Recording the current- voltage characteristics of a solar battery as a function of the irradiance

objectives:

1-Recording the current-voltage characteristics of a solar battery.
2-Determinig the power P as a function of the load resistance
3-Determinig the maximum power P_{max} ,the associated load resistance R_{max} and the fill factor of a solar battery.

Theory:

_A solar cell is a semiconductor component at whose p/n transition the radiation energy of incoming sun light is directly converted into electrical energy. The semiconductor component is a photodiode with a large surface area constructed so that the light can penetrate the p/n transition through a thin n or p conducting layer (see Fig.1)and then creates electron-hole pairs. These are separated by the intrinsic electric field in the barrier layer and can migrate in the reverse direction. Electrons migrate into the p-doped region and the holes migrate into the p-doped region.

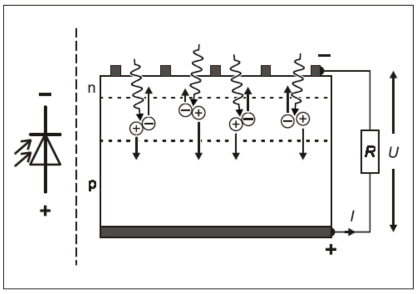


Fig. 1 Principle of operation of a solar

if the external metal contacts are shorted, a short-circuit current I_s flows in the reverse direction of the photodiode. This current is substantially proportional to the number of electron-hole pair created per unit time.i.e it is proportional to the irradiance of the incoming light and the surface area of the solar cell..

if the metal contacts are open ,this reverse current leads to an open-circuit voltage U_0 ,which in turn leads to an equal diffusion current I_D in the forward direction of the diode so that no current flows at all.

If a load with an arbitrary resistance R is connected the current I flowing through the load depends on the resultant voltage U between the metal contacts .In a simplified way .it can be considered to be the difference between the current I_s in the reverse direction and the current I_D of the non-irradiated semiconductor diode in forward direction.

$$\boldsymbol{I} = \boldsymbol{I_s}(\boldsymbol{\Phi}) - \boldsymbol{I_D}(\mathbf{U}) \qquad \text{eq.1}$$

In this way, the current-voltage characteristics typical of a solar cell are obtained (see Fig. 2). In the case of small load resistances, the solar cell behaves like a constant-current source as the forward current I_D can be neglected. In the case of greater load resistances, the behavior corresponds approximately to that of a constant-voltage source because then the current $I_D(U)$ increases quickly if the voltage changes slightly.

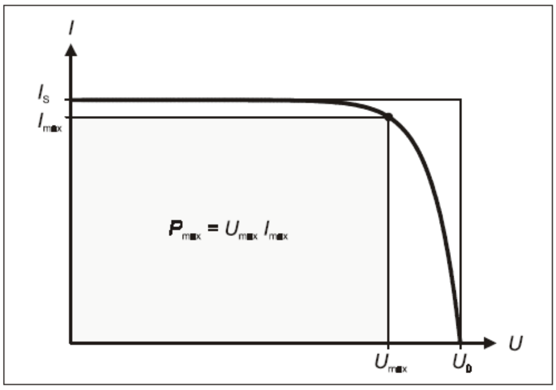


Fig. 2 I-V characteristic of a solar battery for a given irradiance

(U_{max} I_{max} :pint of maximum power)

the power delivered to a resistive load can, in general, be written as:

$$P = V \times I \qquad (2)$$

At the optimum value, we have

$$\frac{dP}{dV} = I + V \quad , \quad \frac{dP}{dV} = 0 \qquad (3)$$

or $$\frac{I}{V} = -\frac{dI}{dV} \qquad (4)$$

Equation (4) shows that at the optimum operating point the negative of the slope of the Battery characteristic equals the slope of the line drawn from the origin to the optimum point.

Now if P is plotted as a function of V , a peak will be obtained where one finds I_{max} and V_{max} (see fig. 4).

At a fixed irradiance, the power supplied by the solar cell depends on the load resistance R. The solar cell reaches its maximum power Pmax at a load resistance Rmax which, to a good approximation, is equal to the so-called internal resistance.

$$R_i = \frac{U_0}{I_s} \qquad \text{eq. 5}$$

This maximum power is smaller than the product of the open- circuit voltage and the short-circuit current (see Fig. II). The ratios often called fill factor.

$$F = \frac{P_{max}}{U_0 I_s} \qquad \text{eq.6}$$

Often several solar cells are combined to form a solar battery. Series connection leads to a greater open-circuit voltage U_0 whereas parallel connection leads to a greater short-circuit current I_S

. In the experiment, a series connection of four solar cells is set up.

Apparatus:

solar cell-plug-in board -pair of board holders-Potentiometer-bridging plugs-voltmeter-ammeter-halogen lamp housing-incandescent lamp-transformers connecting leads-saddle base.

Procedure:

1-The experimental setup is illustrated in Fig. 3.

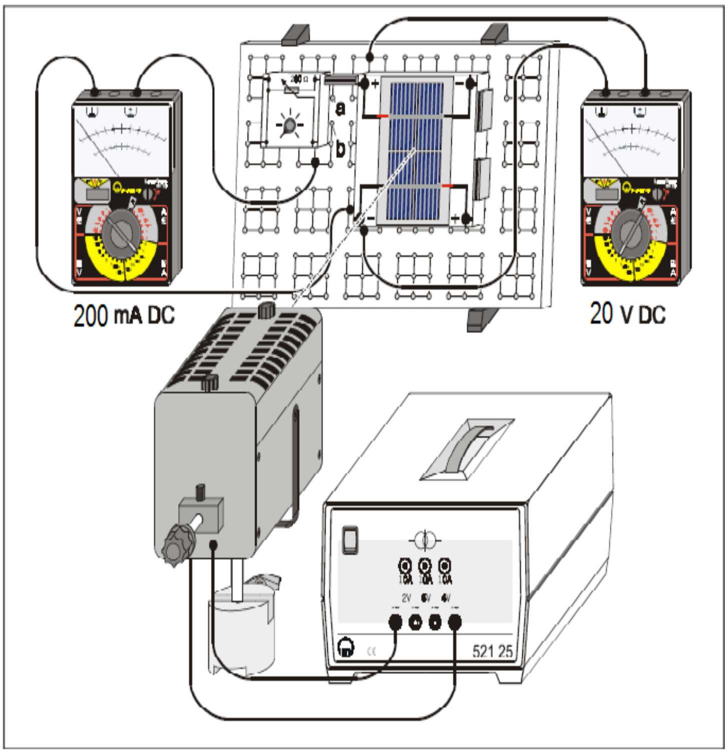


Fig. 3 Experimental setup for recording I-V characteristic of a solar cell

-Plug the STE solar cell into the plug-in board, and connect the upper negative pole to the lower positive pole using two bridging plugs (series connection of four solar cells).
-Plug in the potentiometer as a variable resistor, and connect it to the solar battery using bridging plugs.
- Connect the ammeter in series with the solar battery and the variable resistor. Select the measuring range 100 mA DC.
-Connect the voltmeter in parallel to the solar battery, and select the measuring range 3 V DC.
– Connect the halogen lamp to the transformer, and align it so that the solar battery is uniformly irradiated.

2-close the circuit ,first shorting the variable resistor with an additional bridging plug between the points **a** and **b** and choose the distance of the halogen lamp so that the short circuit is approximately 100 mA.
3-remove the shorting bridging plug, and increase the terminal voltage or decrease the current respectively, step by step by changing the load resistance .For each step read the current and the voltage ,and take them down. Record at least 15 readings.
4-Finally, interrupt the circuit ,and measure the open circuit voltage.

Measurements:

table:

I(mA)	V(v)	P(mW)

Results:

Graph:

Plot I versus v and P versus V on the same graph . see fig.4

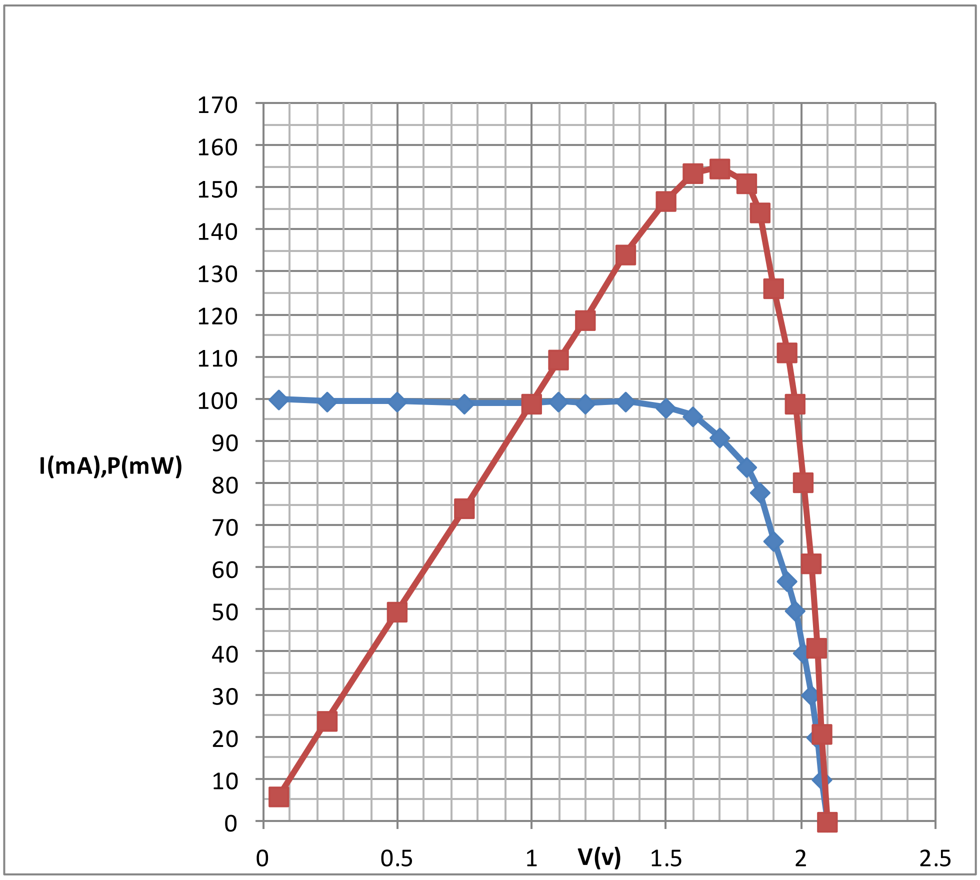


Fig. 4 I-V characteristic and P versus v of a solar cell

calculations:

-Find the values of P_{max} ,V_{max} , and I_{max} from the graph and then calculate the value of the optimum load resistance .

$$R_{max} = \frac{V_{max}}{I_{max}}$$

$$R_{max} = \frac{P_{max}}{I^2{}_{max}}$$

-prove that $\frac{I}{V} = -\frac{dI}{dV}$

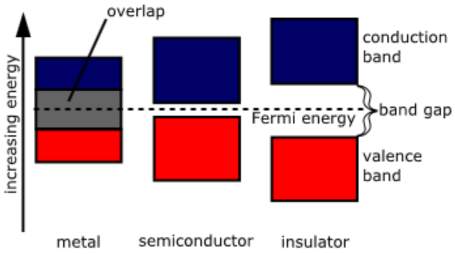
-Find the fill factor

Semiconductors and P-n Junction

What is a semiconductor?

Semiconductors are materials that have properties in between normal **conductors** (materials that allow electric current to pass, e.g. aluminium) and **insulators** (which block electric current, e.g. sulphur).

A useful way to visualize the difference between conductors, insulators and semiconductors is to plot the available energies for electrons in the materials. Instead of having discrete energies as in the case of free atoms, the available energy states form bands. Crucial to the conduction process is whether or not there are electrons in the conduction band. In insulators the electrons in the valence band are separated by a large gap from the conduction band, in conductors like metals the valence band overlaps the conduction band, and in semiconductors there is a small enough gap between the valence and conduction bands that thermal or other excitations can bridge the gap. With such a small gap, the presence of a small percentage of a doping material can increase conductivity dramatically.



Semiconductors fall into two broad categories. First, there are **intrinsic** semiconductors. These are composed of only one kind of material. Silicon and germanium are two examples. They are also called "undoped semiconductors" or "i-type semiconductors".

Extrinsic semiconductors are made of intrinsic semiconductors that have had other substances added to them to alter their properties.

Doping:

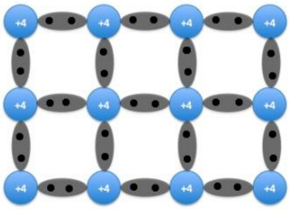
Doping is a technique used to vary the number of electrons and holes in semiconductors.

Doping creates N-type material when semiconductor materials from group IV are doped with group V atoms. P-type materials are created when semiconductor materials from group IV are doped with group III atoms.

N-type materials increase the conductivity of a semiconductor by increasing the number of available electrons; P-type materials increase conductivity by increasing the number of holes present.

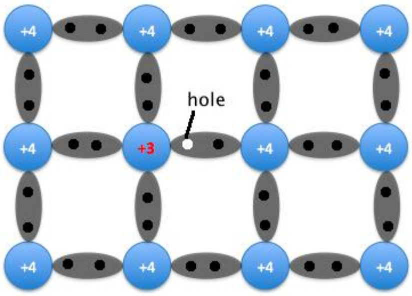
p-type

In a pure (intrinsic) Si or Ge semiconductor, each nucleus uses its four valence electrons to form four covalent bonds with its neighbors (see figure below). Each ionic core, consisting of the nucleus and non-valent electrons, has a net charge of +4, and is surrounded by 4 valence electrons. Since there are no excess electrons or holes In this case, the number of electrons and holes present at any given time will always be equal.



An intrinsic semiconductor. Note each +4 ion is surrounded by four electrons.

Now, if one of the atoms in the semiconductor lattice is replaced by an element with three valence electrons, such as a Group 3 element like Boron (B) or Gallium (Ga), the electron-hole balance will be changed. This impurity will only be able to contribute three valence electrons to the lattice, therefore leaving one excess hole (see figure below). Since holes will "accept" free electrons, a Group 3 impurity is also called an acceptor.

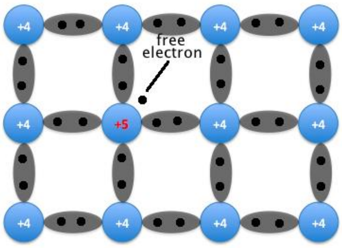


A semiconductor doped with an acceptor. An excess hole is now present.

Because an acceptor donates excess holes, which are considered to be positively charged, a semiconductor that has been doped with an acceptor is called a p-type semiconductor; "p" stands for positive. Notice that the material as a whole remains electrically neutral. In a p-type semiconductor, current is largely carried by the holes, which outnumber the free electrons. In this case, the holes are the majority carriers, while the electrons are the minority carriers.

n-type

In addition to replacing one of the lattice atoms with a Group 3 atom, we can also replace it by an atom with five valence electrons, such as the Group 5 atoms arsenic (As) or phosphorus (P). In this case, the impurity adds five valence electrons to the lattice where it can only hold four. This means that there is now one excess electron in the lattice (see figure below). Because it donates an electron, a Group 5 impurity is called a donor. Note that the material remains electrically neutral.



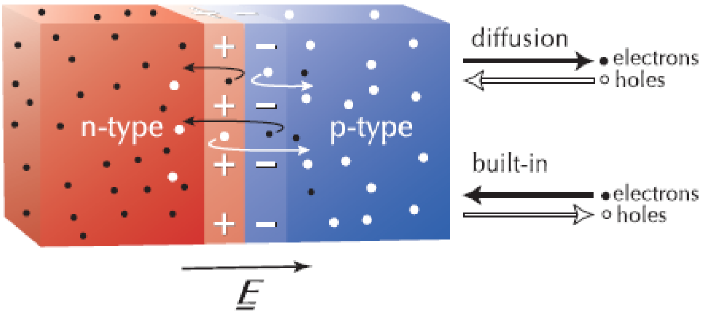
A semiconductor doped with a donor. A free electron is now present.

Donor impurities donate negatively charged electrons to the lattice, so a semiconductor that has been doped with a donor is called an n-type semiconductor; "n" stands for negative. Free electrons outnumber holes in an n-type material, so the electrons are the majority carriers and holes are the minority carriers.

P-n Junction

P-n junctions are formed by joining n-type and p-type semiconductor materials, as shown below. Since the n-type region has a high electron concentration and the p-type a high hole concentration, electrons diffuse from the n-type side to the p-type side. Similarly, holes flow by diffusion from the p-type side to the n-type side. If the electrons and holes were not charged, this diffusion process would continue until the concentration of electrons and holes on the two sides were the same, as happens if two gasses come into contact with each other. However, in a p-n junction, when the electrons and holes move to the other side of the junction, they leave behind exposed charges on dopant atom sites, which are fixed in the crystal lattice and are unable to move. On the n-type side, positive ion cores are exposed. On the p-type side, negative ion cores are exposed. An electric field Ê forms between the positive ion cores in then-type material and negative ion cores in the p-type material. This region is called the "depletion region" since the electric field quickly sweeps free carriers out, hence the region is depleted of free carriers. A "built in" potential Vbi due to Ê is formed at the junction. The animation below shows the formation of the Ê at the junction between and p-type material.

A mobile electron or hole near the "built-in" electric field will be attracted and swept back into its original volume. At the junction there are two effects occurring (1) diffusion with electrons moving from n-type to p-type and, (2) the "built in" electric field sweeping locally affected electrons back into the n-type volume. The holes are affected similarly but in opposite directions.



photodiode

A photodiode is a p-n junction or PIN structure. When a photon of sufficient energy strikes the diode, it excites an electron, thereby creating a free electron (and a positively charged electron hole). This mechanism is also known as the inner photoelectric effect. If the absorption occurs in the junction's depletion region, or one diffusion length away from it, these carriers are swept from the junction by the built-in electric field of the depletion region. Thus holes move toward the anode, and electrons toward the cathode, and a photocurrent is produced. The total current through the photodiode is the sum of the dark current (current that flows with or without light) and the photocurrent, so the dark current must be minimized to maximize the sensitivity of the device.

Photovoltaic mode

When used in zero bias or *photovoltaic mode*, the flow of photocurrent out of the device is restricted and a voltage builds up. This mode exploits the photovoltaic effect, which is the basis for solar cells – a traditional solar cell is just a large area photodiode.