Solutions week 6

2015-02-27, Niklas Sköld

Cameras

1. A signal of $\bar{n} = 10$ gives you $\sigma_{shot} = \sqrt{10}$

   a) $SNR = \frac{\bar{n}}{\sqrt{\sigma_{shot}{}^2 + \sigma_{read}{}^2}} = \frac{10}{\sqrt{10+12^2}} = 0.8$

   b) You are in the shot noise limited regime when the shot noise exceeds the read noise ->$\bar{n} = \sigma_{read}{}^2 = 12^2$

      ⇨ To increase the signal from 10 to 12^2=144 you should binn the pixels 4x4. This gives a factor 16 increase in your signal before the readout noise is added.

      ⇨ $SNR = \frac{160}{\sqrt{160+12^2}} = 9.2$

2. The charge accumulates where stare 2 is imaged by a rate 40+30= 70 counts/s.
   The maximum integration time is then 16000/70=228 s
   After this time an average signal of $\bar{n} = 20 * 228 = 4560$ has accumulated
   The signal thus reads $n = \bar{n} \pm \sigma_{shot} = \bar{n} \pm \sqrt{\bar{n}}$

   At the same time average background signal accumulates $\overline{bg} = 30 * 228 = 6840$

   ⇨ $bg = \overline{bg} \pm \sigma_{bg} = \overline{bg} \pm \sqrt{\overline{bg}}$

   ⇨ $SNR = \frac{\bar{n}}{\sqrt{\sigma_{shot}{}^2 + \sigma_{bg}{}^2}} = \frac{4560}{\sqrt{4560+6840}} = 43$

3. a) Fill factor: fraction of pixel area that is occupied by the photodetector. It is lower for the CMOS camera since there are several transistors sitting on each pixel. This gives a fast readout speed but it also removes space that could have been used to collect light.

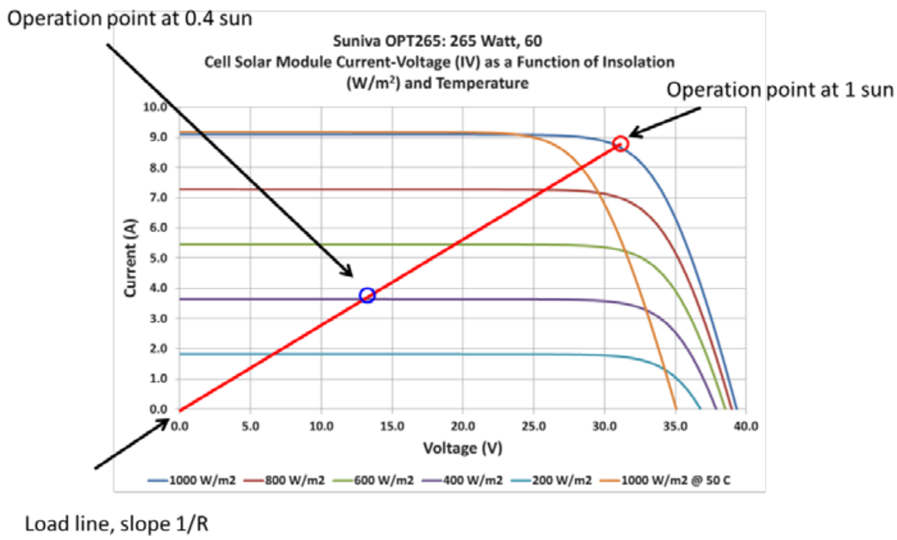
   b) SNR will be a factor $\sqrt{0.7/0.95}$ worse

Solar cells

1. Suniva
   a) They are connected in series in order to build up a substantial voltage.
   b) Each cell contributes with $V = \frac{V_{mp}}{60} = 0.512\ V$ and $I = I_{mp} = 8.64\ A$
   c) In order to stay at maximum power you should apply a load of

$$R = \frac{V_{mp}}{I_{mp}} = \frac{30.7}{8.64} = 3.55\ \Omega$$

   d) In the IV curve for different illumination powers you can draw the load line



For 0.4 Suns we will end up at the blue point. This is at the flat part of the IV curve where the current essentially is the short circuit current. The photogenerated current at 0.4 suns is of course 0.4 * photogenerated current at 1 sun. This gives:

$$I = I_{sc}(0.4\ sun) = 0.4 * I_{sc}(1\ sun) = 0.4 * 9.12 = 3.65\ A$$

The power generated is thus

$$P = I^2 * R = 3.65^2 * 3.55 = 47.3\ W$$

We can find the area (A) from the fact that under 1 sun illumination (1000 W/m^2) the efficiency is 16.33%

$$1000 * A * 0.1633 = 265\ W$$

⇨ $A = 1.62 m^2$

For an input power density of 400 W/m^2on the Area 1.62m^2 generating a output power 47.3 W the efficiency is:

$$\eta = \frac{47.3}{400 * 1.62} = 7.3\%$$

Note: this shows that as the light intensity changes the load must also be changed.

2. a) Solar cell development

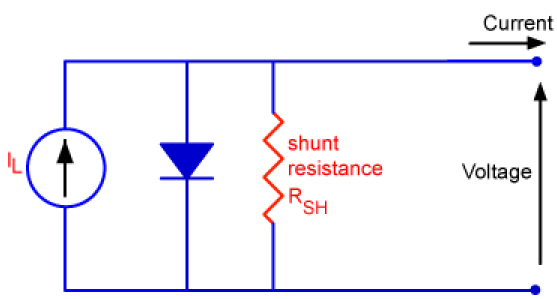
Test 1. The short circuit current has dropped. This should be equal to the photogenerated current so the JV curve indicates that not all of the light is absorbed.

It could be so that the cell is too thin altogether but GaAs is a direct bandgap material and most of the light should have been absorbed in the 3.5 µm given.

It could also be so that the diffusion length is too short so that the photogenerated minority carriers doesn't reach the junction. A short diffusion length would be due to a too high doping level. As free carriers would be scattered more frequently on dopant ions. But if your doping sources are calibrated properly this shouldn't be the case.

The most likely scenario is that the authors of the study used a antireflective coating or surface texture to minimize reflection losses at the front surface. The drop in current looks roughly like 30% which is the reflectivity from a semiconductor. It could also be so that the contacts shadow too much of the solar cell.

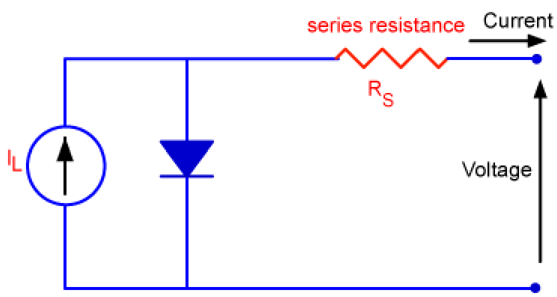
Test 2. This looks like a **low** shunt resistance: a resistance in parallel with the diode creating an alternative current path. The impact is greatest at low biases so this is where the curve deviates from the reference curve. At high biases the diode has already started to turn on so a large current can run this way. Then it doesn't matter if you have a little leakage in parallel.



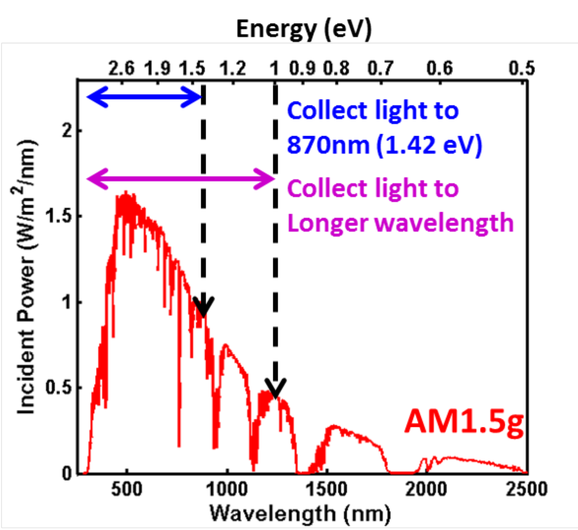
The shunt resistance comes from leakage due to defects where the minority carriers can recombine. This can be due to surface recombination centres or recombination at the contacts. Prevent the minority carriers from reaching these sites. Passivate surface with a high bandgap material. Dope the regions around contacts heavily so that the high concentration of majority carriers prevents minority carriers from going there.

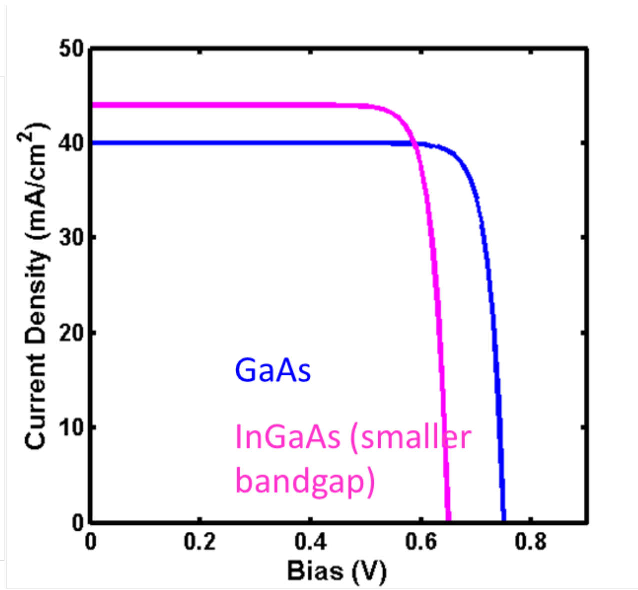
Test 3. This looks like a high series resistance. It mainly changes the IV curve close to open circuit. The diode "sees" the voltage V+I*Rs. At low V nothing really changes since you are far from turn on. At higher bias the the I*Rs term is what pushes the diode over the edge and it turns on a bit sooner than it would if there was no series resistance.

Series resistances come from various current pathways. Perhaps the contacts are spaced too far apart. Perhaps the contact fingers need to be wider. Perhaps you need to anneal the contacts at higher temperature so that they mix properly with the semiconductor.



2. b)





Smaller bandgap: More photons can be collected

⇒ Higher current

But the diode turns on earlier.

⇒ Current cannot be sustained at high voltages

2. c

We estimate the point where the J*V will have its maximum value. It will be somewhere around the "knee".

	Test 1	Test 2	Test 3
J_{mp}	29	32	38
V_{mp}	0.72	0.71	0.62

From this we calculate the maximum power density:

$$P_{max} = J_{mp} * V_{mp}$$

And calculate the efficiency

$$\eta = \frac{P_{max}}{P_{in}} = \frac{P_{max}}{100\ mW/cm^2}$$

	Test 1	Test 2	Test 3
P_{max} (mW/cm^2)	20.9	22.7	23.6
η (%)	20.9	22.7	23.6

The three parameters that represent the characteristics of the solar cell are:

J_{sc} Read from graph

V_{oc} Read from graph

FF $FF = \frac{J_{mp}*V_{mp}}{J_{sc}*V_{oc}}$

	Test 1	Test 2	Test 3
J_{sc} ($mA/\ cm^2$)	30	40	40
V_{oc} (V)	0.8	0.8	0.8
FF (%)	87%	71%	74%