Quantum Detectors

"Detectors Based on Photoelectric Method"

Quantum detectors are sensitive photon detectors that use the photoelectric effect to provide an electric signal that is proportional to the incident light intensity. They include:

1- Photoemissive detectors (Vacuum Photodiode, Photomultipliers).
2- Photoconductive detectors (semiconductor Photodiode, Avalanch Photodiode).
3- Photovoltaic detectors (Si solar cell).
4- Photoionization detectors.

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The general characteristics of quantum detectors are:

1. **Responsivity (S):**

$$S = \frac{Y}{X} = \frac{detector\ output\ current}{radiation\ input\ power} \qquad (A/W)$$

For X=0, Y=Y_0 (dark signal) $\Longrightarrow S = \frac{Y-Y_0}{X}$

S: is wavelength dependent. This depends is described by

Spectral Responsivity S(λ):

$$S(\lambda) = \frac{dY(\lambda)}{dX(\lambda)} = \frac{fraction\ of\ output\ at\ \lambda}{radiation\ \ input\ at\ \lambda}$$

2.**Quantum efficiency(Q.E.):**

$$Q.E. = \frac{number\ of\ basic\ signal\ elements}{number\ of\ incident\ photons} = \frac{number\ of\ photoelectrons\ emitted}{number\ of\ incident\ photons}$$

The quantum efficiency is given in percent. It can be calculated (in case of photoemissive detectors) from:

$$Q.E. = \frac{124 S(\lambda)}{\lambda}$$

Here, S(λ) (also called radiation sensitivity) is given in mA/W and λ in nm.

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3. Response Time (τ):

it is the time takes a detector output to reach $(1-\frac{1}{e})$ or 63% of its final value when suddenly subjected to irradiance. If the irradiance is suddenly turned off, the detector output falls to $\frac{1}{e}$ or 37% of its Initial value in **one time constant**.

4. Noise equivalent Power (NEP):

It is a measure of the minimum power that can be detected. Its value is stated at a specific λ, detector area, temperature, and detector band width. NEP is frequency quoted in $W/Hz^{1/2}$.

NEP = Noise-equivalent input (NEI) x detector area (A).

Where NEI represents the minimum irradiance required to produce a signal-to-noise ratio of unity (S/N=1).

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5. Detectivity (D):

It represents the reciprocal of NEP;

$$D = \frac{1}{NEP}$$

It gives a figure of merit which is larger for more sensitive detectors.

6. Normalized Detectivity (D*):

As the detector noise is proportional to its sensitive area (A), the detectivity varies inversely with A $^{1/2}$. Normalized detectivity (D*) is introduced to remove the dependence of NEP on A, it therefore, allow comparison of types of detector independent of its area and bandwidth [where the noise power is proportional to $(\Delta f)^{1/2}$].

$$D^* = D\, A^{1/2}\, \Delta f^{1/2} = \frac{1}{NEP}(A\Delta f)^{1/2}$$

Δf: bandwidth

The units of D^* are cm $Hz^{1/2}$/W.

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Photoemissive detectors:

In these devises, an electron is emitted from a photocathode by the absorption of a photon. This electron must have enough energy to overcome the work function (ϕ) of the surface and escape from it.

The max.kinetic energy of a photoelectron ejected is:

$$(K.E)_{max} = \frac{1}{2} mV_{max}^2 = h\nu - \phi$$

For K.E. =0, $h\nu = h\nu_c = \phi$, where ν_c is threshold frequency (i.e. minimum frequency that can cause photoelectric emission)

Hence, photoemissive of electrons from solid materials becomes possible at $\lambda \leq 1.2$ µm (or $h\nu \geq 1$ eV).

Pure metals are rarely used as photoemissive surfaces because of their very low quantum yield (~ 0.1%) and their high ϕ values, that only UV photons have enough energy to eject an electron.

Alkali materials are usually used because of their low ϕ, namely Cs,Sb,Na,K,….

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The photoemissive detectors have the following properties:

1. The no. of emitted photoelectrons is directly proportional to the intensity of incident light. The kinetic energy of the photoelectron depends on the frequency of radiation, not on intensity.
2. The time between incident radiation and the emission of photoelectron is very short (<10 ns), hence photoemissive detectors can follow rapidly changing radiation levels.
3. Detectivity is very hight than that of thermal detectors, but over a limited λ range.
4. The detection mechanisms are wavelength dependent. There is a peak in responsivity with a fall off at both long and short wavelengths. The long λ (low photon energy) cut-off occurs because there is a certain minimum energy required to cause photoemission. The short λ cut-off is a function of two effects:
   a) The responsivity in terms of power drops off because there are fewer short λ photons per watt.

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b) At very short λ end, the energetic photons may no longer be absorbed in the sensitive region. In the deep uV, absorption of photons before reaching the sensitive region is also a problem. Detector windows are strong uV absorbers.

5. The major source of noise in the o/p signal is due to the thermoionic emission of electrons from the photocathods, i.e. the current produced in the absence of illumination. It is known as "dark current", and is given by:

$$I_{dark} = 120\, T^2 e^{-\frac{h\nu_c}{KT}} \qquad \text{A/cm}^2$$

ν_c: cut-off frequency, k : Boltzmann const.=1.38×10^{-23} J/k .

The dark current is related to NEP such that:

$$NEP = \frac{h\nu}{(Q.E).e}\sqrt{2eI_{dark}}\,\Delta f \qquad \text{watt}$$

Where Δf is the bandwidth of the measuring system.

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Problem: A photoemissive detector with 1 μm cut-off wavelength and quantum efficiency (Q.E.) of 1%.find:

a) The dark current for a 2 cm^2 sensitive area at T=300k.
b) The noise-equivalent power NEP, detectivity D and normalized detectivity D^*. Take Δf=1MHz.
c) Compare the results with that for λc = 2.5 μm. discuss?

Vacuum photodiode:

This is the basic photoemissive device. UV to near IR photons causes emission of electrons from photocathode surfaces placed in a vacuum. These electrons are collected at anode and a current is produced in the external circuit. This current is proportional to the intensity of incident light. The O/P is low and requires an amplification.

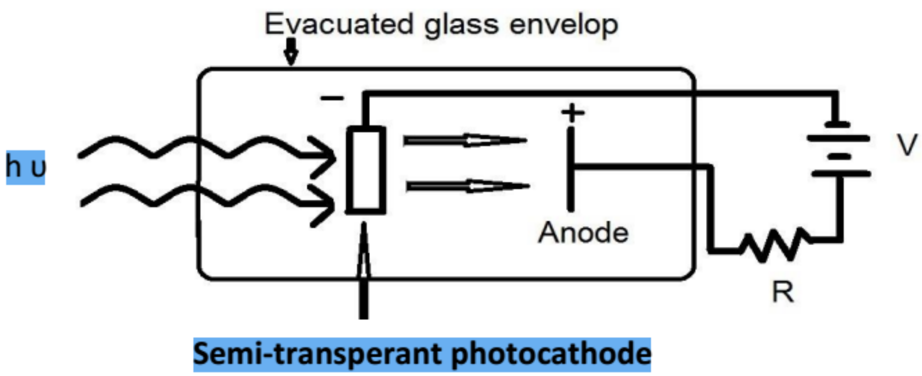

Fig.(1); Vacuum Photodiode Detector

A parallel-plate structure consisting of a photo cathode and positively biased anode with applied voltage V.

The o/p current can be increased by:

1. Using Ar gas under low pressure (≤ 1 mbar). This led the photoelectrons to cause more ionizations in the gas atoms.
2. Using an electron multiplier.
3. Vacuum photodiodes have low quantum efficiency. They have been replaced by silicon photodiodes which have higher quantum efficiency and are more convenient to use.

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