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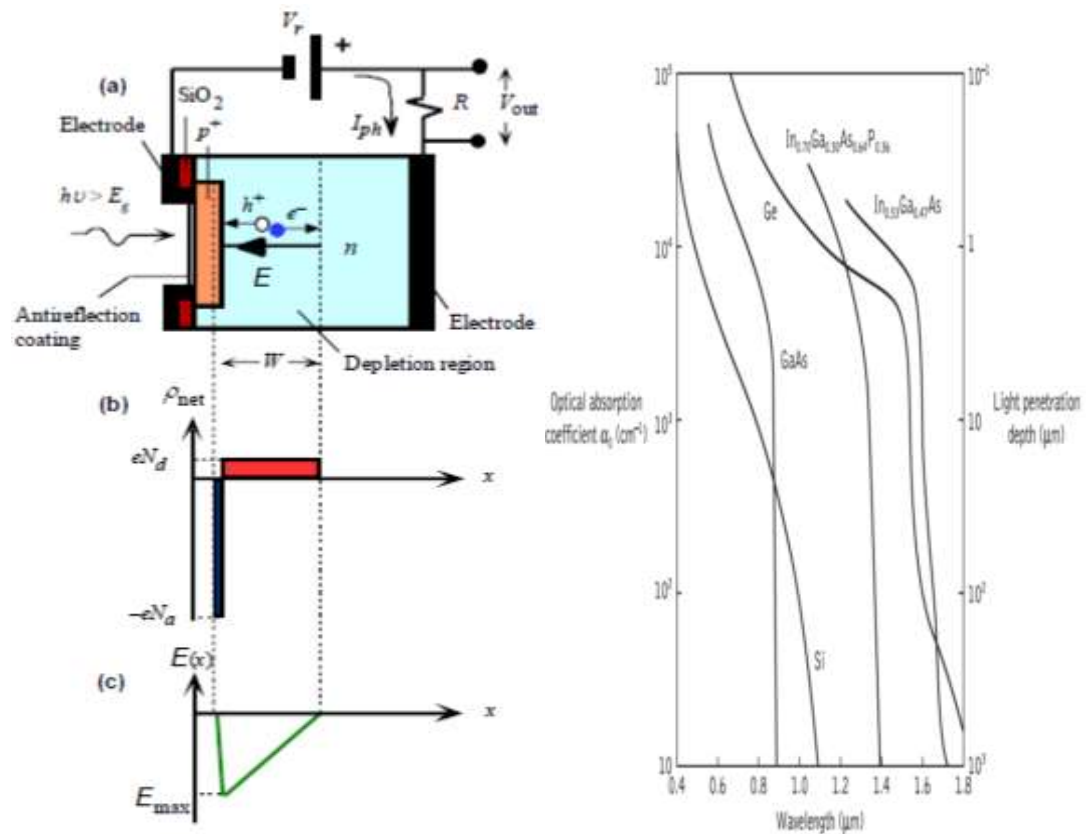
EE 23551
Optical Communications

Quiz #3
Monday 3/8/2026

Name:.....



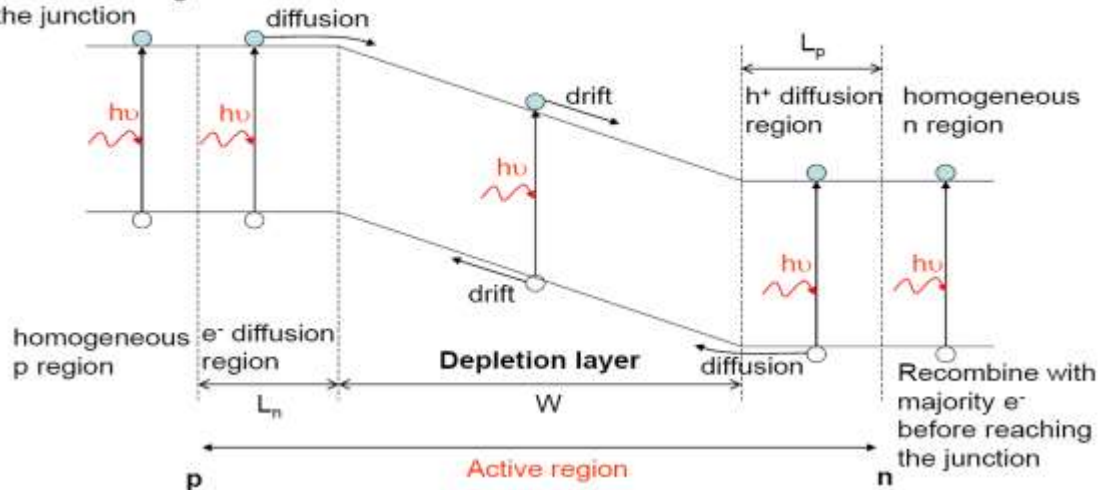
Q.1) Explain in details how the pn photodiode works.



Solution: [10-Points]

- The *semiconductor photodiode detector* is a p-n junction structure that is based on the internal photoeffect.
- The photoresponse of a photodiode results from the *photogeneration of electron-hole pairs through band-to-band optical absorption*.
=> The *threshold photon energy* of a semiconductor photodiode is the bandgap energy E_g of its active region.
- The *photogenerated* electrons and holes in the *depletion layer* are subjected to the local electric field within that layer. The electron/hole carriers *drift* in opposite directions. This *transport process* induces an electric current in the external circuit.
- Here, we will focus on semiconductor *homojunctions*.

Recombine with majority h^+ before reaching the junction



- **In the depletion layer**, the internal electric field sweeps the photogenerated electron to the n side and the photogenerated hole to the p side.
=> a *drift current* that flows in the *reverse* direction from the n side (cathode) to the p side (anode).
- Within one of the **diffusion regions** at the edges of the depletion layer, the photogenerated *minority* carrier (*hole in the n side and electron in the p side*) can reach the depletion layer by *diffusion* and then be swept to the other side by the internal field.
=> a *diffusion current* that also flows in the *reverse* direction.
- In the p or n **homogeneous region**, *essentially no current is generated* because there is essentially no internal field to separate the charges and a minority carrier generated in a homogeneous region *cannot diffuse to the depletion layer before recombining with a majority carrier*.

- The absorption coefficients of semiconductor materials are strongly dependent on wavelength.
- This is illustrated for some common semiconductors in Figure 8.2. It may be observed that there is a variation between the absorption curves for the materials shown and that they are each suitable for different wavelength applications.

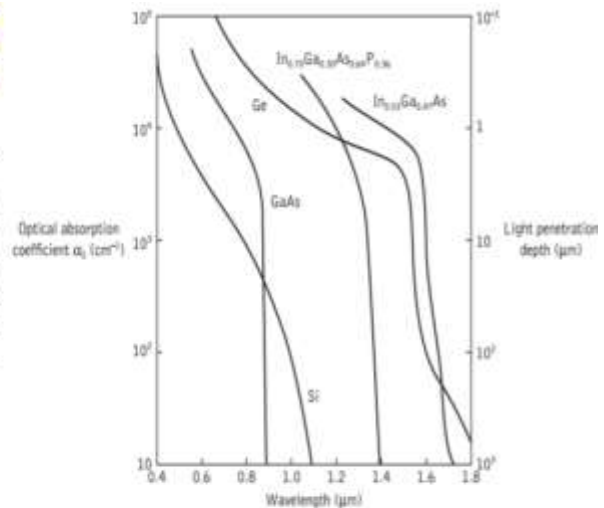
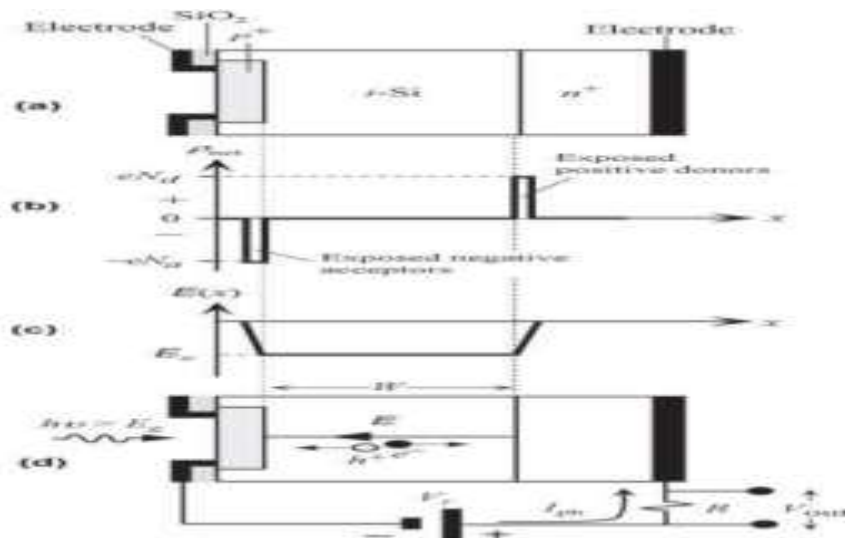


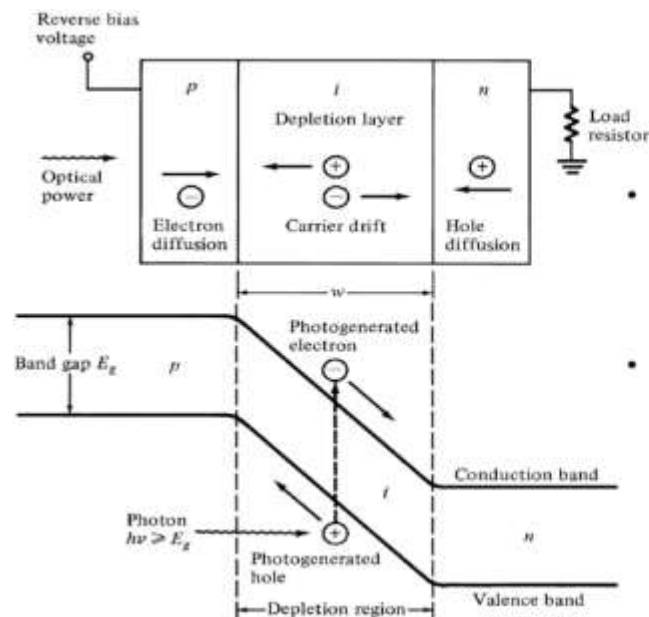
Figure 8.2 Optical absorption curves for some common semiconductor photodiode materials (silicon, germanium, gallium arsenide, indium gallium arsenide and indium gallium arsenide phosphide)

Q.2) Explain in details how the pin photodiode works.

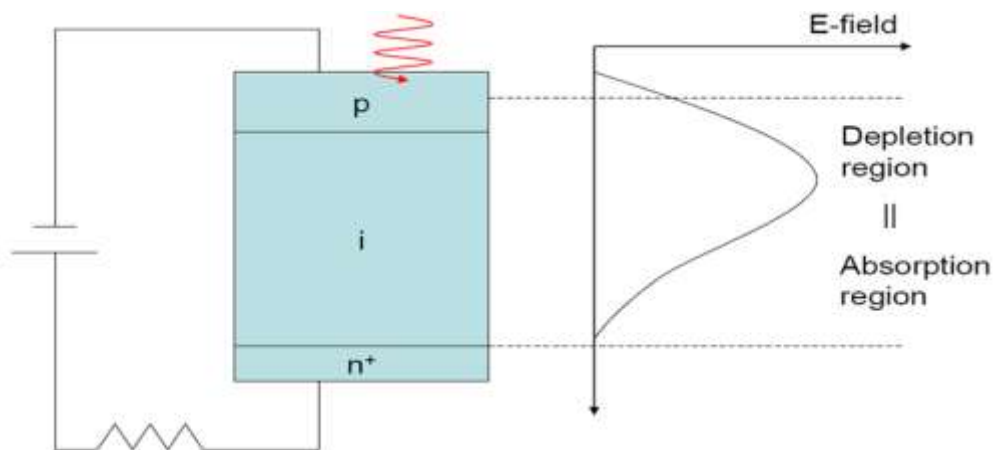


Solution: [10-Points]

- pn photodiodes are reversed biased
- A strong negative bias is generated over a very small lateral dimension in the p⁺ side
- The depletion region extends deep into the thickness of the n side of the device
- The total bias in the device $V = V_0 + V_r$ where V_0 is the built in voltage inherent in the junction
- When a photon of energy greater than the bandgap is incident, it becomes absorbed and is said to photogenerate a free electron hole pair (EHP)
- Usually the energy of the photon is such that the photogeneration takes place in the depletion layer
- The electric field present in the depletion layer pulls the EHP apart until they reach the neutral regions of the device
- Motion of the electrons photogenerated in the device by the electric field produces a photocurrent, I_{ph} in the device

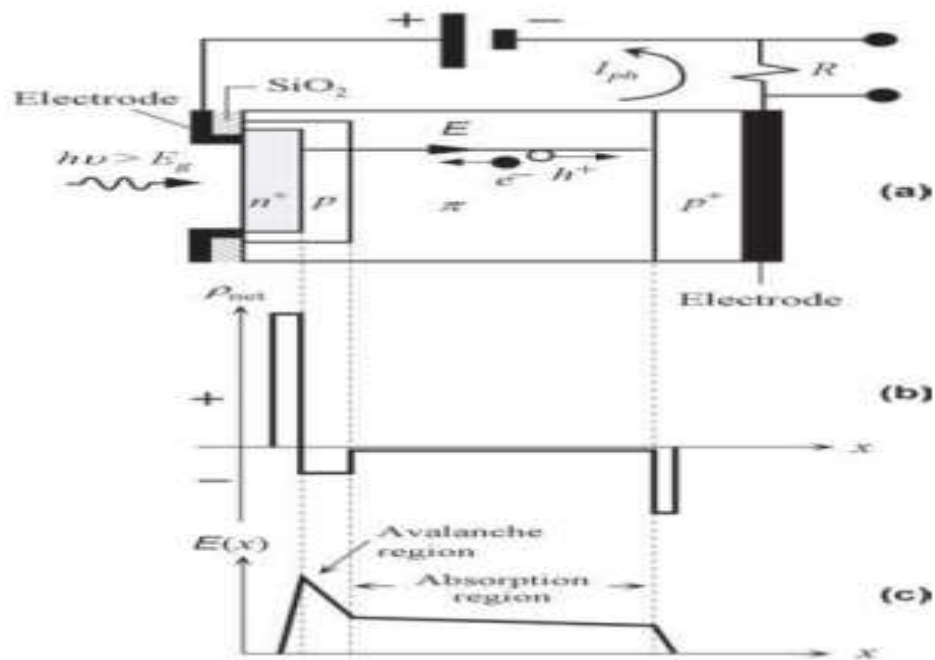


- A p-i-n photodiode consists of an *intrinsic* region sandwiched between heavily doped p^+ and n^+ regions. The *depletion layer* is almost completely defined by the intrinsic region.
- In practice, the *intrinsic* region does not have to be truly *intrinsic* but only has to be *highly resistive* (lightly doped p or n region).



- All the absorption takes place in the depletion region. The n-type material is doped so lightly that it can be considered *intrinsic*, and to make a low resistance contact a highly doped n-type (n^+) layer is added.

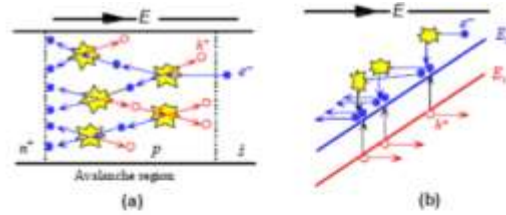
Q.3) Explain in details how the APD photodiode works.



Solution: [10-Points]

- Avalanche photodiodes (APDs) are used widely in optical communications due to their high speed and internal gain
- The n^+ side is very thin and illuminated directly by light incident upon it
- Three p type layers are buried within the thickness of the substrate.
 - A thin p - layer is diffused or implanted under the n^+ region
 - The middle layer is nearly intrinsic yielding only a slight potential across the thickness of the device
 - p^+ region is located at the counter electrode
- The diode is reversed biased to increase fields within the depletion region where absorption occurs.

- When drifting electrons generated within the near intrinsic region drift diffuse into the p- region then they experience large E fields that provide sufficient kinetic energy (greater than E_g) to impact-ionize some of the Si covalent bonds and release more EHPs.
- The secondary EHPs are also accelerated by the same high fields, ionize and generate even more EHPs
- This effect leads to an avalanche of impact ionization processes and the photodiode can be said to possess and internal gain mechanism that amplifies the effect of a single EHP absorption in the intrinsic region
- The photocurrent generated in the APD in the presence of avalanche multiplication thus corresponds to a quantum efficiency greater than 1



(a) A pictorial view of impact ionization processes releasing EHPs and the resulting avalanche multiplication. (b) Impact of an energetic conduction electron with crystal vibrations transfers the electron's kinetic energy to a valence electron and thereby excites it to the conduction band.

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- The avalanche multiplication factor applied to efficiency and responsivity calculations is

$$M = \frac{\text{Multiplied_photocurrent}}{\text{Primary_unmultiplied_photocurrent}} = \frac{I_{ph}}{I_{ph0}}$$

$$M = \frac{1}{1 - \left(\frac{V_r}{V_{br}} \right)^n}$$

- V_{br} is the avalanche breakdown voltage, V_r is the reverse bias, and n is a characteristic index that is used to best fit the experimental data

