PH 301

ENGINEERING OPTICS

Lecture_Optical Detectors_26

Optical Detectors: Photographic emulsion, Thermal detectors, Photodiodes, Photomultiplier tubes, Detector arrays, Charge-coupled device (CCD), Complementary metal-oxide semiconductor (CMOS)

Photographic Emulsion

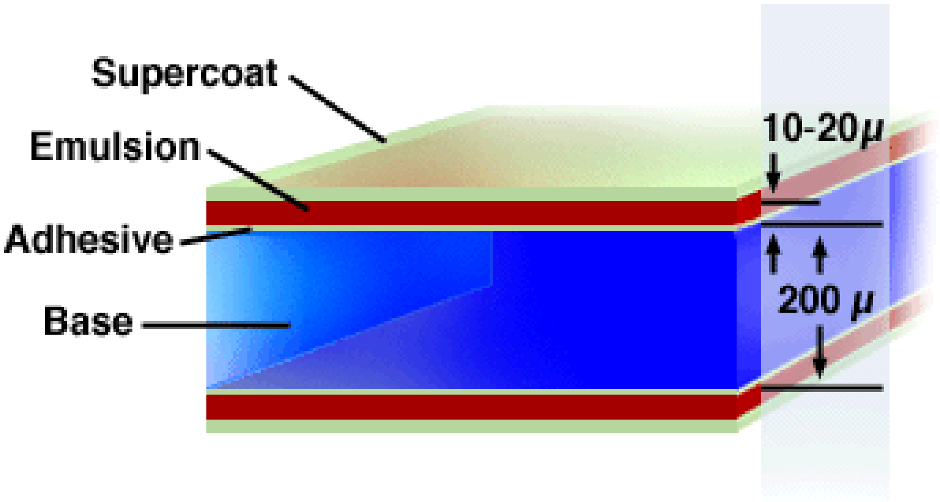
- **Word *emulsion* is customarily used in a photographic context. Gelatin or gum arabic layers sensitized with dichromate used in dichromated colloid processes carbon & gum bichromate are sometimes called *emulsions*.**

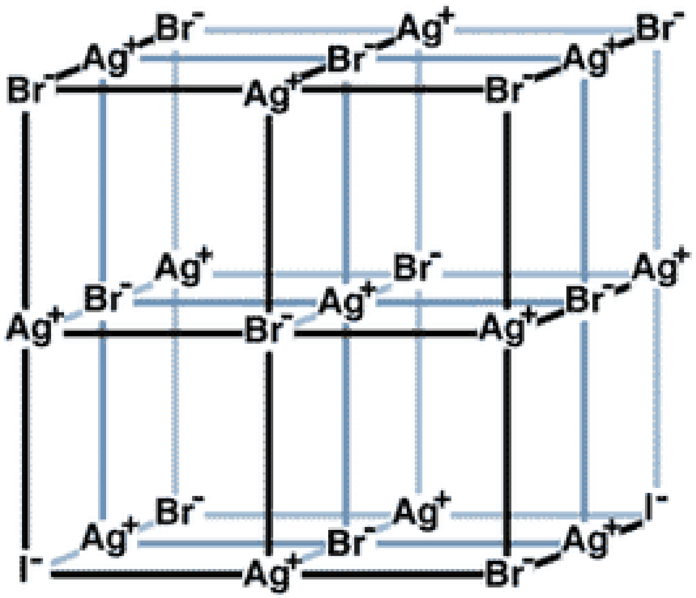
- **Photographic emulsion is a fine suspension of insoluble light-sensitive crystals in a colloid solution, usually consisting of gelatin.**

- **Light-sensitive component is one or a mixture of silver halides: silver bromide, chloride, & iodide.**

- **Silver bromide (AgBr), a soft, pale-yellow, insoluble salt well-known (along with other silver halides) for its unusual sensitivity to light.**

- **This property has allowed silver halides to become the basis of modern photographic materials.**





- Photographic emulsion is usually 10 to 30 µm thick & is composed of silver halide grains dispersed within gelatin.

- Grains are 1 µm or greater in diameter; large grains facilitate greater sensitivity, small grains enable finer resolution.

- Grains consist of silver, bromine, & iodine ions arranged in a crystal lattice. Sulfur-containing compounds are often added in order to form specks silver sulfide, which increase photosensitivity.

Chemical properties of photographic film

- **Film base is usually plastic such as tri-acetate or polyester which is coated with a light sensitive emulsion.**

- **Photographic emulsion is not a true emulsion, it is a dispersion of small solid particles in a liquid medium which is then allowed to cool & set.**

- **Light sensitive crystals are prepared by combination of silver-Ag- & a halogen. Due to very low solubility of silver halides mixing aqueous solutions of silver ions & halide ions will result in the precipitation of silver halide crystals.**

Silver nitrate ($AgNO_3$) + Potassium bromide -----> Silver bromide (AgBr) + Potassium nitrate (KNO_3)

Or

Ag^+ (silver ion in solution) + Br^- (bromide ion in solution) --------> Ag^+Br^- (silver bromide crystal)

Silver bromide is a lattice crystal containing millions of pairs of ions.

Formation of Latent Image

Step 1: Light Activation

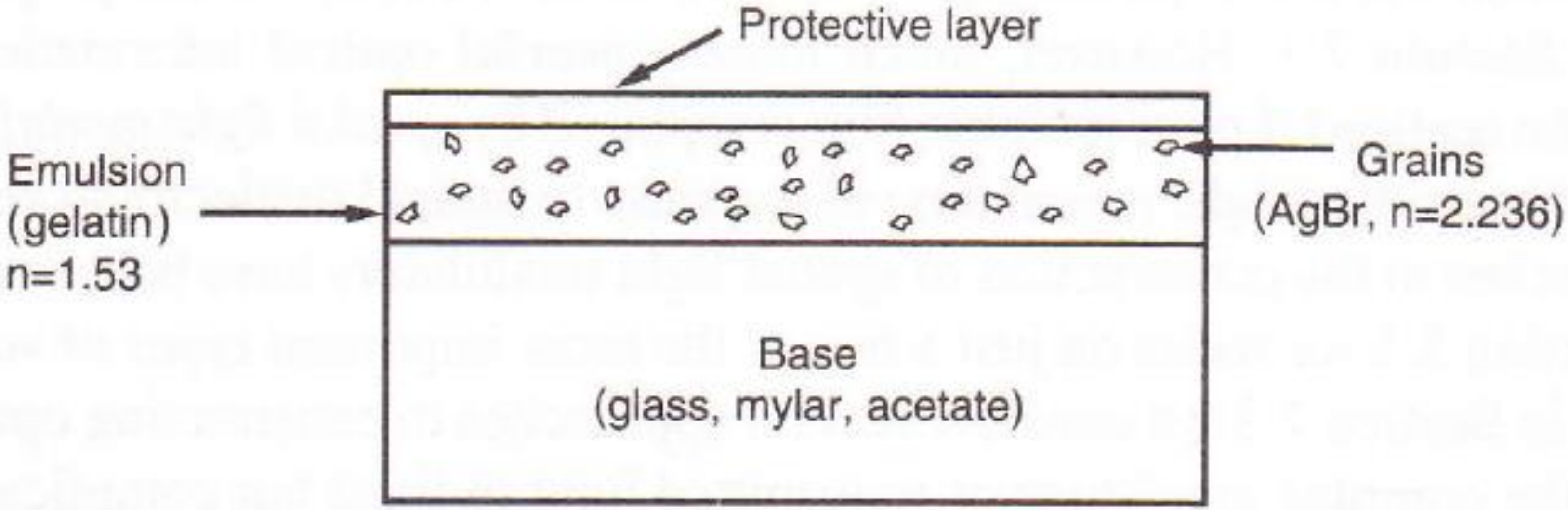
Energy is released when photon strikes silver halide crystal freeing electrons from bromide ion. Bromide ion is released from crystal as bromine & is absorbed by gelatin.

Step 2: Movement of electrons

Free electrons move through crystal to a 'sensitivity speck' caused by imperfections in crystal structure or created during sensitizing process during manufacture.

Step 3: Deposition of Silver Ions

Negatively charged speck attracts positive silver ions which are neutralized to form silver atoms. If enough silver atoms form at a single point then a latent image is created. Latent image is not visible, even under a microscope so the only way to tell if it is present is to chemically develop the film to reveal the image.



Structure of a photographic film or plate

Development of Latent Image

Development

Developing agent supplies electrons to latent image thus attracting & neutralizing silver ions to produce metallic silver which form a visible image. Developing agents: Metol, Phenidone, Hydroquinone

Stop

When predetermined development time is reached, film is moved from developer to a ‘stop bath’ which neutralizes developer & prevents any further development of image. Stop bath: 1% solution acetic acid

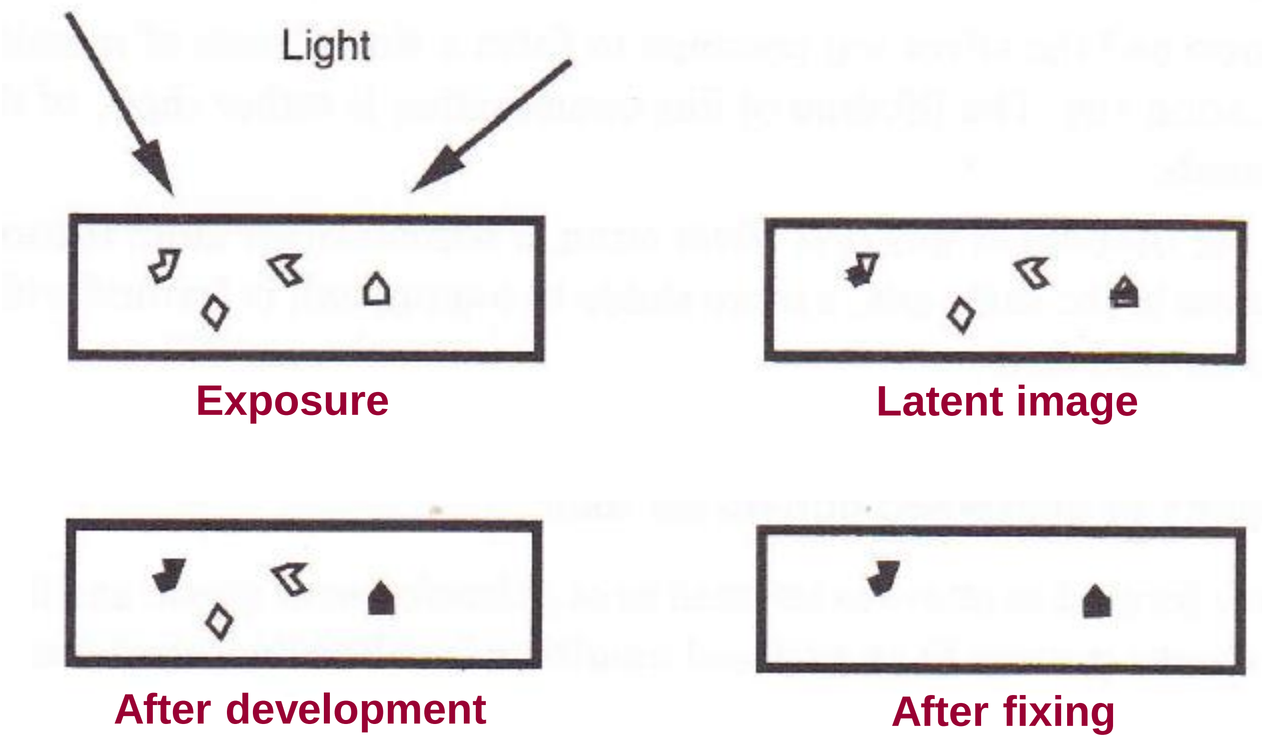
Fixing

After development, emulsion still contains unexposed & undeveloped silver halides. Film will look cloudy or milky if exposed to light. Fixer, commonly sodium thiosulphate, converts unexposed silver halide to soluble salts, which can be washed out.

Washing

Processed film is washed thoroughly to remove any chemical residue after being dried.

Pictorial representation of photographic process



- Energy incident per unit area on a photographic emulsion during exposure process is called *exposure*. [mJ/cm^2]

$$E(x,y) = I(x,y)\ T$$

- **Intensity transmittance**: Ratio of intensity transmitted by a developed transparency to intensity incident on that transparency, averaged over a region that is large compared with a single grain but small compared with fine structure in original exposure pattern, is called intensity transmittance.

$$\tau(x, y) = \underset{\text{average}}{\text{local}} \left\{ \frac{I \text{ transmitted at } (x, y)}{I \text{ incident at } (x, y)} \right\}$$

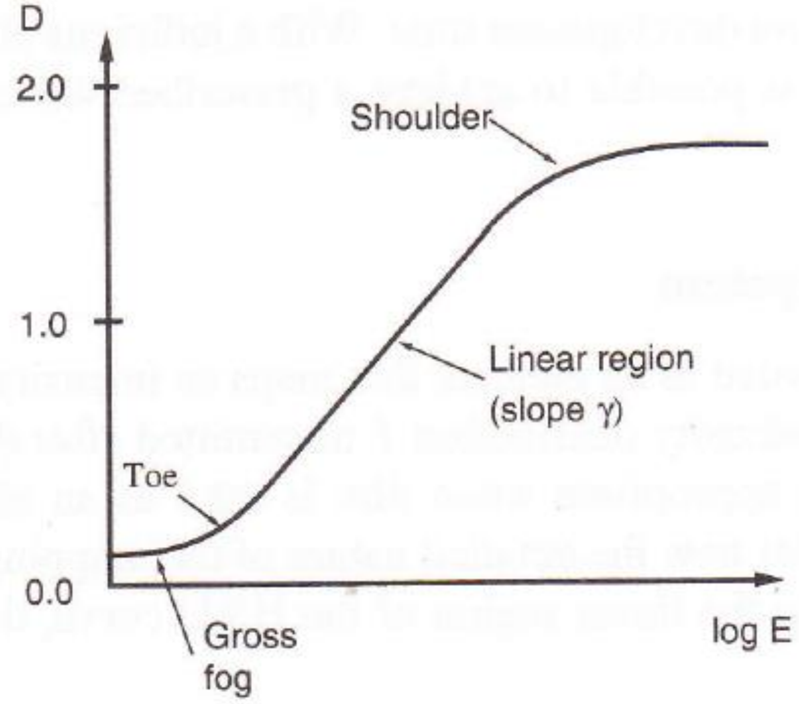
- **Photographic density** [F. Hurter & V. C. Driffield, 1890]: Logarithm of reciprocal of intensity transmittance of a photographic transparency should be proportional to silver mass per unit area of that transparency.

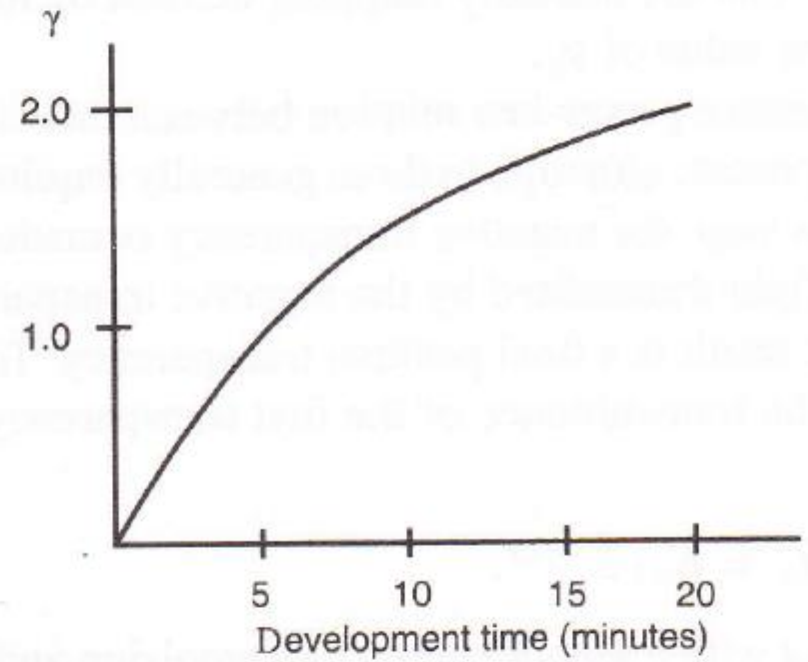
$$D = \log_{10}\left(\frac{1}{\tau}\right)$$

$$\tau = 10^{-D}$$

➢ Hurter-Driffield curve

H-D curve for a typical emulsion

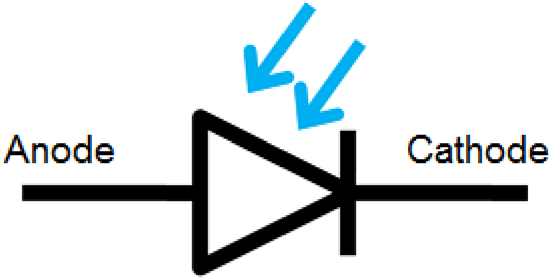




A film with a large value of *γ* is called a *high-contrast* film, while a film with a low *γ* is called a *low-contrast* film.

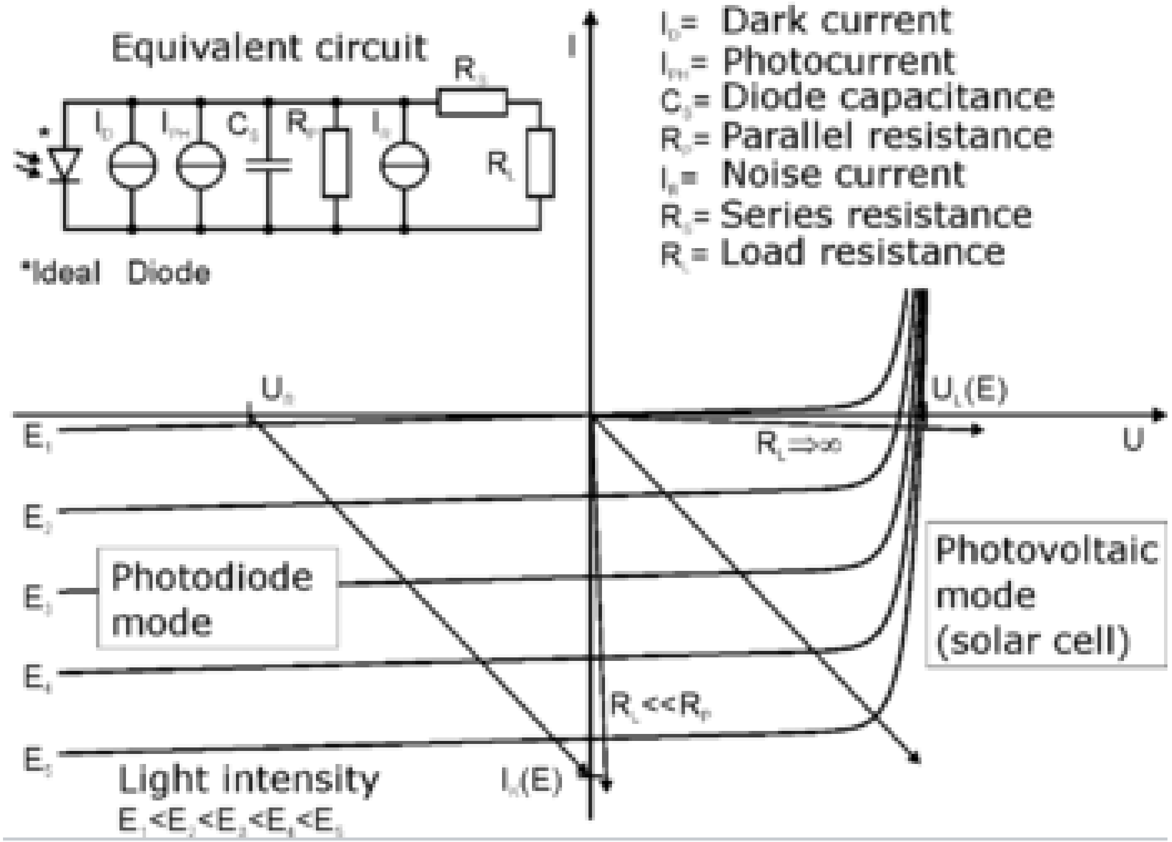
Photodiodes

- A photodiode is a semiconductor device that converts light into an electrical current.
- Current is generated when photons are absorbed in photodiode.
- A small amount of current is also produced when no light is present.
- Photodiodes may contain optical filters, built-in lenses, & may have large or small surface areas.
- Photodiodes usually have a slower response time as their surface area increases.



- Photodiodes are similar to regular semiconductor diodes except that they may be either exposed (to detect vacuum UV or X-rays) or packaged with a window or optical fiber connection to allow light to reach the sensitive part of the device.
- Many diodes designed for use specifically as a photodiode use a PIN junction rather than a p-n junction, to enhance response.
- A photodiode is designed to operate in reverse bias.
- When a photon of sufficient energy strikes diode, it creates an electron-hole pair. This mechanism is known as inner photoelectric effect.
- If absorption occurs in junction's depletion region, these carriers are swept from junction by the built-in electric field of depletion region. Thus holes move toward anode, & electrons toward cathode, & a photocurrent is produced.
- Total current through photodiode is sum of dark current (current generated in absence of light) & photocurrent, so dark current must be minimized to maximize the sensitivity of device.

I-V characteristic of a photodiode

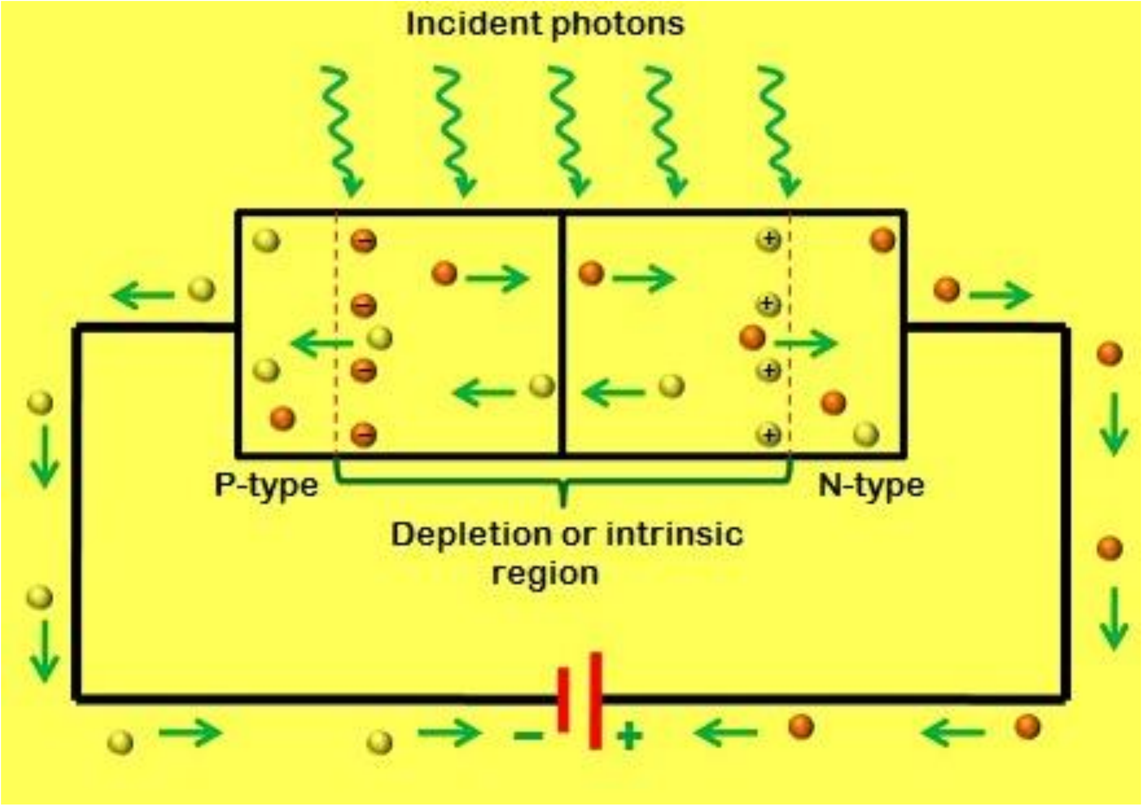


Linear load lines - response of external circuit: I = (Applied bias voltage-Diode voltage)/total resistance. Points of intersection with the curves represent actual current & voltage for a given bias, resistance & illumination.

Materials commonly used to produce photodiodes include

Material	Electromagnetic spectrum wavelength range (nm)
Silicon	190–1100
Germanium	400–1700
Indium gallium arsenide	800–2600
Lead(II) sulfide	<1000–3500
Mercury cadmium telluride	400–14000

Working of a photodiode



- **When light illuminates PN junction, covalent bonds are ionized, which generates hole & electron pairs.**

- **Photocurrents are produced due to generation of electron-hole pairs. Electron hole pairs are formed when photons of energy more than 1.1eV hits the diode.**

- **When photon enters depletion region of diode, it hits atom with high energy. This results in release of electron from atom structure. After the electron release, free electrons & hole are produced.**

- **An electron will have - ve charge & holes will have a + ve charge. Depletion energy will have built in electric filed, due to which, electron hole pairs moves away from junction.**

- **Holes move to anode & electrons move to cathode to produce photo current. Photon absorption intensity & photon energy are directly proportional to each other. When energy of photons is less, absorption will be more.**