# EELE408 Photovoltaics

## Lecture 10 Solar Cell Operation

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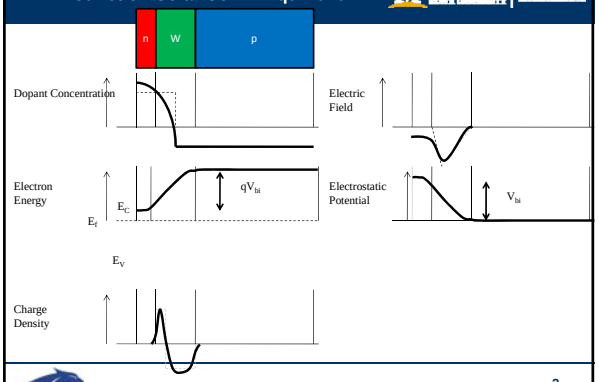
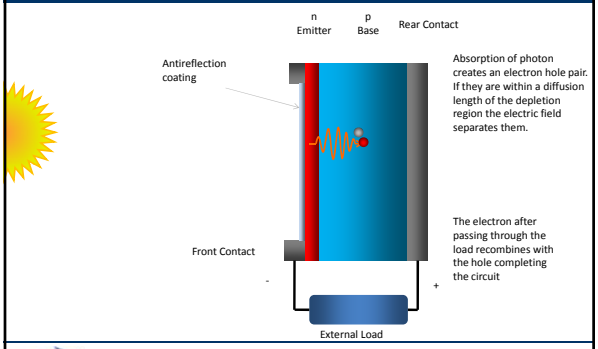
## P-N Junction Solar Cell in Equilibrium






## Solar Cell Operation






## Operation of a Solar Cell

- The creationn of light-generated carriers (Electron Hole Pairs)
- The collection of light-generated carriers to generate a current
- The generation of a voltage across the solar cell
- The dissipation of power in the load and parasitic resistances

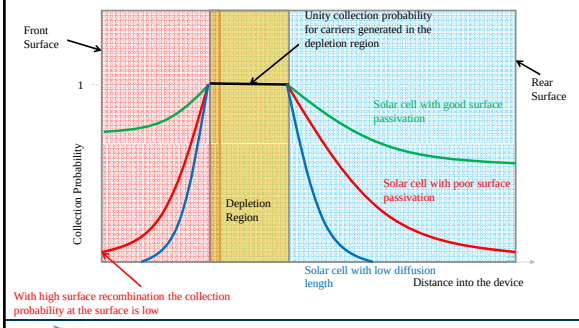


## Collection Probability

- The probability that light generated carriers absorbed in a certain region of the device will be collected and contribute to the photocurrent
- Depends on the distance the light generated carrier must travel compared to the diffusion length
- Depends on surface properties of the device
- Collection probability is unity inside the depletion region.



## Collection Probability Chart



## Light Generated Current

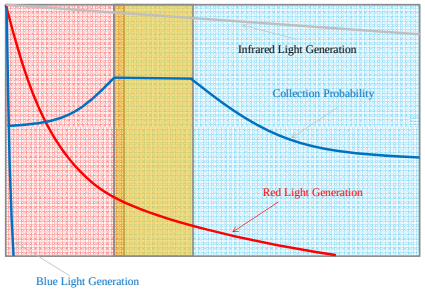
- The light generated current is the integration over the entire device thickness of the generation rate at a point in the device multiplied by the collection probability at that point

$$J_L = q\int_0^w G(x)CP(x)dx$$

$$= q\int_0^w \left[\int \alpha(\lambda)H_0 e^{-\alpha(\lambda)x}d\lambda\right]CP(x)dx$$



## Spectral Dependence in Light Generated Current






## Color Dependence

- Blue Light (0.45 μm)→α = $10^5$/cm
  - Absorbed at front surface
  - If collection probability low at front (Surface States) blue light will not contribute significantly to light generated current
- Red Light (0.8 μm) →α = $10^3$/cm
  - Absorbed deeper in cell
- Infrared Light (1.1 μm) →α = $10^1$/cm
  - Barely absorbed since it is near the band gap of silicon

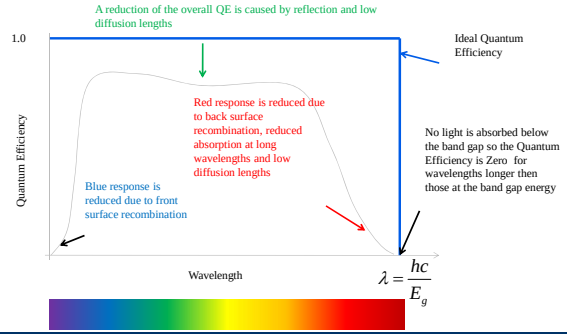


## Quantum Efficiency

- The ratio of the number of carriers collected by the solar cell to the number of photons of a given energy incident on the solar cell
- If all the photons at a certain wavelength are absorbed and the resulting minority carriers are collected then the QE at that wavelength is unity
- The QE for photons below the band gap energy is zero



## Quantum Efficiency Chart



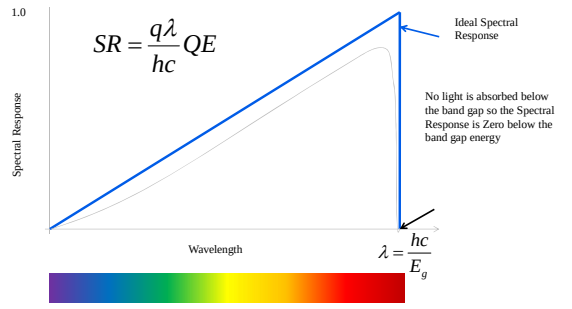



## Spectral Response

- Ratio of current generated by the solar cell to the **power** incident on the solar cell
- Limited at long wavelengths by the inability of the semiconductor to absorb photons with energies below the band gap (Same as QE)
- Any energy above the band gap energy is not utilized by the solar cell and instead goes to heating the solar cell
- This is a measured quantity and used to calculate the Quantum Efficiency

$$SR = \frac{q\lambda}{hc}QE$$

## Spectral Response






## Photovoltaic Effect

- Collection of photogenerated carriers does not produce power, a voltage must be generated as well as a current
- Short Circuit
  - The collection of photogenerated carriers by the p-n junction causes a movement of electrons to the n-side and holes to the p-side.
  - There is no build up of charge as the carriers exit the junction as photogenerated current called the **Short Circuit Current ($I_{sc}$)**



## Photovoltaic Effect (2)

- Open Circuit
  - Photogenerated carriers are prevented from leaving the solar cell.
  - Photogenerated carriers causes an increase in the number of electrons on the n-side and holes on the p-side
    - This creates an electric field that opposes the existing field reducing the net electric field
    - This results in an increase in the diffusion current by lowering the potential barrier

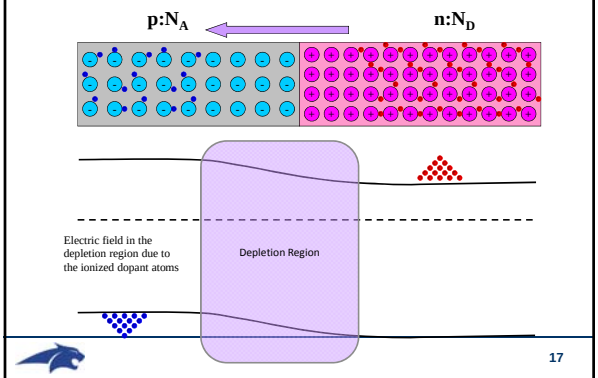


## Photovoltaic Effect (3)

- Open Circuit (cont.)
  - A new equilibrium is reached in which a voltage exists across the p-n junction
  - The current from the solar cell is the difference of $I_L$ and the forward bias current
  - The forward bias of the junction increases to a point where the light generated current is exactly balanced by the forward bias diffusion current
  - The voltage required to balance these two currents is called the **Open Circuit Voltage ($V_{oc}$)**

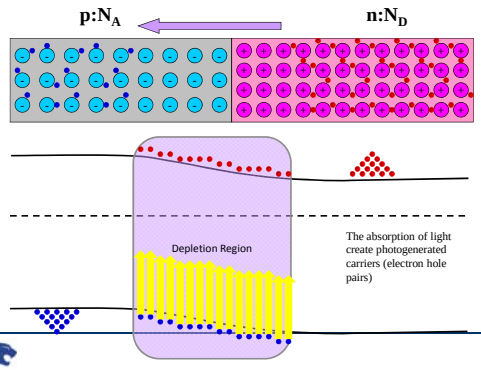


## pn Junction in Thermal Equilibrium

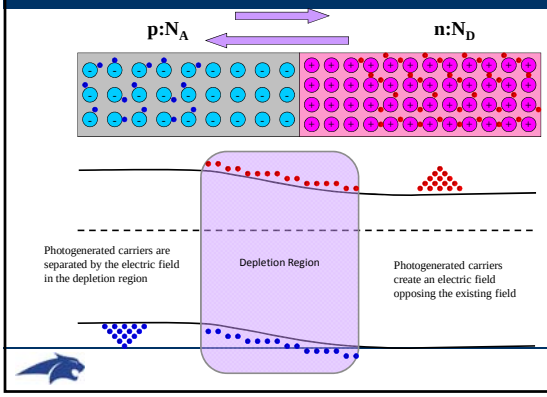





## pn Junction with Illumination 1



## pn Junction with Illumination 2

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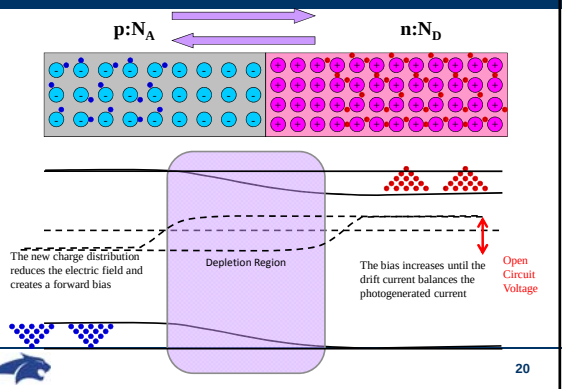
## pn Junction with Illumination 3

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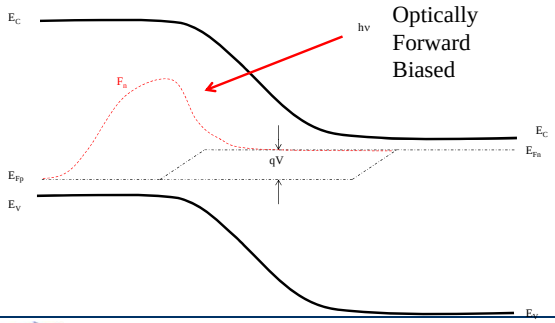
## Forward Bias

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## Solar Cell Parameters

- Quantum Efficiency
- Spectral Response
- Open Circuit Voltage
- Short Circuit Current
- I-V Curve
- Fill Factor
- Efficiency

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