PH 301

ENGINEERING OPTICS

Lecture_Optical Detectors_27

Photodiode Array

- A 1-D array of hundreds or thousands of photodiodes can be used as a position sensor.

- Photodiode arrays (PDAs) allow high speed parallel read out since the driving electronics may not be built in like a traditional CMOS or CCD sensor.

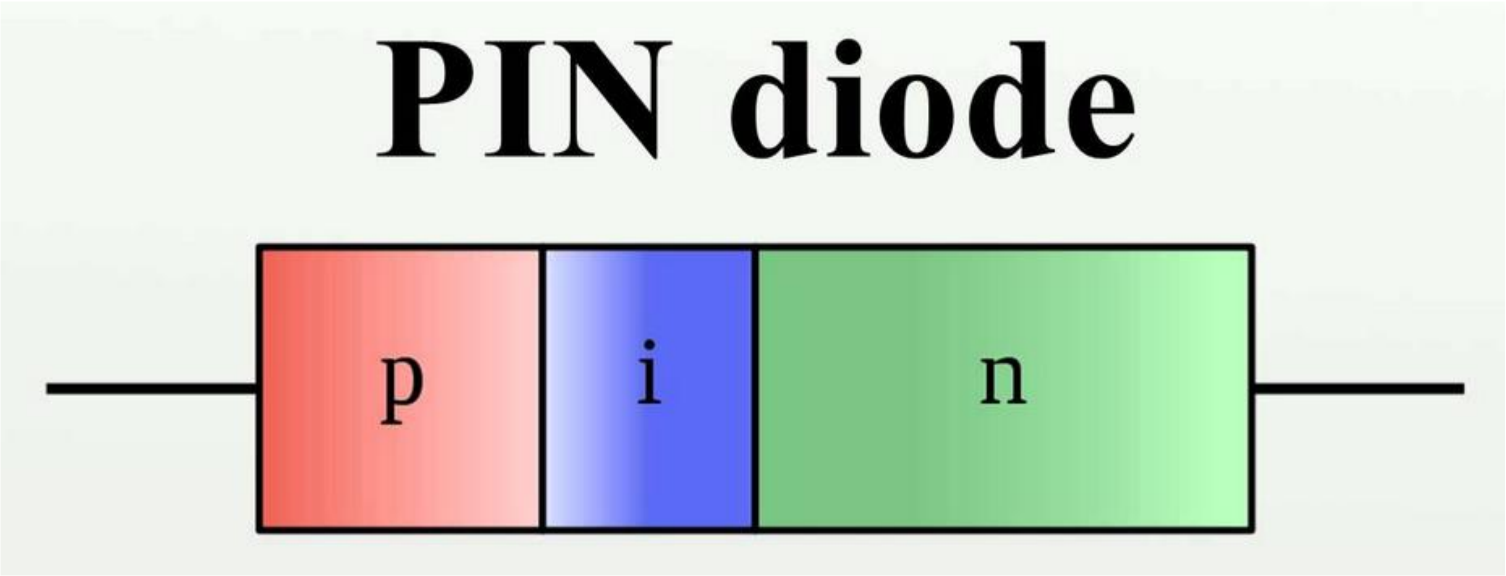
A 2 × 2 cm photodiode array chip with more than 200 diodes.

Types of Photodiode

Types of photodiodes based on its construction & functions:

1. **PN Photodiode**
2. **Schottky Photodiode**
3. **PIN Photodiode**
4. **Avalanche Photodiode**

These diodes are widely used in applications where detection of presence of light, color, position, intensity is required.



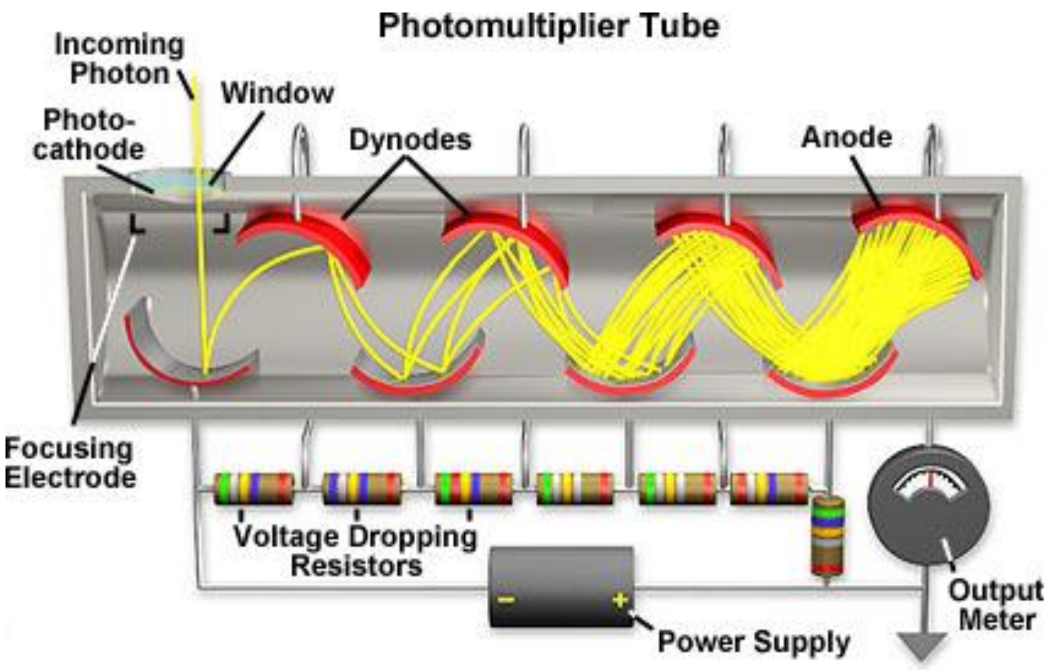
PIN *junction* consists of three differently doped regions.

There is an intrinsic or undoped layer sandwiched between a p- & an n-doped region.

Typically this kind of *junction* is fabricated from amorphous silicon with a band gap of about 1.8 eV.

Photomultiplier Tube

A photomultiplier tube, useful for light detection of very weak signals, is a photoemissive device in which absorption of a photon results in emission of an electron.



These detectors work by amplifying electrons generated by a photocathode exposed to a photon flux.

- Photomultipliers are extremely sensitive detectors of light including visible light, UV & near IR.

- Advantage of photomultipliers: Extreme sensitivity. They are able to multiply the signal produced by incident light by figures up to 100 million.

- In addition to their very high levels of gain, photomultipliers also exhibit a low noise level, high frequency response & a large collection area.

- Despite all advances in photodiode technology, photomultipliers are still used (particle physics, astronomy, medical imaging, & motion picture film scanning) in virtually all cases when low levels of light need to be detected.

Photomultiplier tube construction

Photomultipliers are contained within a glass tube that maintains a vacuum within device. There are three main electrodes within a photomultiplier:

1. Photocathode
2. Dynodes
3. Anode

- Within the envelope of photomultiplier, there is one photocathode, one anode, but there are several dynodes.

- Anode & dynode are traditional metallic electrodes with coated surfaces, but photocathode is actually a thin deposit on the entry window.

- Dynode is an electrode in a vacuum tube that serves as an electron multiplier through secondary emission.

Photomultiplier operation

- **Photons enter photomultiplier tube & strike photocathode. When this occurs, electrons are produced as a result of *photoelectric effect*.**
- **Generated electrons are directed towards an area of photomultiplier called *electron multiplier*. This area serves to increase or multiply no. of electrons by a process known as *secondary emission*.**
- **Electron multiplier is made up from a no. of electrodes, called dynodes. These dynodes have different voltages on them, each one is more positive voltage than previous one to provide the required environment to produce electron multiplication effect.**
- **This is operated by pulling electrons progressively towards more positive areas in following way:**

  Electrons leave photocathode with the energy received from incoming photon. They move towards first dynode & are accelerated by electric field & arrive with much greater energy than they left the cathode.

- **When they strike first dynode low energy electrons are released, & these are in turn attracted by greater positive field of next dynode, & these electrons are similarly accelerated by greater positive potential of 2nd dynode, & this process is repeated along all dynodes until electrons reach anode where they are collected.**

- **Geometry of dynode chain is carefully designed so that *a cascade effect* occurs along its length with an ever increasing no. of electrons being produced at each stage.**

- **When anode is reached, accumulation of charge results in a sharp current pulse for the arrival of each photon at photocathode.**

Photomultiplier Use

- Photomultiplier tubes require high voltage (typically in range of 1-2 kV) for their operation.

- Anode is the most positive electrode.

- Dynodes are held at intermediate voltages that are normally generated using a resistive potential divider.

- It is necessary to ensure that photomultiplier is mounted & used with care. Stray magnetic fields can affect their operation as electron stream can be bent & operation of device can be impaired.

- It is also necessary to screen a photomultiplier tube from excessive light levels while in operation. High light levels can destroy a photomultiplier because it can become over-excited.

Advantages compared to photomultipliers

1. Excellent linearity of output current as a function of incident light
2. Spectral response from 190 nm to 1100 nm (silicon), longer wavelengths with other semiconductor materials
3. Low noise
4. Ruggedized to mechanical stress
5. Low cost
6. Compact & light weight
7. Long lifetime
8. High quantum efficiency, typically 60-80%
9. No high voltage required

Disadvantages compared to photomultipliers

1. Small area
2. No internal gain (except avalanche photodiodes, but their gain is typically 10^2-10^3 compared to 10^5-10^8 for the photomultiplier)
3. Much lower overall sensitivity
4. Photon counting only possible with specially designed, usually cooled photodiodes, with special electronic circuits
5. Response time for many designs is slower
6. Latent effect

Charge-coupled Device (CCD)

- CCDs are used for high resolution imaging. They are particularly useful in Astronomy, where scientists have taken advantage of extreme sensitivity to light.
- This aspect of the device has many practical applications including laboratory research where detection of low light levels is needed.
- Images taken by a CCD need to be corrected for certain factors, including dark noise, readout noise, & saturation, among others.
- Correction is done through collection of dark frames & flat fields, which can be subtracted from an image using image data reduction software.

- **A CCD is a device used in digital photography that converts an optical image into electrical signal.**

- **CCD chips can detect faint amounts of light & are capable of producing high resolution images needed in scientific research & applications thereof.**

- **Theoretically, CCDs are linear-producing accurate images, transmitting the value they detect in a 1:1 ratio.**

Basic Theory of a CCD

- **CCD is a special integrated circuit consisting of a flat, 2D array of small light detectors referred to as pixels.**
- **CCD chip is an array of Metal-Oxide-Semiconductor capacitors (MOS capacitors), each capacitor represents a pixel.**
- **Each pixel acts like a bucket for electrons.**
- **A CCD chip acquires data as light or electrical charge. During an exposure, each pixel fills up with electrons in proportion to the amount of light that enters it.**
- **CCD takes this optical or electronic input & converts it into an electronic signal, which is then processed by some other equipment &/or software to either produce an image or to give user valuable information.**

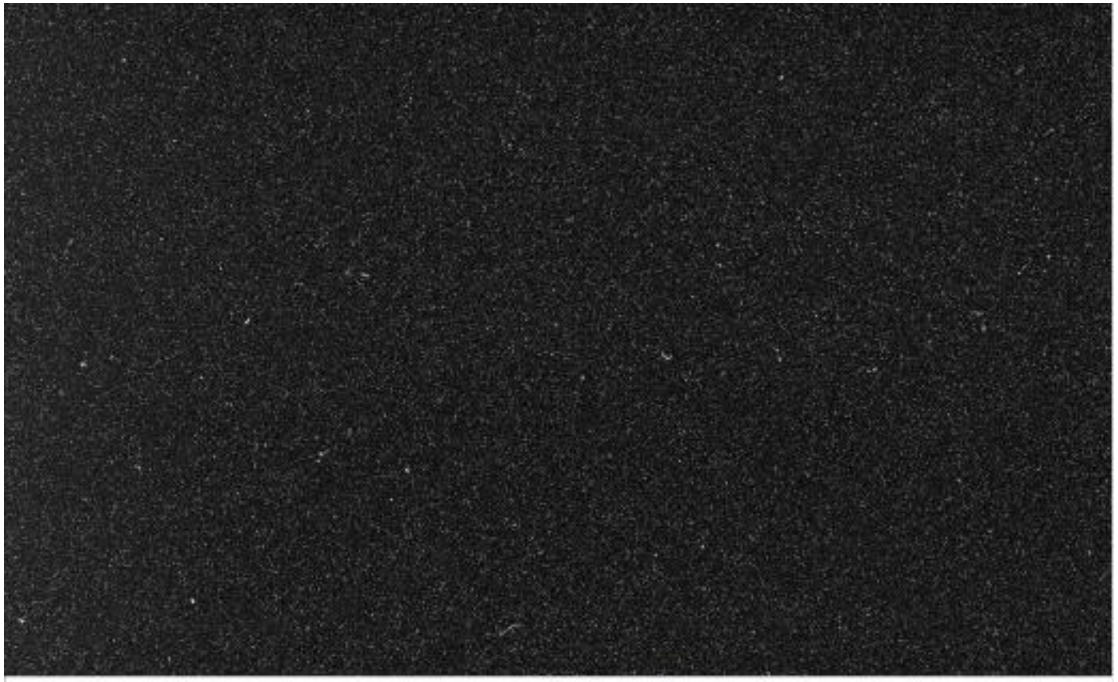
Specifications of a CCD camera

(Santa Barbara Instrumentation Group, Model: ST-8300M/C)

CCD	Kodak KAF-8300
Pixel array	3326 × 2504 pixels
Total pixels	8.3 Megapixels
Pixel size	5.4 × 5.4 microns
Shutter type	Electromechanical
Exposure	0.1 to 3600 seconds
Dimensions	4 × 5 × 2 inches

Dark Frames: **A dark frame is an image taken, theoretically, with no exposure to light.**

Shutter remains closed, but light may still leak in to a certain degree. In order to obtain a decent dark frame, it may be necessary to take one's images in a so-called "dark room".



A one second dark frame

- **As one can see, the image has a sort of salt and pepper" look to it. This is due to a few factors, one of which is the fact that some pixels are "hot pixels".**

- **Dark current: A pixel in an ideal CCD, in the absence of light, would maintain a steady value. When exposed to light, the pixel's value would increase in response to light but then as soon as the light went away the pixel would maintain its value again.**

- **In reality, CCD pixels suffer from the affects of dark current whereby the**
  pixel"s value slowly increases, or brightens, over time.

- **"Hot Pixels" are those where dark current is higher than average.**

Averaging Images

- **It is important when dealing with such high resolution images dependent on sensitive electronics.**
- **Every five second dark frame is not identical due to the fact that electronics operate a little differently each time & pixels may exhibit some degree of variance.**
- **Some pixels may become saturated, that is too many photons hit it & signal can no longer increase. In order to obtain a more accurate dark frame, one should average a series of images. To do this, one must collect an odd no. of images, preferably about 15-19, all at a certain integration time.**
- **Once images are collected, software is used to obtain the mean value from collection.**
- **Once an averaged, or mean, dark image is obtained, it is called a Master Frame & can be used again & again, being subtracted from actual images of the same integration time.**
- **But averaging is not only used for dark imaging; it is also useful when taking images of evenly distributed light, or flats.**

Flat Frames

- Flat frames, or flat fields, are images of evenly distributed light. A good light source to provide uniform distribution at a certain wavelength is an LED, or light emitting diode.

- Light should be reflected off of a white surface aimed at by the CCD camera. It is difficult to acquire a perfect flat image because of the sensitivity of the CCD & shadows cast by a lens over CCD.

- A good flat should portray how each pixel responds to light. Flats can be used to correct vignetting, or obstruction of light paths by parts of the instrument, as well as effects of dust particles on a lens.

- Flats can be averaged & subtracted from an image just like darks in order to remove the effects of vignetting & dust as well as the effects of a shutter from an image, particular one of fast exposure time.

- By taking a series of flats at different exposure times, subtracting out the appropriate darks, & combining the flats with IRAF, one can create a “shutter map” which can be useful in correcting shutter effects.

A flat frame taken by an SBIG camera with a Nikon lens