



Al-Mustaqbal University / College of Engineering & Technology
Department of Medical Instrumentation Techniques Engineering

Class: 4th

Subject: Medical Laser Systems

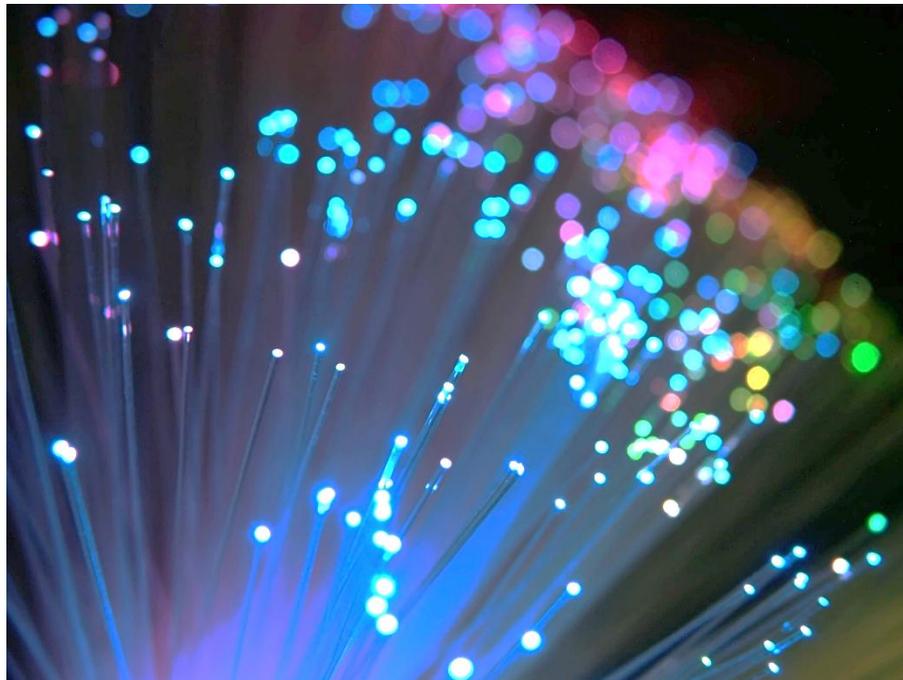
Lecturer: MSc. Huda Wasfi Hassoon

2nd term – Lecture No. 11 & Lecture Name: Photoemissive detectors



Lecture 11

Photoemissive detectors



Lecturer:
MSc. Huda Wasfi Hassoon



Photoemissive Detectors

Photoemissive detectors are devices in which an electron is emitted from a photocathode when the surface absorbs a photon of incident radiation. For the electron to escape from the surface, it must have sufficient energy to overcome the work function of the material.

Work Function (ϕ): The minimum energy required for an electron to escape from the surface of a material.

1. Maximum Kinetic Energy of the Photoelectron

The maximum kinetic energy of the emitted electron is given by:

$$K.E_{max} = h\nu - \phi$$

Where:

- **K.E** = Kinetic Energy of the emitted electron
- **h** = Planck's constant
- **ν** = Frequency of the incident radiation
- **ϕ** = Work function of the photocathode material

2. Threshold Frequency

If the kinetic energy of the emitted electron becomes zero:

$$K.E = 0$$

then:

$$h\nu = \phi$$



The frequency at this point is called the threshold frequency:

$$\nu_c$$

The minimum frequency required to produce photoelectric emission.

3. Condition for Photoemission

Photoemission from solid materials occurs when:

$$\lambda \leq 1.2 \mu m$$

or when:

$$h\nu \geq 1 \text{ eV}$$

- λ = Wavelength of the incident radiation
- eV = Electron volt

4. Materials Used in Photocathodes

Pure metals are rarely used as photoemissive surfaces because:

- They have a **very low quantum yield** (about **0.1%**).
- They have **high work function values**, so only **ultraviolet (UV) photons** have enough energy to eject electrons.

For this reason, **alkali materials** are commonly used because they have **low work functions**, such as:

- Cs (Cesium)
- Sb (Antimony)
- Na (Sodium)



- **K** (Potassium)

5. Properties of Photoemissive Detectors

1. Relation Between Light Intensity and Emitted Electrons

The number of emitted photoelectrons is directly proportional to the intensity of the incident light. However, the kinetic energy of the emitted electrons depends on the frequency of radiation, not on the light intensity.

2. Fast Response Time

The time between the arrival of radiation and the emission of the electron is very short:

$$t < 10 \text{ ns}$$

Therefore, photoemissive detectors can detect rapid changes in radiation intensity.

3. Detectivity

The **detectivity** of photoemissive detectors is higher than that of thermal detectors, but they operate over a limited wavelength range.

4. Wavelength Dependence

The detection mechanism depends strongly on wavelength. The detector usually has a peak responsivity, with a decrease at both long and short wavelengths.

Long wavelength cut-off: At long wavelengths, the photon energy becomes too low to overcome the **work function**, so photoemission does not occur.

Short wavelength cut-off: The decrease in responsivity at short wavelengths occurs due to two reasons:



- a) The responsivity in terms of power decreases because fewer photons exist per watt at shorter wavelengths.
- b) At very short wavelengths, photons may not be absorbed in the sensitive region of the detector.

In the deep ultraviolet (UV) region, photons may be absorbed before reaching the sensitive region, and the detector window itself absorbs UV radiation.

6. Dark Current

The main source of noise in the output signal is the **thermionic emission of electrons** from the photocathode even when no light is present.

This current is called **dark current**.

It can be expressed approximately as:

$$J = AT^2 e^{-\frac{\phi}{kT}}$$

Where:

- **J** = Current density (A/cm²)
- **A** = Constant depending on the material
- **T** = Absolute temperature (Kelvin)
- **φ** = Work function
- **k** = Boltzmann constant

$$k = 1.38 \times 10^{-23} \text{ J/K}$$

So:

$$I_d = J \times A_d$$



7. Relation Between Dark Current and NEP

The Noise Equivalent Power (NEP) is related to the dark current by:

$$NEP \propto \sqrt{\Delta f}$$

Where:

- NEP = Noise Equivalent Power (Watt)
- Δf = Bandwidth of the measuring system

Problem: A photoemissive detector with 1 μm cut-off wavelength and quantum efficiency (Q.E.) of 1%. Find the dark current for a 2 cm^2 sensitive area at $T = 300$ K. Take $\Delta f = 1\text{MHz}$.

Given

- Cut-off wavelength

$$\lambda_c = 1 \mu\text{m}$$

- Quantum Efficiency

$$Q.E = 1\% = 0.01$$

- Sensitive area

$$A = 2 \text{cm}^2$$

- Temperature

$$T = 300 \text{K}$$

- Bandwidth

$$\Delta f = 1 \text{MHz} = 10^6 \text{Hz}$$



Step 1: Calculate the Work Function

$$h = 6.63 \times 10^{-34} \text{ J} \cdot \text{s}$$

$$c = 3 \times 10^8 \text{ m/s}$$

$$\lambda_c = 1 \times 10^{-6} \text{ m}$$

$$\phi = \frac{(6.63 \times 10^{-34})(3 \times 10^8)}{1 \times 10^{-6}}$$

$$\phi = 1.99 \times 10^{-19} \text{ J}$$

$$\phi \approx 1.24 \text{ eV}$$

Step 2: Dark Current

$$J = A_0 T^2 e^{-\frac{\phi}{kT}}$$

$$A_0 \approx 120 \text{ A/cm}^2 \text{K}^2$$

$$k = 1.38 \times 10^{-23} \text{ J/K}$$

$$kT = (1.38 \times 10^{-23})(300)$$

$$kT = 4.14 \times 10^{-21} \text{ J}$$

$$\frac{\phi}{kT} = \frac{1.99 \times 10^{-19}}{4.14 \times 10^{-21}}$$

$$\frac{\phi}{kT} \approx 48$$

$$J = 120(300)^2 e^{-48}$$

$$J \approx 1.5 \times 10^{-14} \text{ A/cm}^2$$

$$A = 2 \text{ cm}^2$$



$$I_d = J \times A$$

$$I_d = (1.5 \times 10^{-14})(2)$$

$$I_d \approx 3 \times 10^{-14} \text{ A}$$

Vacuum Photodiode

A vacuum photodiode is the simplest type of photoemissive detector. In this device, photons in the ultraviolet (UV) to near-infrared (IR) region strike a photocathode placed inside a vacuum tube. When the photons are absorbed by the photocathode surface, photoelectrons are emitted due to the photoelectric effect.

These emitted electrons travel through the vacuum and are collected by the anode, producing an electric current in the external circuit. The generated current is proportional to the intensity of the incident light. However, the output signal is usually small, so it often requires amplification.

Structure of a Vacuum Photodiode

The device consists of a **parallel-plate structure** that includes:

- **Photocathode:** The light-sensitive surface that emits electrons when illuminated.
- **Anode:** A positively biased electrode that collects the emitted electrons.
- **Applied voltage (V):** A voltage applied between the photocathode and the anode to accelerate the emitted electrons toward the anode.

When light strikes the photocathode:

1. Photons are absorbed.
2. Electrons are emitted from the photocathode surface.



3. The applied electric field accelerates these electrons toward the anode.
4. The collected electrons create a **photocurrent** in the external circuit.

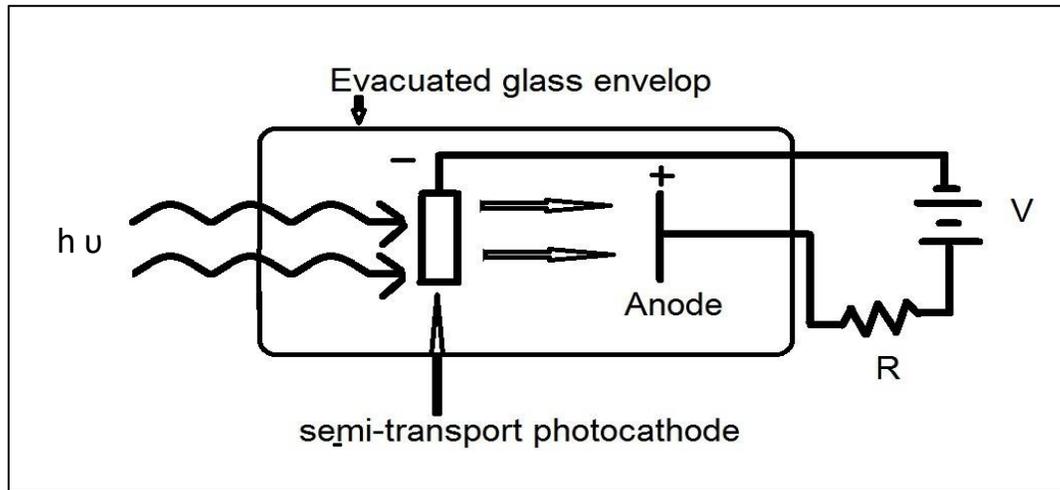


Fig. (1) Vacuum Photodiode Detector.

Methods to Increase the Output Current:

The output current of a vacuum photodiode can be increased by the following methods:

1. Using Low-Pressure Argon Gas

Argon (Ar) gas can be introduced into the tube at low pressure (≤ 1 mbar). The emitted photoelectrons collide with the gas atoms and cause additional ionization, producing more electrons and increasing the current.

2. Using an Electron Multiplier

An electron multiplier can be added to amplify the number of electrons. Each incoming electron causes the emission of several secondary electrons, which significantly increases the output signal.



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3. Using Alternative Photodetectors

Vacuum photodiodes generally have low quantum efficiency, meaning only a small fraction of the incident photons produce electrons. Because of this limitation, they have largely been replaced by silicon photodiodes, which:

- Have higher quantum efficiency
- Are more stable and easier to use
- Do not require a vacuum tube