Efficiency of solar cell

- The dark current of an p-n junction can be written as:

$$I_D = I_0\left[e^{(qV/kT)} - 1\right]$$

Where,
I_0 is the saturated dark current
q is the electron charge
k is the boltzmann's constant and
T is the absolute temperature (K)

So, the junction current with light can be written as:

$$I_{out} = I_{sc} - I_0\left[e^{(qV/kT)} - 1\right]$$

Where,
I_{sc} is the short-circuit current

Efficiency of solar cell

When the load is an open circuit ($I_{out} = 0$), corresponding voltage is called the open-circuit voltage (V_{oc})

Thus,

$$V_{oc} = \frac{kT}{q} ln\left(\frac{I_{sc}}{I_0} + 1\right)$$
$$\approx \frac{kT}{q} ln\left(\frac{I_{sc}}{I_0}\right)$$

The output power is $P_{out} = V_{out} \times I_{out}$

Maximum power output, $P_m = V_m \times I_m$

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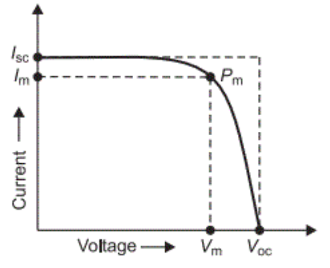
Efficiency of solar cell

- ✓ **Fill factor** is a measure of quality of a solar cell.
- ✓ This is the available power at the maximum power point (Pm) divided by the open circuit voltage (V_{OC}) and the short circuit current (I_{SC}):

$$FF = \frac{P_m}{V_{oc} \times I_{sc}}$$

$$FF = \frac{V_m \times I_m}{V_{oc} \times I_{sc}}$$



So, the maximum power conversion efficiency is:

$$\eta = \frac{P_m}{P_{in}} = \frac{V_{oc} \times I_{sc} \times FF}{incident\ solar\ power}$$

Efficiency limiting factors

Bandgap Energy (E_g):

- ✓ Doping concentration increases the E_g
- ✓ V_{oc} increases with increasing E_g.
- ✓ On the other hand J_{sc} decreases with increasing E_g.
- ✓ As a result , solar cell efficiency became peak at a certain E_g.

Temperature:

- ✓ Efficiency decreases with increasing temperature
- ✓ For every 1°C increase in temperature, V_{oc} drop by about 0.4% of its room temperature value.
- ✓ Thermal loss increases.

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Efficiency limiting factors

Recombination Lifetime:

- ✓ Long carrier-recombination lifetimes are desirable mainly because they help to achieve large I_{sc}
- ✓ The key to achieve long recombination lifetimes is to avoid introducing recombination centers during material preparation and cell fabrication.

Light Intensity:

- ✓ Directly related to the output power.

Doping Density & Profile:

- ✓ With increasing doping density the V_{oc} is increasing.
- ✓ As well as the dark saturation current density also increase with increasing doping density.
- ✓ Defect density increase.

Efficiency limiting factors

Surface Recombination Velocities:

- ✓ Low surface recombination velocities help enhance I_{sc}
- ✓ Back surface filed (BSF) is usually use to minimize surface recombination velocity.
- ✓ Passivation layers also help to decrease it.

Series Resistance:

- ✓ Comes from lead, metal contact grid, bulk cell resistance.
- ✓ Can minimized by spacing the metal lines closely.

Metal Grid and Optical Reflection:

- ✓ Metal grids on the front surface are opaque to sunlight.
- ✓ To maximize I_{sc} the metal grid area should minimize.
- ✓ The reflectivity of the bare silicon surface is about 40%
- ✓ it can be reduced by using antireflection coating.

Design consideration

Steps for designing a typical silicon solar cell:

- **Take a p-type single crystalline silicon.**
  - ✓ Usually Czochralski (C-Z) technique is used.
  - ✓ Slicing it to the proper plane.
  - ✓ Chemical etching (by mixture of Nitric, HF, acetic acid) to remove oxidized layer.
  - ✓ Polishing is done by sic and Al_2O_3 slurry.
- **Then dope with thin layer of n-type.**
  - ✓ n-region is thin and highly doped
  - ✓ To make ohmic contact easer.
- **Chose a proper material for making electrodes.**
  - ✓ Choose proper metal to reduce the series resistance.
  - ✓ Annealing of the metal-semiconductor junction decrease the contact resistance.

Design consideration

- **On top of the cell place finger electrodes.**
  - ✓ Maximize light transfer to the substrate.
  - ✓ Reduce the contact resistance.
  - ✓ Increase carrier collection efficiency.
- **Series resistance must be low with high sunt resistance.**
  - ✓ It reduces the solar cell efficiency.
  - ✓ It reduces the fill factor of the cell
  - ✓ May come from unsmooth metal-semiconductor junction
  - ✓ May due to manufacturing fault.
- **Choose a proper antireflection coating material.**
  - ✓ Need so that most of the solar radiation be absorbed by the cell and not reflected back.
  - ✓ Proper dielectric material with proper thickness.
  - ✓ Refractive index of the coating material;

$$\eta = \sqrt{R.I\ of\ the\ air \times R.I\ of\ the\ solar\ energy\ material}$$

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Design consideration

- **Cote the material with proper thickness.**

$$Thickness = m.\frac{\lambda}{4}.\frac{1}{\eta}$$

Thickness of the coating material should be the odd multiple of the quarter wavelength.

- **Protecting layer of the cell**

Solar modules and panels

- Solar panel or module is an array of several solar cells.
- The array can be formed by connecting them in parallel or series connection depending upon the energy required.
- In series to increase the output voltage
- In parallel to increase the output current

Solar modules and panels

❖ **Mono-Si:**

- ➢ Crystal Lattice of entire sample is continuous.
- ➢ Since they are cut from single crystal, they gives the module a uniform appearance.

Advantages:

- ✓ Highest efficient module till now.
- ✓ Greater heat resistance
- ✓ Large share in the market.
- ✓ Long life time.

Disadvantages:

- ✓ More expensive to produce.
- ✓ High amount of Si is needed.
- ✓ High processing temperature and pressure.

Solar modules and panels

❖ **Poly-Si:**

- ➢ Composed of a number of different crystals, fused together to make a single cell.
- ➢ Have a non-uniform texture, visible crystal grain present due to manufacturing process.

Advantages:

- ✓ Moderate efficiency.
- ✓ Cost effective manufacture compared to the single crystal.
- ✓ Commonly available in market.

Disadvantages:

- ✓ Not as efficient as mono-crystal.
- ✓ Required large amount of Si.
- ✓ High processing temperature and pressure.

Solar modules and panels

❖ **Amorphous Si:**

➢ Non-crystalline allotrope of Si with no definite arrangement of atoms.

Advantages:

✓ Partially shade tolerant.
✓ More effective in hotter climate
✓ Uses less silicon-low processing temperature and pressure
✓ No aluminum frame is required

Disadvantages:

✓ Less efficient compared to mono and poly
✓ Less market share
✓ Takes up more space for same output
✓ Comparatively new technology- less proven reliability.

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