DATE 10/24/2016

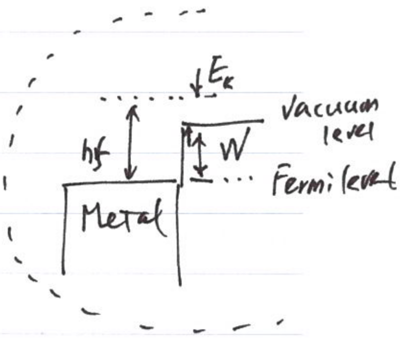
CH.13

13-2 photon Detector

- photoelectric effect

In 1905, Einstein proposed

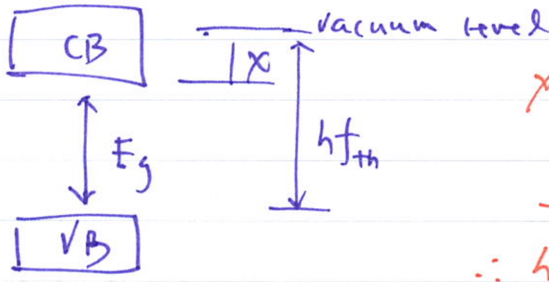
light quanta vs. electrons



$$K_e = hf - W \text{ (work fn)}$$

※ For photoelectric effect, $hf > W$, $\bar{e}$s are ejected!

In Semiconductor (or metal),



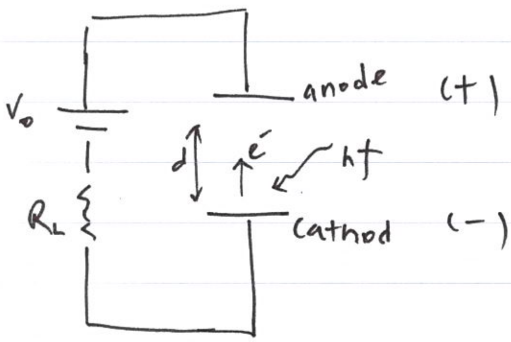
χ: Energy required to eject $\bar{e}$s → electron affinity

$\therefore hf > E_g + \chi$ for photo-emission

ex) $Na_2KSb:Cs$, $hf_{th} \sim 1.55\,eV$

- Vacuum Photodiode

: to collect ejected $\bar{e}$



$$i = \frac{P_{in}}{hf} e\eta \quad (A)$$

$$R \equiv \frac{i}{P_{in}} = \frac{e\eta}{hf} \quad \left(\frac{A}{W}\right)$$

(detector responsivity)

ex) $\eta = 0.2$, $\lambda = 1300\,nm$

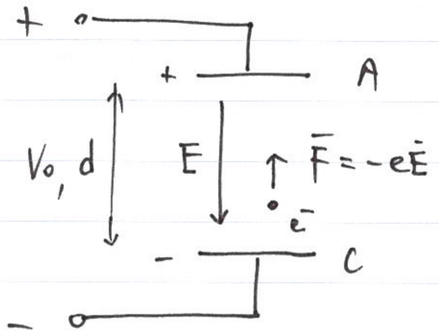
What is R ?

Sol)

$$R \equiv \frac{e\eta}{hf} = \frac{e\lambda\eta}{hc} = \frac{(1.6\times10^{-19})(1.3\times10^{-6})}{(6.63\times10^{-34})(3\cdot10^{8})}\eta = 1.046\,\eta\,(\frac{A}{W}$$

Q. what does the time dependence of the current pulse look like when a single e^- is ejected?

A. continuous current. during the e^- transits.



· Work done on e^- during Δt

$\Delta W = \bar{F}\Delta x = eE\Delta x$

$= eEv\Delta t$,

v: speed of e^-

$E = V_0/d$

· Electric Power supplied :

$P = V_0 i = eEv$

$$\therefore \boxed{i(t) = \frac{eE}{V_0}\, v(t)}$$

e^- velocity

<time response of a photon ~~dect~~ detector>

$F = ma = eE \rightarrow a = \frac{eE}{m}$, e^- acceleration

$\rightarrow v(t) = at = \frac{eE}{m}t \rightarrow x(t) = \frac{1}{2}at^2 = \frac{1}{2}\frac{eE}{m}t^2$

$\hookrightarrow d = \frac{1}{2}\frac{eE}{m}\tau^2$

$\therefore \tau = \sqrt{\frac{2md}{eE}} = d\sqrt{\frac{2m}{eV_0}}$

· The time response τ is better for larger V_0,
shorter d.

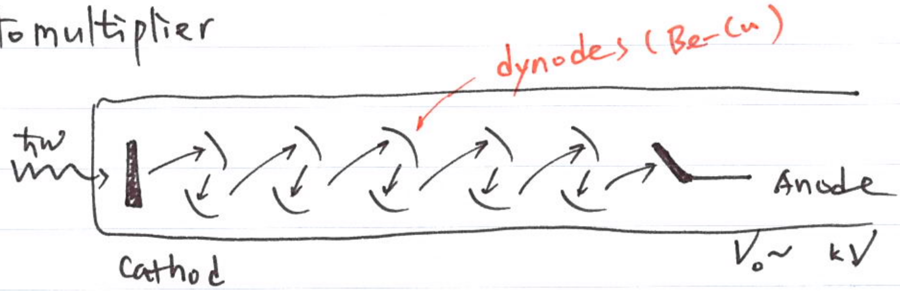
For shorter d, however, capacitance increases!

$$\left(C = \epsilon \frac{A}{d} \right)$$

$\Rightarrow$ High Voltage is used for better time response.
($\sim$ kV) ($< \text{ns}$)

$\rightarrow$ Not good for low light level. (sensitivity problem!)

- photomultiplier



· e^- hits on the dynode, the dynode ejects additional e^-.

$\rightarrow$ avalanche process

ex) Each dynode generates δ e^-.
For N dynodes, what is gain?

Sol) $G = \frac{Q}{e} = \delta^N$

ex) $\delta = 5$, $N = 10$, $G = 5^{10} \sim 10^7$

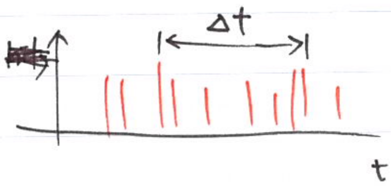
13-3 Noise in Photon ~~Dect~~ Detectors

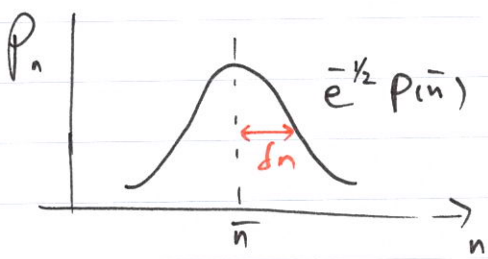
- Shot noise
  - Current generation by e^-s are statistical
    $\rightarrow$ Poisson distribution

$$P_{(n)} = \frac{(\bar{n})^n e^{-\bar{n}}}{n!} \quad , \text{ probability}$$

$\bar{n} = \left(\frac{\bar{i}}{e}\right)\Delta t$ (n e^-s)

: average # of e^-





- For large n,
  - $n \sim \bar{n}$ (max)

  $\rightarrow$ Gaussian P_n
- Width :

  $\delta n = \sqrt{\bar{n}}$ (root mean square)

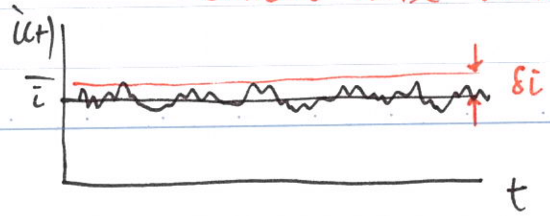
- Width of distribution : Square root of the center.
- Ratio of width to center value : $\frac{\delta n}{\bar{n}} = \frac{1}{\sqrt{\bar{n}}}$

$\rightarrow$ Distribution gets sharper as $\bar{n}$ increases!

- Current fluctuation during Δt : $\delta i = \frac{e}{\Delta t}\delta n$

$$\rightarrow \delta i = \frac{e}{\Delta t}\sqrt{\bar{n}} = \frac{e}{\Delta t}\sqrt{\left(\frac{\bar{i}}{e}\right)\Delta t} = \sqrt{\frac{e\bar{i}}{\Delta t}}$$

: Current noise increases as Δt decreases!



· Bandwidth, B :

$$B = \frac{K}{\Delta t}, \quad K = \frac{1}{2}$$

$\rightarrow$ $\delta i = \sqrt{2e\bar{i}B}$: current noise

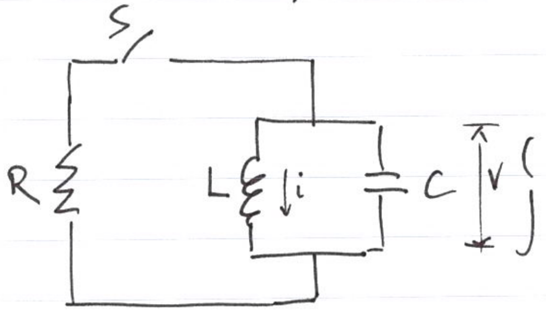
$\uparrow$ shot noise

$\uparrow$ detector bandwidth

— Johnson Noise : thermal noise / Nyquist noise

— observed in 1927 by Johnson

theorized in 1928 by Nyquist



LC oscillator $\left(\omega_0 = \frac{1}{\sqrt{LC}}\right)$

$\rightarrow$ $E = \frac{1}{2}Li^2 + \frac{1}{2}CV^2$

$\rightarrow$ Thermal energy $\frac{1}{2}k_B T$

· In LC oscillator, $\delta E = k_B T$: energy fluctuation even w/o input.

· Power generated in LC circuit (A) = Power dissipated in R (B)

A: $\delta P \sim \frac{\delta E}{\Delta t} \sim \frac{k_B T}{\Delta t}$

B: $\delta P \sim \frac{V_N^2}{R}$; V_N, voltage fluctuation across R

$\rightarrow$ noise voltage

<Johnson noise voltage>

$\therefore V_N \sim \sqrt{\frac{k_B T R}{\Delta t}} \sim \sqrt{4 k_B T R B}$, $K = \frac{1}{4}$

→ Voltage fluctuation across R becomes smaller, as Δt becomes longer.

· $i_N = \frac{V_N}{R} = \sqrt{\frac{4 k_B T B}{R}}$ (Johnson noise current)