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Photovoltaic Quantum Well Infrared Photodetectors

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Quantum well infrared photodetectors are a promising new approach to long-wavelength infrared detector arrays. Both single-well photovoltaic and multiple-well photoconductive devices have been demonstrated. I will discuss noise considerations as they apply to photovoltaic devices, grating coupling of the infrared light into QWIPs, and recently demonstrated electrically tunable detectors. The use of "light trapping" to enhance the quantum efficiency and reduce cross-talk in an array will also be addressed.

LONG WAVELENGTH QUANTUM WELL DETECTORS
(Quantum Well Infrared Photodetectors)
= QWIP's

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Electrical Engineering, Princeton

Theory & Measurements

Keith Goossen – now at AT&T Bell Labs

Sanjay Parihar – Princeton

Materials

Kambiz Alavi (Siemens) – now at U. of Texas

Mike Santos & Mansour Shayegan – Princeton

I. Background on IR detectors and Quantum Wells

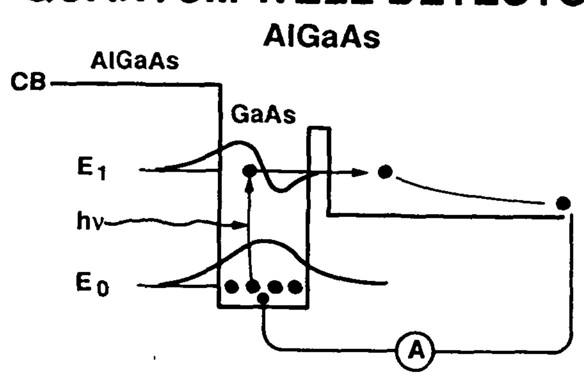
II. Single Well detectors

III. Grating enhanced detectors

VI. Voltage Tunable Detectors

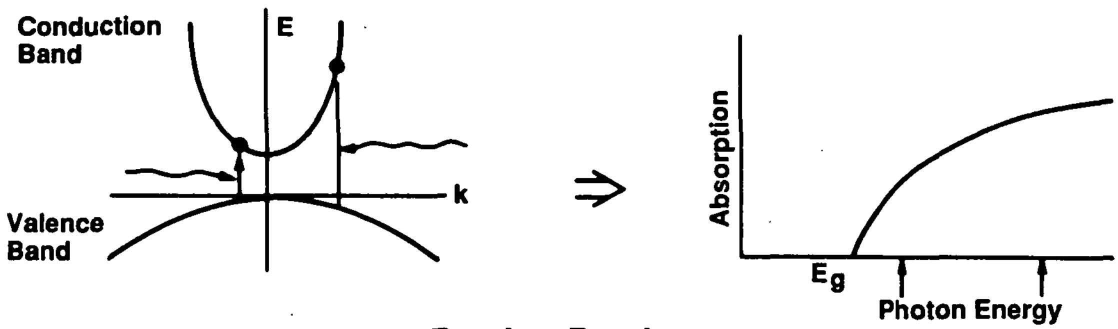
V. Summary

QUANTUM WELL DETECTOR

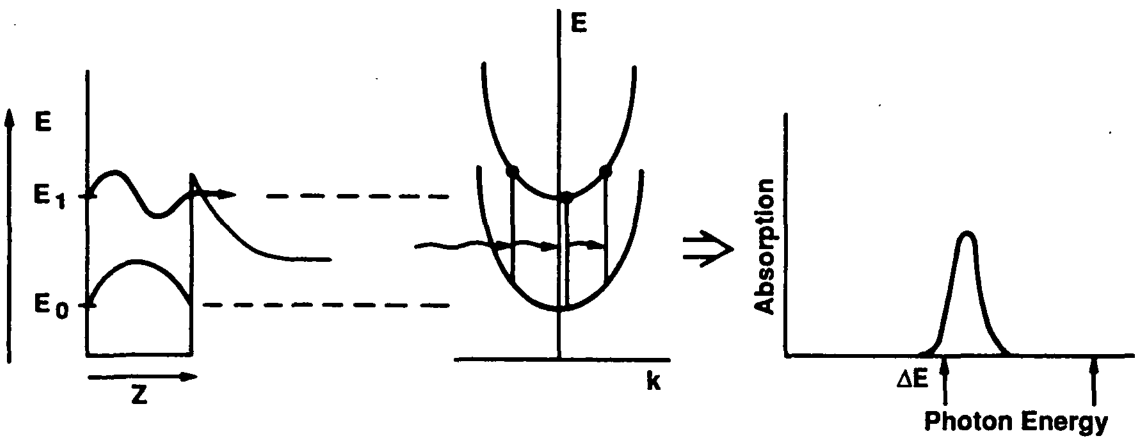


Advantages:
- Easily change structure for different wavelengths
- Long wavelength sensitivity with simple materials
- Voltage tunable

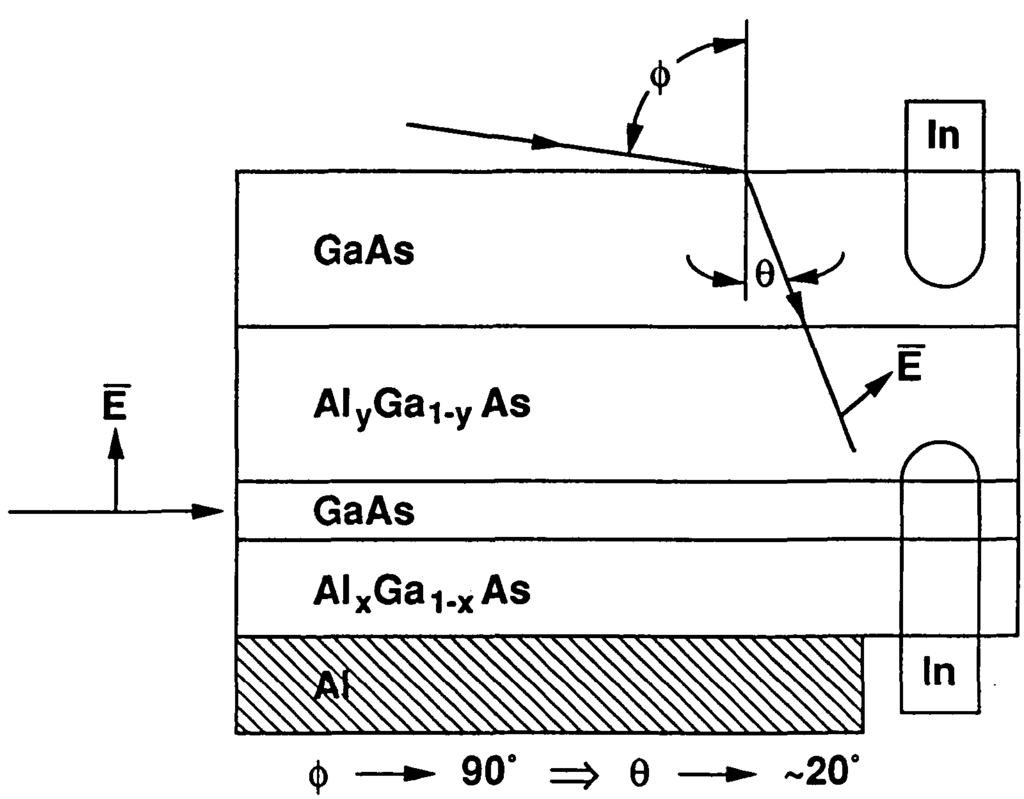
Problems:
- Not many electrons ⇒ low quantum efficiency
- Short relaxation time (intersubband scattering) ⇒ high dark current

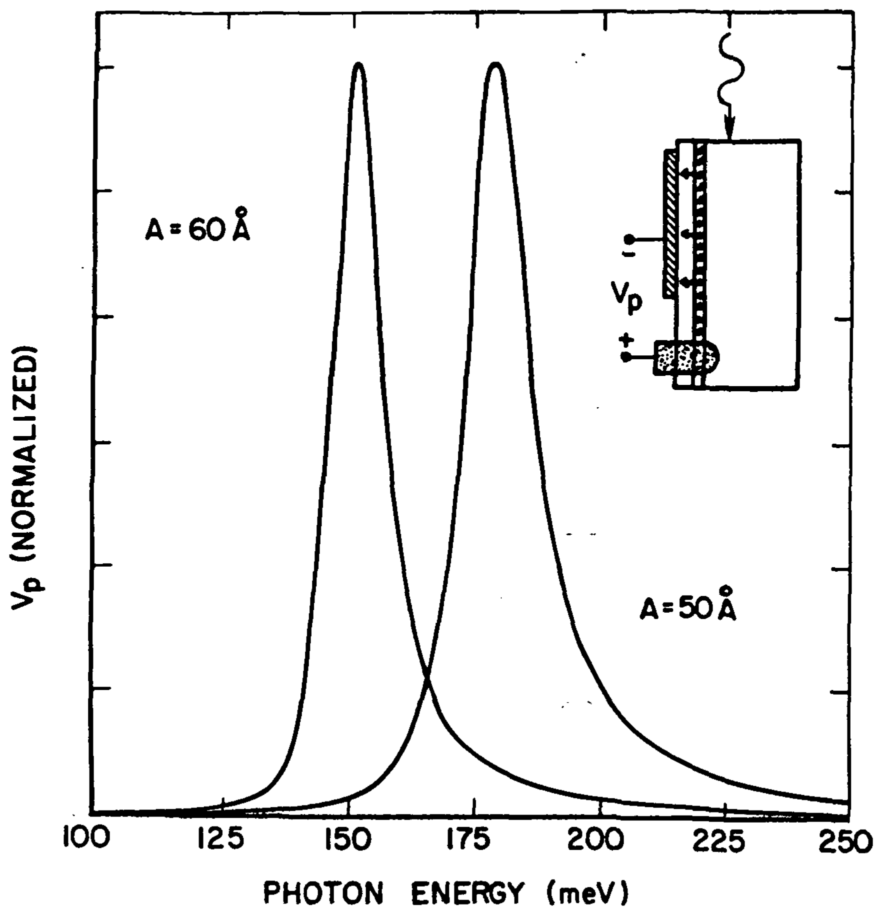


Band-to-Band



Quantum Well (Intersuband)

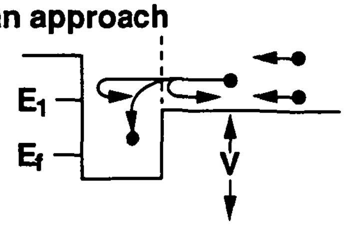




DARK CURRENT (IDEAL)

Use Richardson -Dushman approach

1. Find the rate of electron capture by the well in thermal equilibrium



2. This will also be the emission rate ⇒ dark current under small biases

3. Assume relaxation time of 1 ps

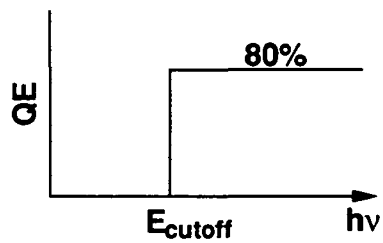
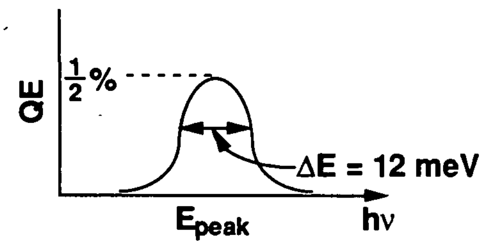
* Unlike usual assumption for a metal:
  - Capture probability < 1
  - Capture probability depends on energy

Dark current ~100x less for QW than metal

Work function ~ $(E_1 - E_f)$ not $(V - E_f)$

STARING ARRAY COMPARISON

50 X 50 μm Pixel   F2 Optics
30 ms frame (integration) time
$T_{Detector}$ = 80K $T_{Background}$ = 300K
10 μm

Ideal band-to-band detector	Single Well QWIP
	

	τ - Auger Limited (Parameters for HgCdTe)	τ - Intersubband Scattering lps
Signal (e^-/cm^2-sec)	3×10^{16}	3×10^{13}
Dark Current (e^-/cm^2-sec)	1.0×10^{14}	1.5×10^{15}
Signal/Noise	1.2×10^{5}	1×10^{3} (NETD = 0.1K)

IMPROVING QUANTUM EFFICIENCY

1. Multiple Wells

   Absorption ∝ # wells

   Dark Noise ∝ $\sqrt{\#\text{wells}}$ (ideal)

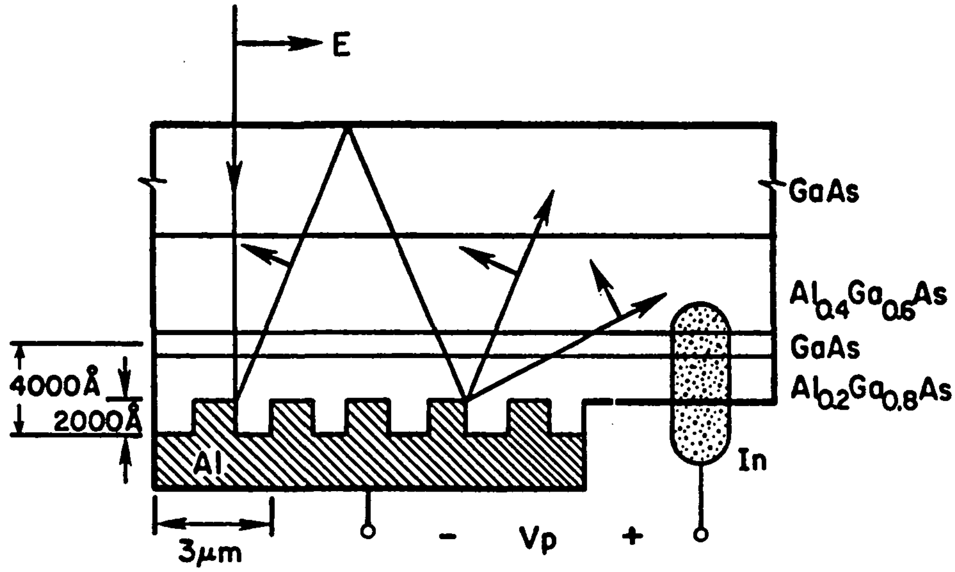
   ∴ D* ∝ $\sqrt{\#\text{wells}}$

2. "Light Trapping"

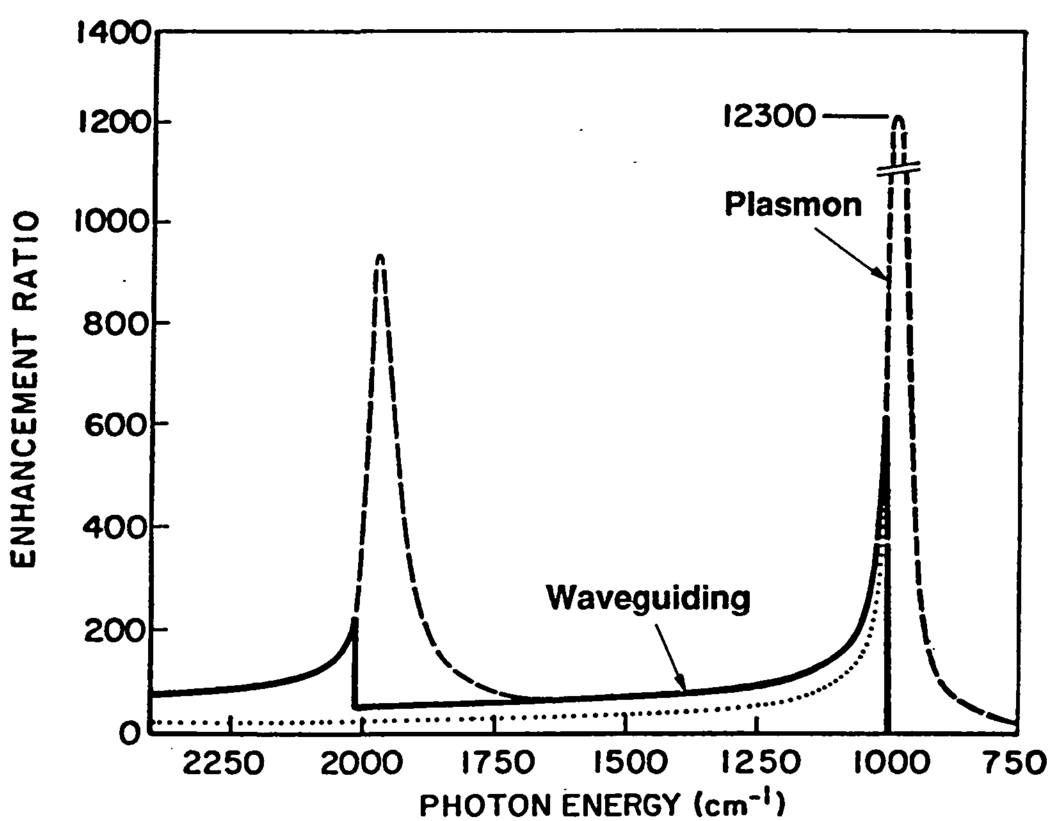
   Surface Plasmons on gratings

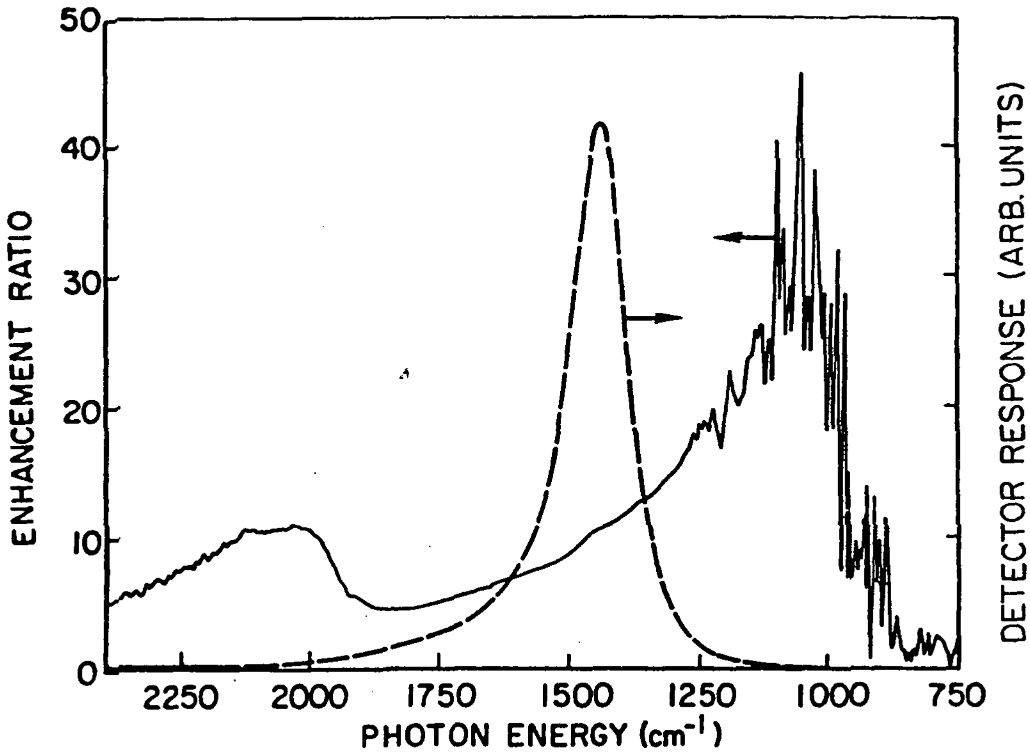
   Waveguiding in GaAs

WAVEGUIDING

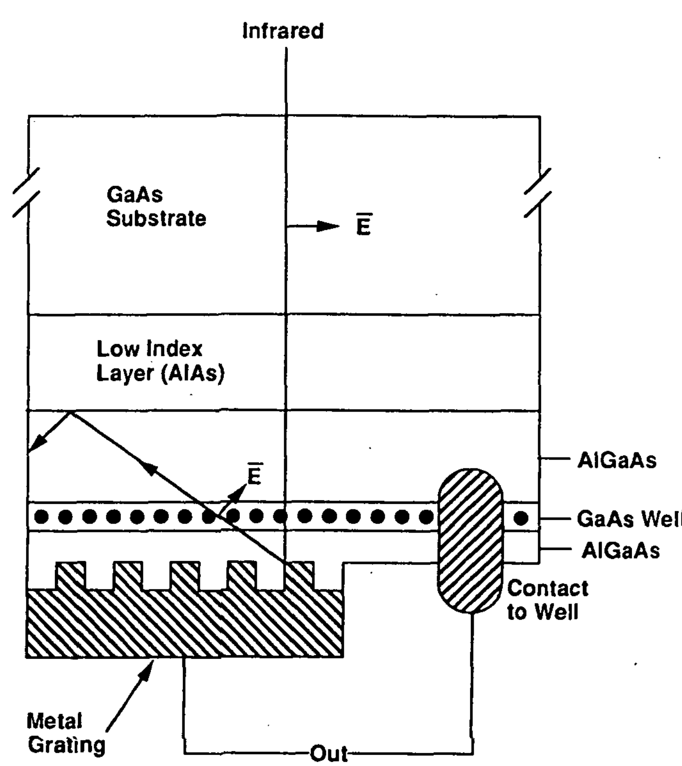


K. W. Goossen, S. A. Lyon, and K. Alavi
Appl. Phys. Lett. 53, 1027 (1988)

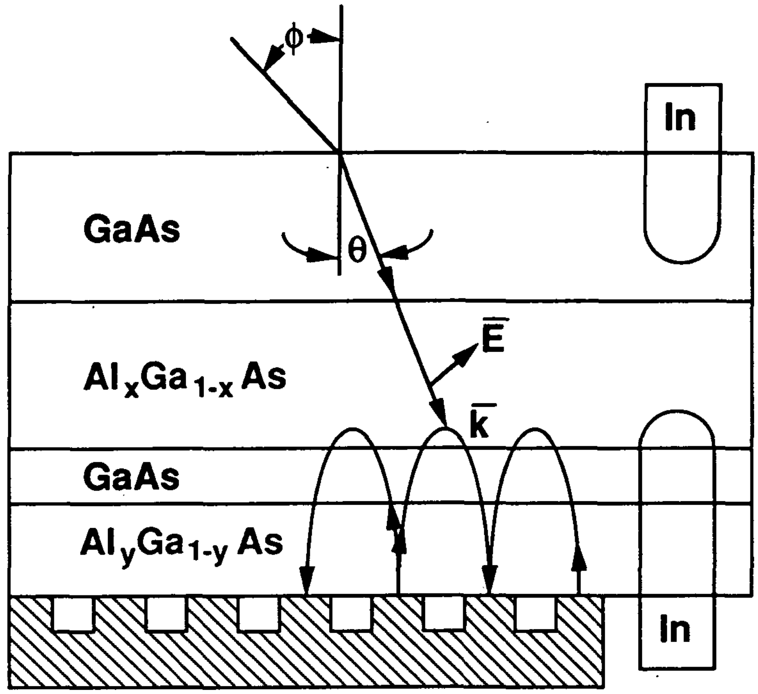




WAVEGUIDING

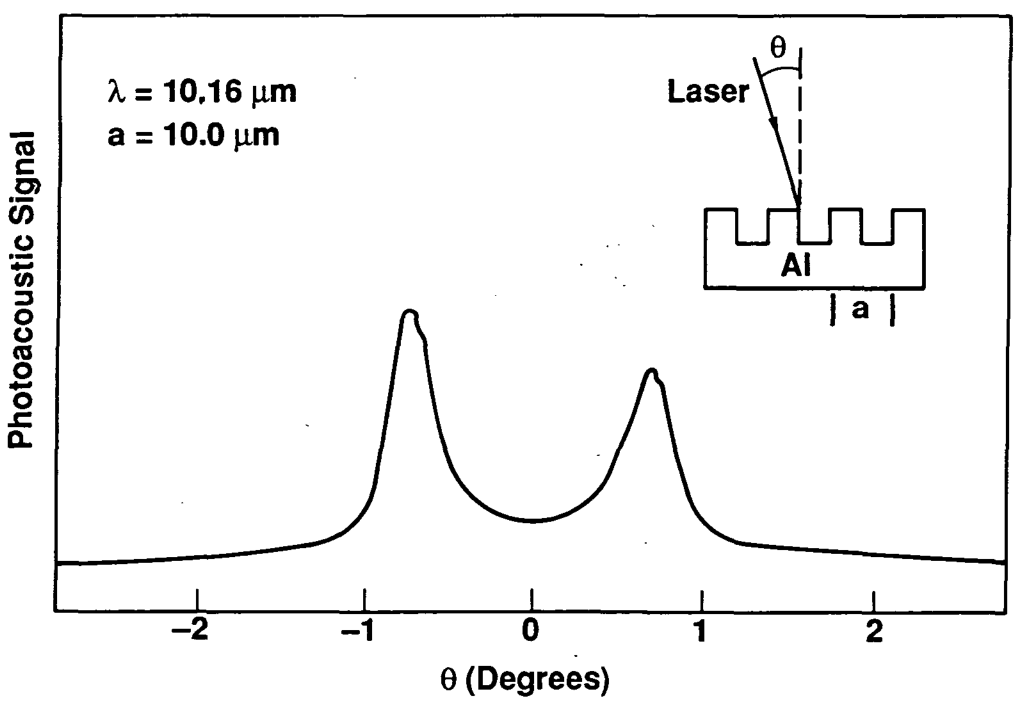


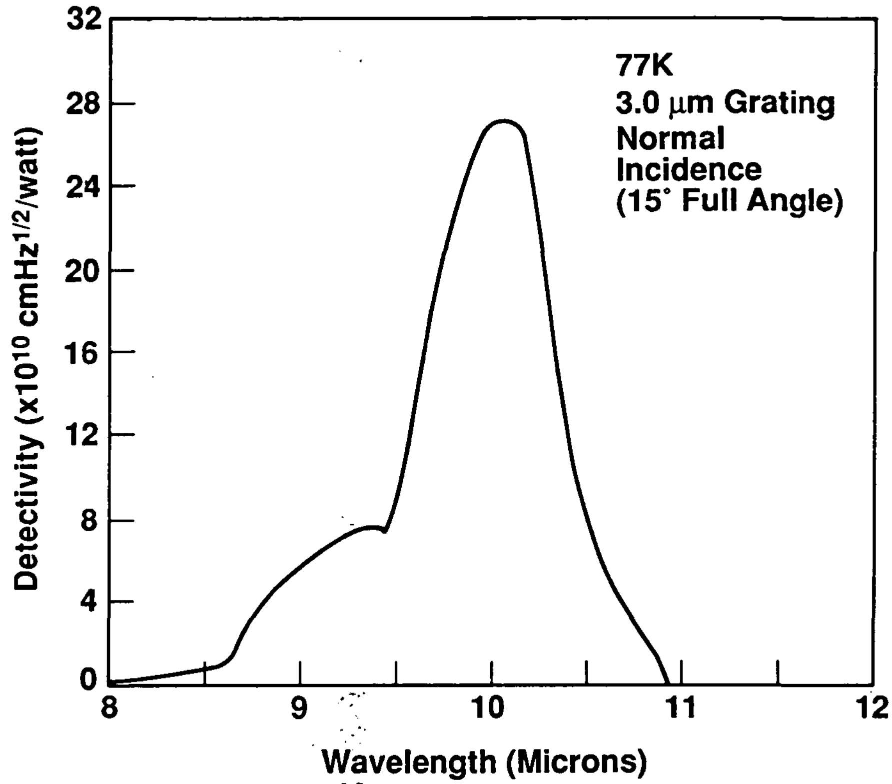
PLASMON ENHANCEMENT



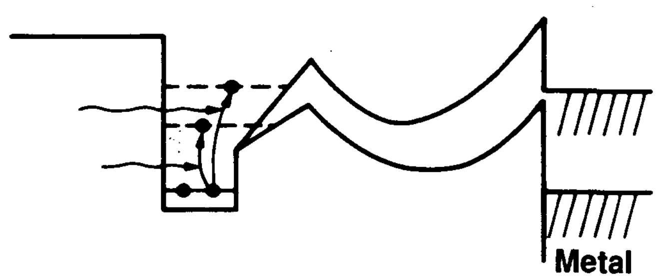
K. W. Goossen and S. A. Lyon
Appl. Phys. Lett. 47, 1257 (1985)

SURFACE PLASMON EXCITATION

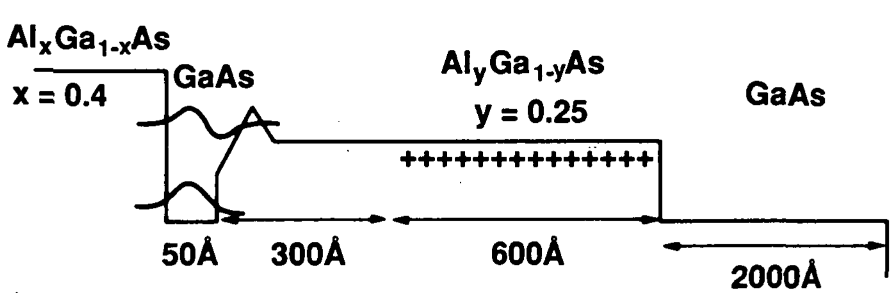




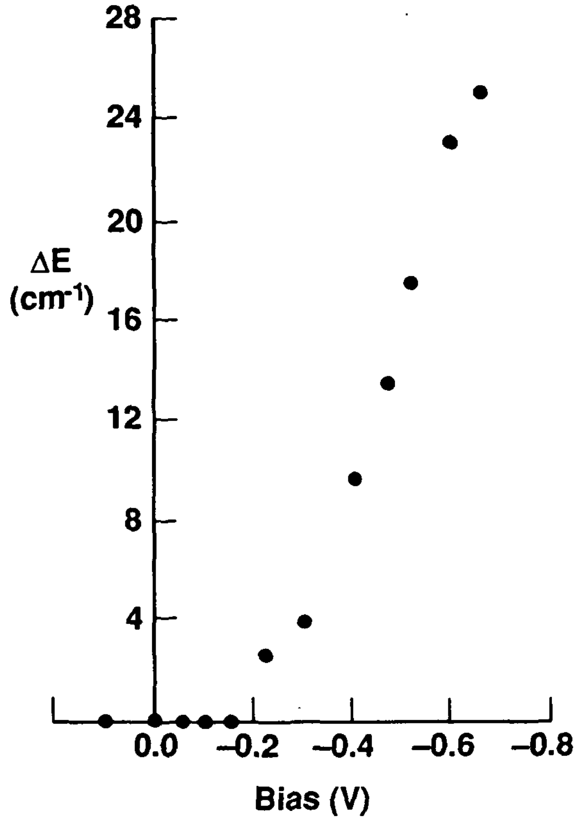
TUNABLE DETECTOR



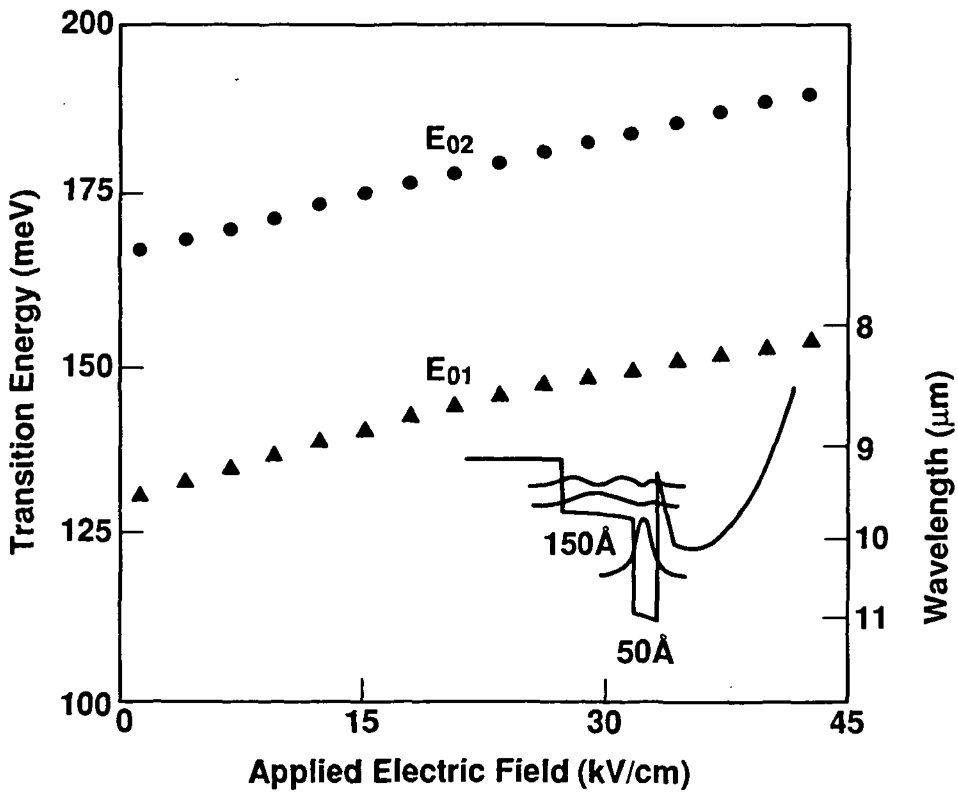
Actual Sample
(Santos & Shayegan)



ENERGY SHIFT VS BIAS FOR GRADED WELL



S. A. Lyon, MSS-4 (July 1989).
S. R. Parihar, S. A. Lyon, M. Santos and M. Shayegan Appl. Phys. Lett. 55, 2417 (1989)



CONCLUSIONS

1. Single-well QWIP's work as expected
   — Quantum Efficiency (~1/2 – 1%)
   — Dark Current

2. Incorporation of a diffraction grating allows operation at normal incidence

3. As a <u>single element detector</u> QWIP's cannot compete with photoconductive HgCdTe

4. Single-well QWIP's <u>can compete</u> in a <u>staring array</u>

5. Waveguiding shows promise for enhancing quantum efficiency without the noise penalty of multiple wells

6. Voltage tunable detectors have been demonstrated
   — Similar structures expected to show large optical nonlinearities