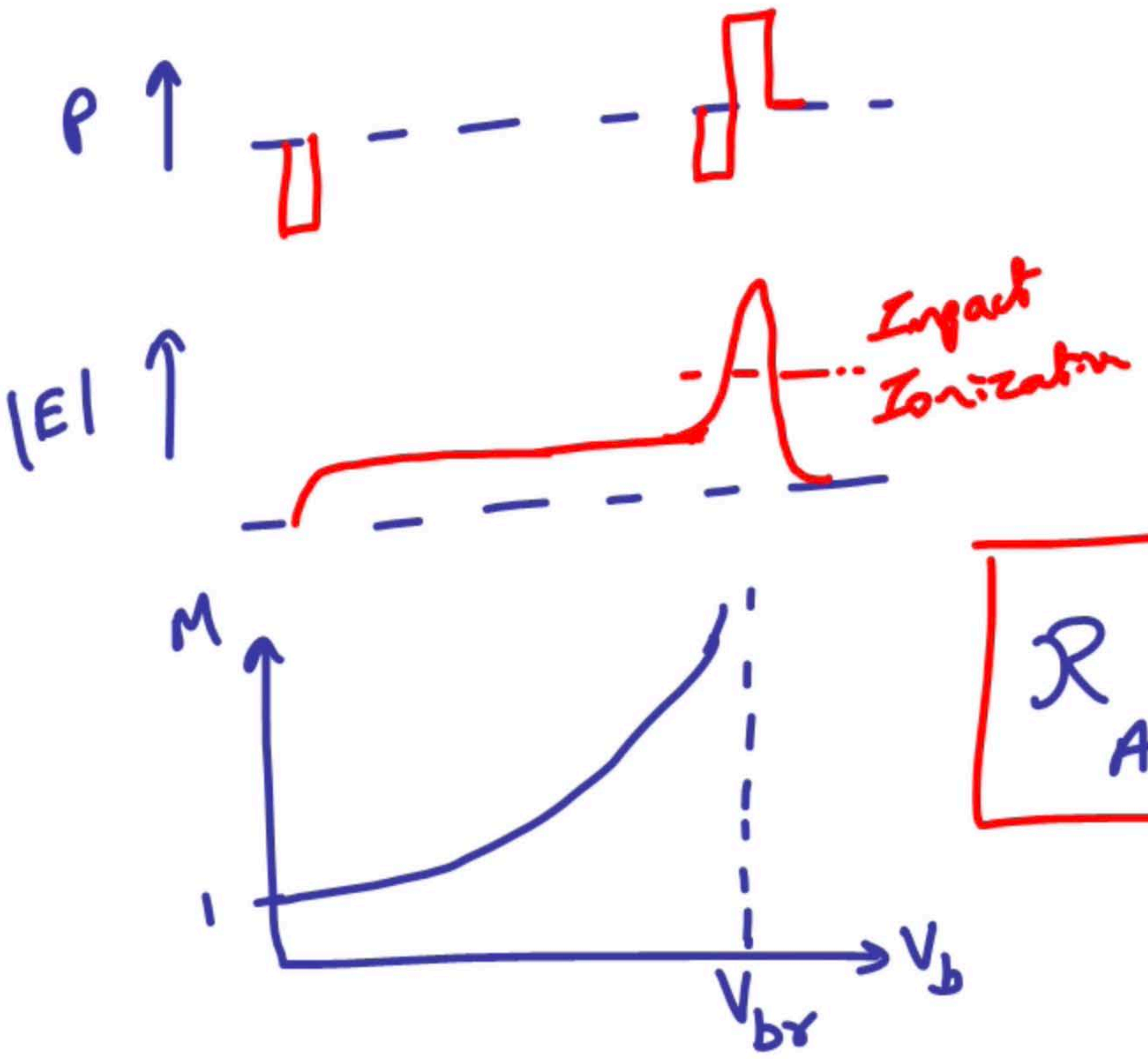
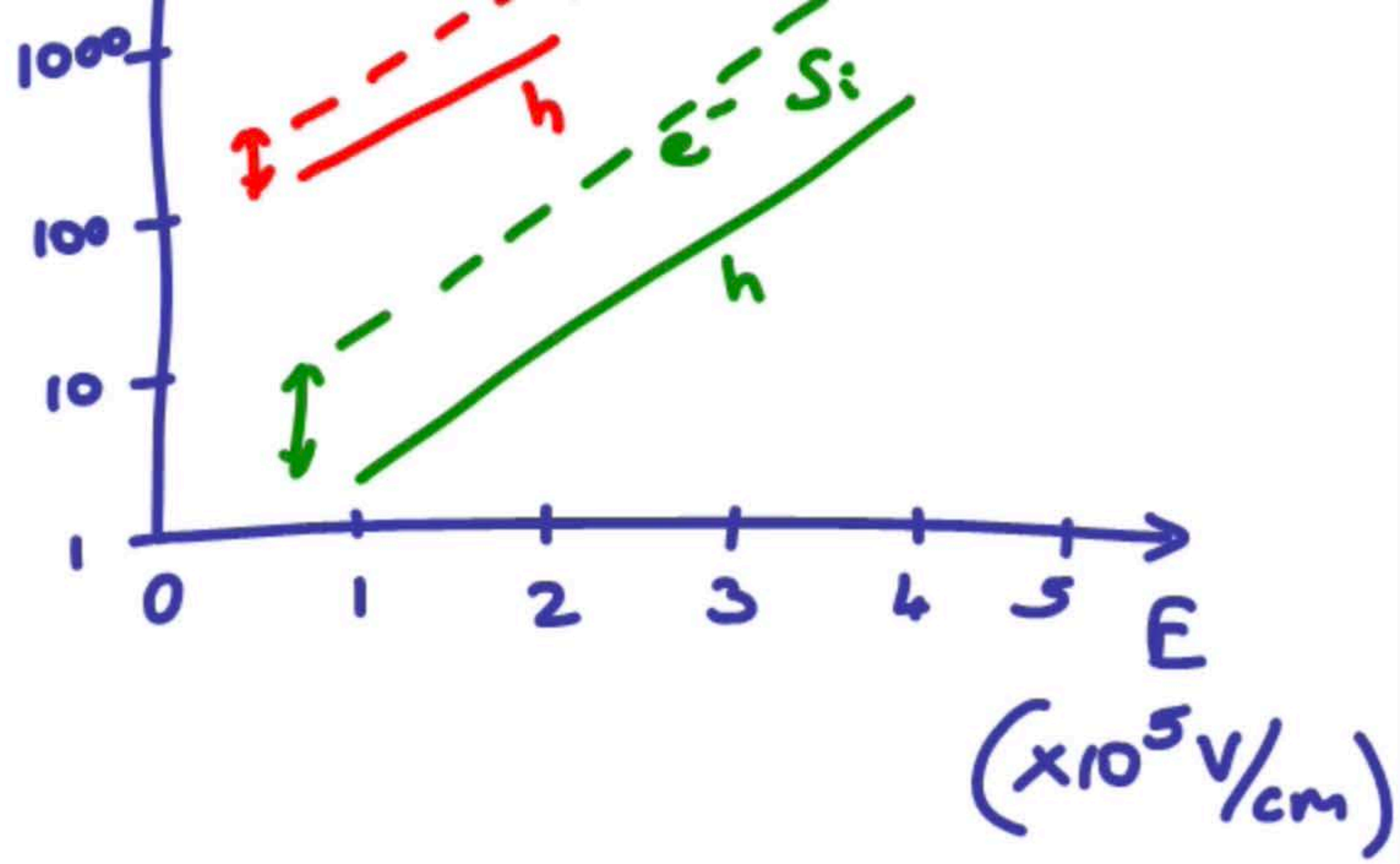




$$\boxed{\mathcal{R}_{APD} = M \cdot \mathcal{R}_{PIN}}$$

Tutorial 5
Introduction to Photonics - EE5500

1. At room temperature the intrinsic carrier concentration in GaAs is 1.8×10^6 cm^{-3}. The radiative electron hole recombination parameter is $t_r = 10^{-10}$ cm^3/s. Find the
   (a) Electroluminescence rate
   (b) Optical power density if it emits the 900 nm
   (c) Intensity produced by 4 µm layer of GaAs
   (d) Repeat part b and c for wavelength of 1 µm

2. The radiative and non radiative recombination lifetimes of the minority carriers in the active region of a double hetrojunction LED are 60 ns ad 100 ns respectively. Determine the total carrier recombination lifetime and the power internally generated within the device when the peak emission wavelength is 870 nm at a drive current of 40 mA?

3. A double heterojunction InGaAsP LED emitting at a peak wavelength of 1310 nm has radiative and nonradiative recombination times of 30 and 100 ns, respectively. The drive current is 40 mA and external quantum efficiency is 0.7. Find the bulk recombination lifetime (carrier lifetime) and output light power?

4. The forward current through a GaAsP (refractive index = 3.5) red LED emitting 660 nm wavelength with a spectral width of 30 nm is 30 mA at 4 V. The internal quantum efficiency of GaAsP is 0.1 and and carrier lifetime is 1 ns.
   (a) Carrier Injection Rate
   (b) Steady State Carrier Concentration
   (c) Optical power generated by LED
   (d) Optical power available at the output of LED
   (e) Responsivity
   (f) Fastest modulation achievable from this LED

5. The minority carrier recombination lifetime for an LED is 5 ns. When a constant dc drive current is applied to the device the optical output power is 300 µW. Determine the optical output power when the device is modulated with an rms drive current corresponding to the dc drive current at frequencies of (a) 20 MHz; (b) 100 MHz.

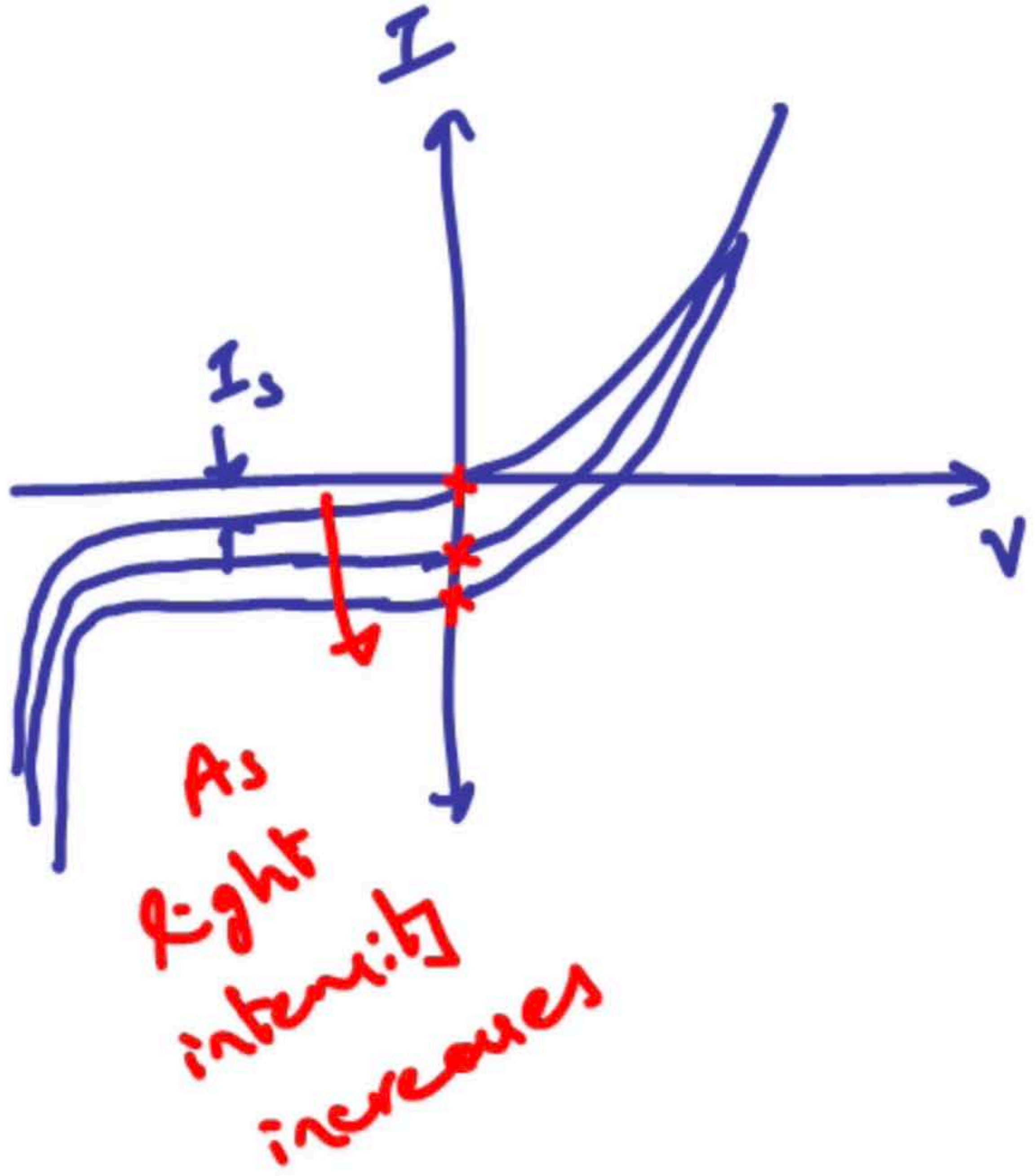
   Hint: Given

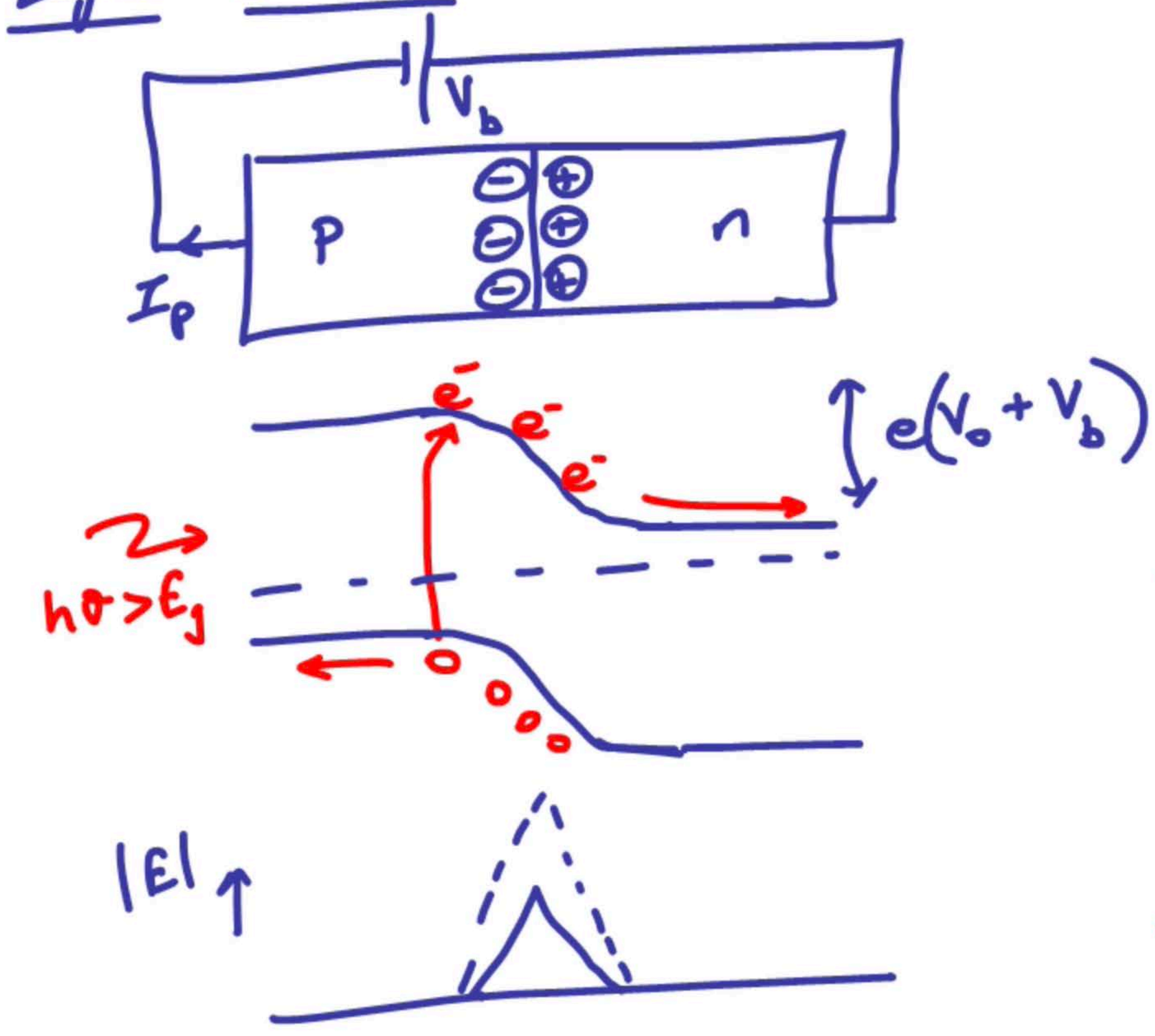
$$\frac{P_e(\omega)}{P_{dc}} = \frac{1}{[1 + (\omega\tau_i)^2]^{\frac{1}{2}}}$$

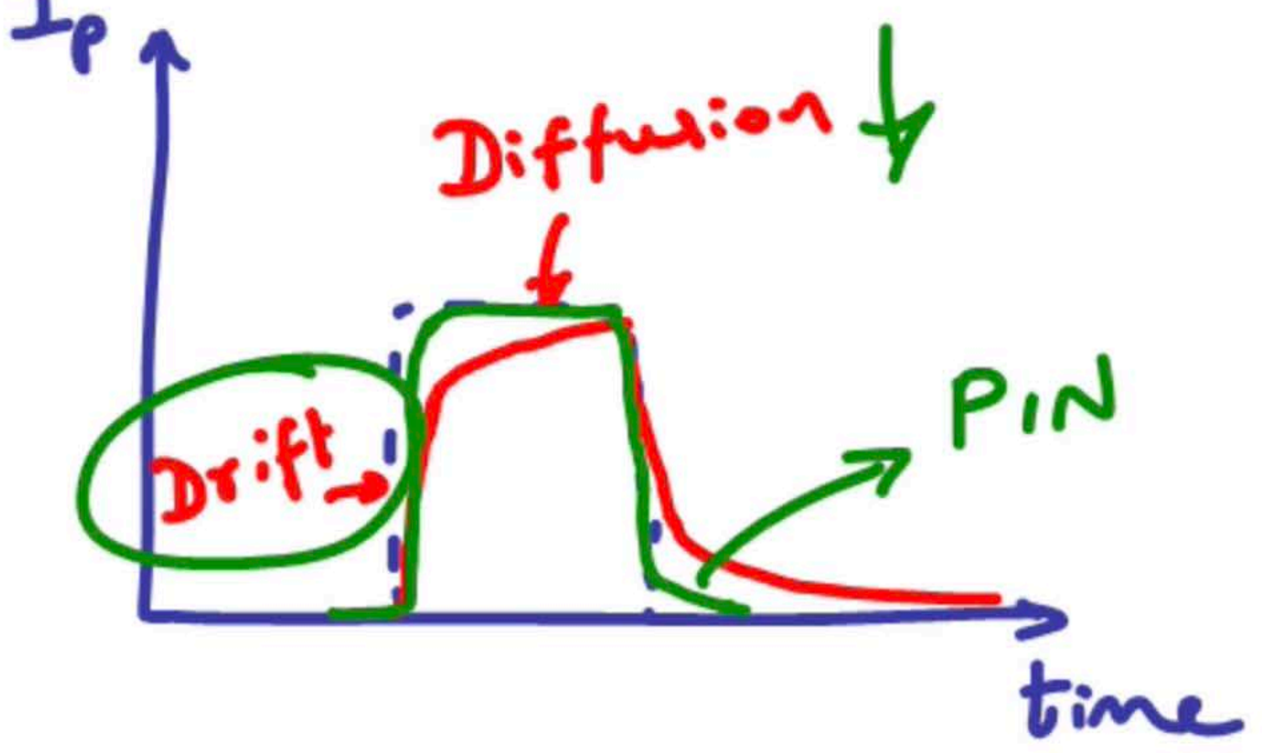
   where $P_e(\omega)$ is the optical power output, ω is the angular frequency, P_{dc} is the dc drive current and τ_i is the minority carrier lifetime.

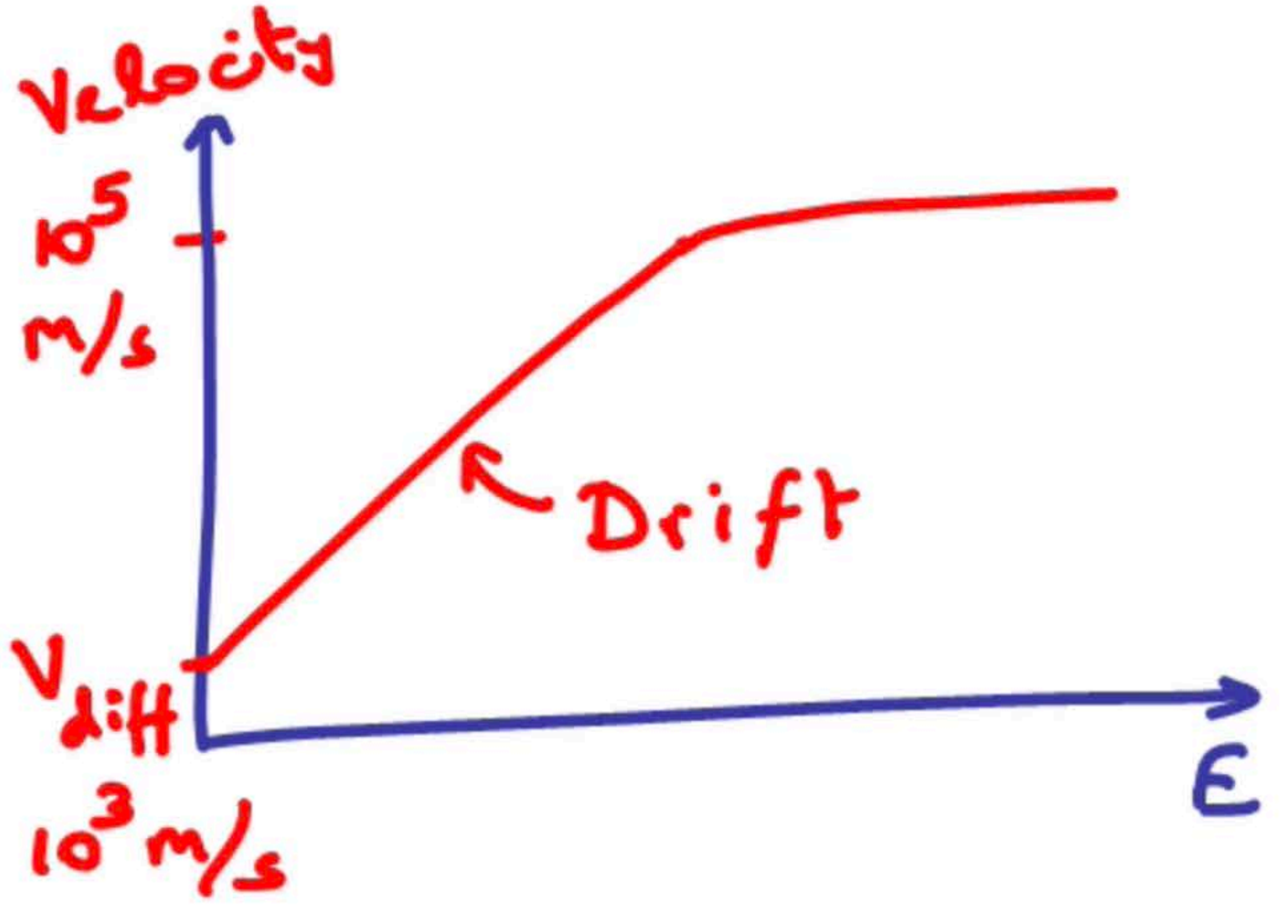
6. Given a two pin device, how would you conclusively identify whether it is an LED or Laser - both are emitting red light?

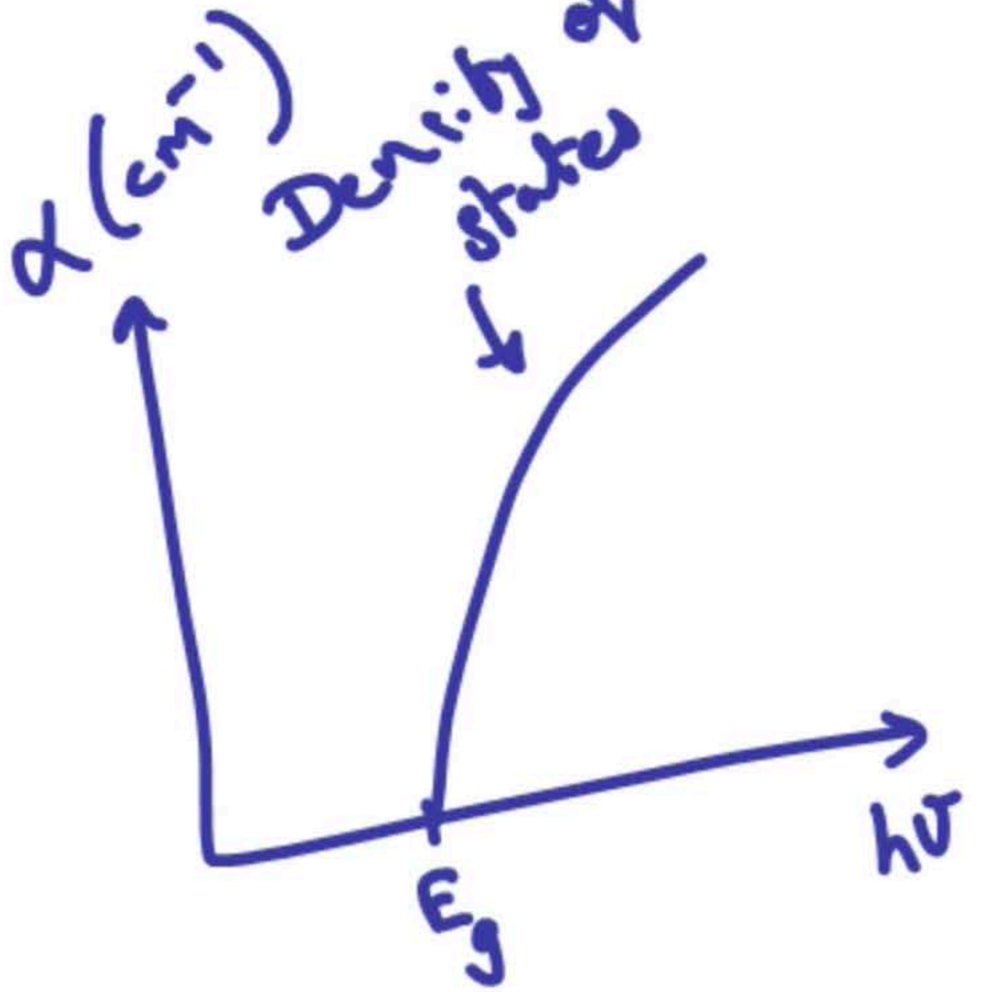
Semiconductor Light Detectors:

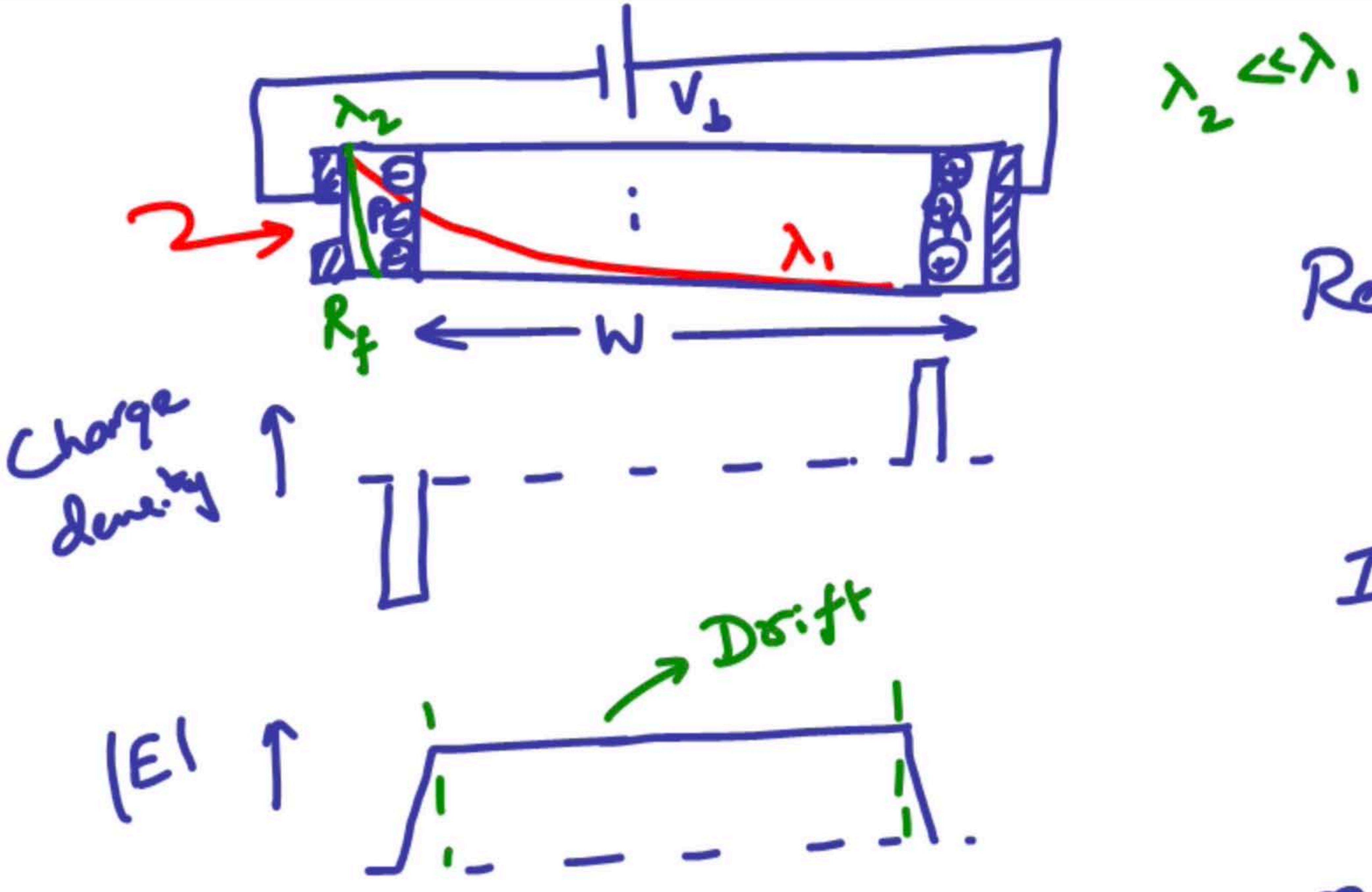












Responsivity, $\mathcal{R} = \frac{I_p}{P_{in}}$ (A/W)

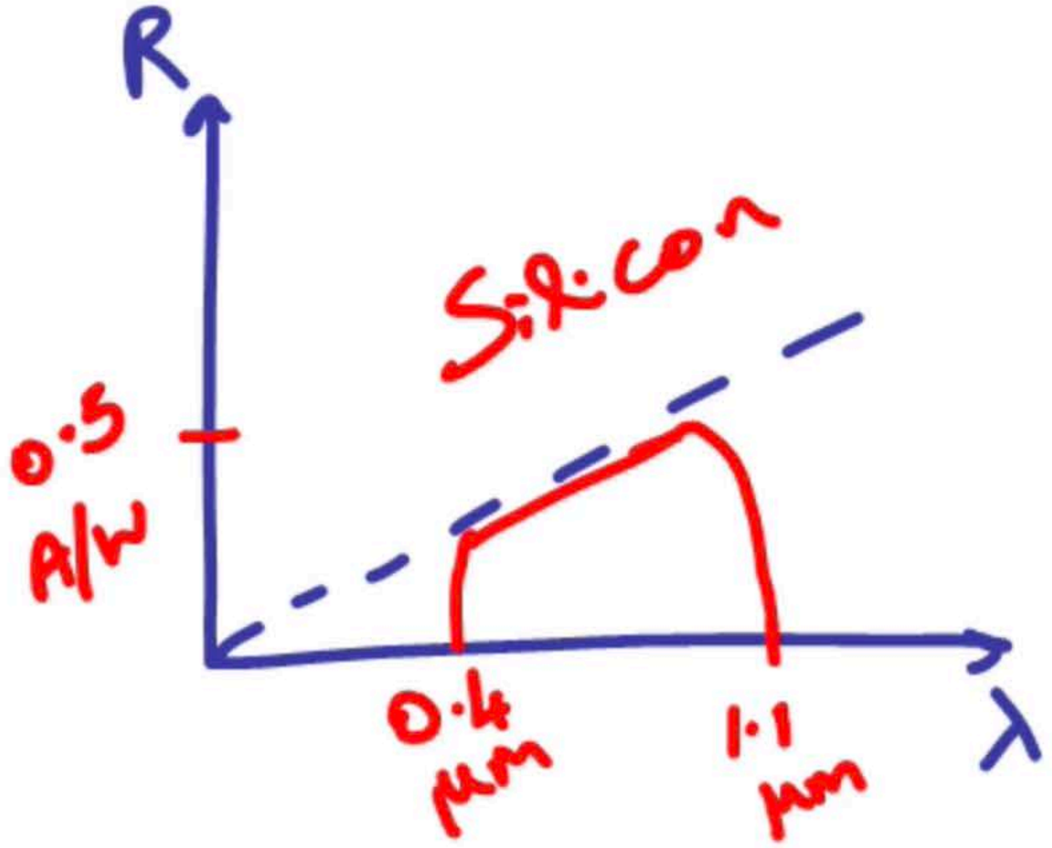
$$I_p = \frac{P_{in}}{h\nu}\underbrace{(1-R_f)\,\zeta\,(1-e^{-\alpha W})}_{\eta}\,e$$

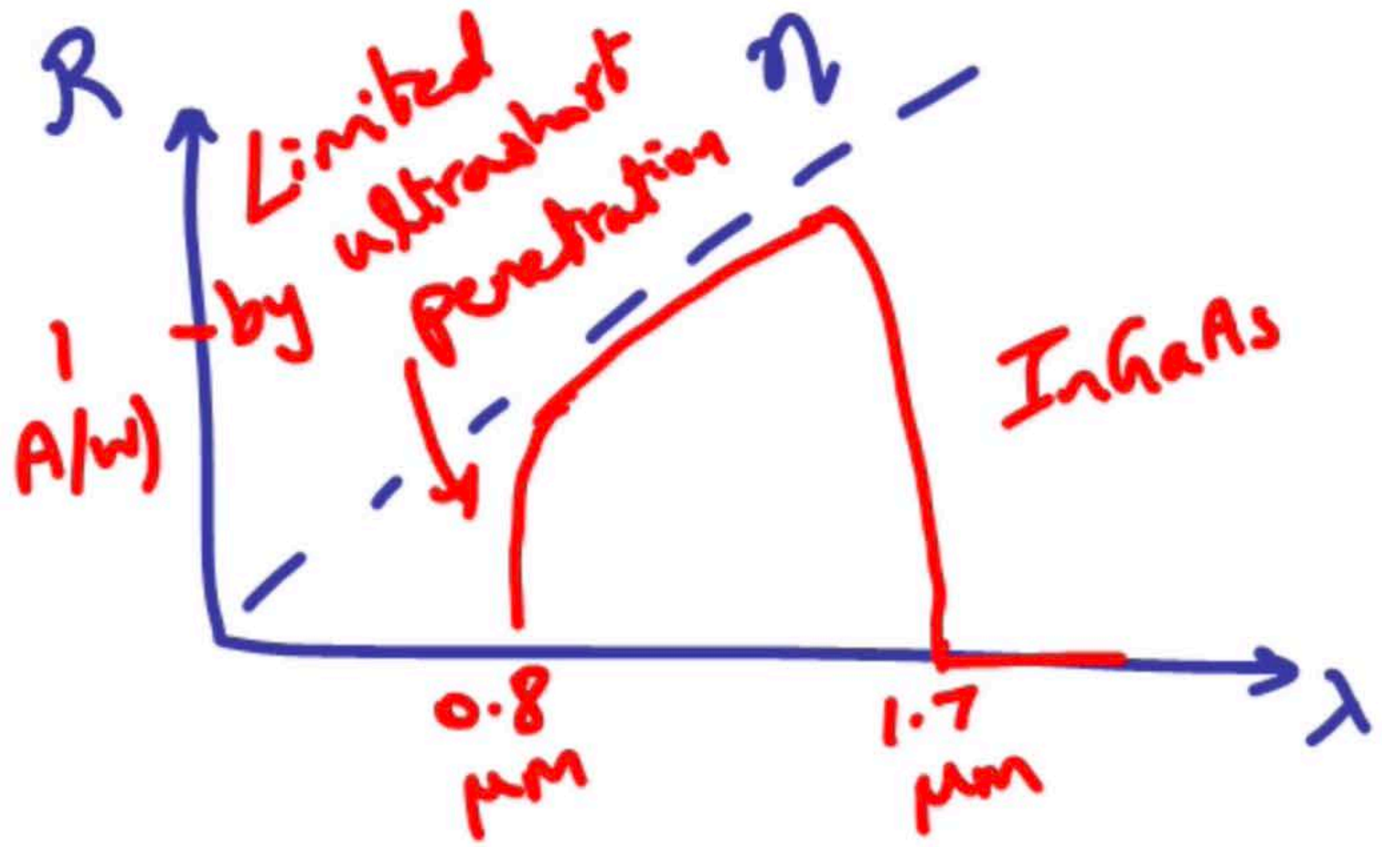
ζ → 0.9 for InGaAs

0.7 for Si

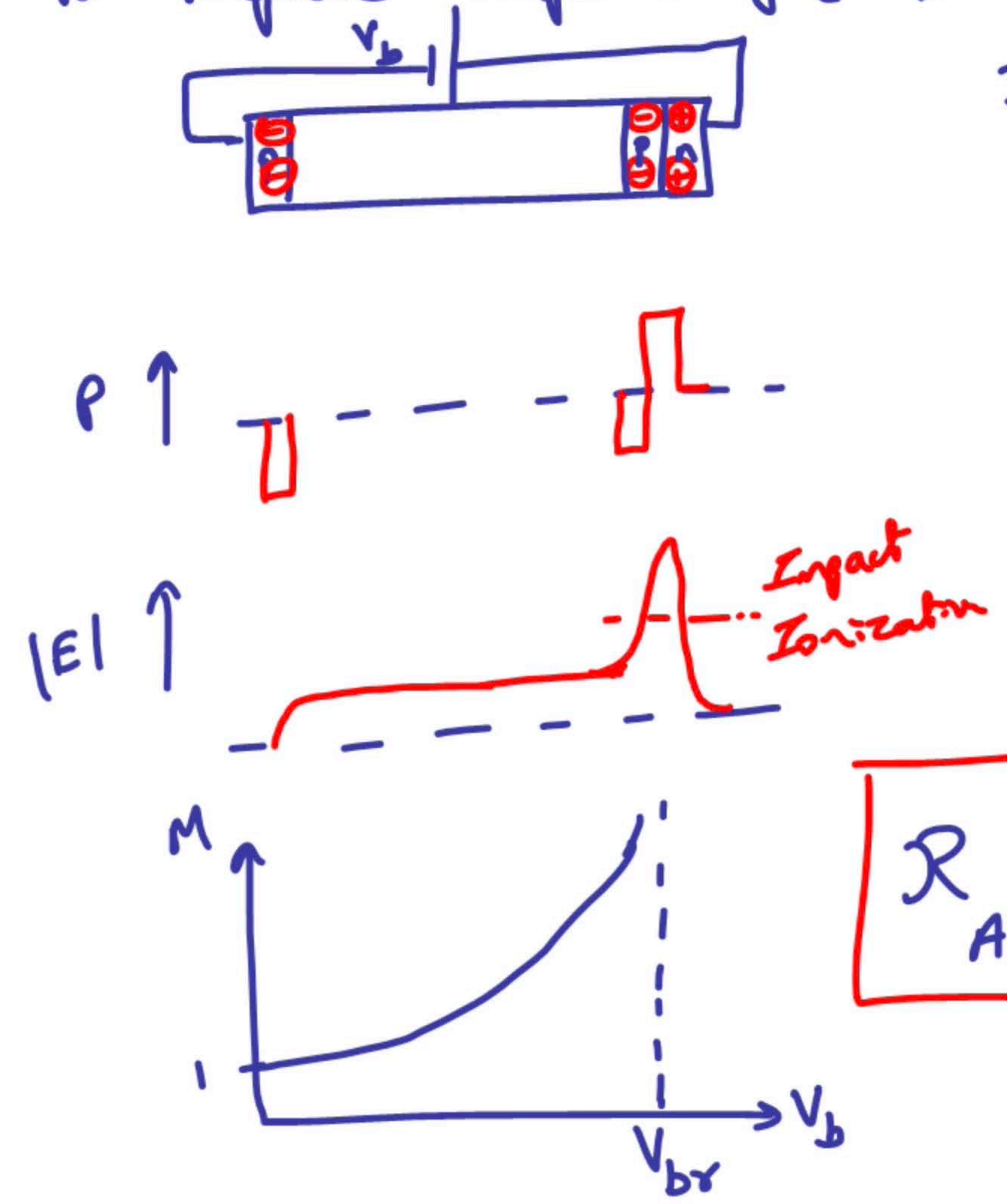
$$\mathcal{R} = \frac{\eta e}{h\nu} \text{ A/W}$$

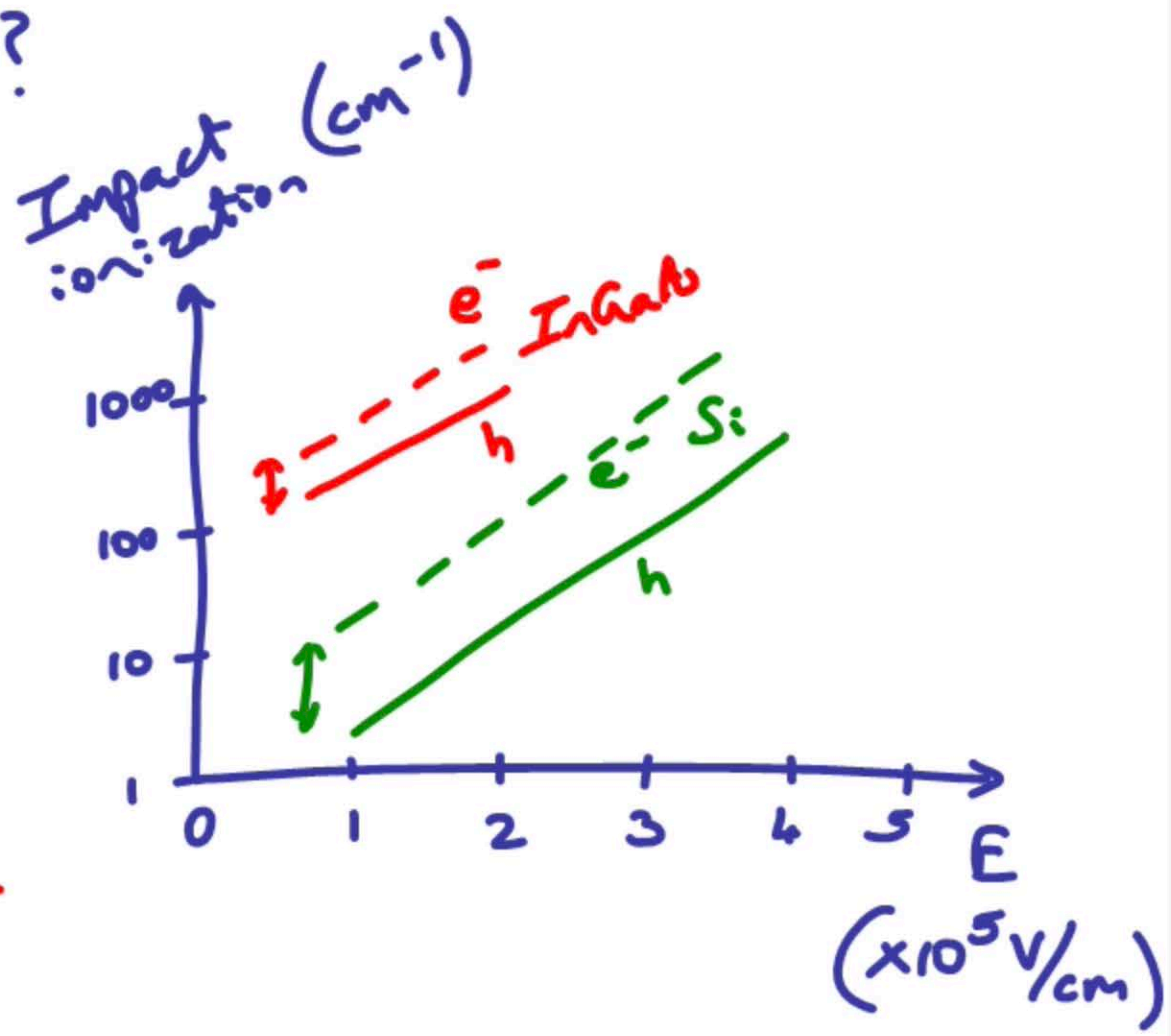
$$\boxed{\mathcal{R} = \frac{\eta\,\lambda(\mu m)}{1.24}}$$





How to improve responsivity (R)?





$$\boxed{\mathcal{R}_{APD} = M \cdot \mathcal{R}_{PIN}}$$

9. Consider a PIN photodetector made of InGaAs with an absorption coefficient of $\alpha = 1 \times 10^6\ \mathrm{m}^{-1}$. If the intrinsic region is 2.197 μm long, assuming antireflection coating at the surfaces and $\zeta = 0.9$, find the following.
   (a) Quantum efficiency
   (b) Responsivity of the PIN diode at 1300 nm and 1550 nm
   (c) Bandwidth (neglecting RC time constant; drift velocity $V_{dr} = 10^5\ \mathrm{ms}^{-1}$).

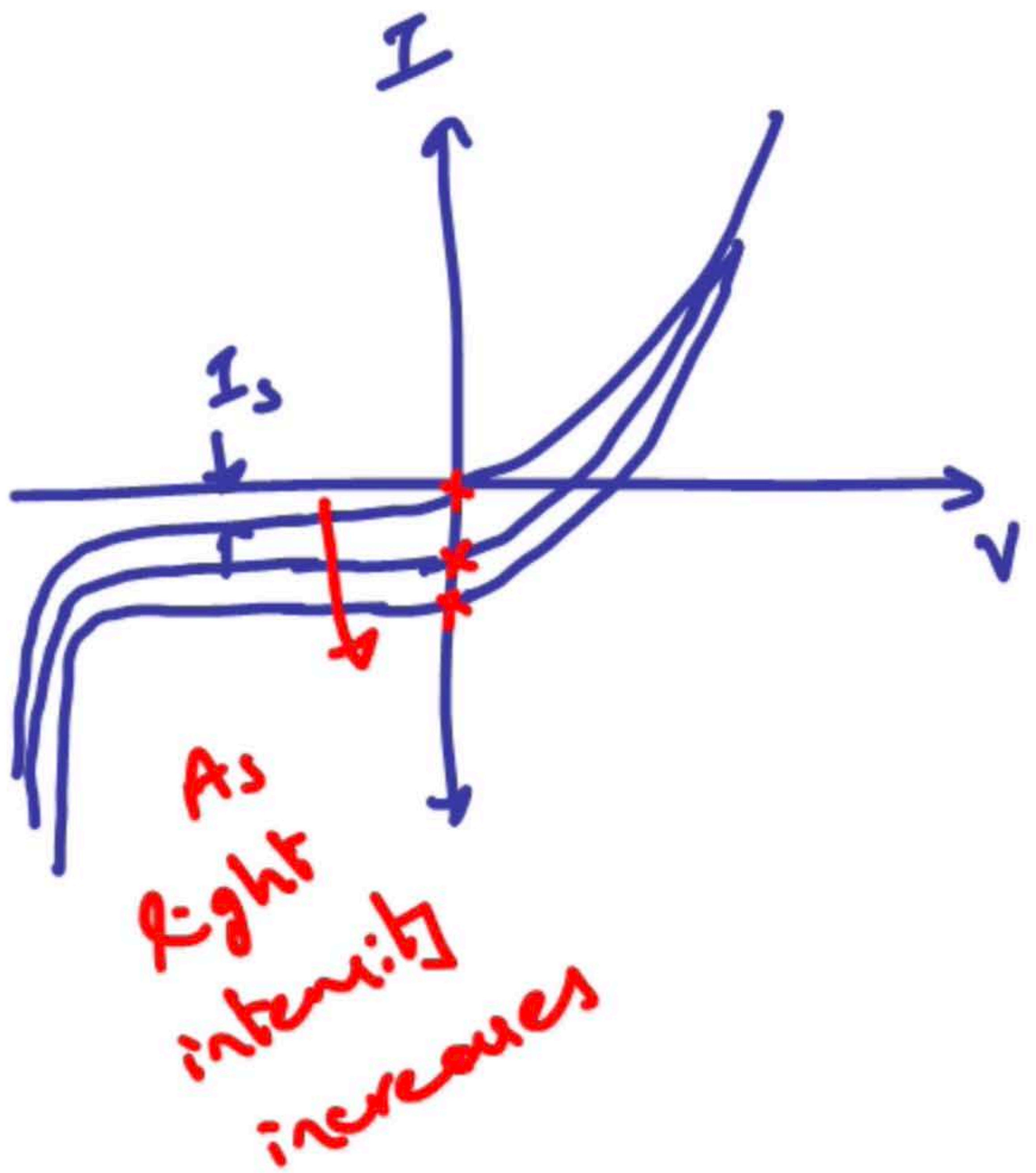
10. An InGaAs based PIN photodiode has to be designed for 1650 nm with 1 GHz bandwidth and 1 A/W responsivity. Find the following.
    (a) Quantum efficiency
    (b) Length of the intrinsic region
    (c) Transit time
    (d) Cross sectional area of PIN diode.

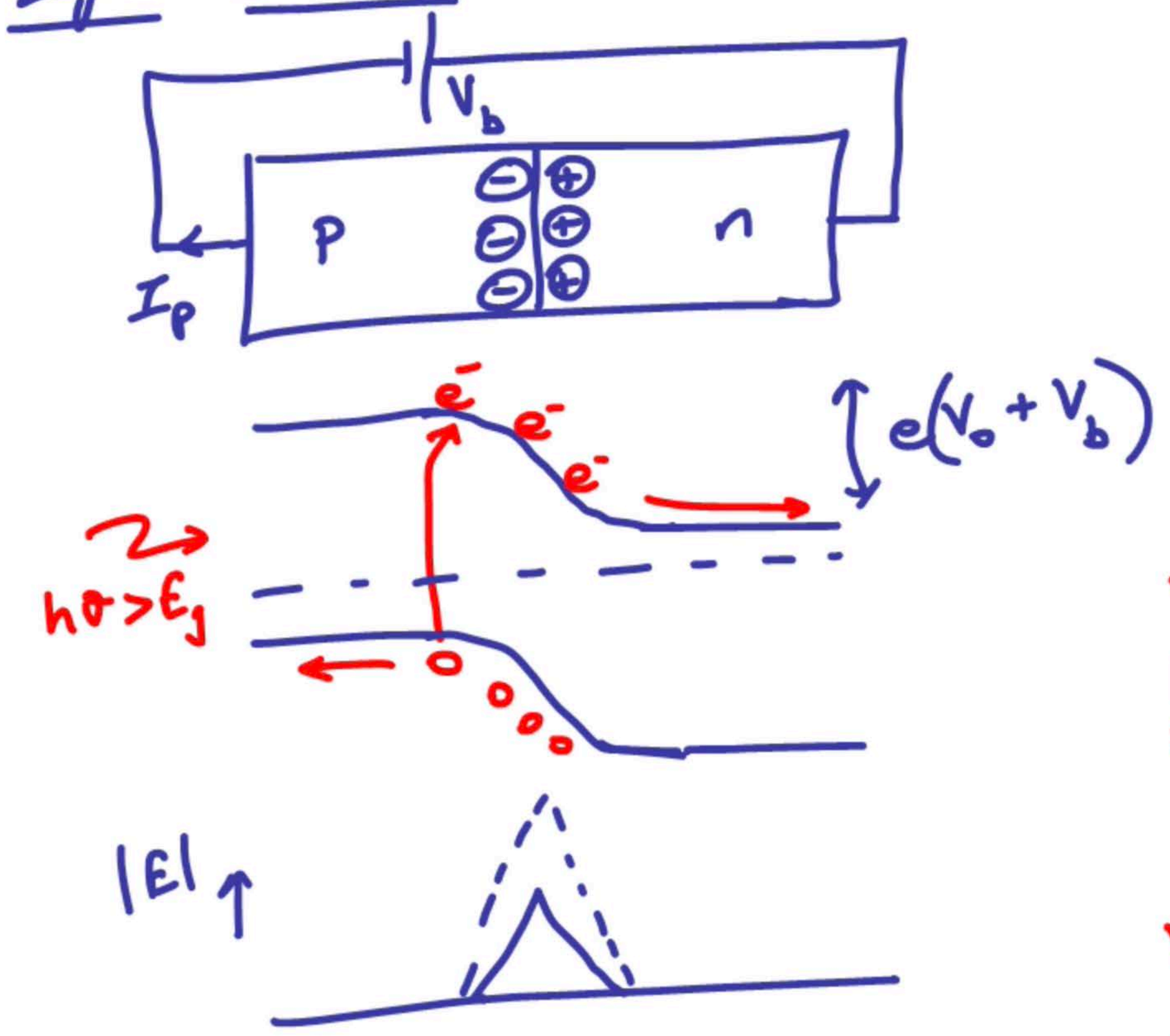
    (Absorption coefficient $\alpha = 1 \times 10^6\ \mathrm{m}^{-1}$, $V_{dr} = 10^5\ \mathrm{ms}^{-1}$, anti-reflection coating at the surfaces and $\zeta \approx 1$, $\varepsilon_r = 10$, series resistance $R = 1\ \Omega$)

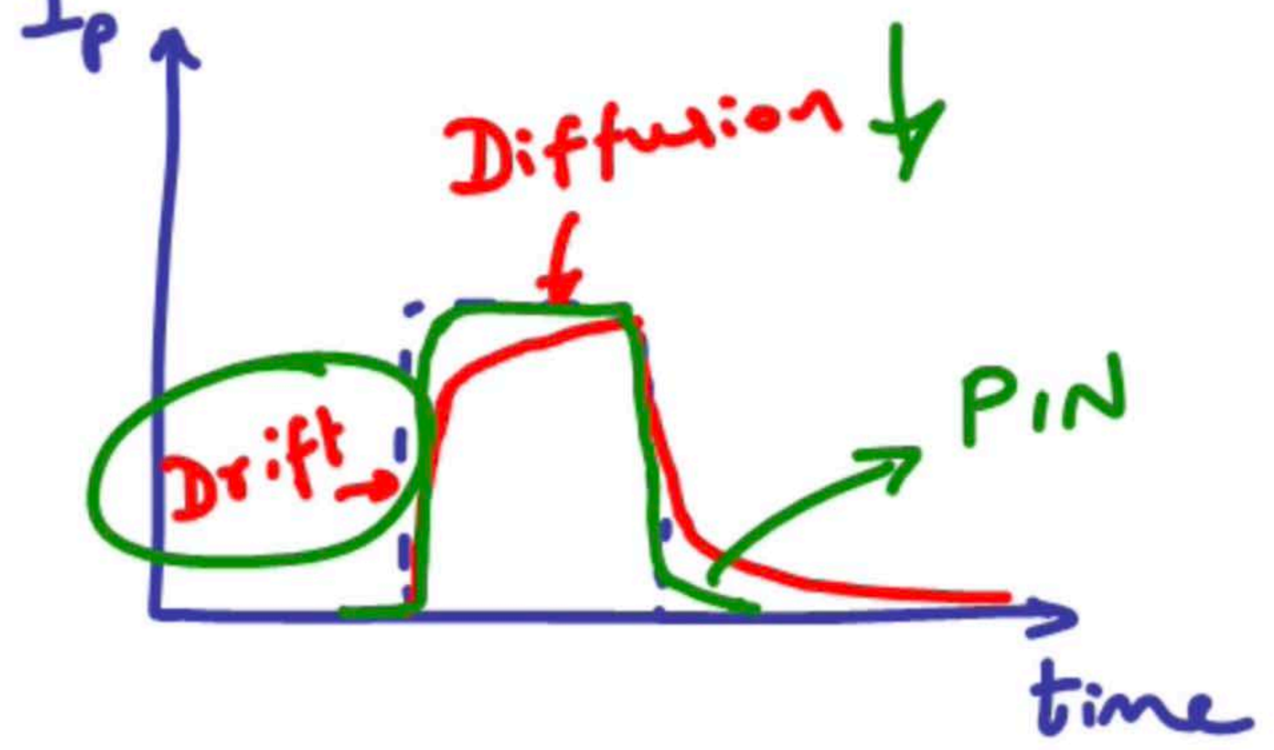
11. Derive an expression for multiplicative factor of an APD. Consider a Si APD biased at 100 V. Calculate the multiplication factor given the multiplication region is of length 4.5 μm. Assume 90% of voltage drops across multiplication region. Also assume that the length of depletion region at the multiplication region is same as length of multiplication region.

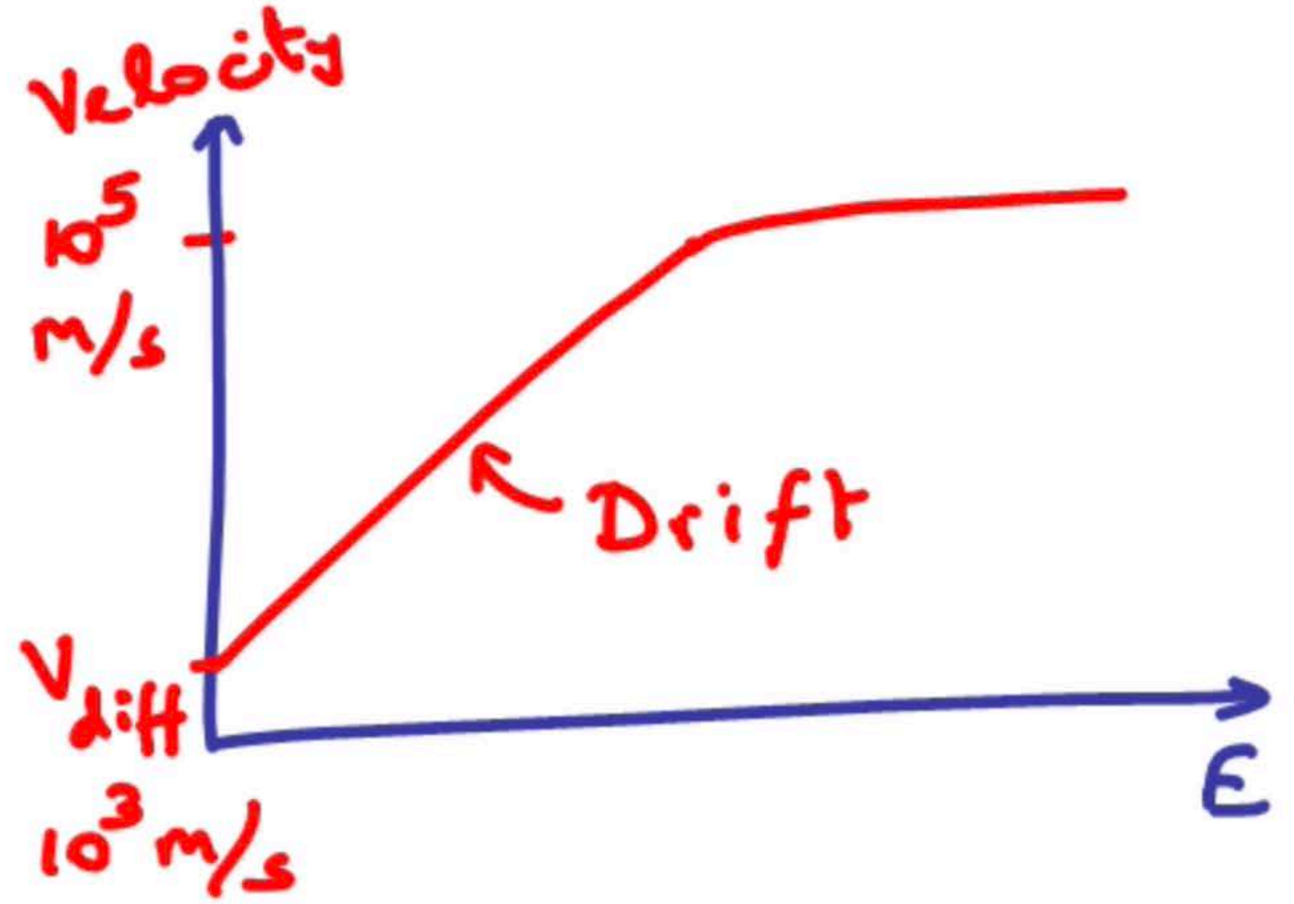
    (Hint: Find the electric field across multiplication region and refer any standard text book for finding corresponding ionisation rate)

Semiconductor Light Detectors:









Example 1 :

InGaAs $(0.8\,eV \simeq \lambda_c = 1.6\,\mu m)$

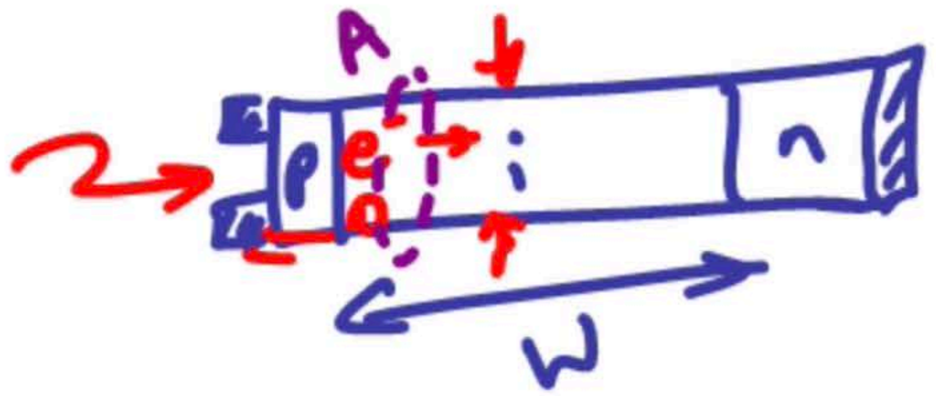
(a) Quantum Efficiency, $\eta = (1-\underbrace{R_f}_{0})\,\underbrace{\zeta}_{0.9}\,\left(1 - e^{-\overbrace{\alpha}^{1\times10^{-6}\,m^{-1}}\overbrace{w}^{2.197\times10^{-6}\,m}}\right)$

$= 0.8$

(b) Responsivity, $\mathcal{R} = \dfrac{\eta\,\lambda(\mu m)}{1.24} \Rightarrow \mathcal{R}_{1550} = \dfrac{0.8\times1.55}{1.24} = 1\,A/W$

$\mathcal{R}_{1300} = \dfrac{0.8\times1.3}{1.24} = 0.84\,A/W$

(c) Bandwidth.



Response time, $\tau = \tau_{tr} + \tau_{RC}$

$= \dfrac{W}{v_{dr}} + \cancel{RC}$ reducing active area

$C = \dfrac{\epsilon A}{d} = \dfrac{\epsilon A}{W}$

Example 1: InGaAs $(0.8\,eV \simeq \lambda_c = 1.6\,\mu m)$

(a) Quantum Efficiency. $\eta = (1 - R_f)\,\zeta\,(1 - e^{-\alpha W})$

$1\times10^{-6}\,m^{-1}$ (for α), $2.197\times10^{-6}\,m$ (for W)

$R_f \to 0$, $\zeta \to 0.9$

$= 0.8$

(b) Responsivity, $\mathcal{R} = \dfrac{\eta\,\lambda(\mu m)}{1.24} \Rightarrow \mathcal{R}_{1550} = \dfrac{0.8\times1.55}{1.24} = 1\ A/W$

$\mathcal{R}_{1300} = \dfrac{0.8\times1.3}{1.24} = 0.84\ A/W$

(c) Bandwidth.

Response time, $\tau = \tau_{tr} + \tau_{RC} + \tau_M$

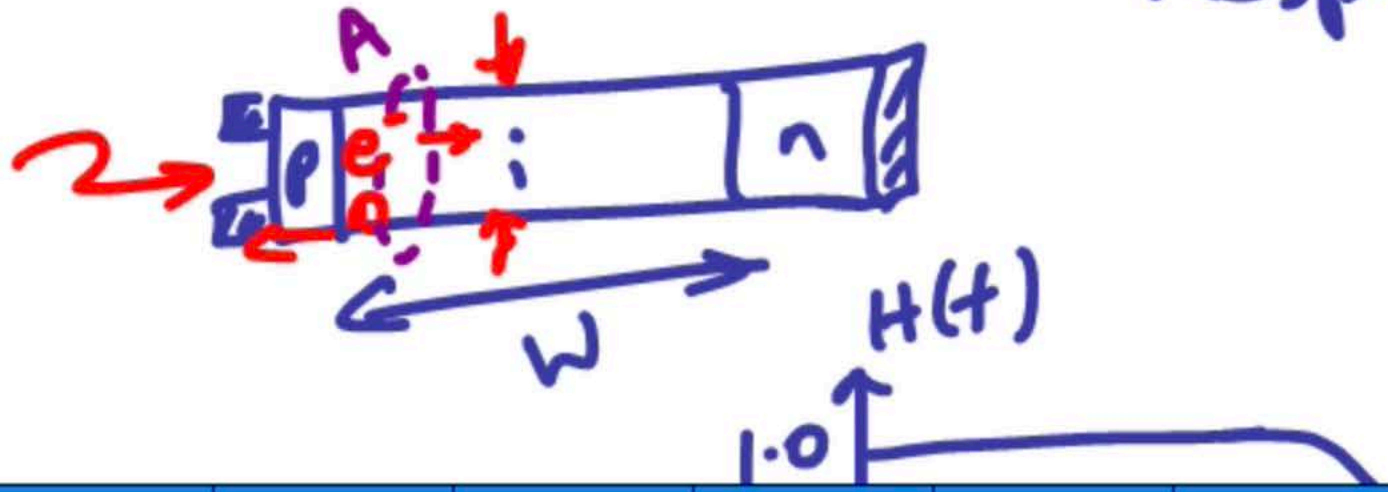
Multiplication time for APD

$= \dfrac{W}{v_{dr}} + RC$

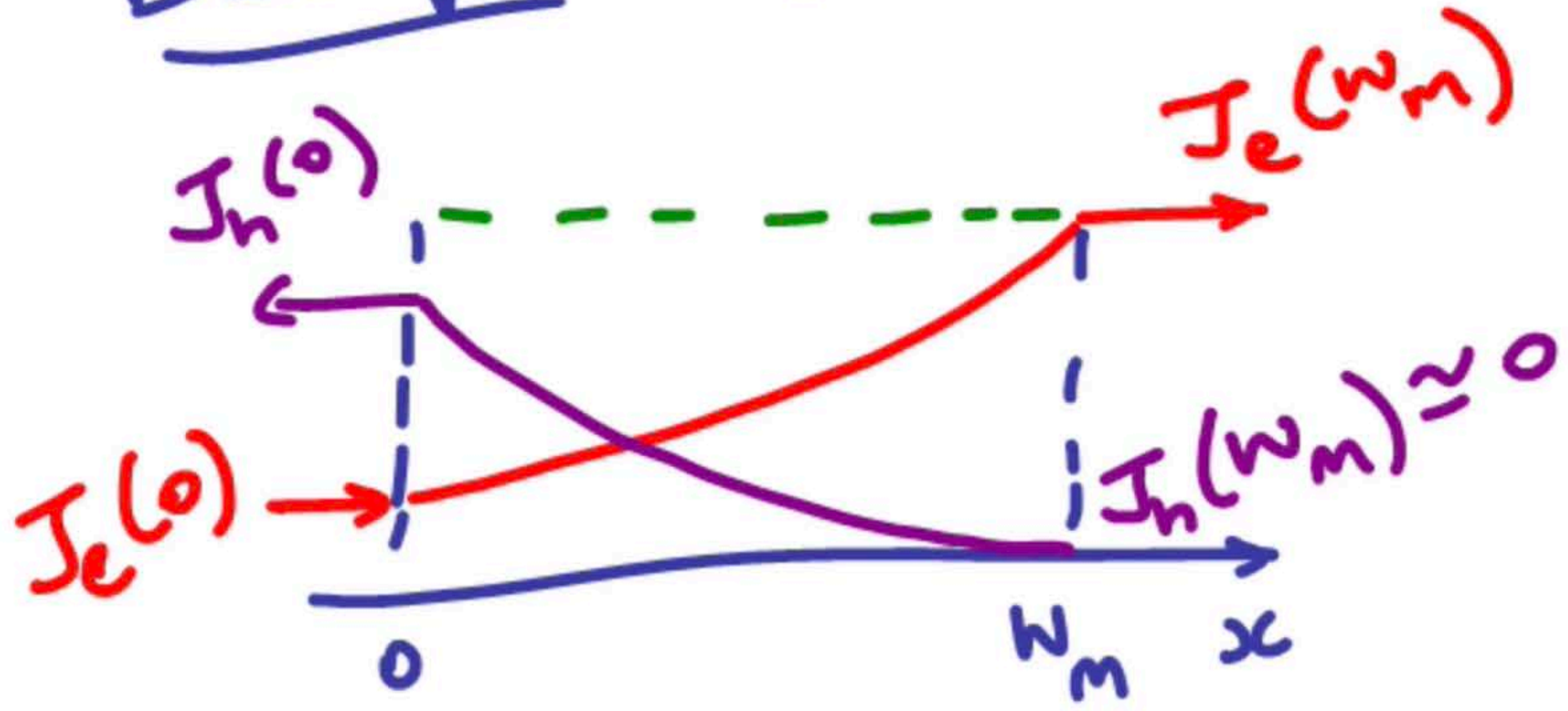
$\sim 22\,ps$

reducing active area

$C = \dfrac{\epsilon A}{d} = \dfrac{\epsilon A}{W}$



Example: APD



$$M = \frac{J_e(W_m)}{J_e(0)}$$

$$\frac{dJ_e}{dx} = \alpha_e J_e(x) + \alpha_h J_h(x)$$

Charge neutrality $\quad \dfrac{dJ_e}{dx} = -\dfrac{dJ_h}{dx} \qquad J_e(x) + J_h(x) = \text{const.} = J_e(W_m)$

$$M = \frac{\alpha_e - \alpha_h}{\alpha_e \exp\left[-(\alpha_e - \alpha_h)W_m\right] - \alpha_h}$$