20.309

Optical Microscopy and Spectroscopy for Biology and Medicine

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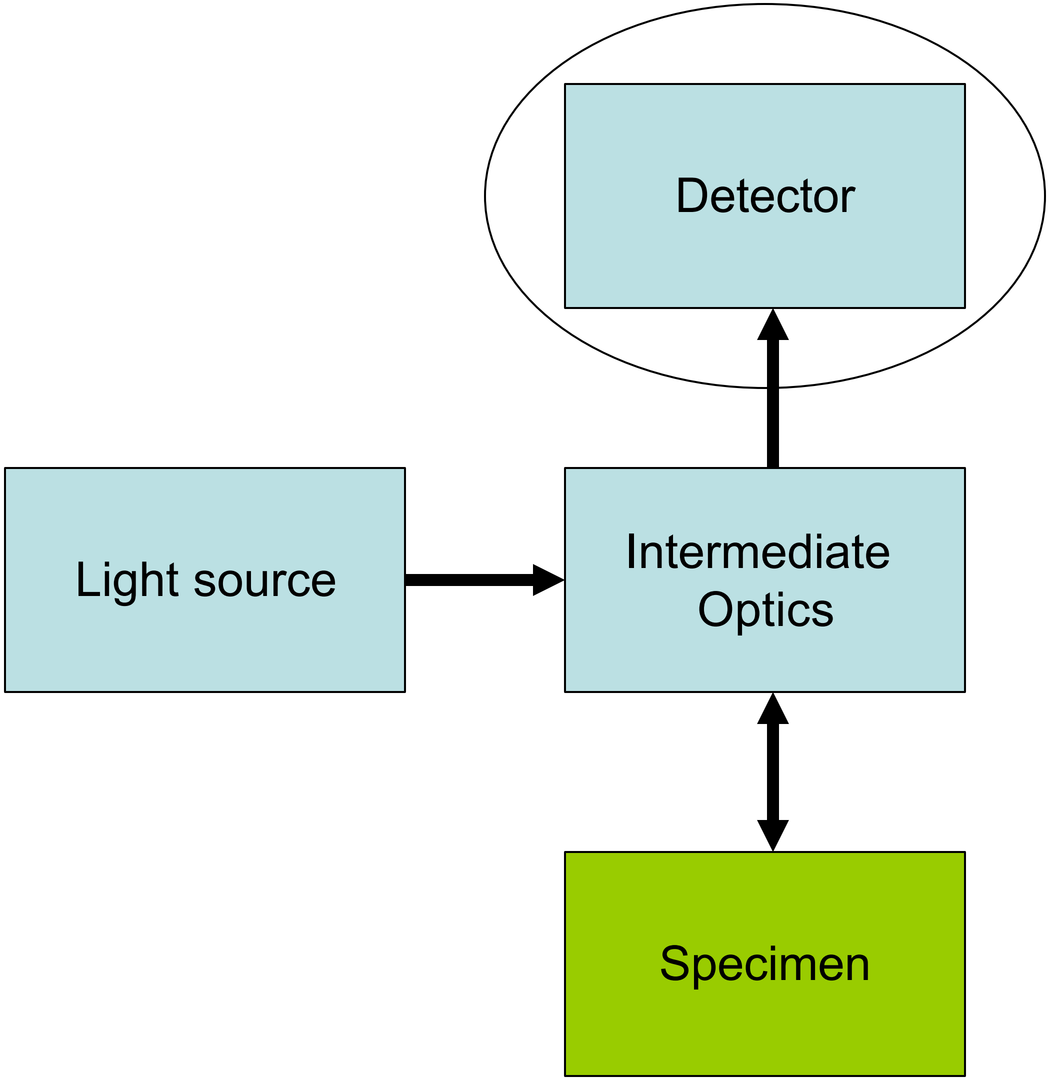
A typical biomedical optics experiment



Noise Sources of A Detector

1. Photon Shot Noise – Counting statistics of the signal photons

2. Dark Current Noise – Counting statistics of spontaneous electron generated in the device

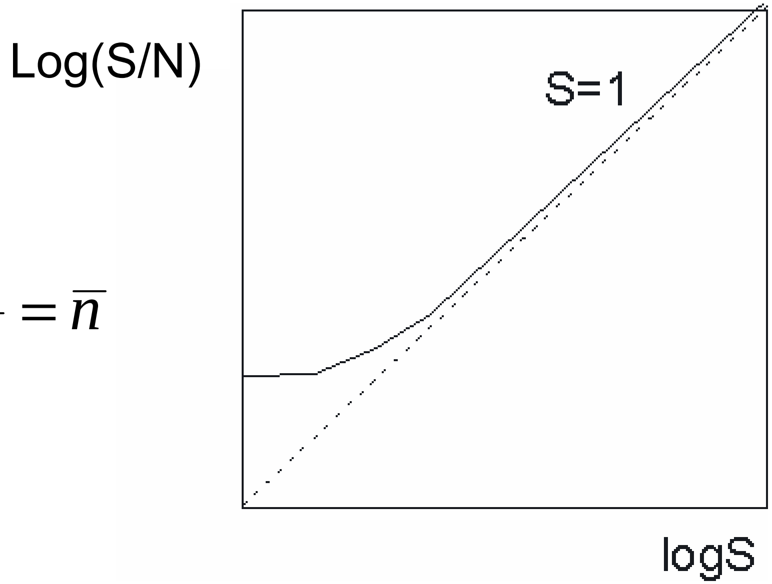
3. Johnson Noise – Thermally induced current in the transimpedence amplifier

Photon Shot Noise

Originates from the Poisson distribution of signal photons as a function of time

$$\tilde{N}_s(f,\Delta f) = 2Raq < I > \Delta f$$

$$SNR = \frac{< I >}{2aq\Delta f} = \frac{aq\bar{n}/\Delta t}{2aq\Delta f} = \frac{2aq\bar{n}\Delta f}{2aq\Delta f} = \bar{n}$$



Dark Current Noise

The ideal photoelectric or photovoltic device does not produces current (electrons) in the absence of light. However, thermal effect results in some probability of spontaneous production of free electrons. This effect is measured by the dark current amplitude of the device: $< I_d >$

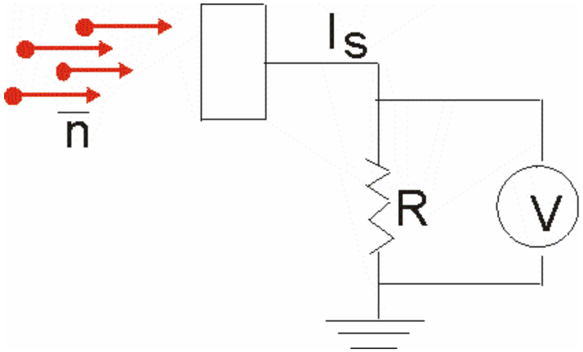
The average dark current is constant at constant temperature, but the electron generated fluctuate in time according to Poisson statistic similar to the fluctuation of the signal photons.

From our discussion of photon shot noise, we have immediately

$$\tilde{N}_d(f, \Delta f) = 2Raq < I_d > \Delta f$$

Johnson Noise

Johnson noise originates from the temperature dependent fluctuation in the load resistance R of the transimpedance detection circuit.



Consider a simple dimensional analysis argument:

Thermal energy: kT

Thermal power: $kT\Delta f$

Power of Johnson noise current I_J : $I_J^2 R$

$$I_J = \sqrt{\frac{kT\Delta f}{R}}$$

$$\tilde{N}_J(f, \Delta f) = kT\Delta f$$

Characterizing Photodetectors

1. Quantum Efficiency: The probability of generating of a photoelectron from an incident photon

2. Internal Amplification: The amplification ratio for converting a photoelectron into an output current

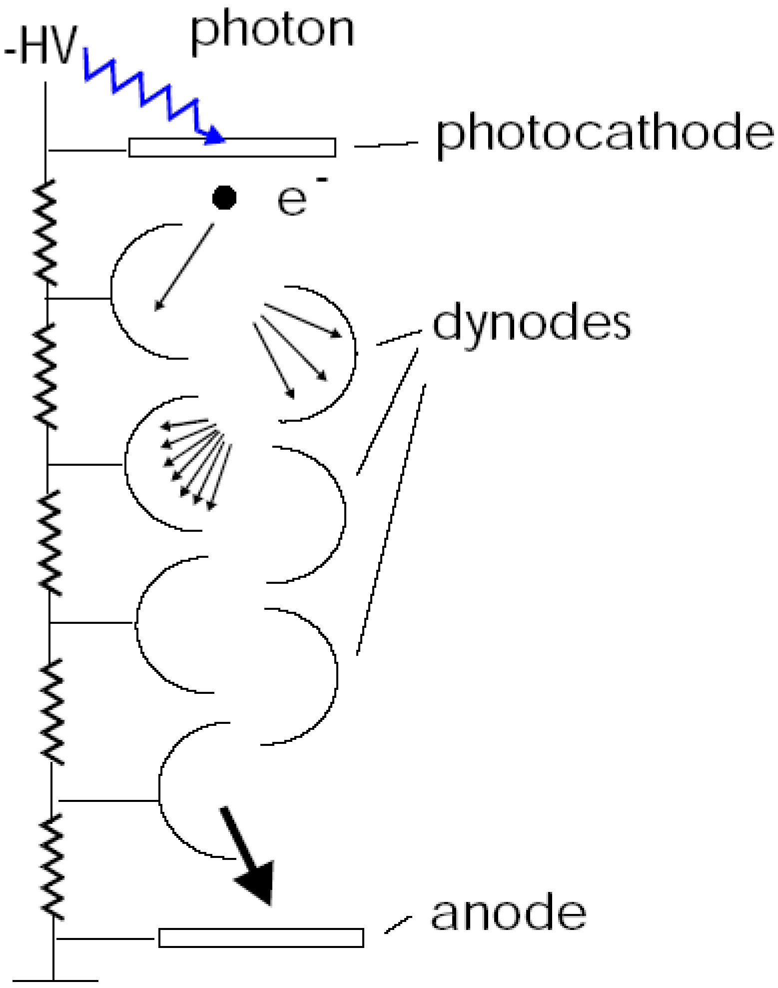
3. Dynamic Range: What is the largest and the lowest signal that can be measured linearly

4. Response Speed: The time difference and spread between an incoming photon and the output current burst

5. Geometric form factor: Size and shape of the active area and the detector

6. Noise: Discussed extensively already

Photomultiplier tube (PMT)



The PMT are characterized by two important parameters

Cathode sensitivity, *S* (A/W): 0.06 A/W

Gain, α: 10^7 to 10^8

We can relate current measured at the anode to the number of incident photons, *n*, arriving within a time interval Δt

$$I = S \cdot a \cdot E_g \cdot n / \Delta t$$

E_g is photon energy

For green (500 nm wavelength) photons:

$$E_g = \frac{hc}{l} = \frac{6.6\times10^{-34}\,Js \cdot 3\times10^{8}\,m/s}{5\times10^{-7}\,m} = 4\times10^{-19}\,J$$

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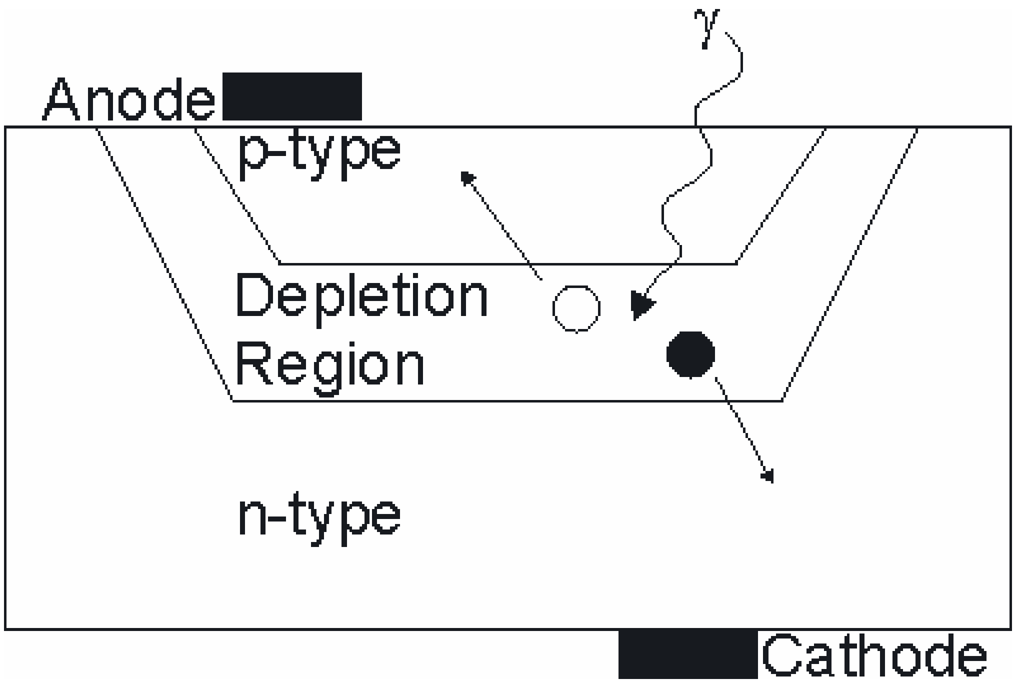
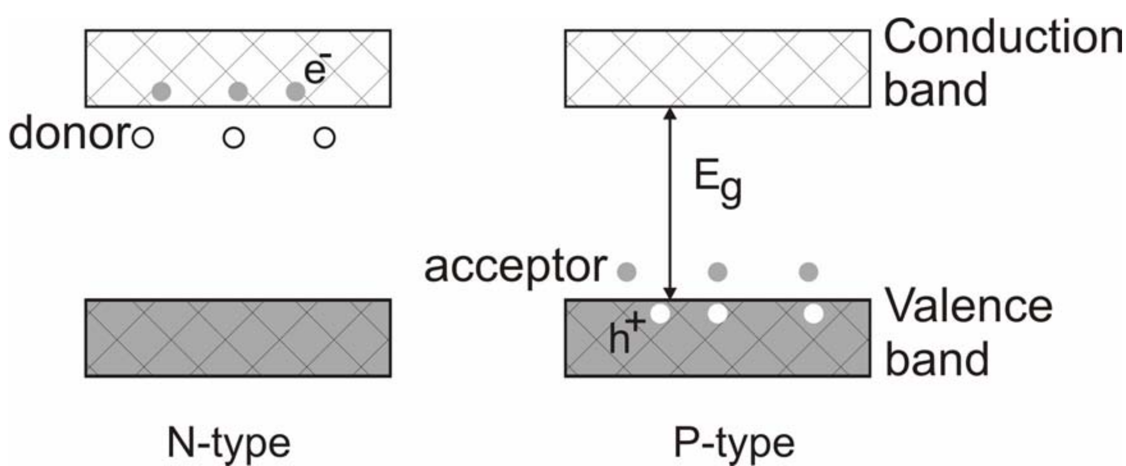
Graph of PMT Cathode Sensitivity as a function of material, from Hamamatsu Corporation.

Photodiodes

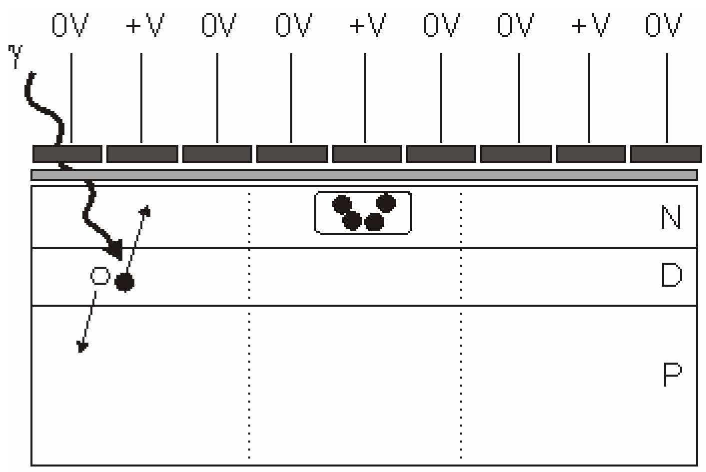


Biasing can increase
device temporal
Response speed

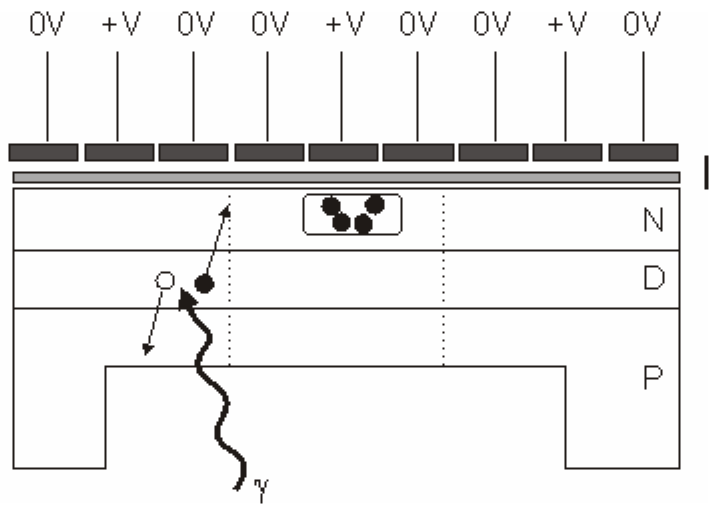
Recall:



Charge Coupled Device (CCD) Cameras

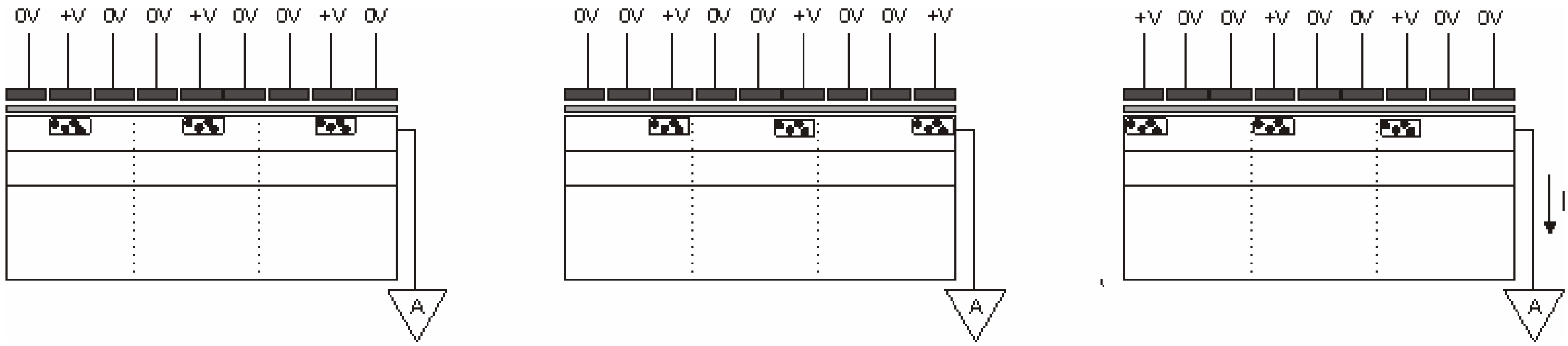


Front Illuminated



Back (thinned) Illuminated

Readout Sequence Principle of CCD



A Comparison of Detector Characteristics

	PMT	Photodiode	APD	CCD
QE	40%	80%	80%	80%
Spectral Range	UV-Green	Blue-NIR	Blue-NIR	Blue-NIR
Internal Gain	10^6-10^8	1	100-1000	1
Dark Noise	e^-/sec	1000 e^-/sec	e^-/sec	e^-/sec
Electronic (Read) Noise	NA	1000 e^-	NA	3-1000 e^-
Response Speed	+++	+++	+	-
Pixel Size	cm	mm	mm	µm