CLEAN ENERGY GENERATION, INTEGRATION AND STORAGE (EEE-801)

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Lecture-7

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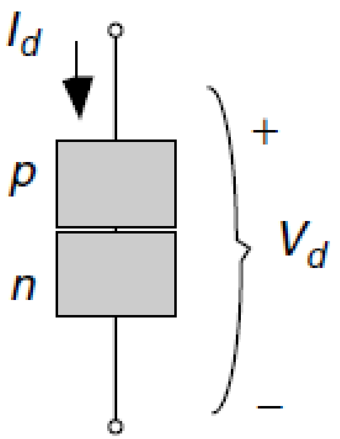
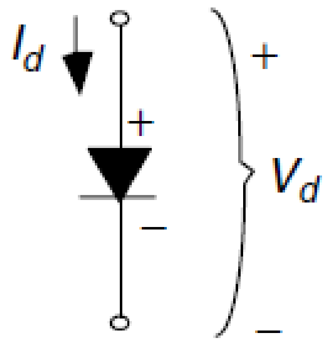
PV: The p-n Junction Diode

- **The characteristics of conventional p–n junction diode, is presented in Fig.**
- **If we were to apply a voltage V_d across the diode terminals, forward current would flow easily through the diode from the p-side to the n-side; but if we try to send current in the reverse direction, only a very small (≈10^–12 A/cm^2) reverse saturation current I_o will flow.**
- **The symbol for a real diode is shown here as a blackened triangle with a bar; the triangle suggests an arrow, which is a convenient reminder of the direction in which current flows easily. The triangle is blackened to distinguish it from an "ideal" diode. Ideal diodes have no voltage drop across them in the forward direction, and no current at all flows in the reverse direction.**

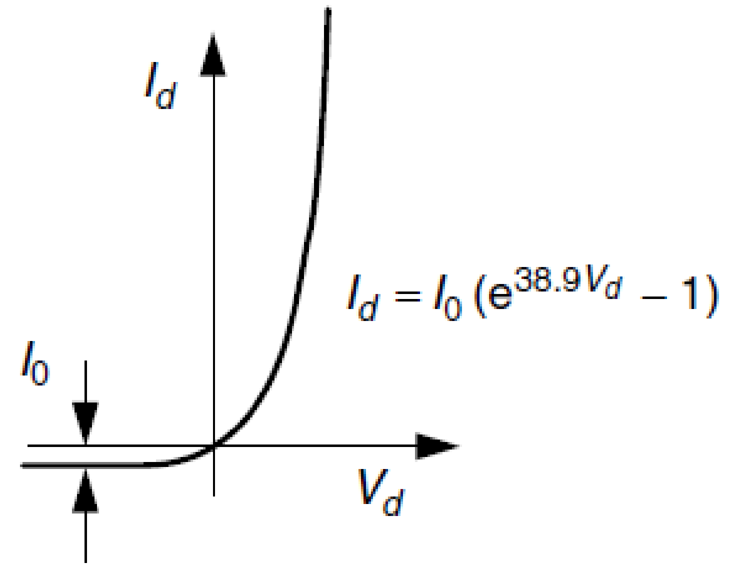
PV: The p-n Junction Diode (Continued)



(a) p–n junction diode



(b) Symbol for real diode



(c) Diode characteristic curve

PV: The p-n Junction Diode (Continued)

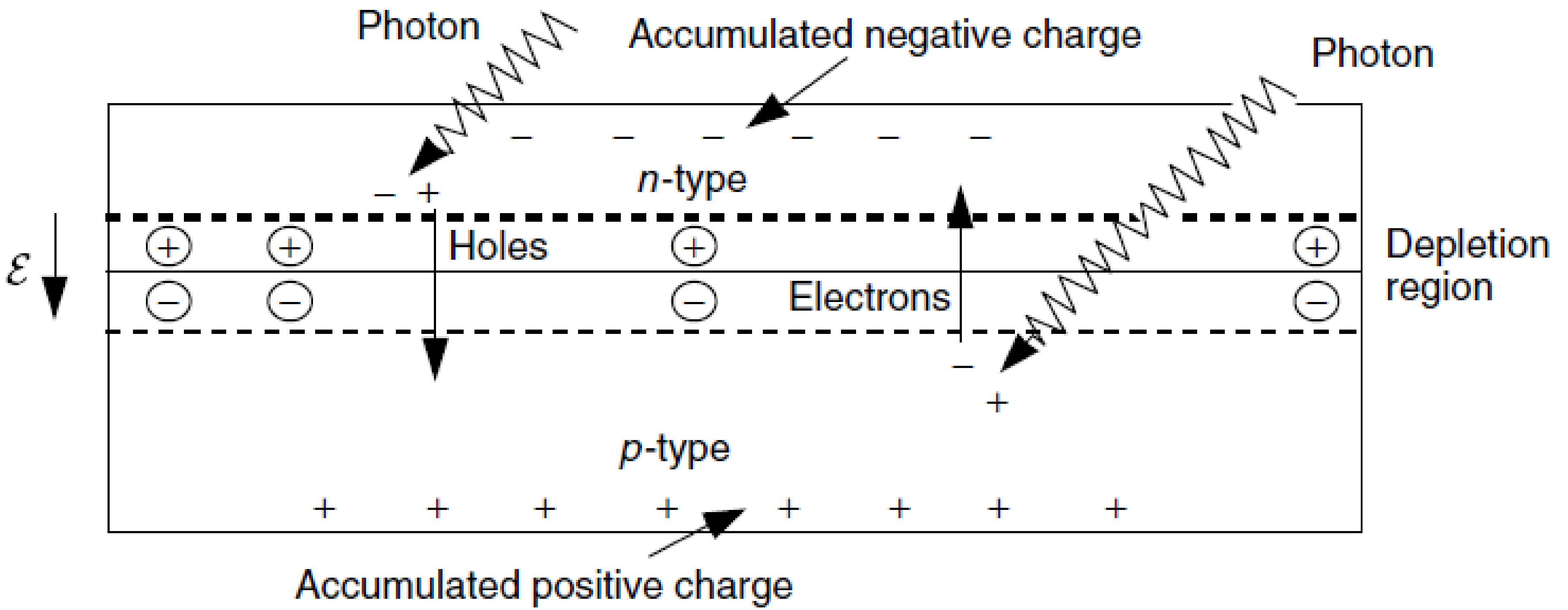
- **The voltage–current characteristic curve for the p–n junction diode is described by the following Shockley diode equation:**
- $I_d = I_o(e^{qV_d/kT} - 1)$ **(1)**
- **where I_d is the diode current in the direction of the arrow (A), V_d is the voltage across the diode terminals from the p-side to the n-side (V), I_o is the reverse saturation current (A), q is the electron charge (1.602×10^{-19}C), k is Boltzmann's constant (1.381×10^{-23}J/K), and T is the junction temperature (K).**

- **Substituting the above constants into the exponent of equation (1) gives**
- $$\frac{qV_d}{kT} = \frac{1.602 \times 10^{-19}}{1.381 \times 10^{-23}} \frac{V_d}{T} = 11,600 \frac{V_d}{T}$$
- **A junction temperature of 25℃ is often used as a standard, which results in the following diode equation:**
- $$I_d = I_o(e^{38.9V_d} - 1) \qquad \text{(at 25℃)}$$

PV: A Generic Photovoltaic Cell

- **What happens in the vicinity of a p–n junction when it is exposed to sunlight? As photons are absorbed, hole-electron pairs may be formed. If these mobile charge carriers reach the vicinity of the junction, the electric field in the depletion region will push the holes into the p-side and push the electrons into the n-side, as shown in Fig.**
- **The p-side accumulates holes and the n-side accumulates electrons, which creates a voltage that can be used to deliver current to a load.**

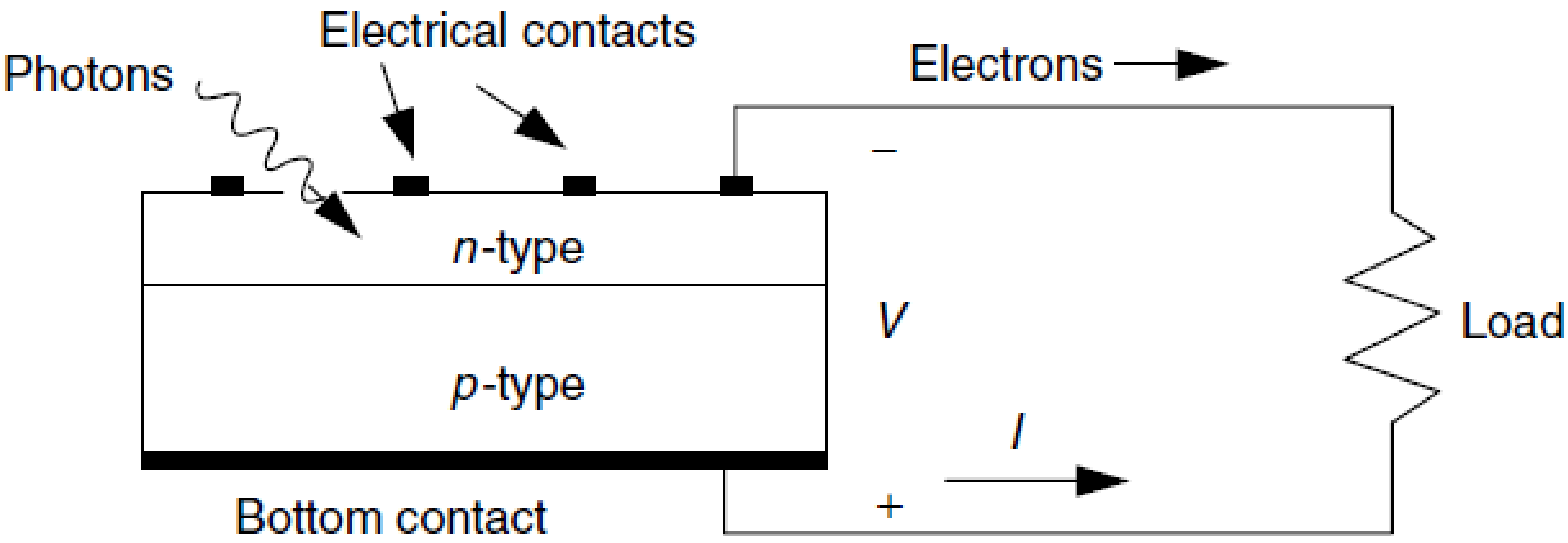
PV: A Generic Photovoltaic Cell (Continued)



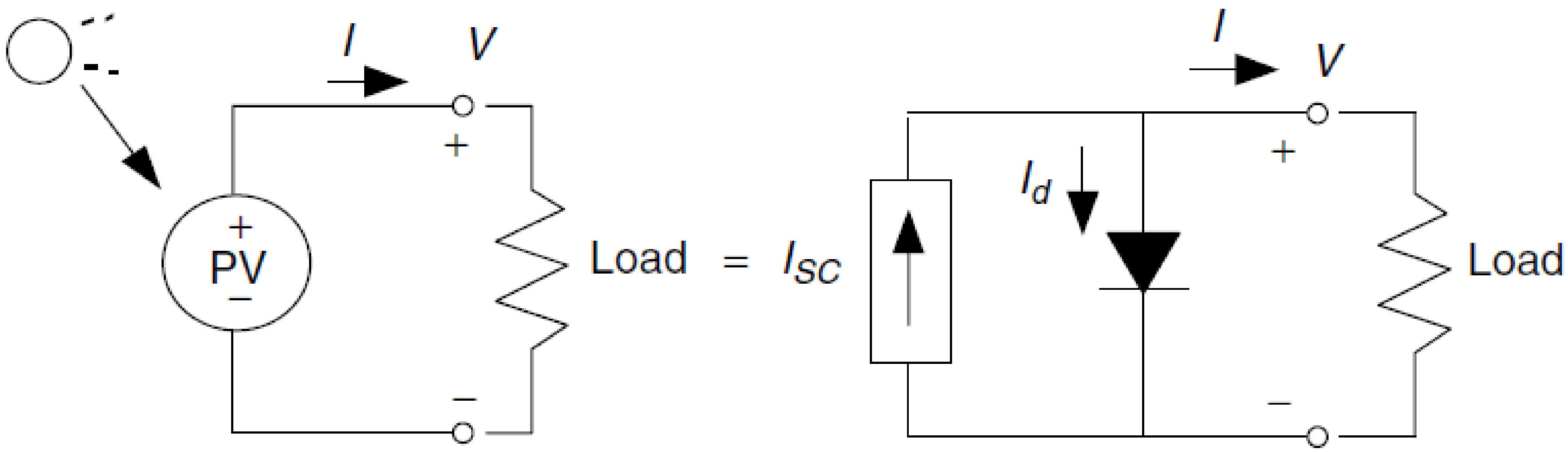
PV: A Generic Photovoltaic Cell (Continued)

- **If electrical contacts are attached to the top and bottom of the cell, electrons will flow out of the n-side into the connecting wire, through the load and back to the p-side as shown in Fig.**
- **Since wire cannot conduct holes, it is only the electrons that actually move around the circuit. When they reach the p-side, they recombine with holes completing the circuit.**
- **By convention, positive current flows in the direction opposite to electron flow, so the current arrow in the figure shows current going from the p-side to the load and back into the n-side.**

PV: A Generic Photovoltaic Cell (Continued)



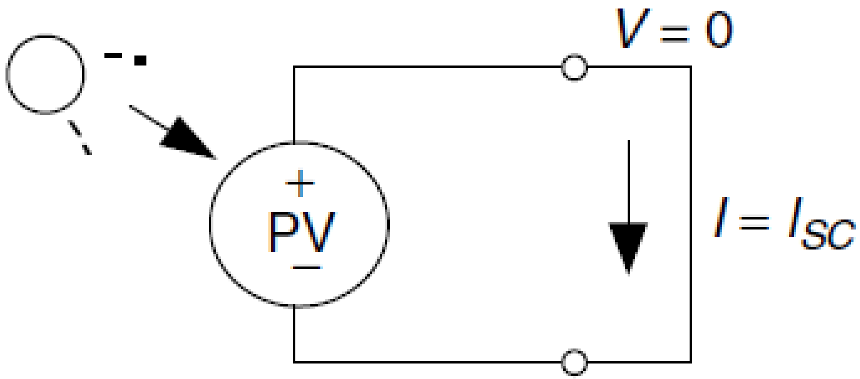
➢ **A simple equivalent circuit model for a photovoltaic cell consists of a real diode in parallel with an ideal current source as shown in Fig. The ideal current source delivers current in proportion to the solar flux to which it is exposed.**



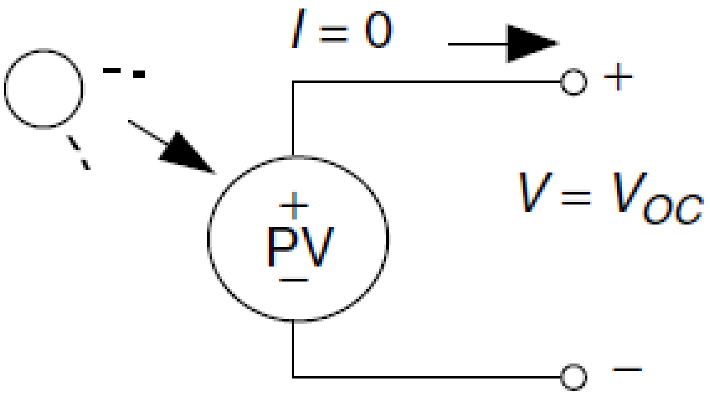
PV: Simplest Equivalent Circuit for a Photovoltaic Cell (Cont)

- **There are two conditions of particular interest for the actual PV and for its equivalent circuit. As shown in Fig, they are: (1) the current that flows when the terminals are shorted together (the short-circuit current, I_{sc}) and (2) the voltage across the terminals when the leads are left open (the open-circuit voltage, V_{oc}).**
- **When the leads of the equivalent circuit for the PV cell are shorted together, no current flows in the (real) diode since V_d = 0, so all of the current from the ideal source flows through the shorted leads. Since that short-circuit current must equal I_{sc}, the magnitude of the ideal current source itself must be equal to I_{sc}.**

PV: Simplest Equivalent Circuit for a Photovoltaic Cell (Cont)



(a) Short-circuit current



(b) Open-circuit voltage

PV: Simplest Equivalent Circuit for a Photovoltaic Cell (Cont)

- $I = I_{sc} - I_o\left(e^{qV/kT} - 1\right)$ **(2)**
- **Figure shows the current–voltage relationship for a PV cell when it is dark (no illumination) and light (illuminated) based on (2).**
- **When the leads from the PV cell are left open, I = 0 and we can solve (2) for the open-circuit voltage V_{oc} :**
- $V_{oc} = \frac{kT}{q}\ln\left(\frac{I_{sc}}{I_o} + 1\right)$ **(3)**
- **At 25 °C, (2) and (3) becomes**
- $I = I_{sc} - I_o(e^{38.9V} - 1)$ **(4)**
- $V_{oc} = 0.0257\ln\left(\frac{I_{sc}}{I_o} + 1\right)$ **(5)**

PV: Simplest Equivalent Circuit for a Photovoltaic Cell (Cont)