

**Fundamental Limits to Performance
of Quantum Well Infrared Detectors**

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ABSTRACT

Radiometric, density of states (material), and thermal considerations are used to obtain the figure of merit of the quantum-well GaAs/GaAlAs infrared detectors described by Smith et. al(1). The results are compared with HgCdTe, the present industry standard, as well as with recent experiments at other laboratories.

(1) J.S. Smith, L.C. Chiu, S. Margalit, A. Yariv and A.Y. Cho, J. Vac. Sci. Tech. B, 376 (1986).

Fundamental Limits to Quantum Well Infrared Detectors

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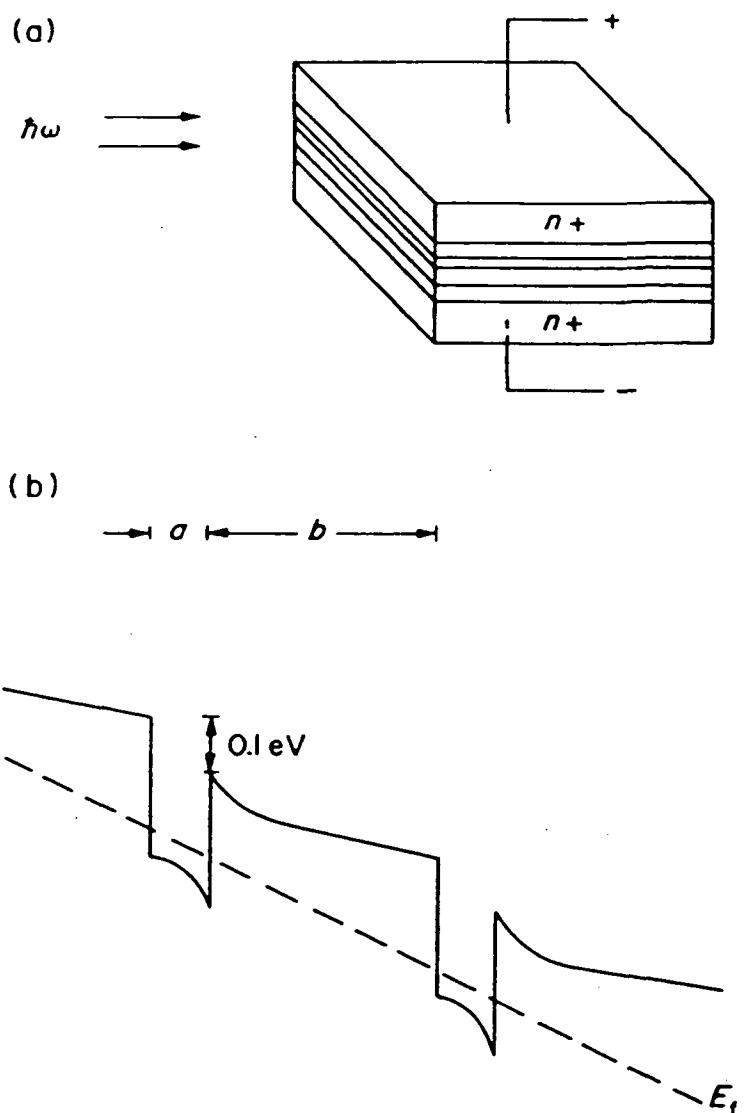
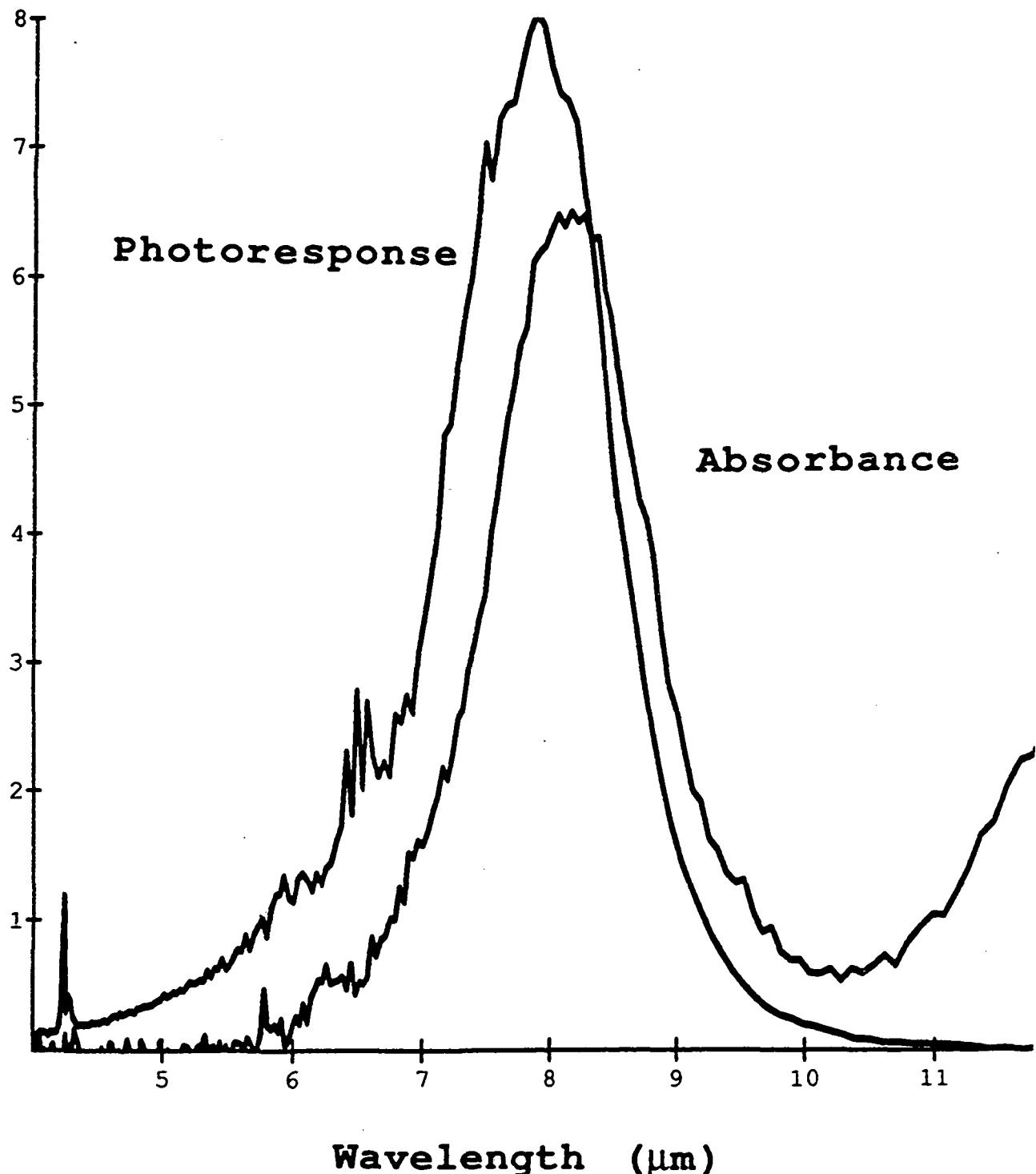


Fig. 3. (a) A schematic drawing of the proposed detector.
 (b) Band diagram of the proposed structure.

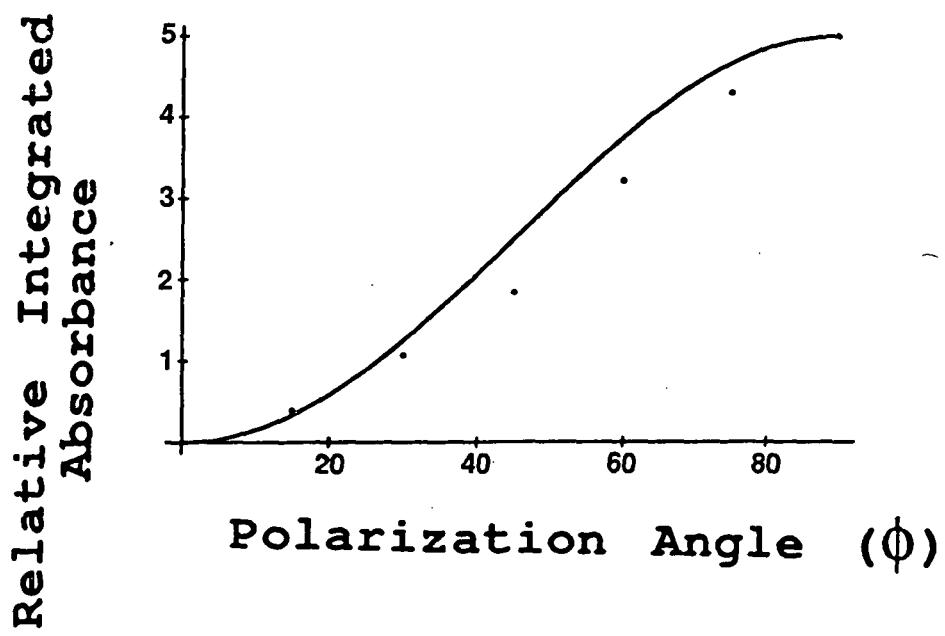
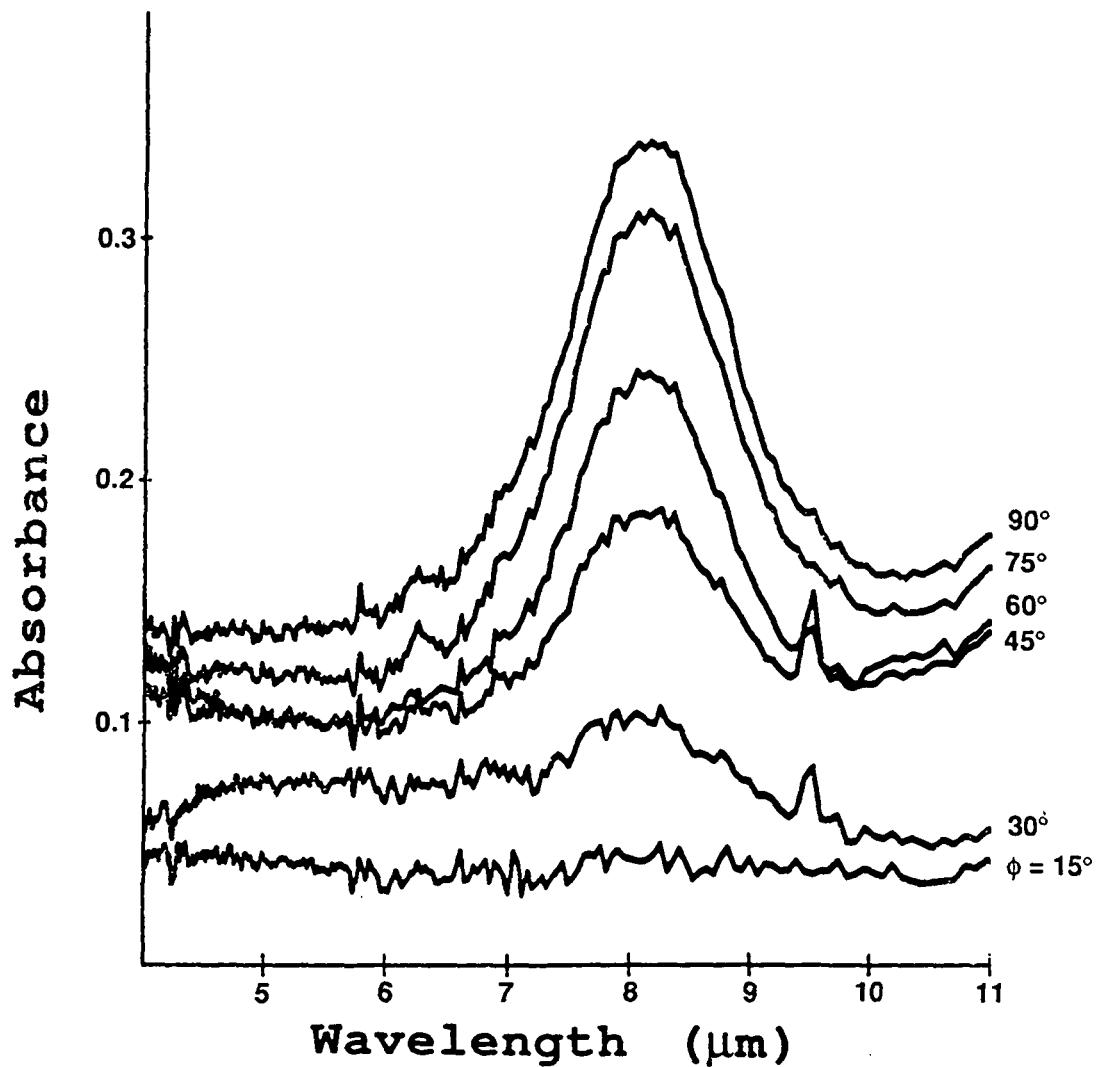
(Smith et. al., Infrared Phys., Vol 23, p. 93, 1983)

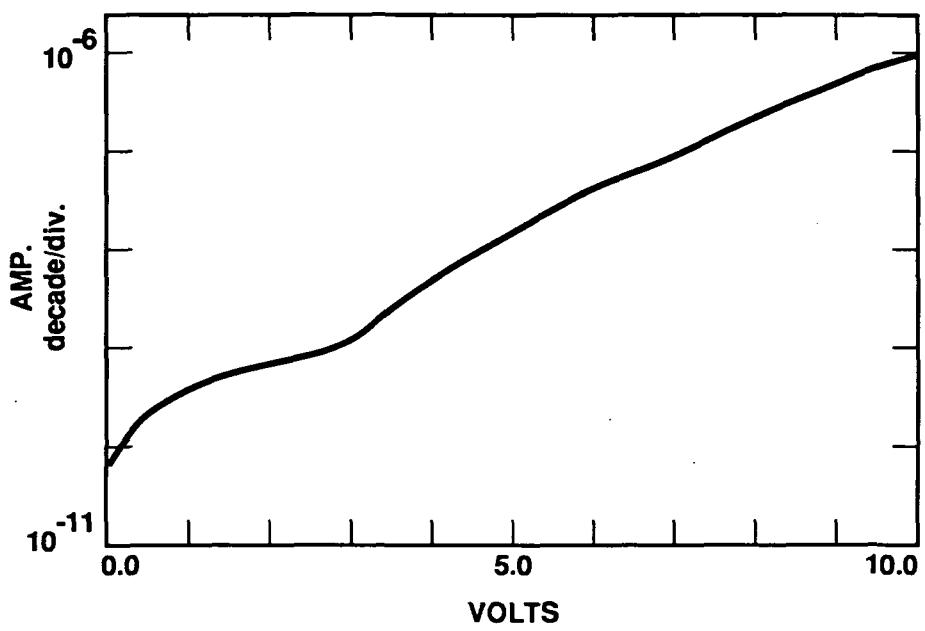


λ PEAK = 8.00 μm

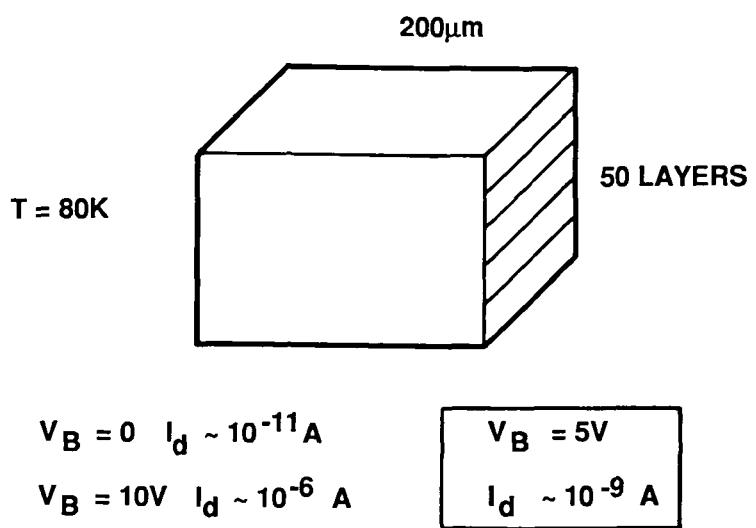
$$\frac{\Delta\lambda}{\lambda} = 20\%$$

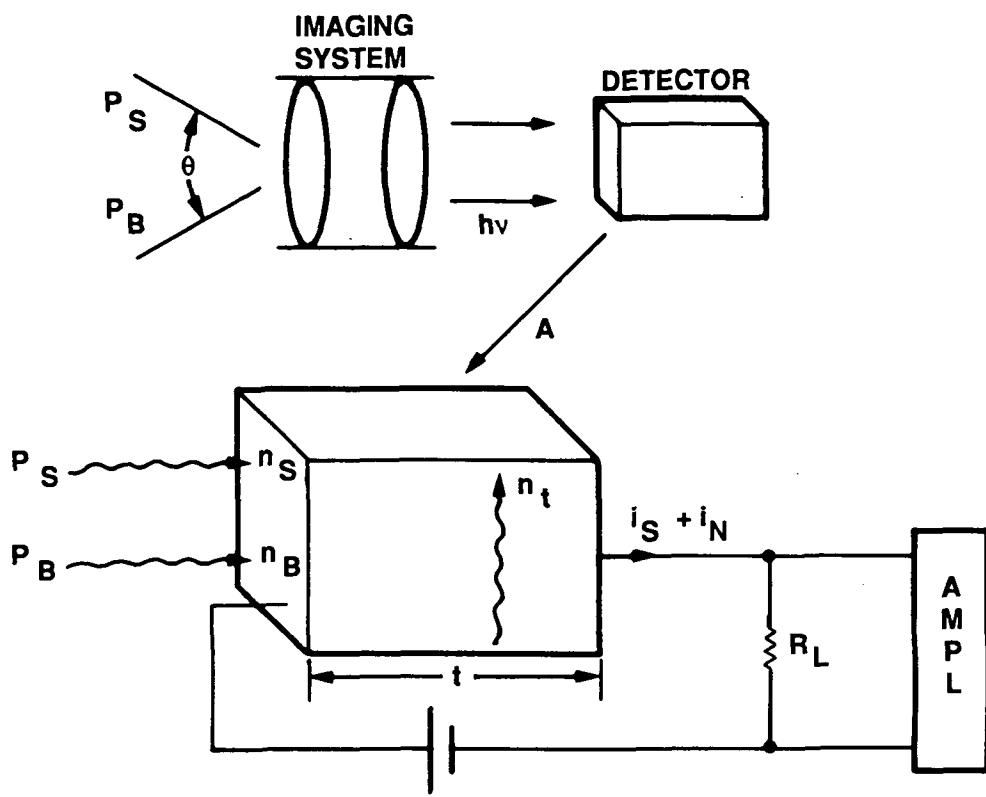
#1045
L = 300 Å
d = 50 Å
50 periods
Ga .76 Al .24 As





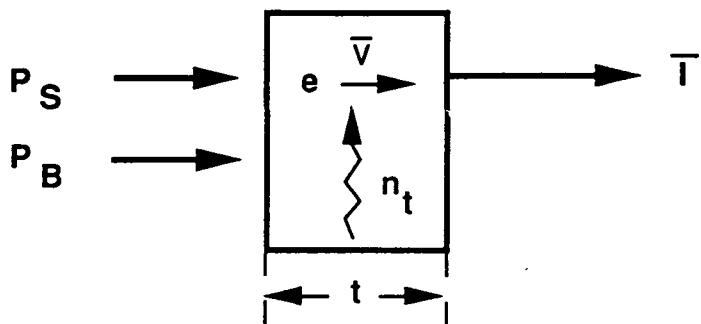
DARK CURRENT OF GaAs/GaAlAs MQW DETECTOR AT 77K





Configuration

NOISE PHYSICS — P.C. DETC.



$$\bar{T} = (n_B + n_t) e \bar{V} A$$

$$\bar{i}_N^2 = 4e\bar{T} \frac{\tau_o}{\tau_d} \Delta\nu \quad \frac{\tau_o}{\tau_d} \equiv g \quad \tau_d \equiv \frac{t}{v} = \text{DRIFT TIME}$$

GENERATION-RECOMBINATION NOISE

$$= 4e(n_B + n_t) e \bar{V} A \left(\frac{\tau_o}{\tau_d} \right) \Delta\nu$$

$$n_B = \frac{(P_B/A) \eta \tau_o}{hvt} = \frac{2\pi h v^3 \Delta\nu (\sin^2 \theta/2)}{c^2 (e h v / k T_B - 1)} \left(\frac{\eta \tau_o}{hvt} \right)$$

NEED TO COOL TILL

$$n_t \approx n_B \quad \underline{\text{BLIP}}$$

BLIP AND D_B^*

ASSUME $n_t < n_B$ (BLIP)

$$\bar{i}_{NB}^2 = 4e (n_B e \bar{v} A) \frac{\tau_o}{\tau_d} \Delta v, \quad \tau_d = \frac{t}{\bar{v}}$$

$$= \frac{4e^2 P_B \eta \Delta v}{h\nu} \left(\frac{\tau_o}{\tau_d} \right)^2, \quad n_B = \left(\frac{P_B \eta \tau_o}{A h \nu t} \right)$$

$$\bar{i}_s^2 = \left(\frac{\eta P_s e}{h\nu} \right)^2 \left(\frac{\tau_o}{\tau_d} \right)^2$$

DEFINE: NEP = VALUE OF P_s WHICH MAKES

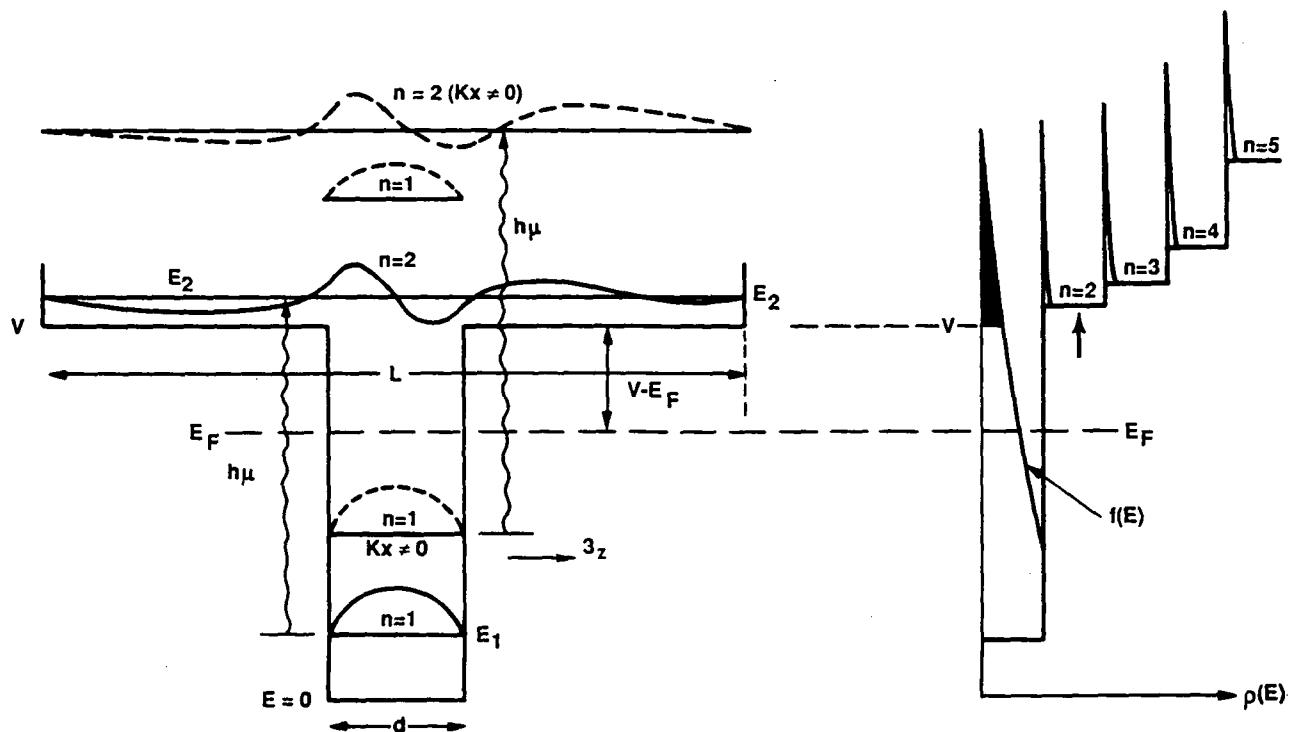
$$\bar{i}_s^2 = \bar{i}_{NB}^2$$

$$NEP = 2 \sqrt{\frac{A \Delta v (P_B / A)}{\eta}}$$

$$D_B^* \equiv \frac{\sqrt{A\Delta\nu}}{NEP} = \frac{1}{2} \sqrt{\frac{\eta}{h\nu(P_B/A)}}$$

REMINDER:

TO OBTAIN D_B^* MUST COOL SO $n_t < n_B$.
 SO NEED TO FIND DEPENDENCE OF n_t ON T.



$$n_t = \frac{m^*}{\pi h^2 L} \int_v^\infty \left\{ 1 + \text{Int} \left[L \left(\frac{2m^*(E-V)}{\pi^2 h^2} \right)^{1/2} \right] \right\} \times \frac{dE}{e^{(E-E_F)/kT} + 1}$$

$$n_t = n_0 \left(\frac{d}{L} \right) \frac{kT}{E_F} \exp [-(V - E_F)/kT]$$

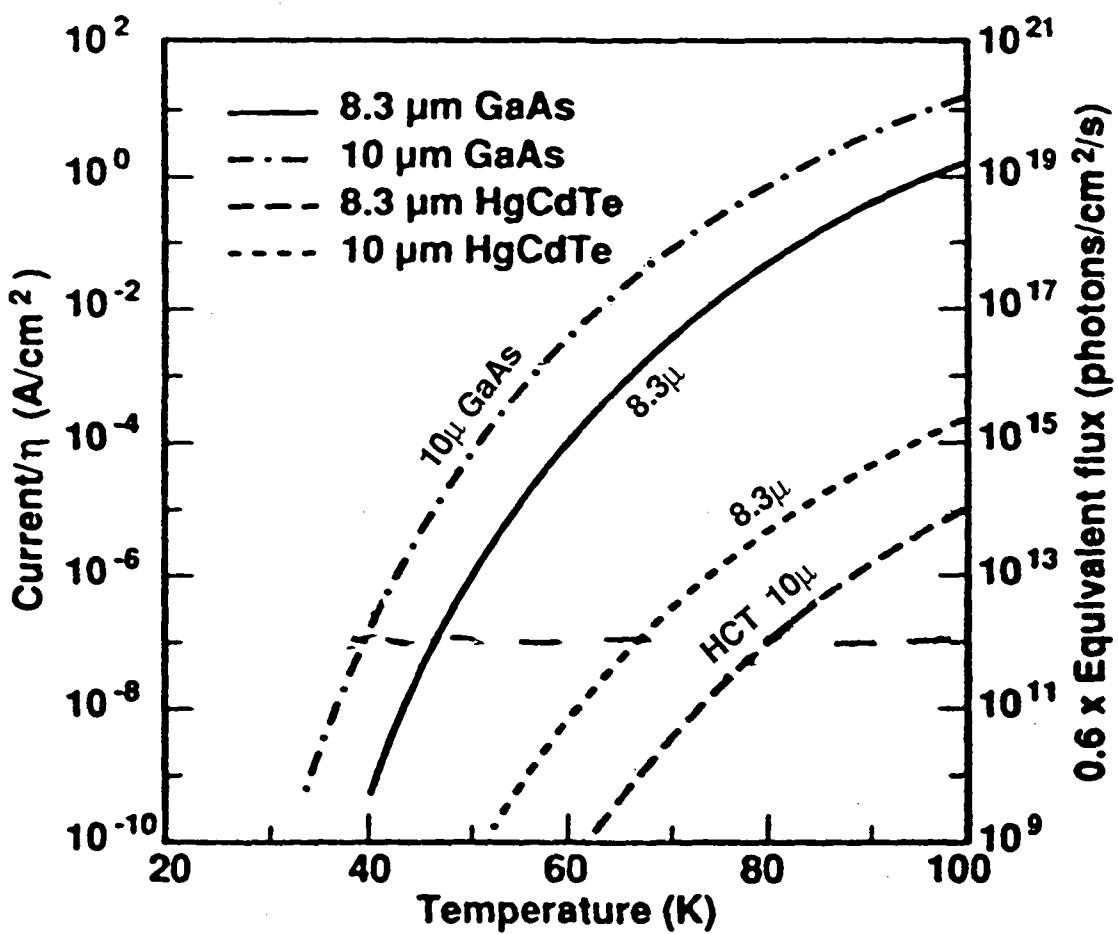
SUMMARY

$$D_B^* = \frac{1}{2} \sqrt{\frac{\eta}{hv(P_B/A)}}$$

$n_t < n_B$ FOR BLIP i.e.

$$n_o \frac{kT}{E_F} \frac{d}{L} e^{- (V - E_F)/kT} \underset{\text{BLIP}}{\approx} \frac{P_B \eta \tau_o}{A h v t}$$

\Rightarrow IF $\tau_o \uparrow$ $T \uparrow$
Q. WELL $\tau \sim 10^{-11}$ s
HCT $\tau \sim 10^{-6}$ s

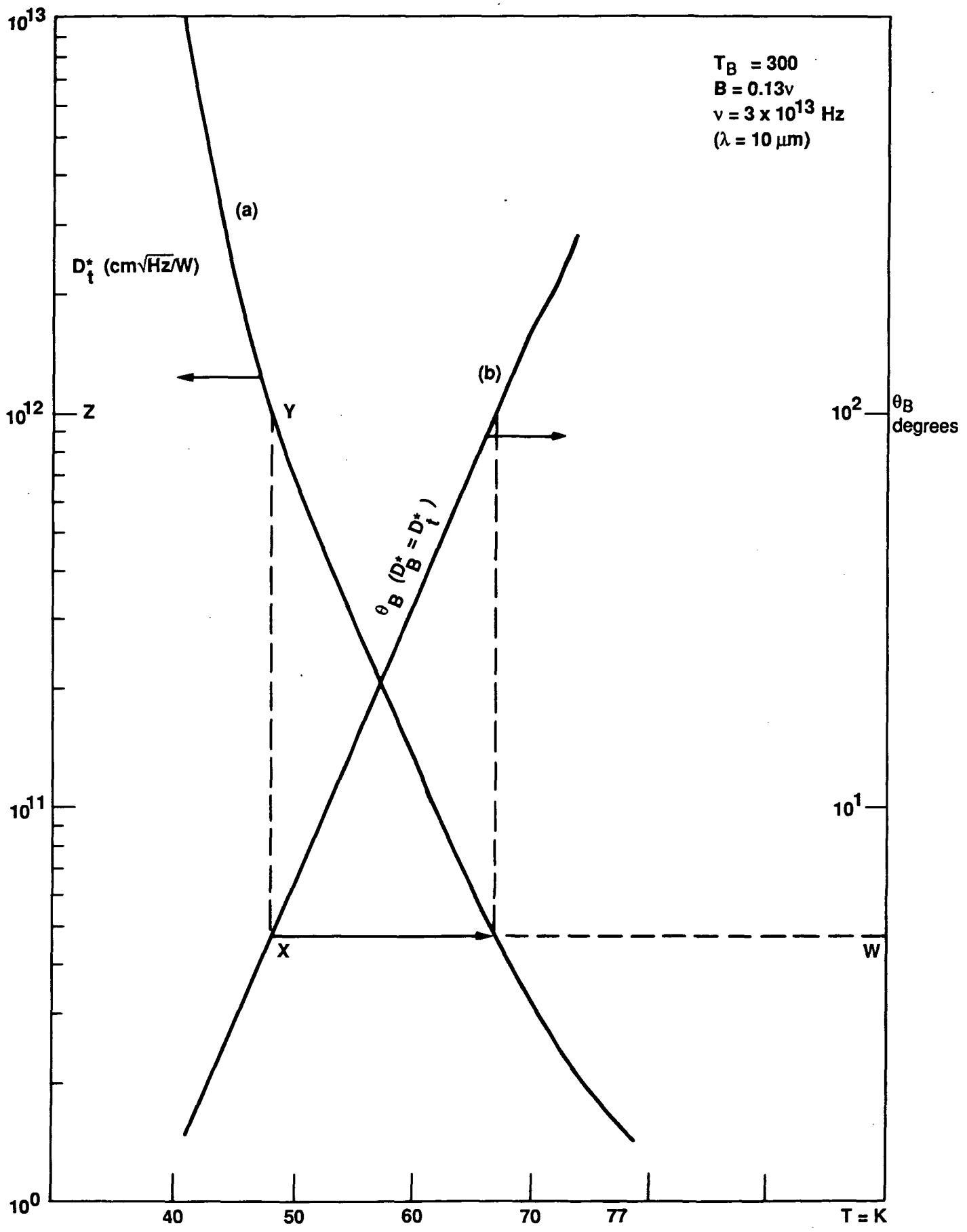


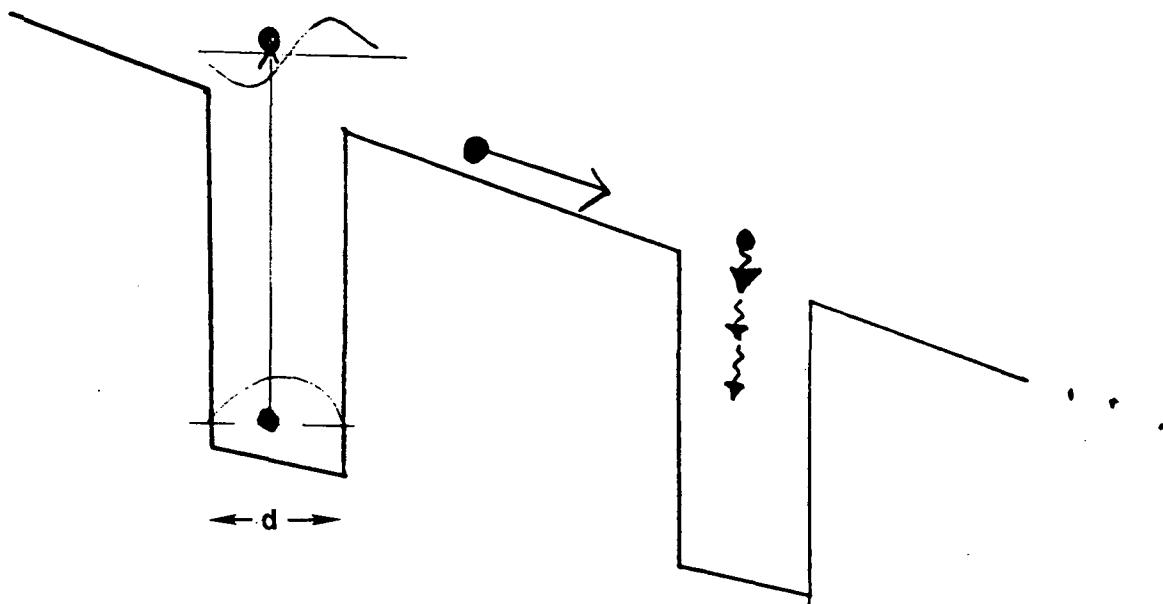
Thermal generation current vs temperature for GaAs/AlGaAs IR superlattices and HgCdTe alloys at $\lambda_c = 8.3$ and $10 \mu\text{m}$. The assumed effective quantum efficiencies are $\eta = 0.125$ and 0.7 for GaAs/AlGaAs and HgCdTe, respectively.

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(APL, Vol. 55, Nov., 1989)



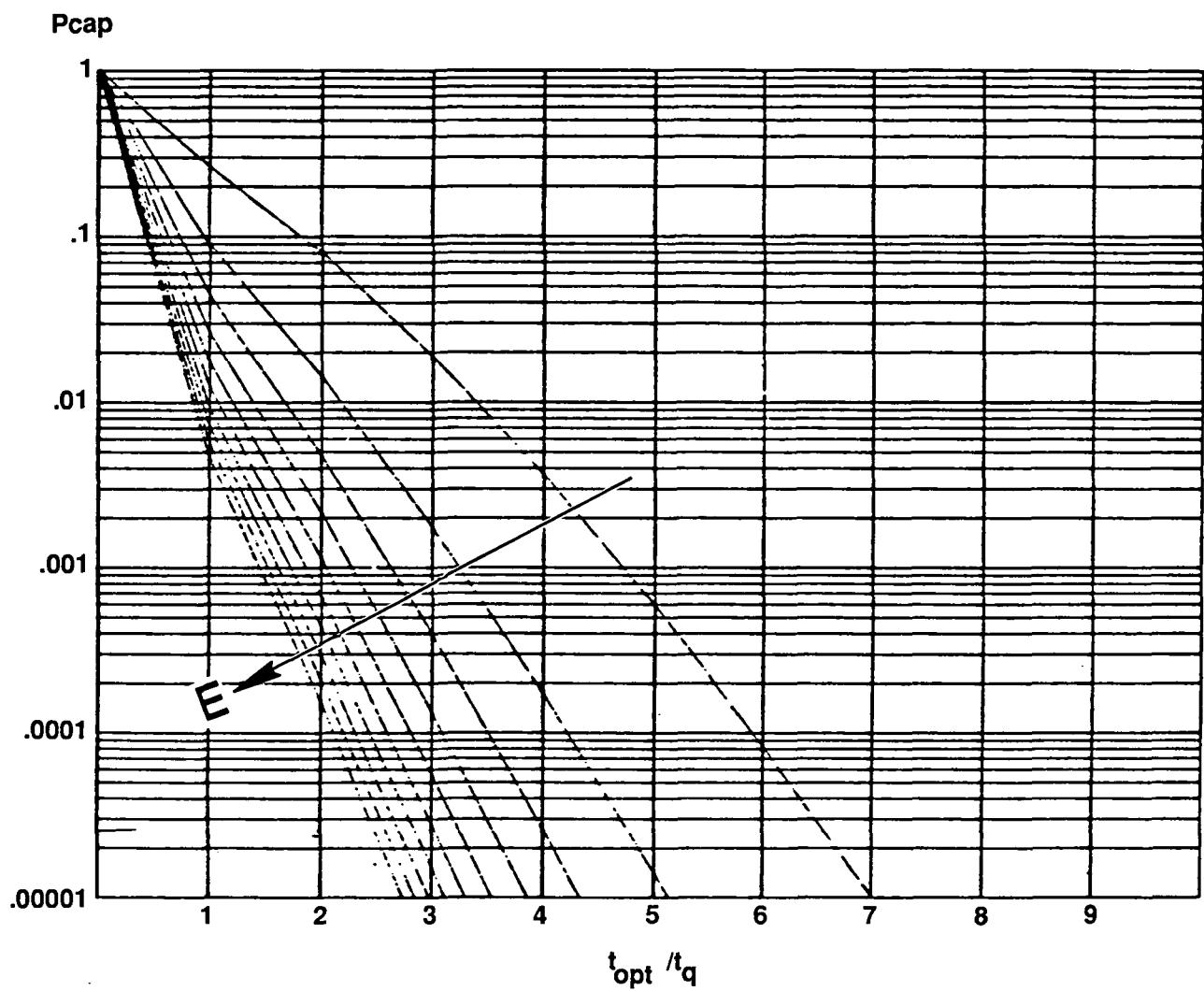


$$t_q = \text{TIME OVER WELL} = \frac{d}{\mu\varepsilon} \sim 5 \times 10^{-14} \text{ s}$$

$$t_{\text{op}} = \text{TIME TO EMIT LO PHONON} \sim 10^{-13} \text{ s}$$

$$t_{\text{op}}/t_q \sim 2 - 5$$

$$P_{\text{cap}}(E) = 1 - \sum_{x=0}^{I_n(E/\hbar\omega_{\text{op}})} \frac{(\tau_{\text{opt}}/t_q)^x}{x!} e^{-\tau_{\text{opt}}/t_q}$$



probability of capture by optical phonon emission as a function
of the energy at injection and (t_{op}/t_q)

(S. Smith, Ph.D. Thesis, Caltech, April, 1986)