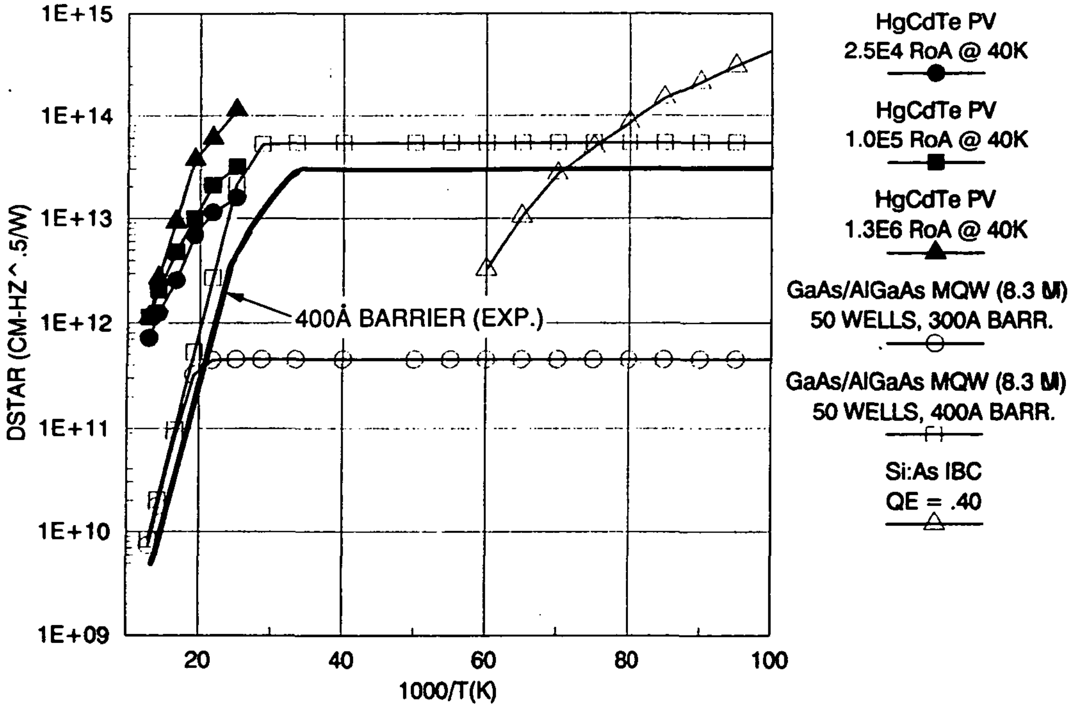
- Approach: Nodal analysis in which analogs of Kirchhoff's current and voltage laws are applied
  - Net current into each internal well (node) is zero
  - Applied bias is the sum of the potential drops across barriers
  - Charge distribution in internal wells, cathode, and anode adjusted until Kirchhoff's laws are satisfied
- Results:
  - Model-generated I-V curves similar to experimental curves
  - Predict substantially reduced dark current ($\times 10^{-4}$) for detector with 400Å barriers





$$\frac{R_{10\,\mu m}}{R_{peak}} = \frac{0.11}{0.31} = 0.36$$


Detectivity vs. T 010890-4a


DSTAR(10 UM) VERSUS INVERSE TEMPERATURE

HgCdTe PV, GaAs/AlGaAs MQW & Si:As IBC DETECTORS

Summary/Conclusions

- High detectivity quantum well IR detectors have been demonstrated
  - $D^* = 1E13 \ \mathrm{cm}\sqrt{\mathrm{Hz}}/\mathrm{W}$ at 10 µm and 20K
- Devices show excellent reproducibility, uniformity, and radiation hardness
  - Simple physical models correctly predict device performance
- Progress in the development of LWIR quantum well detectors has been very rapid, particularly given the small investment made to date
- Future efforts: Increase the device quantum efficiency and develop array concepts