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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 detctors 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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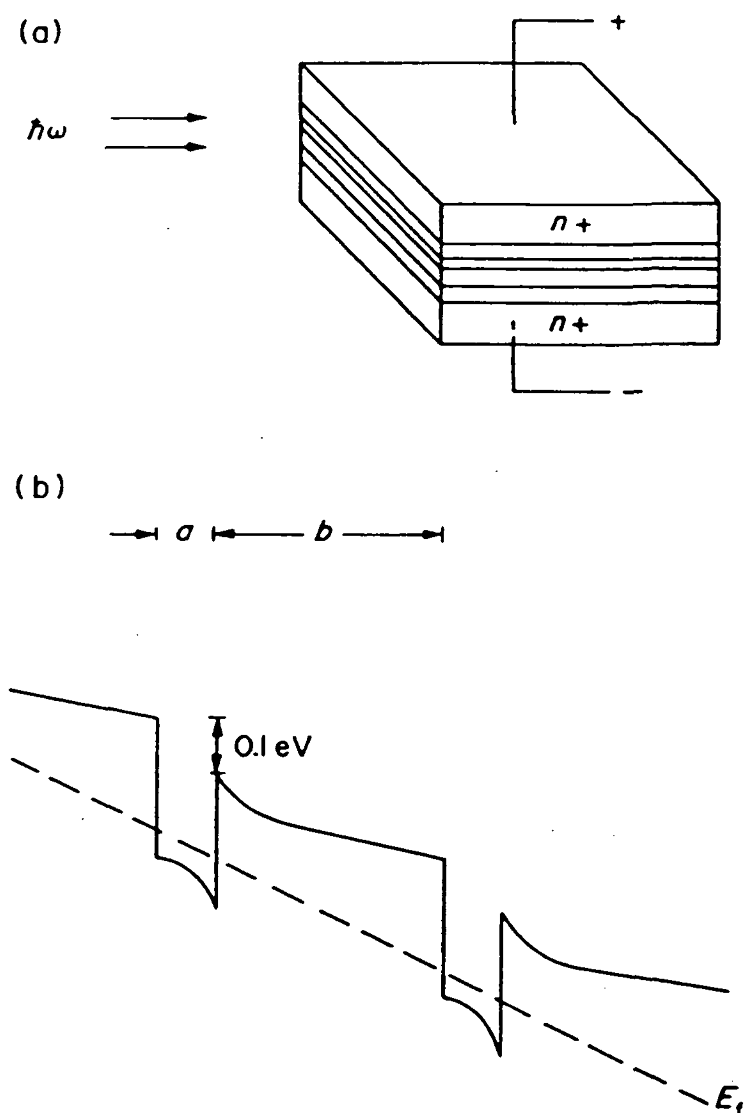
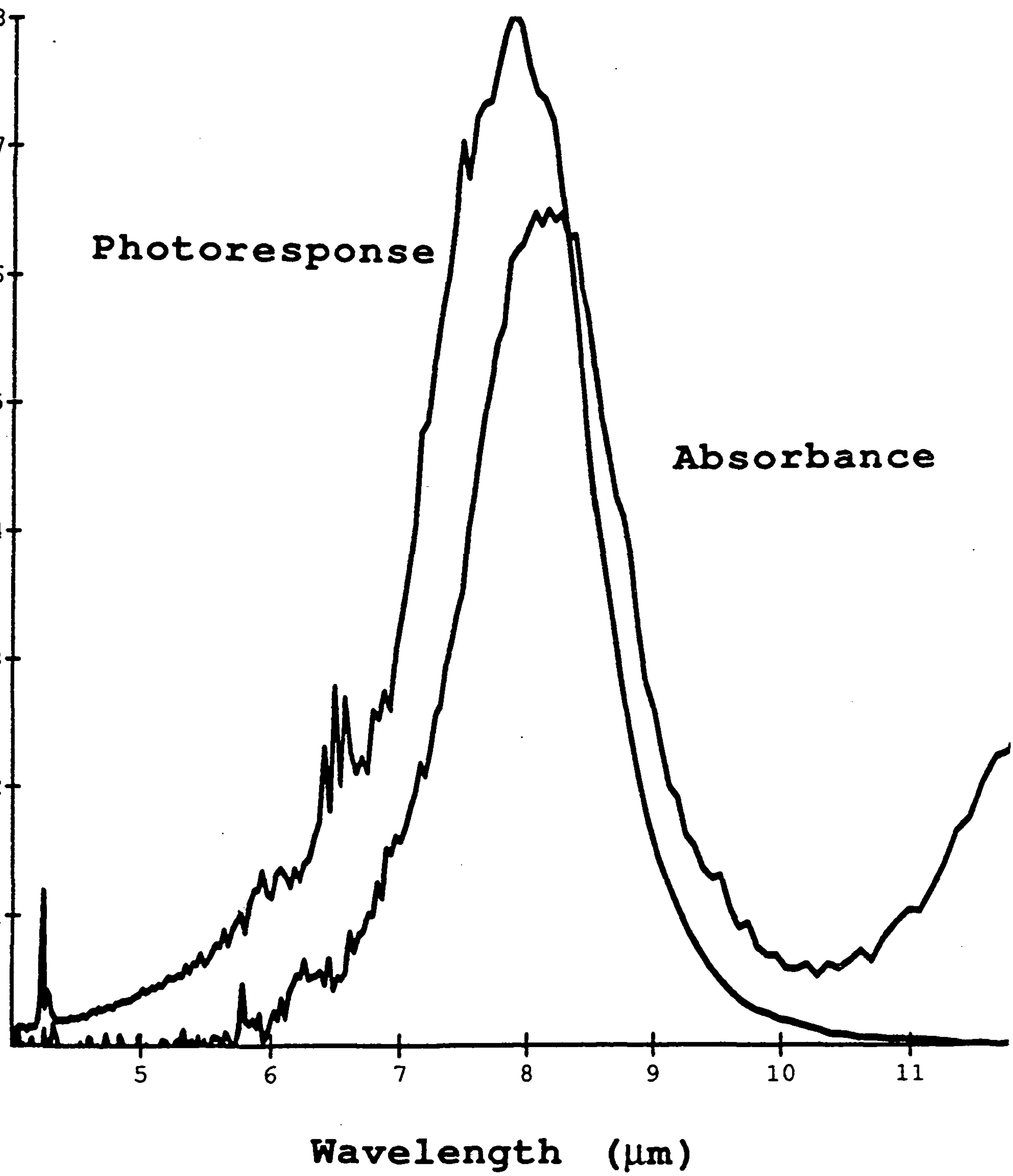


Fig. 3. (a) A schematic drawing of the proposed detector.
(b) Band diagram of the proposed structure.

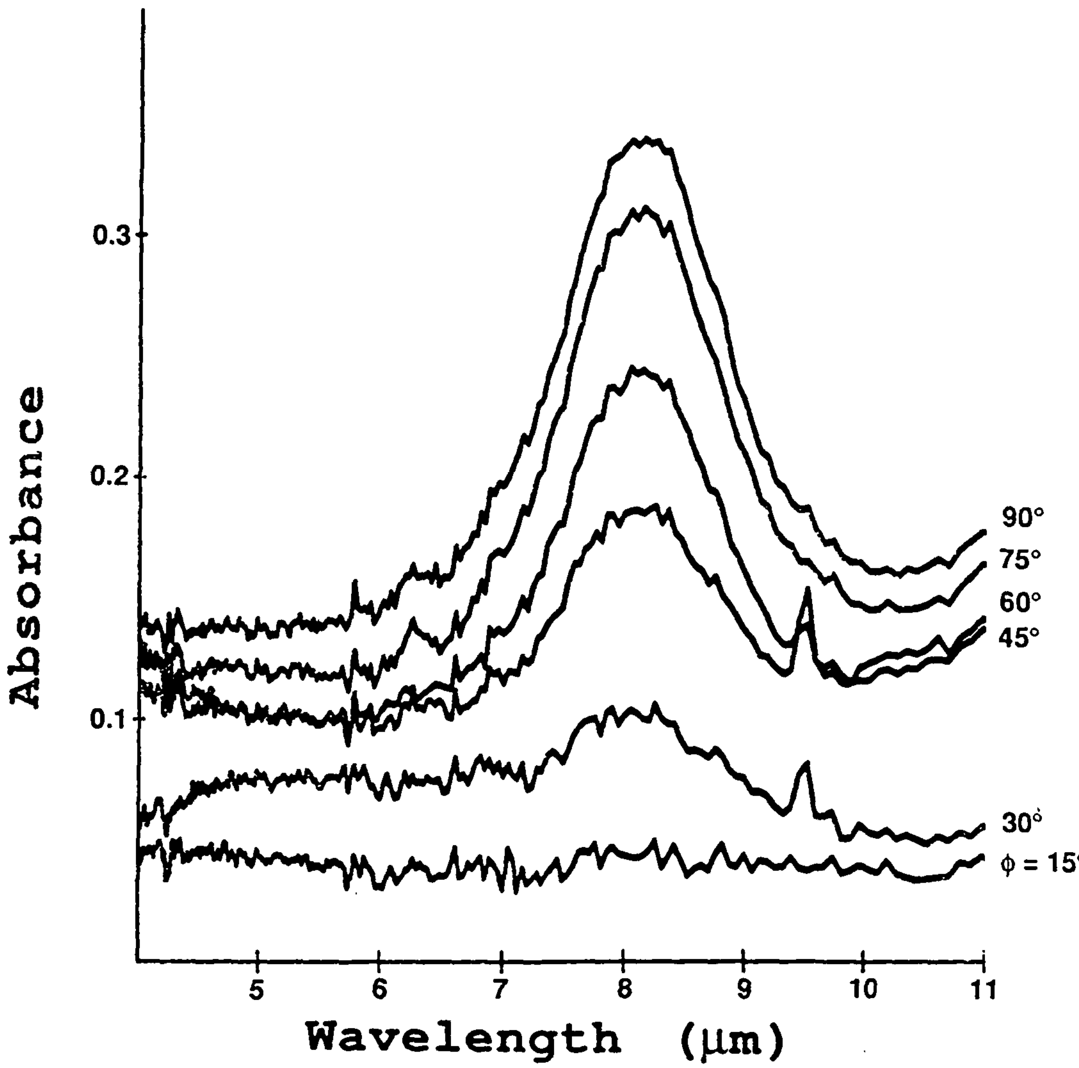
(Smith et. al., Infrared Phys., Vol 23, p. 93, 1983)

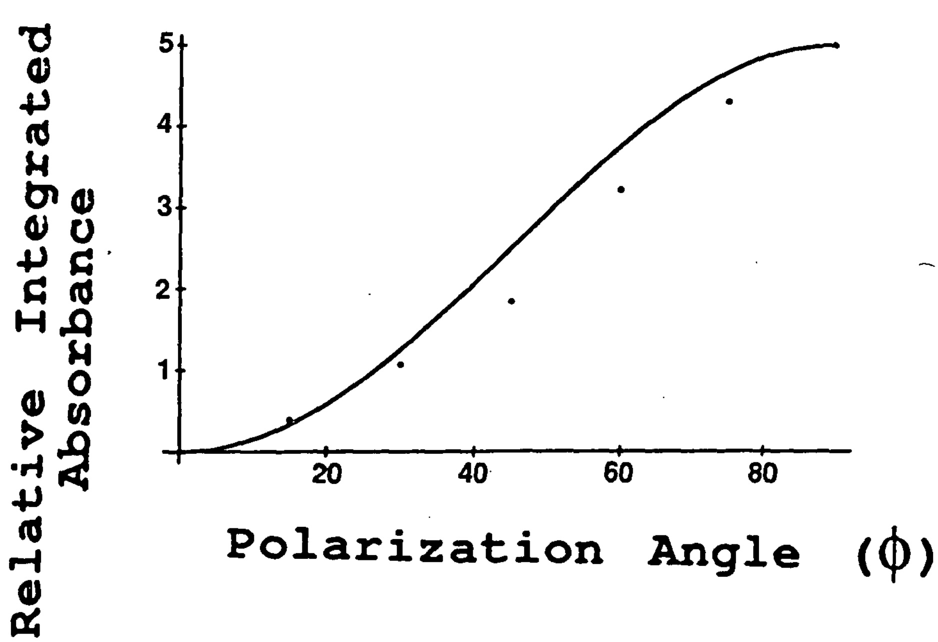


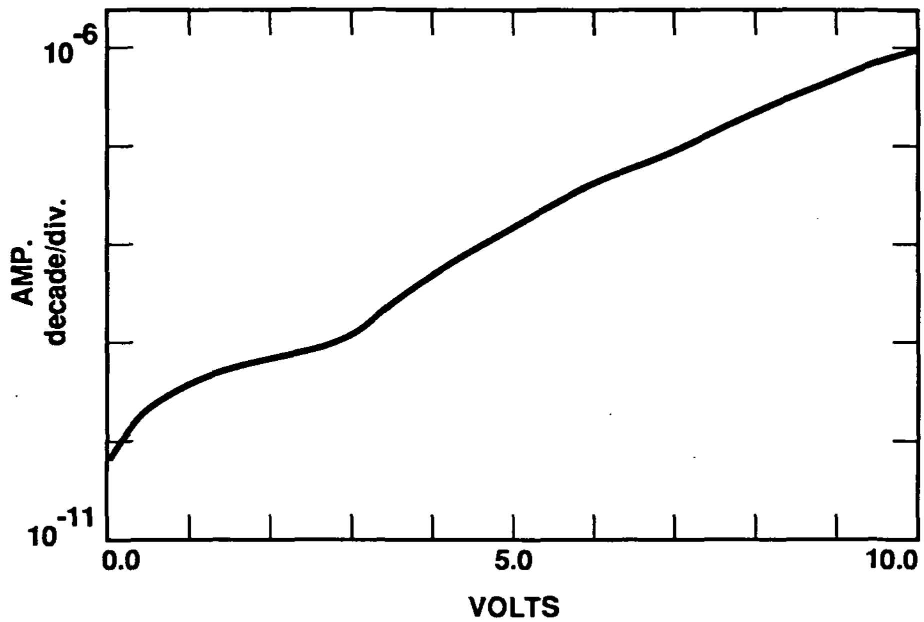
λ_{PEAK} = 8.00 μm

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

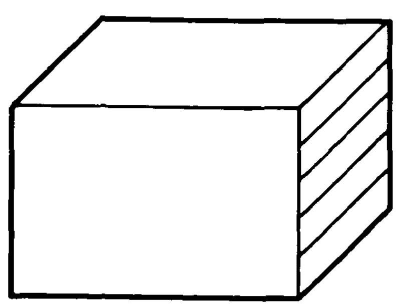
#1045
L = 300 Å
d = 50 Å
50 periods
Ga .76 AL .24 As


Absorbance
0.3
0.2
0.1
5
6
7
8
9
10
11
Wavelength (μm)
90°
75°
60°
45°
30°
ϕ = 15°


Relative Integrated Absorbance
5
4
3
2
1
20
40
60
80
Polarization Angle (ϕ)



DARK CURRENT OF GaAs/GaAlAs MQW DETECTOR AT 77K

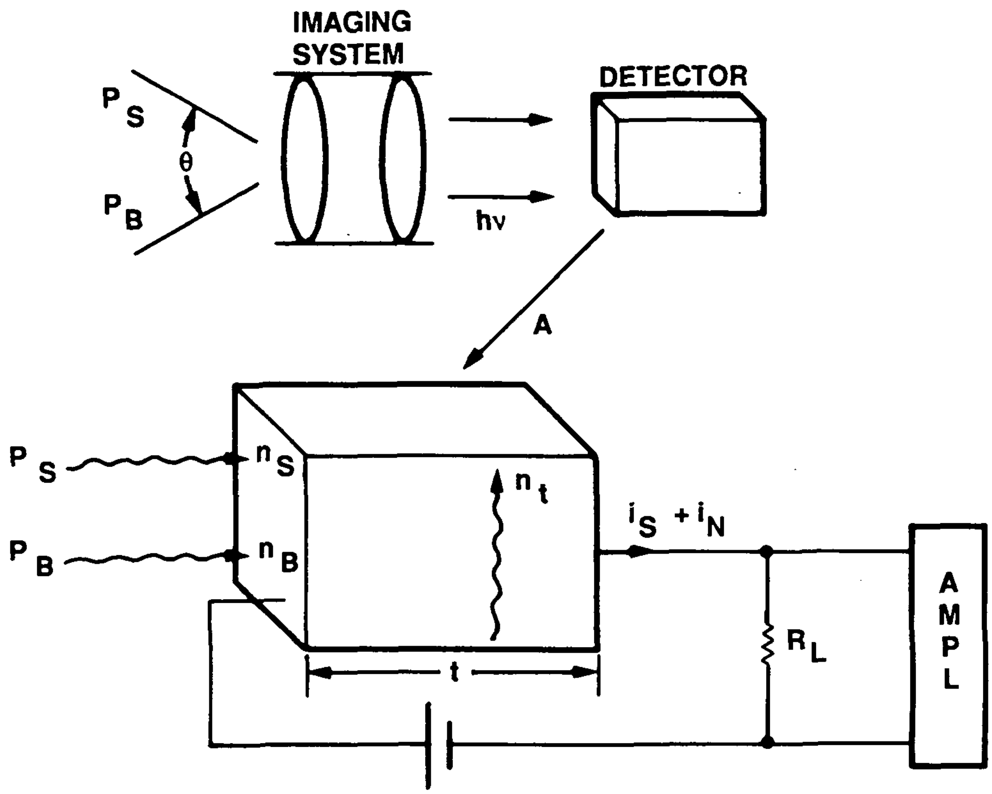


$V_B = 0$ $I_d \sim 10^{-11}$ A

$V_B = 10V$ $I_d \sim 10^{-6}$ A

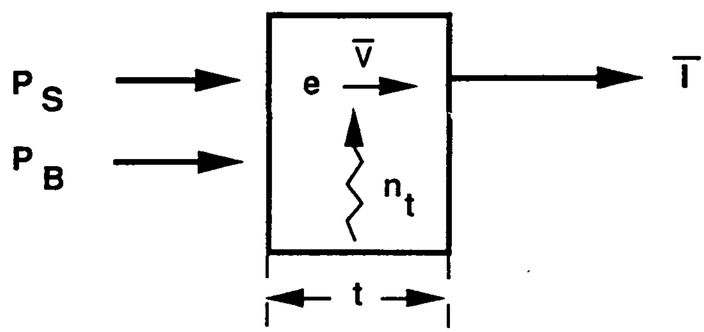
$V_B = 5V$

$I_d \sim 10^{-9}$ A



Configuration

NOISE PHYSICS — P.C. DETC.



$$\bar{I} = (n_B + n_t)\, e \bar{v} A$$

$$\boxed{\overline{i_N^2} = 4e\bar{I}\,\frac{\tau_o}{\tau_d}\,\Delta\nu} \qquad \frac{\tau_o}{\tau_d} \equiv g \qquad \tau_d \equiv \frac{t}{v} = \text{DRIFT TIME}$$

GENERATION-RECOMBINATION NOISE

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

$$n_B = \frac{(P_B/A)\,\eta\tau_o}{h\nu t} = \frac{2\pi h\nu^3 \Delta\nu (\mathrm{Sin}^2\,\theta/2)}{c^2\,(e^{h\nu/kT_B} - 1)} \left(\frac{\eta\tau_o}{h\nu t}\right)$$

NEED TO COOL TILL

$n_t \lesssim n_B$ __BLIP__

BLIP AND D_B^*

ASSUME $n_t < n_B$ (BLIP)

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

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

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

DEFINE: NEP = VALUE OF P_s WHICH MAKES

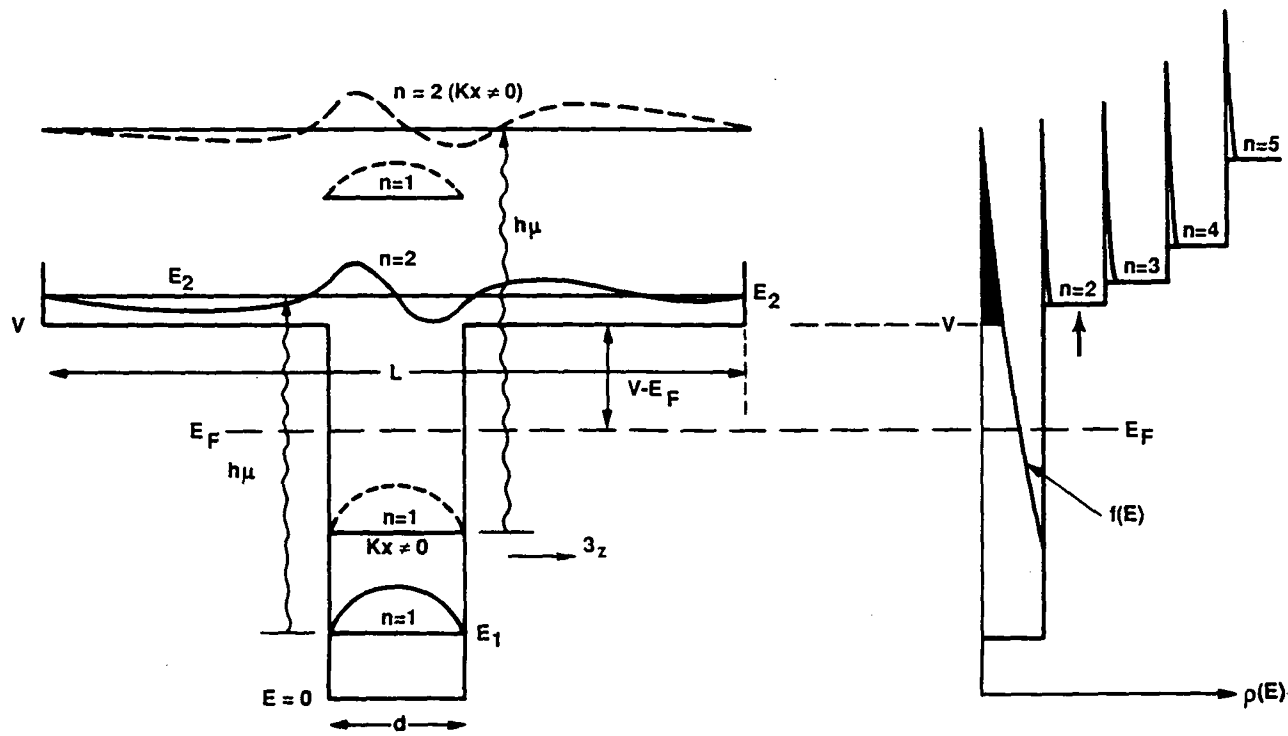
$$\overline{i^2_s} = \overline{i^2_{NB}}$$

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

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

REMINDER:

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



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

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

SUMMARY

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

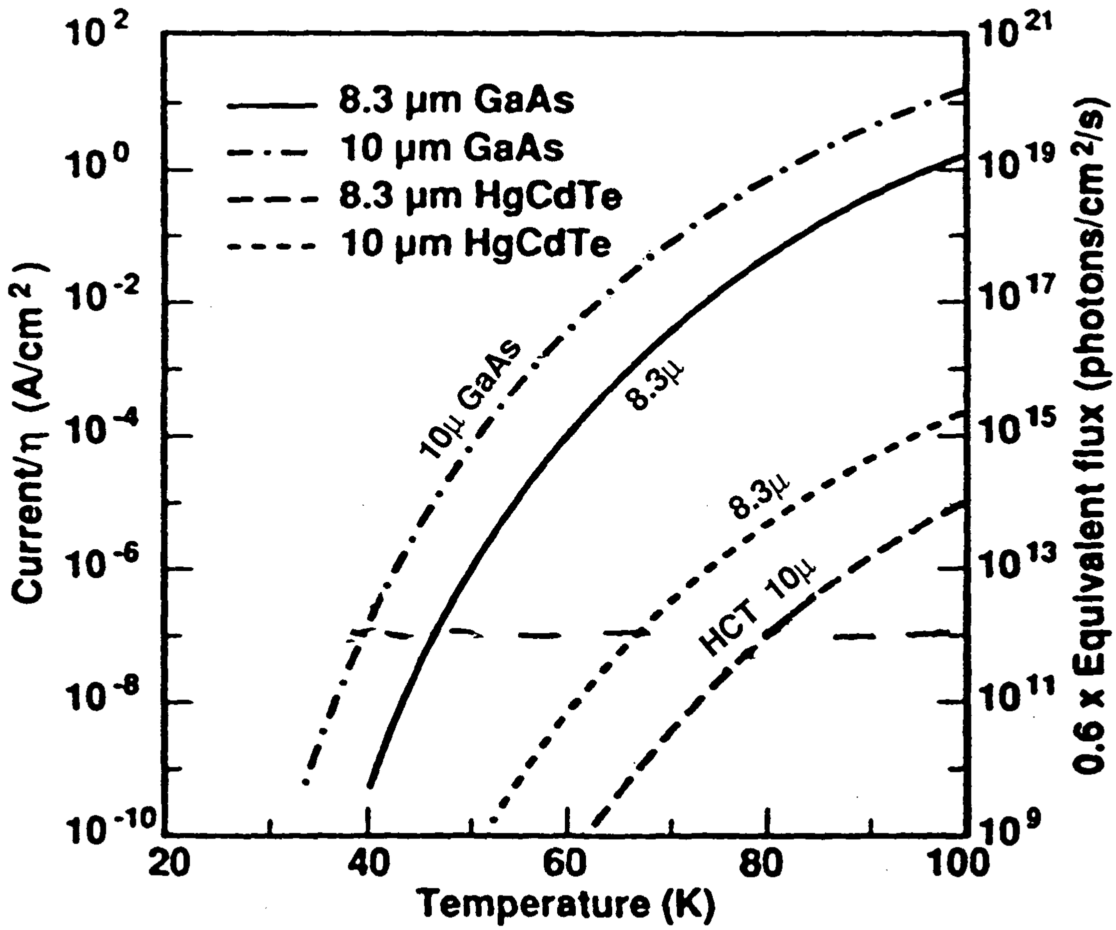
$n_t < n_B$ FOR BLIP i.e.

$$n_o \frac{kT}{E_F} \frac{d}{L} e^{-(V - E_F)/kT} \underset{BLIP}{} \lessapprox \frac{P_B \eta \tau_o}{Ah\nu t}$$

$\Rightarrow$ IF $\tau_o \uparrow$ T $\uparrow$

Q. WELL $\tau \sim 10^{-11}$ s

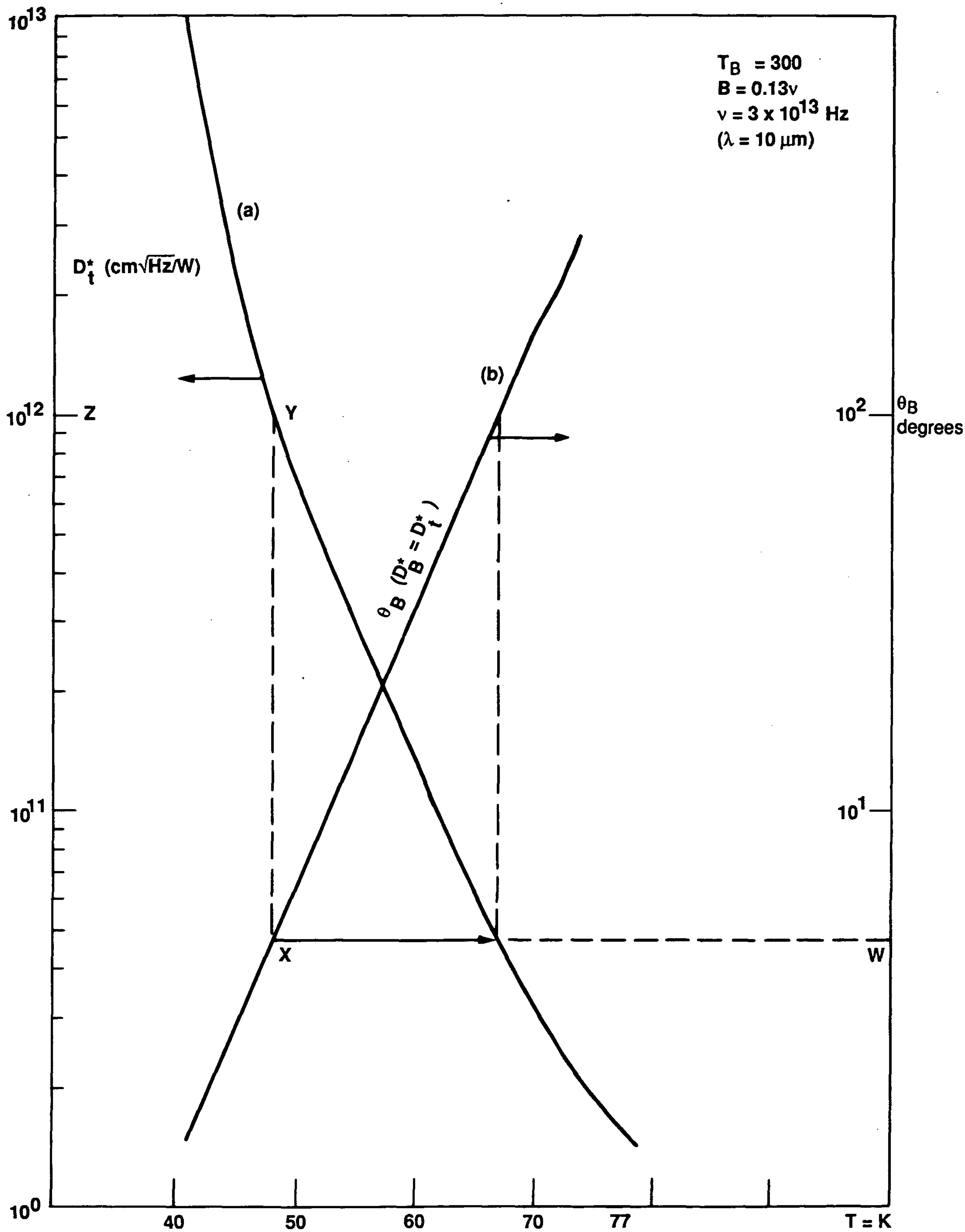
HCT $\tau \sim 10^{-6}$ s



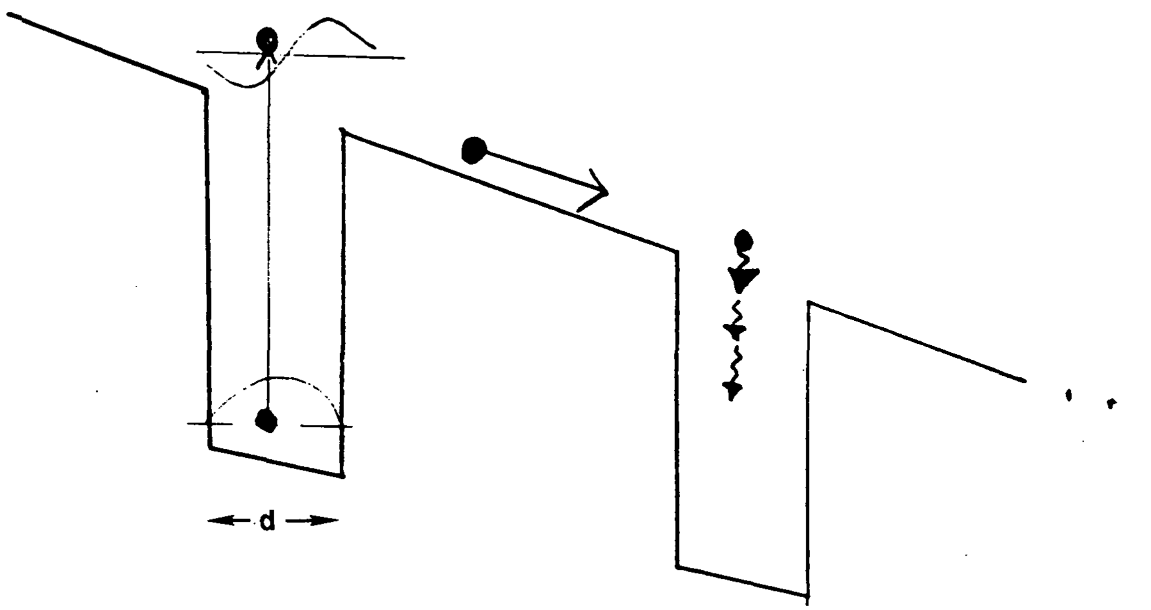
Thermal generation current vs temperature for GaAs/AlGaAs IR superlattices and HgCdTe alloys at $\lambda_c = 8.3$ and $10\,\mu$m. The assumed effective quantum efficiencies are $\eta = 0.125$ and 0.7 for GaAs/AlGaAs and HgCdTe, respectively.

M. A. Kinch and A. Yariv 2094

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



10^{13}
$T_B = 300$
$B = 0.13\nu$
$\nu = 3 \times 10^{13}$ Hz
($\lambda = 10\ \mu m$)
(a)
D_t^* (cm$\sqrt{Hz}$/W)
(b)
10^{12}
Z
Y
10^2
θ_B degrees
θ_B ($D_B^* = D_t^*$)
10^{11}
10^1
X
W
10^0
40
50
60
70
77
T = K

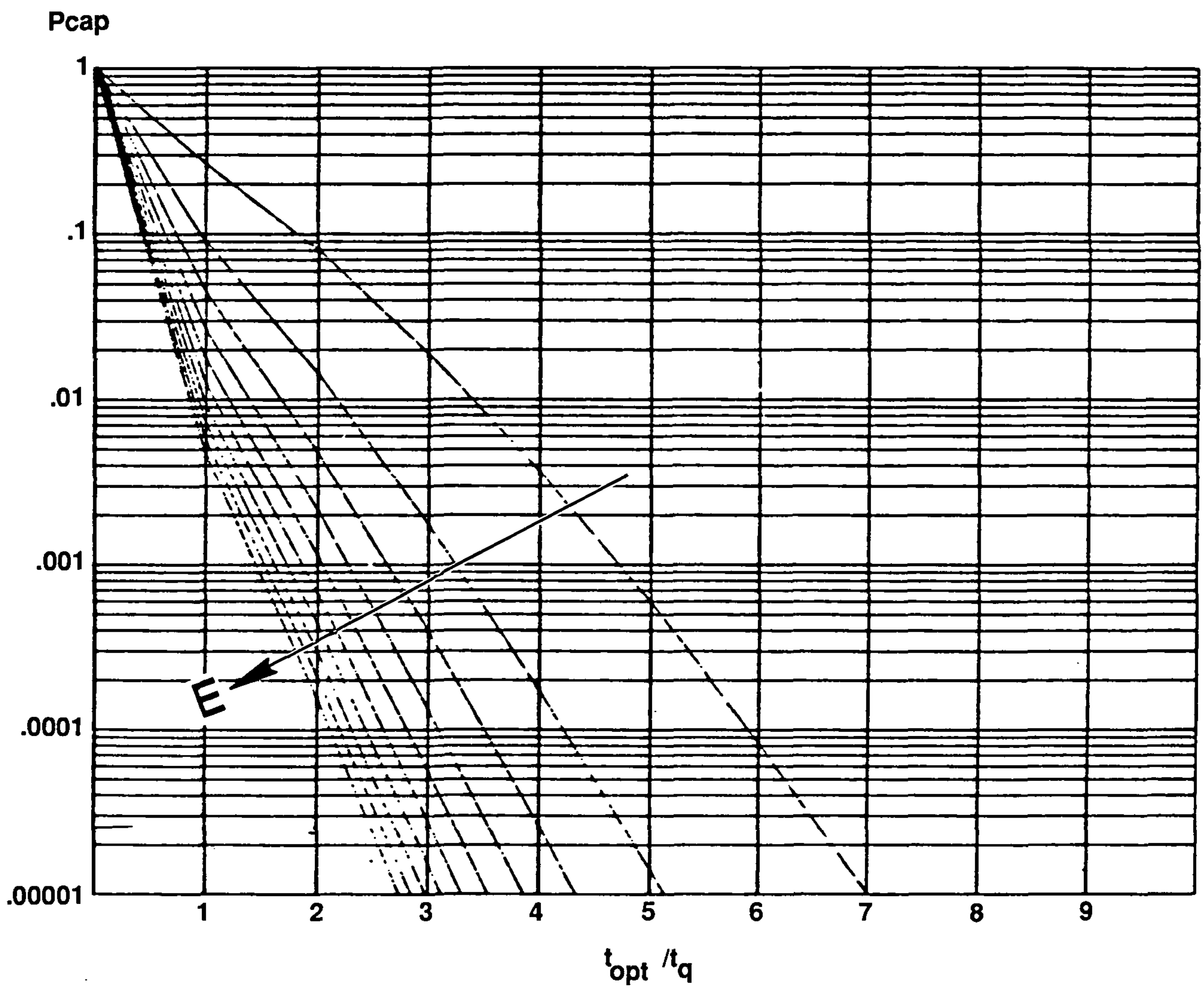


t_q = TIME OVER WELL = $\frac{d}{\mu\varepsilon}$ ~ 5×10^{-14} s

t_{op} = TIME TO EMIT LO PHONON ~10^{-13} s

t_{op}/t_q ~ 2 - 5

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



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

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