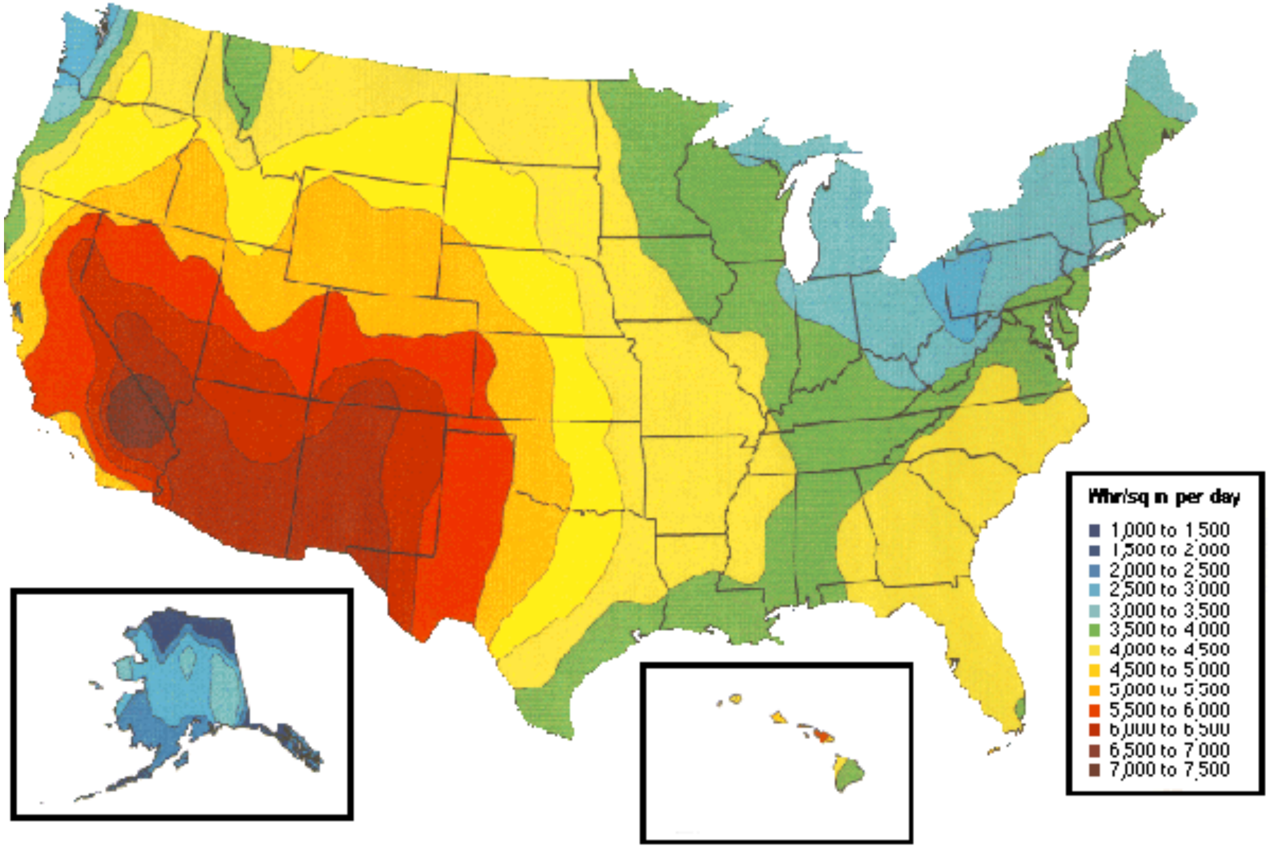
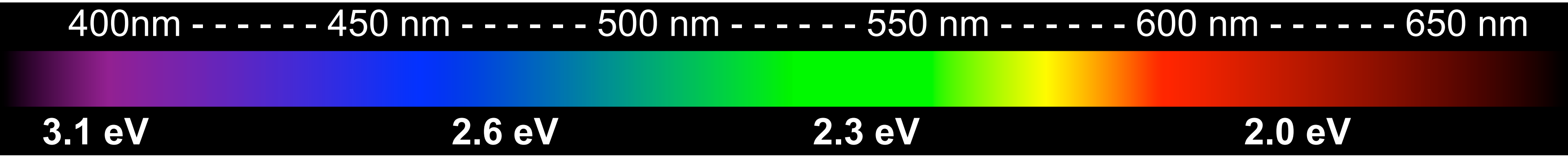
8.1 – Photovoltaics (Solar Cells) and Photodiodes (Detectors)



PN Junction Under Illumination



- Hit Si with λ_{photon}<1.1 μm (E_{photon}> 1.12 eV)
  1 photon = 1 e-h pair

Example, hit 1 cc of Si with 10^{13} photons of light every 1 μs. **Generates excess carriers!**

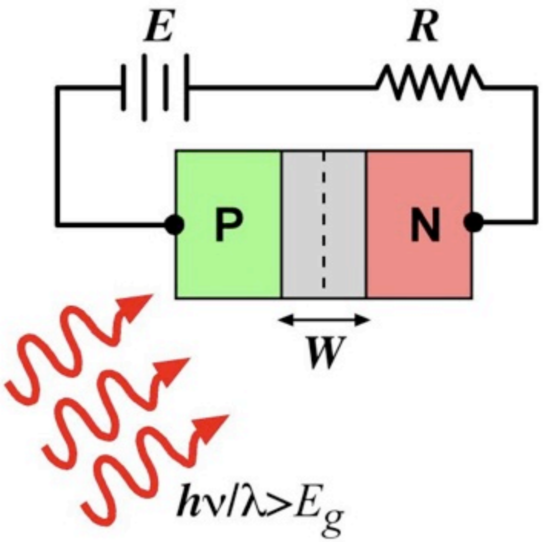
$$g_{op} = 10^{13} / cc - \mu s$$

Minority carrier lifetime is $\tau_n \sim \tau_p = 5$ μs.

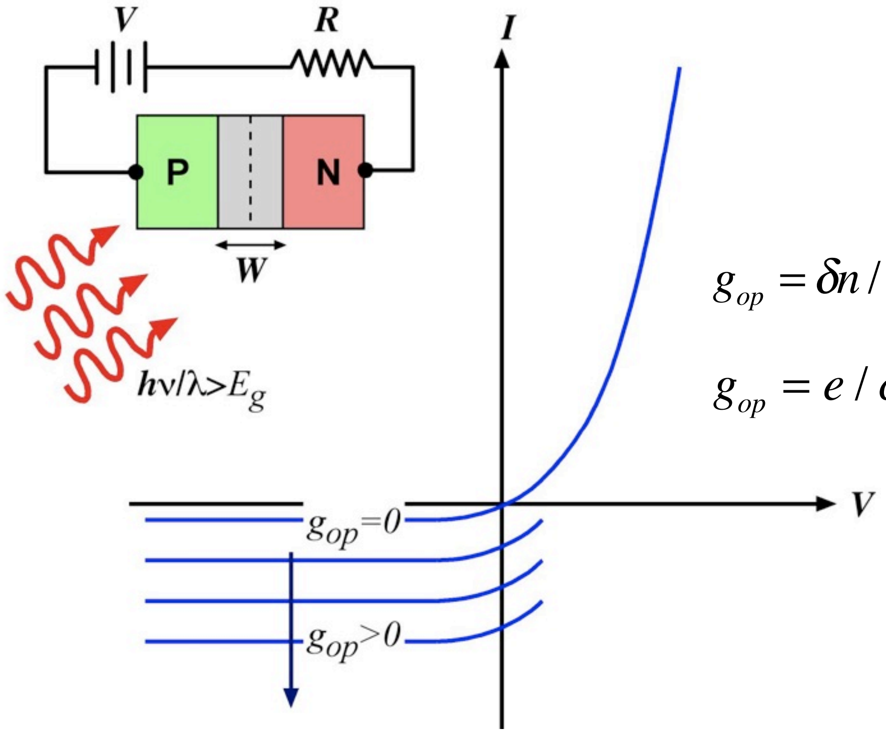
$$\delta n = g_{op} \tau_n \qquad \delta p = \delta n = 5 \times 10^{13} / cc$$

Generation vs. recombination!

- LETS COLLECT OPTICALLY GENERATED CHARGE… BUT HOW?

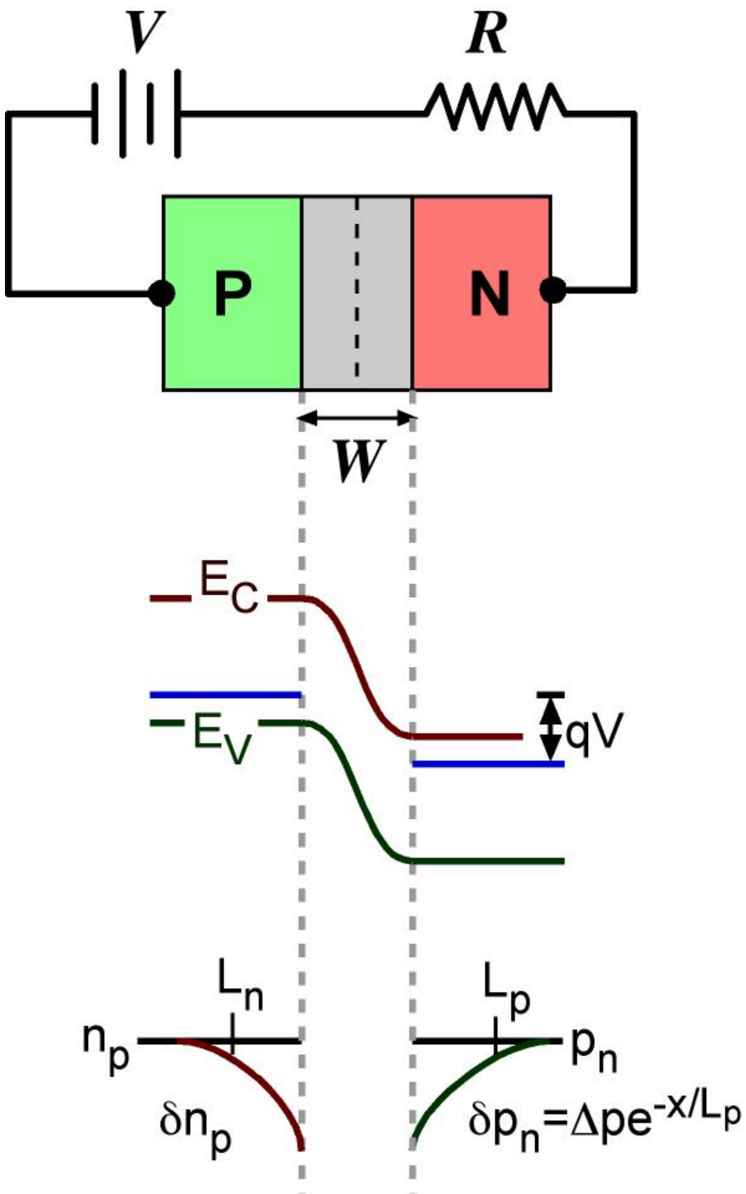


Diode Under Illumination



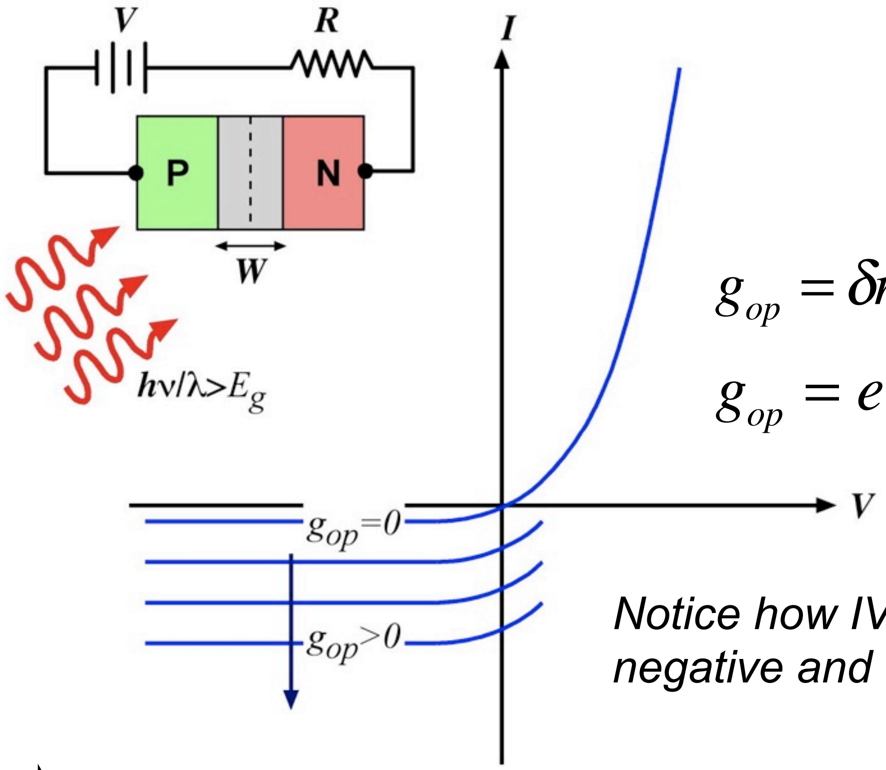
$$g_{op} = \delta n / \tau_n$$

$$g_{op} = e / cc - \mu s$$



- Reverse biased diode… lets ask some questions:
- Carriers generated out in the bulk of the p and n… do they do anything?
- Carriers generated inside the depletion region, what happens?
- Carriers generated within L_p of depletion? Do they do anything? Which matters, majority or minority?

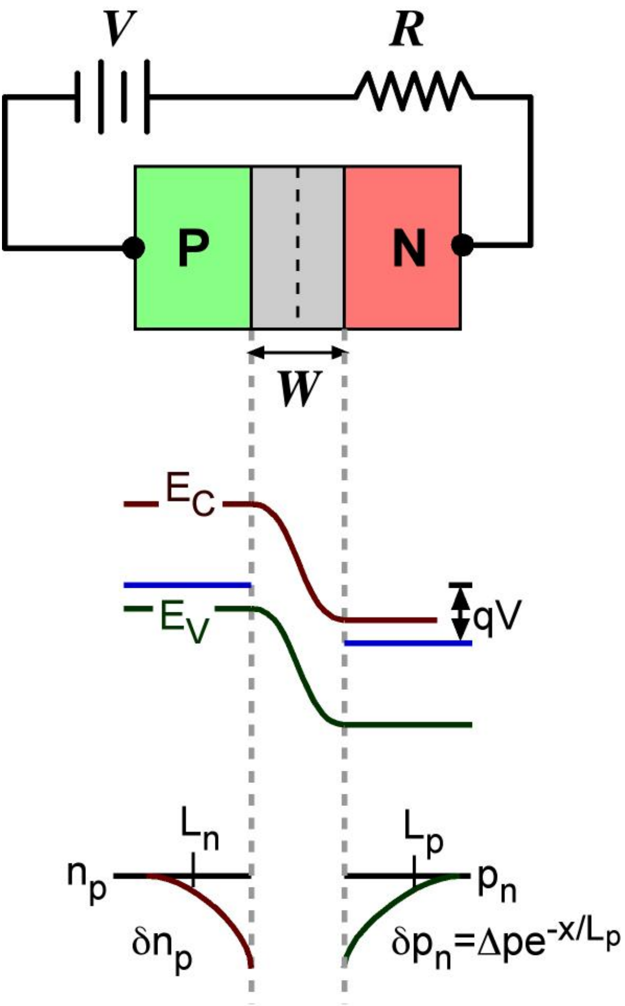
Diode Under Illumination



$$g_{op} = \delta n / \tau_n$$

$$g_{op} = e / cc - \mu s$$

Notice how IV-plot shifts negative and the sign for I_{op}



- $I_{op} = q \times g_{op} \times A \times width \quad = q g_{op} A \left(L_p + L_n + W \right)$
- $I = I_0 \left(e^{qV/kT} - 1 \right) - I_{op}$

$$= qA \left(\frac{L_p}{\tau_p} p_n + \frac{L_n}{\tau_n} n_p \right) \left(e^{qV/kT} - 1 \right) - qAg_{op} \left(L_p + L_n + W \right)$$

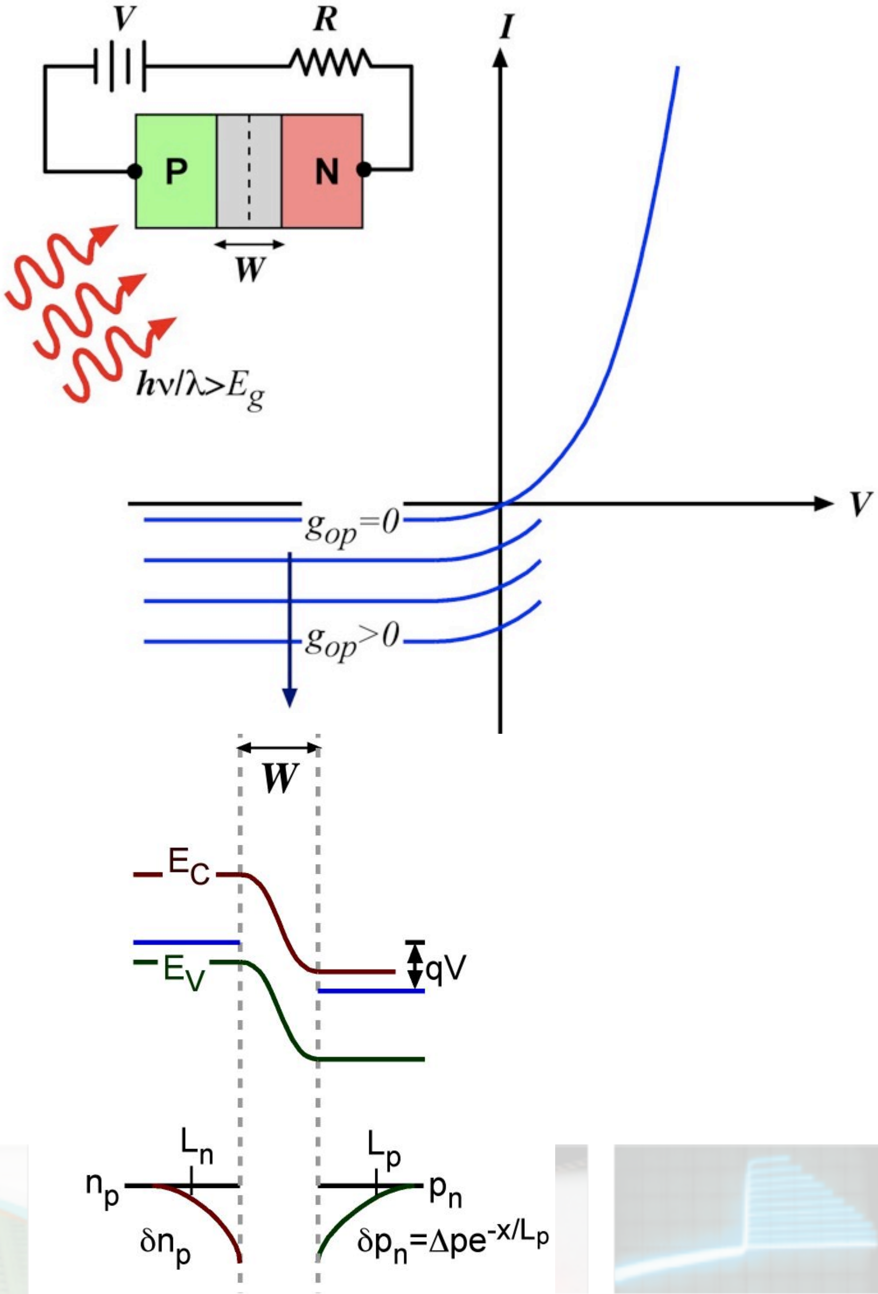
Review! Take a Break!

- Carriers generated out in the bulk of the p and n… do they do anything?

- Carriers generated inside the depletion region (W), what happens?

- Carriers generated within a diffusion length (L) of depletion? Do they do anything? Which matters, majority or minority?

- The optically generated current, do I add it or subtract it from the diode current?



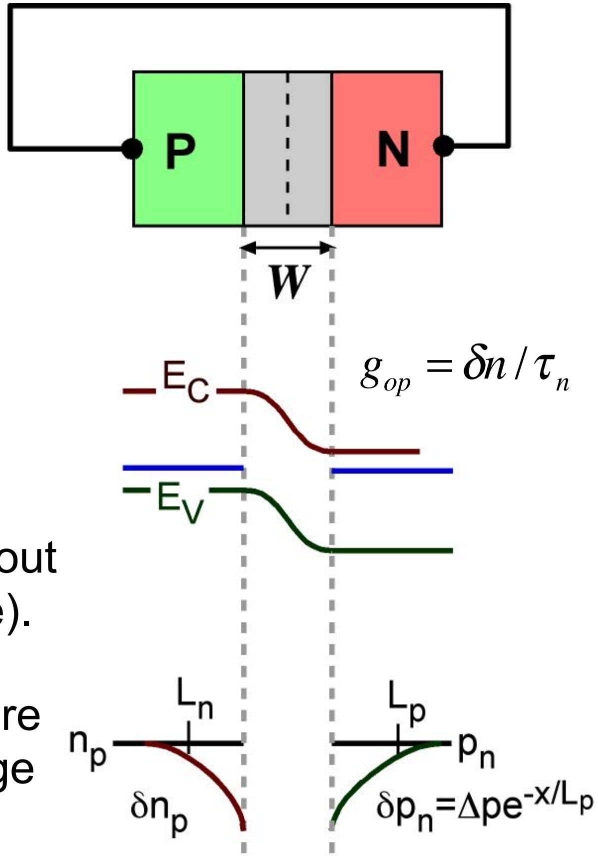
Diode Under Illumination

- **CASE #1** of 3: **<u>shorted</u> (V=0)…. what is I?**

$$I = I_0\left(e^{qV/kT} - 1\right) - I_{op} \qquad I_{op} = qAg_{op}\left(L_p + L_n + W\right)$$

☆ $$I = I_0\left(e^{0} - 1\right) - I_{op}$$

$$I = -I_{op}$$



$g_{op} = \delta n / \tau_n$

$\delta p_n = \Delta p e^{-x/L_p}$

- All we are left with is optically generated carriers inside depletion width W or within L of depletion region.

- One photon, does it result in 2q or 1q collected? Think about the complete circuit (q that must go through the external wire).

- q=1e per photon (only one carrier has to go through the wire to come around and recombine with the other opposite charge carrier).

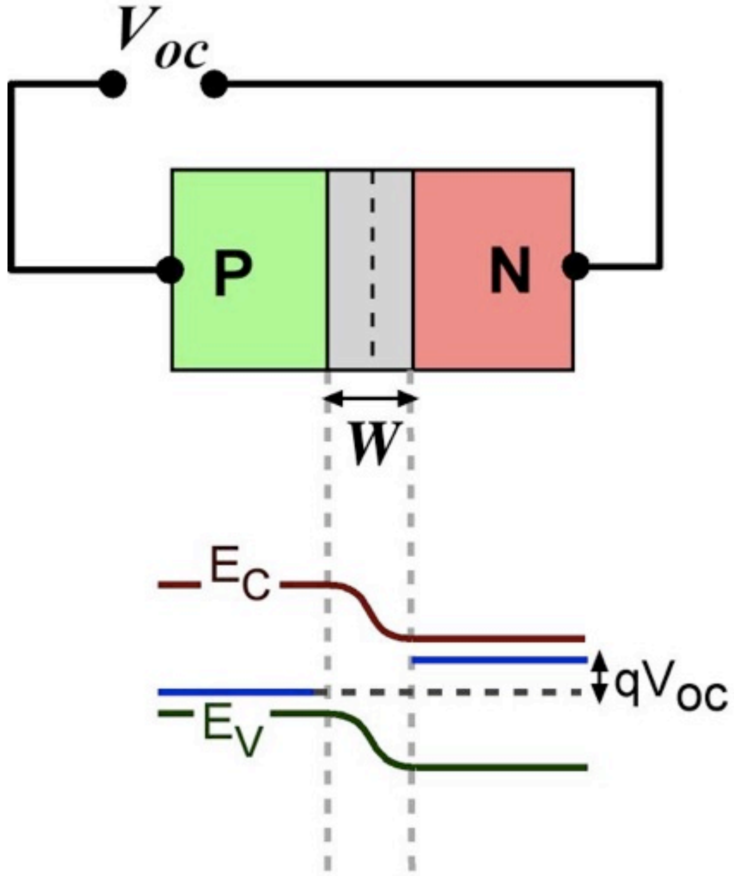
- Which way is the current flow in the top wire, to the left or to the right?

- What doping levels would give you MAXIMUM current if light hits the whole diode?

$$W = \sqrt{\frac{2\varepsilon kT}{q^2}\left(\ln\frac{N_A N_D}{n_i^2}\right)\left(\frac{1}{N_A} + \frac{1}{N_D}\right)} \qquad L_p = \sqrt{D_p \tau_p} \qquad D_p = \frac{kT}{q}\mu_p \qquad \tau_p = \frac{1}{\alpha_r (n_0 + p_0)}$$

Diode Under Illumination

- **CASE #2: open circuit, what will happen?**



☆ $$I = 0 = I_0\left(e^{qVoc/kT}-1\right)-I_{op}$$

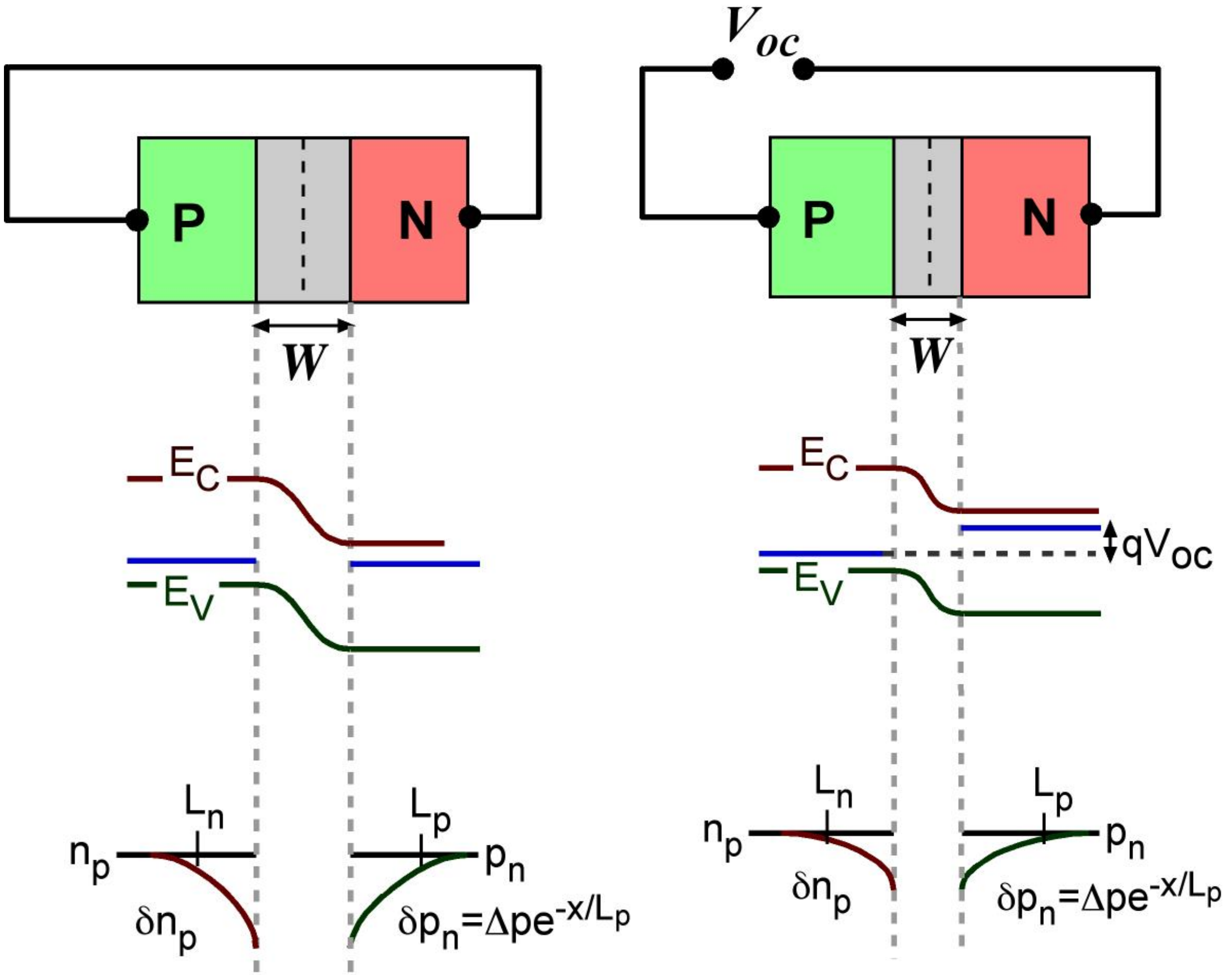
$$V = V_{oc} = \frac{kT}{q}\ln\left[{}^{I_{op}}\!/\!{}_{I_0} + 1\right]$$

$$= \frac{kT}{q}\ln\left[\frac{L_p+L_n+W}{{}^{L_p}\!/\!{}_{\tau_p}\, p_n + {}^{L_n}\!/\!{}_{\tau_n}\, n_p} g_{op}+1\right]$$

- V_{oc} will always be less than V_0 (contact potential)… why?
- FYI, this effect is referred to as the photo<u>voltaic</u> effect!

- Okay, great. But lets make this useful…. what is missing?

Think, if we generate power, how do we use it…

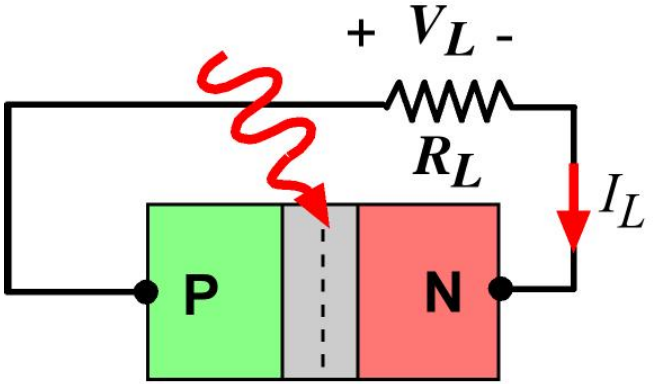


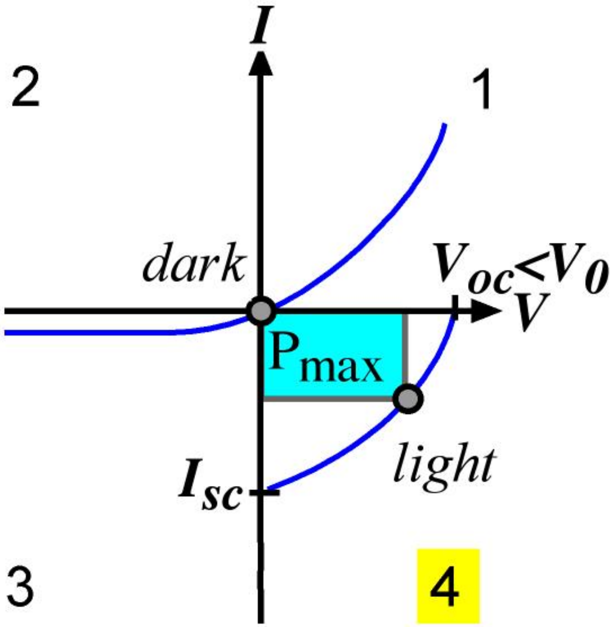
Photovoltaics

- Photovoltaic: powers external load, used as solar cell!
- Our circuit automatically puts us in quadrant #4, how?
- What are these?

  I_{SC}
  V_{OC}
  P_{MAX}

Note, Pmax has negative # only because measured w/ respect to the diode, a resistor (the load) does not care which direction current goes through it!





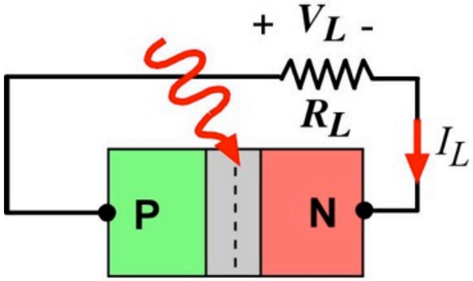
Photovoltaics

- You must set R_L for max power! ☆

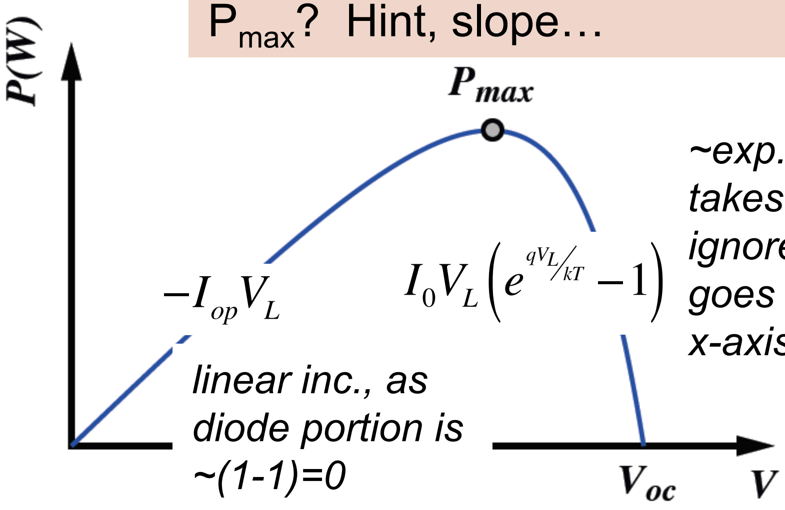
$$I_{op} = qAg_{op}\left(L_p + L_n + W\right)$$

$$I = I_0\left(e^{qV/kT} - 1\right) - I_{op}$$

$$P = IV_L = I_0V_L\left(e^{qV_L/kT} - 1\right) - I_{op}V_L$$



- So how can we solve for P_{max}? Hint, slope…

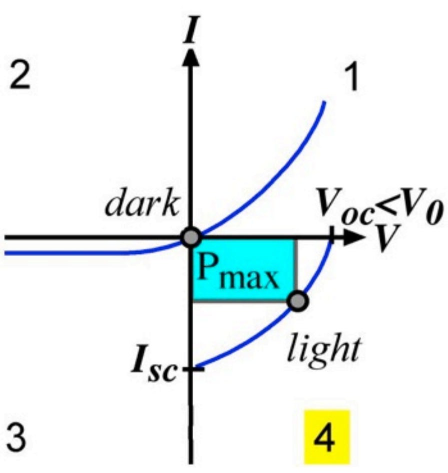


$-I_{op}V_L$

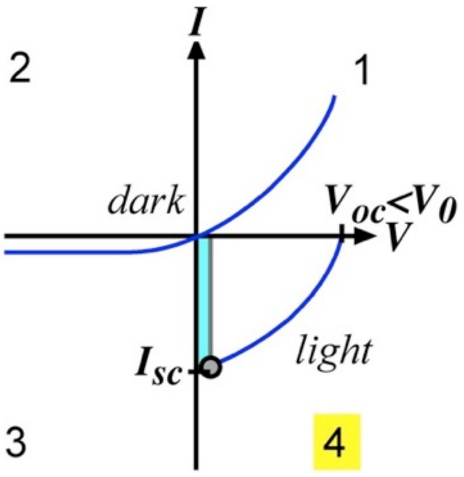
$I_0V_L\left(e^{qV_L/kT} - 1\right)$

linear inc., as diode portion is ~(1-1)=0

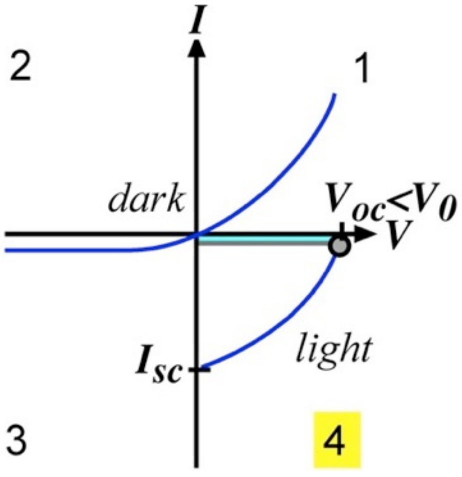
~exp. fall off takes over, ignore once goes below x-axis…



Good design!

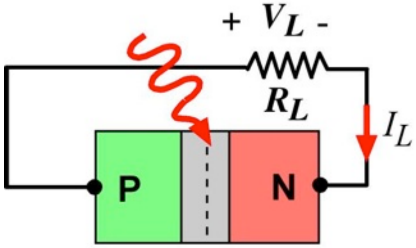


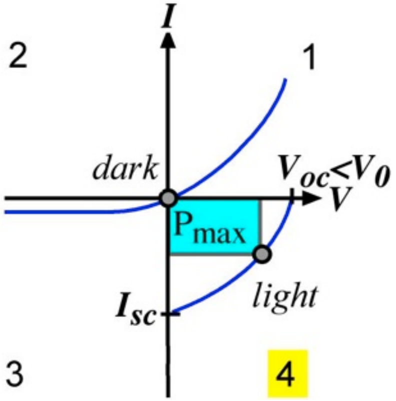
Poor design!

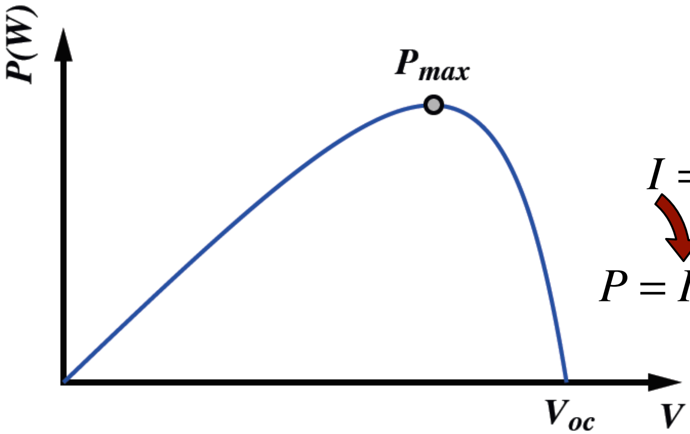


Poor design!

Photovoltaics – Solve for P_{max}







$$I_{op} = qAg_{op}\left(L_p + L_n + W\right)$$

$$I = I_0\left(e^{qV/kT} - 1\right) - I_{op}$$

$$P = IV = I_0V\left(e^{qV/kT} - 1\right) - I_{op}V$$

1. $P = IV = \boxed{I_0V}\boxed{\left(e^{qV/kT} - 1\right)} - I_{op}V$

2. $\frac{dP}{dV} = \boxed{I_0}\left(e^{qV/kT} - 1\right) + I_0V\boxed{\frac{q}{kT}\left(e^{qV/kT}\right)} - I_{op} = 0$

use product rule… and equate it to zero (P_{max})

3. $I_0\left(e^{qV/kT} - 1\right) + I_0V\frac{q}{kT}\left(e^{qV/kT}\right) = I_{op}$

4. $\left(e^{qV/kT} - 1\right) + V\frac{q}{kT}\left(e^{qV/kT}\right) = \frac{I_{op}}{I_0}$

5. $e^{qV/kT} + V\frac{q}{kT}\left(e^{qV/kT}\right) = \frac{I_{op}}{I_0} + 1$

6. $\left(1 + V\frac{q}{kT}\right)\left(e^{qV/kT}\right) = \frac{I_{op}}{I_0} + 1$

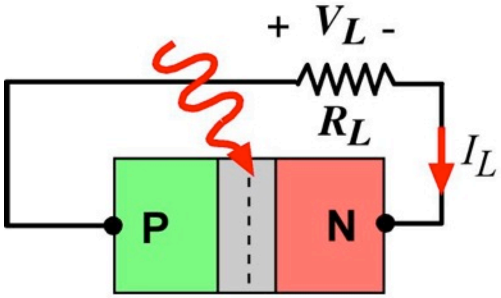
7. $\left(V\frac{q}{kT}\right)\left(e^{qV/kT}\right) = \frac{I_{op}}{I_0}$

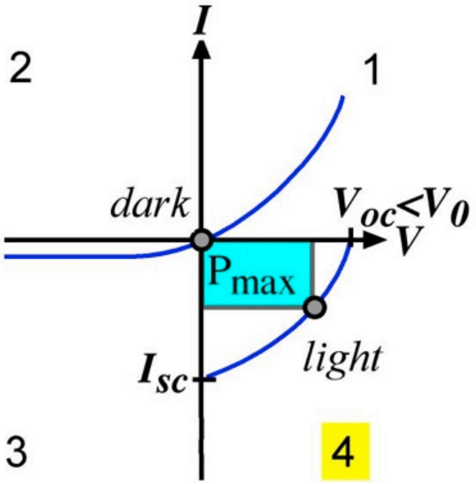
at P_{max}, I_{op} and V are large enough, so simplify!

8. $at\ P_{\max} \Rightarrow \quad I_{op} = I_0\, e^{qV/kT}\, V\frac{q}{kT}$

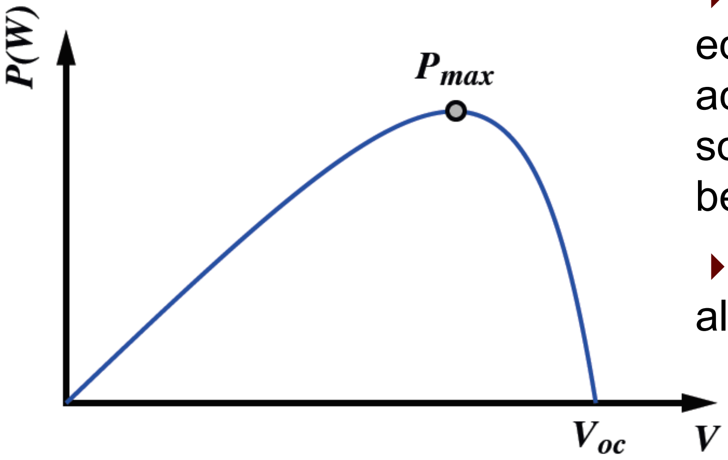
Lets examine in more detail…

Photovoltaics – Solve for P_{max}



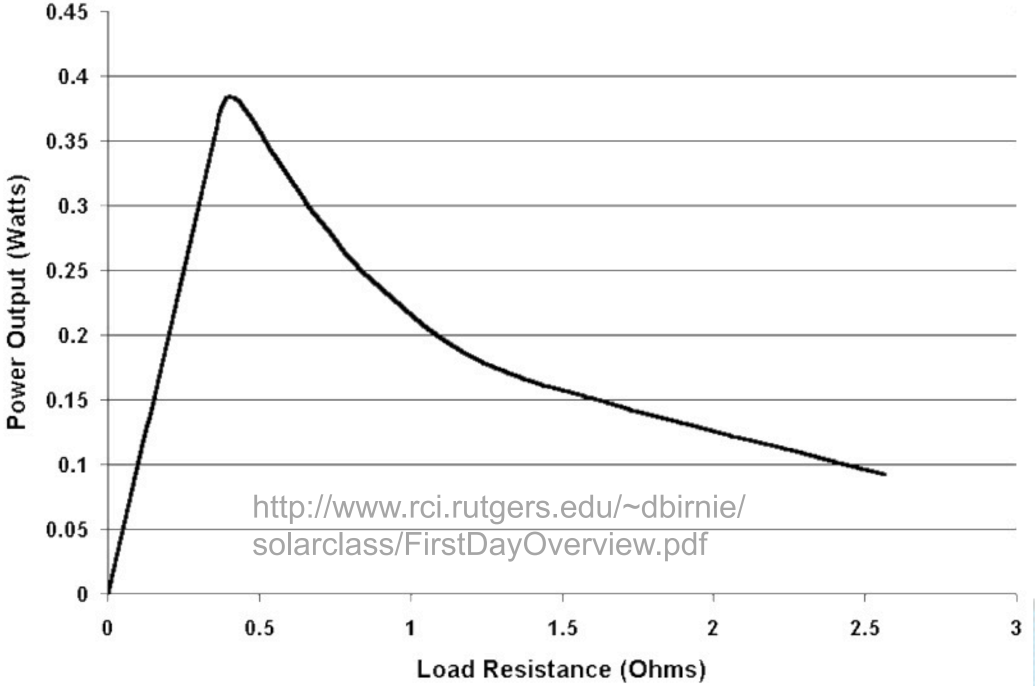


$$at\ P_{\max} \Rightarrow \quad I_{op} = I_0\, e^{qV/kT}\, V \frac{q}{kT}$$



- So you could use the equation, and voltage drop across the resistor to get a solution like that shown below…
- Is that solution good for all times of day?

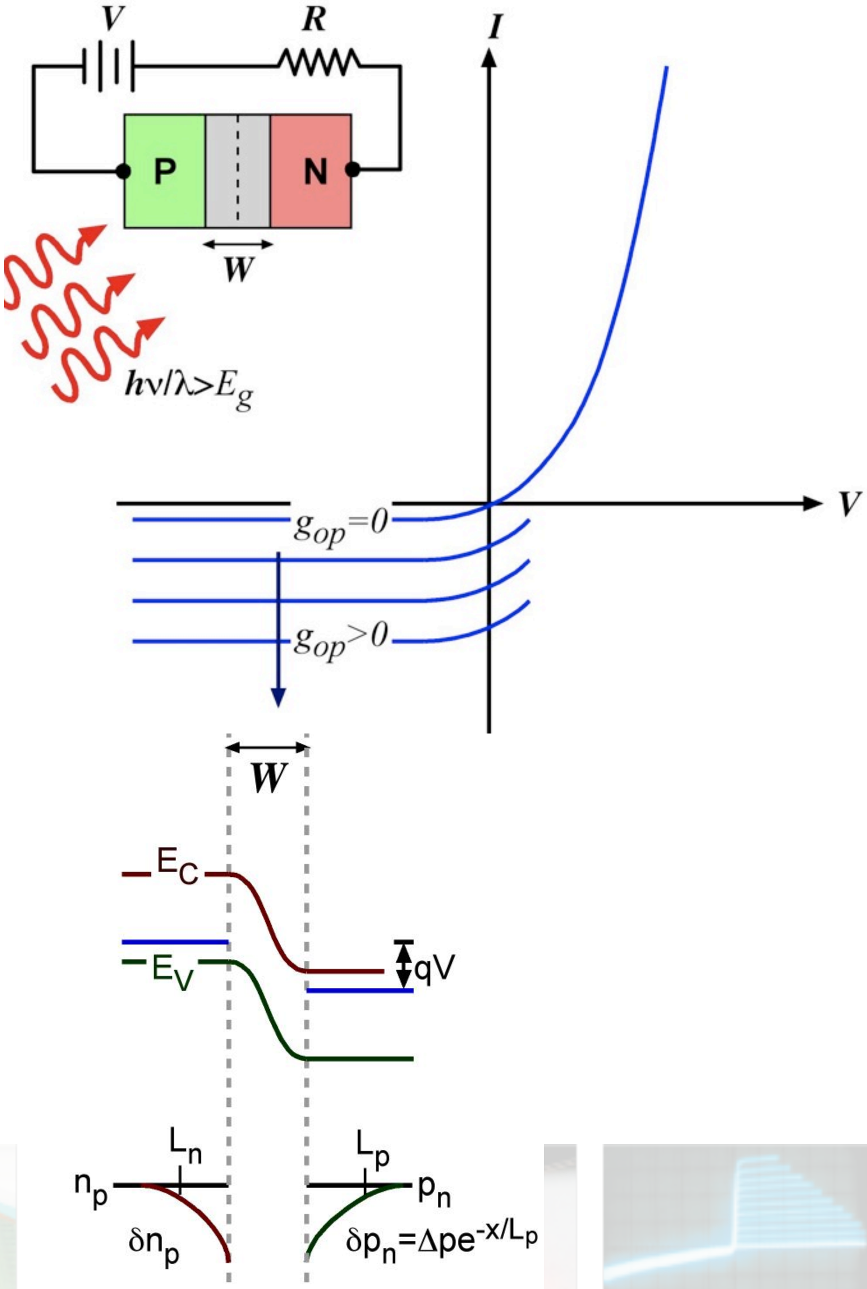
http://en.wikipedia.org/wiki/Maximum_power_point_tracker



http://www.rci.rutgers.edu/~dbirnie/solarclass/FirstDayOverview.pdf

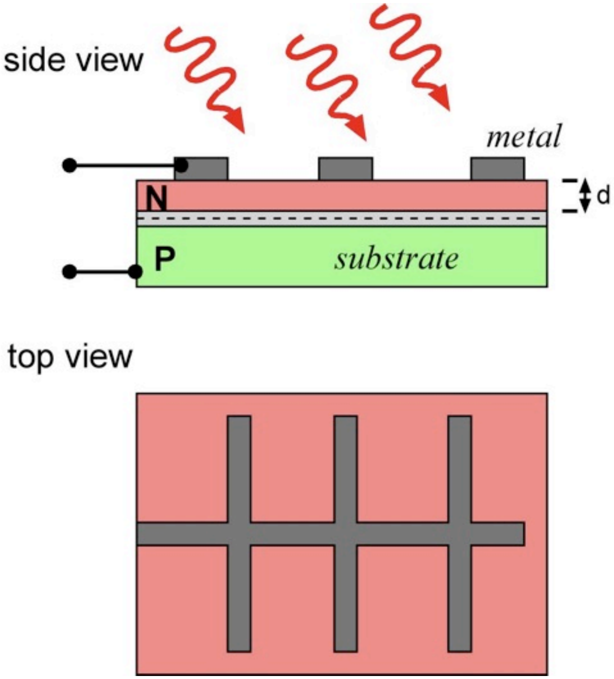
Review! Take a Break!

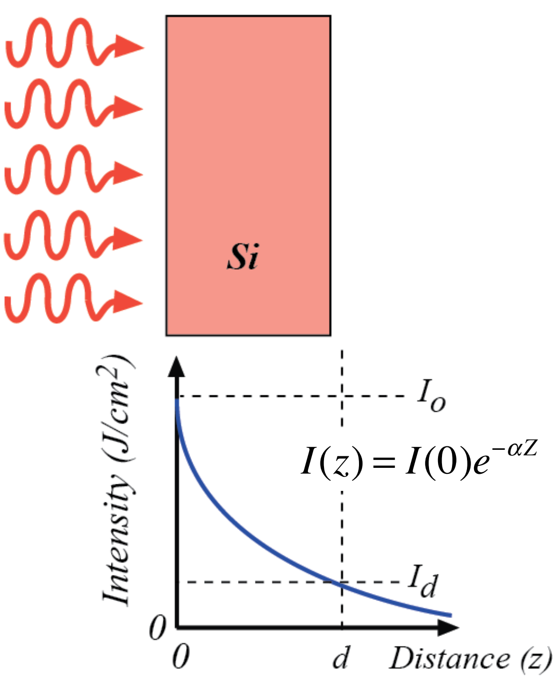
- What happens to the diode at the right if short circuit the wires?
- What happens remove the battery and resistor (cut the wires)?
- If I want to use this for power generation, what one component do I need to add?
- To maximize power generation, what needs to be optimized?



Photovoltaics – Best Design

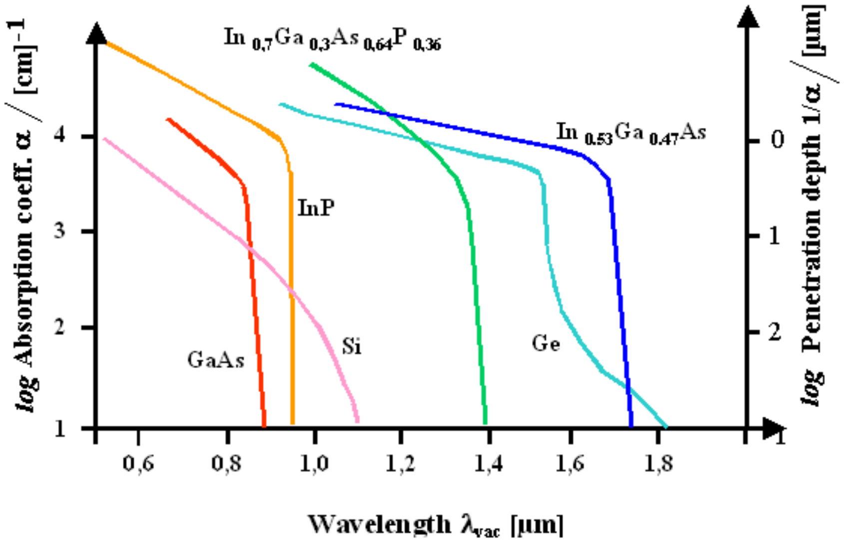
- Design a fast solar car
- *large surface area*
- *minimal electrode area*
- *thin n-layer (why?)*



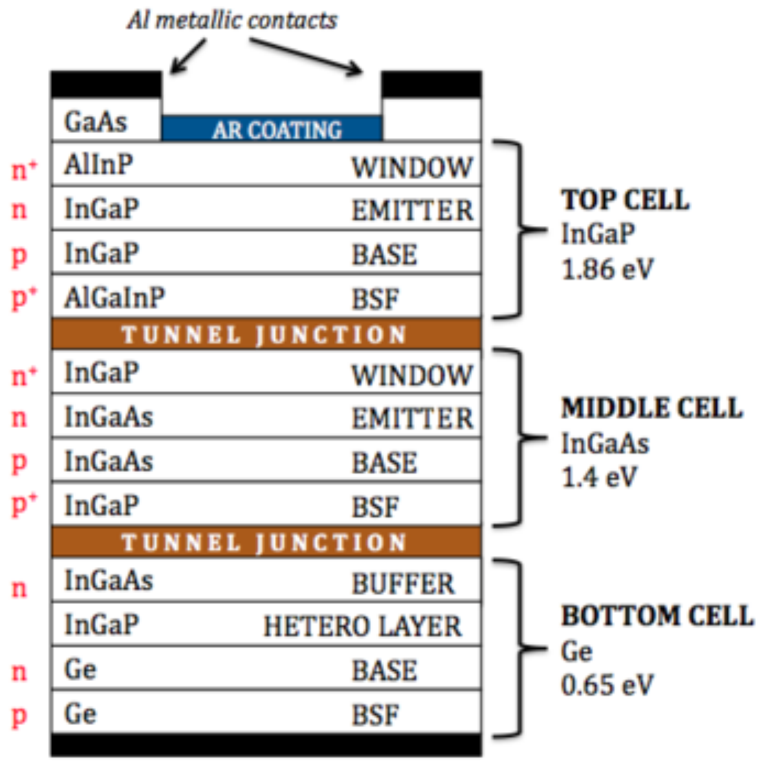


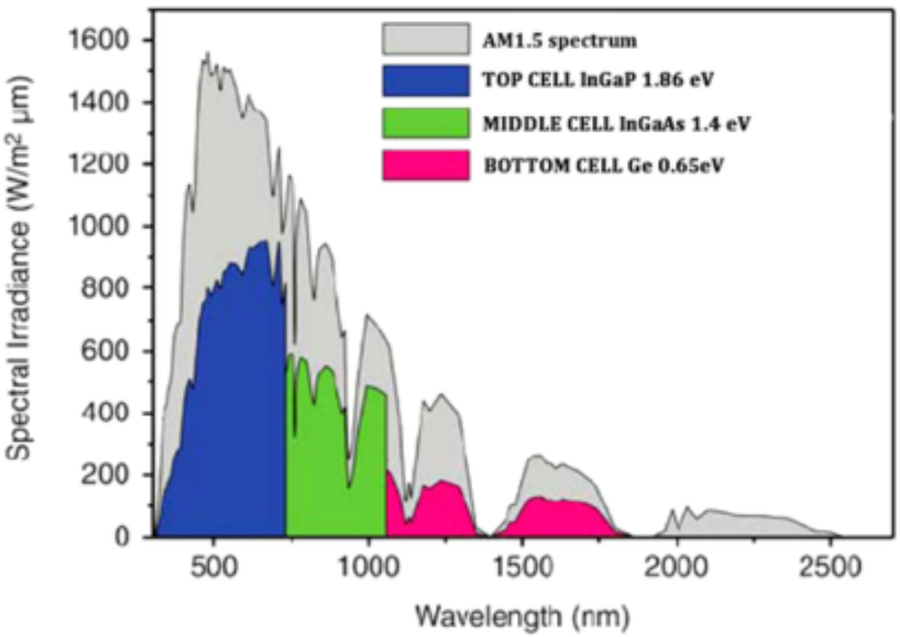
- So make n-layer thin, but there is still an efficiency problem, a lot of the blue and green light (2.2 eV) is still absorbed before reaches depletion region…

- To solve this, some of the most efficient solar cells are 'multi-junction' solar cells… (next slide).

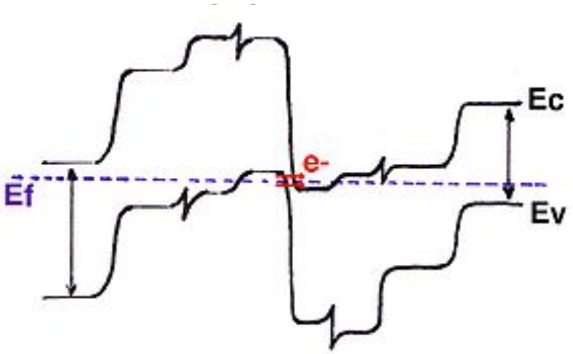


Multi-junction Solar Cells





Src. Wiki commons



- Why do we need a tunnel junction? Look at the stack….

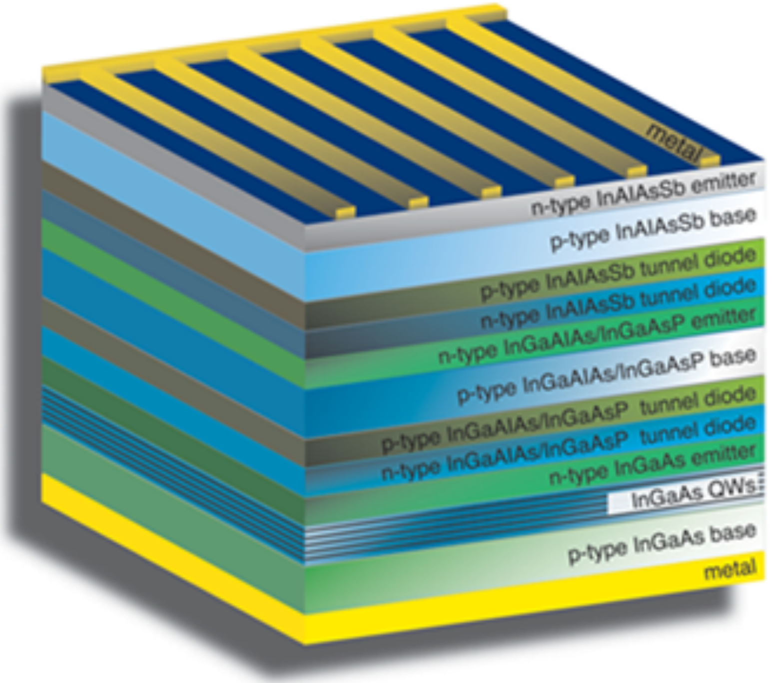
- Hmm. Fermi level beyond E_C or E_V turns a semiconductor into a metal (like 'super highly doped'). Why do we need that for the tunnel junction?

Multi-junction Solar Cells

Multijunction Solar Cell Design Could Exceed 50% Efficiency

WASHINGTON, Jan. 15, 2013 — A lattice-matched, triple-junction solar cell proposed by an international team of scientists has the potential to break the 50 percent conversion efficiency mark, a goal in multijunction photovoltaic development.

Produced by scientists in the Electronics Technology and Science Div. of the US Naval Research Laboratory (NRL), in collaboration with researchers at Imperial College London and MicroLink Devices Inc. of Niles, Ill.….

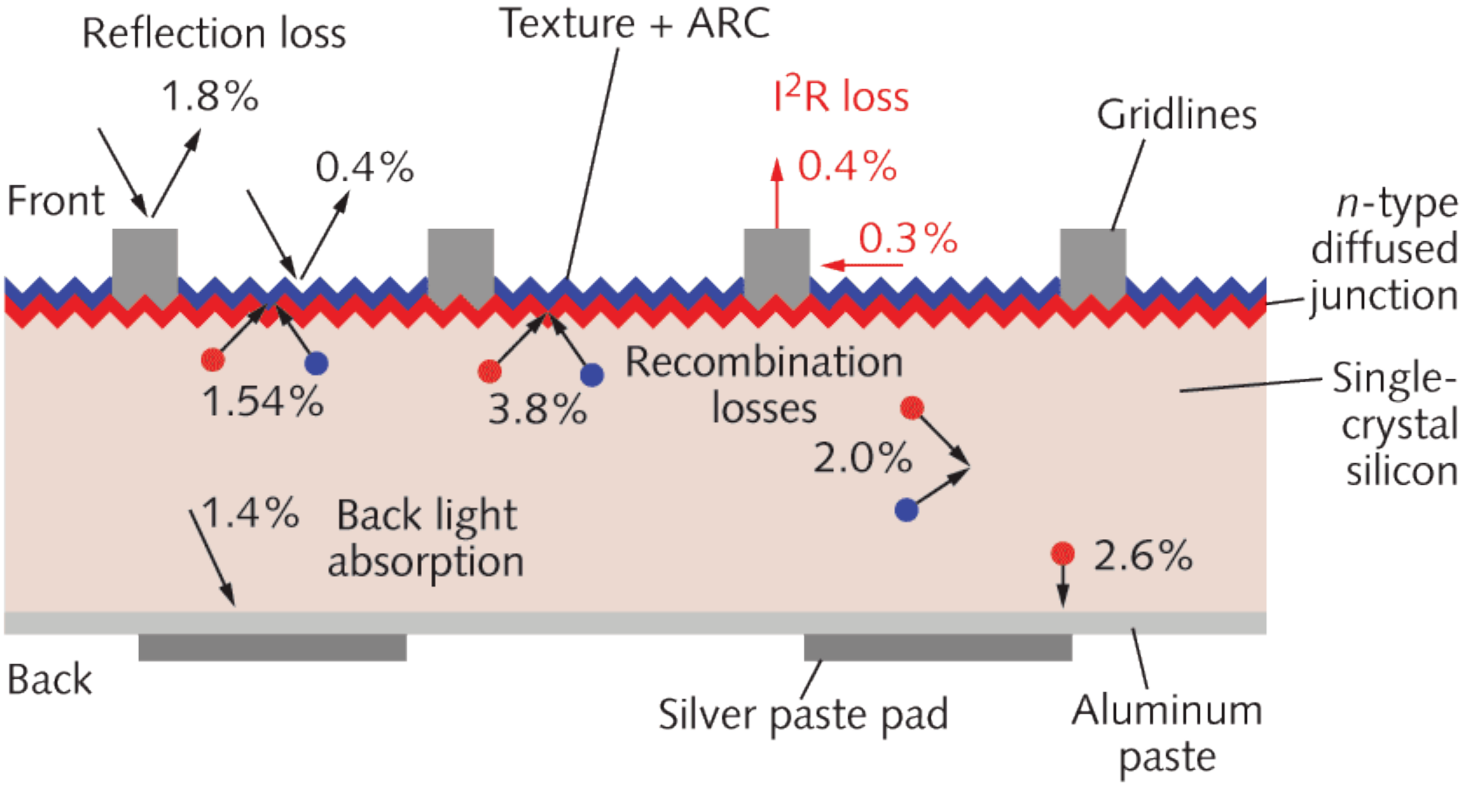


Multijunction solar cells are those in which each junction is tuned to different solar spectrum wavelength bands to enhance efficiency. High bandgap semiconductor material is used to absorb the short-wavelength radiation, with longer-wavelength parts transmitted to subsequent semiconductors.

“Having all lattice-matched materials with this wide range of bandgaps is the key to breaking the current world record,” Walters said.

The NRL scientists, working with MicroLink Devices and Rochester Institute of Technology in New York, will now execute a three-year materials and device development program to realize this photovoltaic technology under a US Department of Energy Advanced Research Projects Agency-Energy project.

Lots of Losses…



Limit cell efficiency	29%
Total losses	-14.3%
Generic cell efficiency	14.7%

FIGURE 1. A generic solar cell has multiple loss mechanisms (losses shown are a percentage of the incident radiation). This device exhibits an efficiency of 14% to 15% and was the mainstay of the solar industry for several years. (Courtesy of SunPower)

Photovoltaics – Datasheet

SUNPOWER

215 SOLAR PANEL

EXCEPTIONAL EFFICIENCY AND PERFORMANCE

Electrical Data

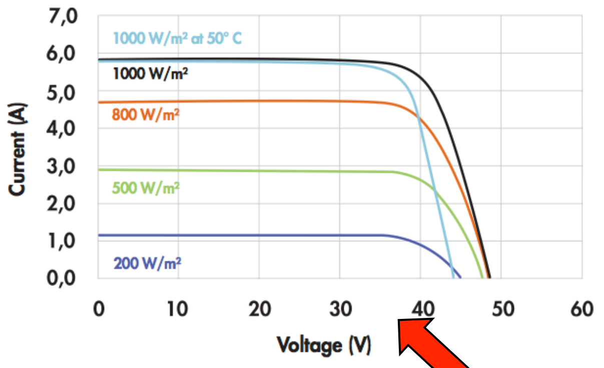
Measured at Standard Test Conditions (STC): irradiance of 1000W/m², AM 1.5, and cell temperature 25° C

Peak Power (+/-5%)	P_{max}	215 W
Rated Voltage	V_{mpp}	39.8 V
Rated Current	I_{mpp}	5.40 A
Open Circuit Voltage	V_{oc}	48.3 V
Short Circuit Current	I_{sc}	5.80 A
Maximum System Voltage	UL	600 V
Temperature Coefficients		
	Power	-0.38% / K
	Voltage (V_{oc})	-136.8mV / K
	Current (I_{sc})	3.5mA / K
NOCT		45° C +/-2° C
Series Fuse Rating		15 A

Mechanical Data

Solar Cells	72 SunPower all-back contact monocrystalline
Front Glass	High transmission tempered glass
Junction Box	IP-65 rated with 3 bypass diodes Dimensions: 32 x 155 x 128 (mm)
Output Cables	1000mm length cables / MultiContact (MC4) connectors
Frame	Anodized aluminum alloy type 6063 (black)
Weight	33.1 lbs. (15.0 kg)

I-V Curve



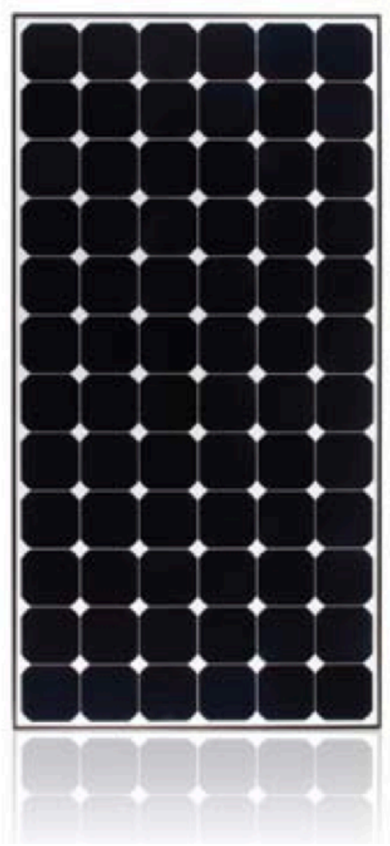
Current/voltage characteristics with dependence on irradiance and module temperature.

Tested Operating Conditions

Temperature	-40° F to +185° F (-40° C to + 85° C)
Max load	113 psf 550kg/m² (5400 Pa) front – e.g. snow; 50 psf 245kg/m² (2400 Pa) front and back – e.g. wind
Impact Resistance	Hail 1 in (25 mm) at 52mph (23 m/s)

Warranties and Certifications

Warranties	25 year limited power warranty
	10 year limited product warranty
Certifications	Tested to UL 1703. Class C Fire Rating



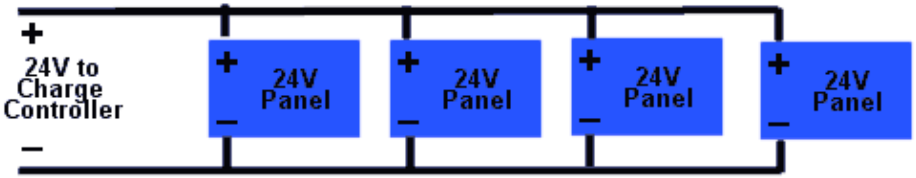
	SunPower
Peak Watts / Panel	215
Efficiency	17.3%
Peak Watts / ft² (m²)	**16 (173)**

Photovoltaics – Datasheet

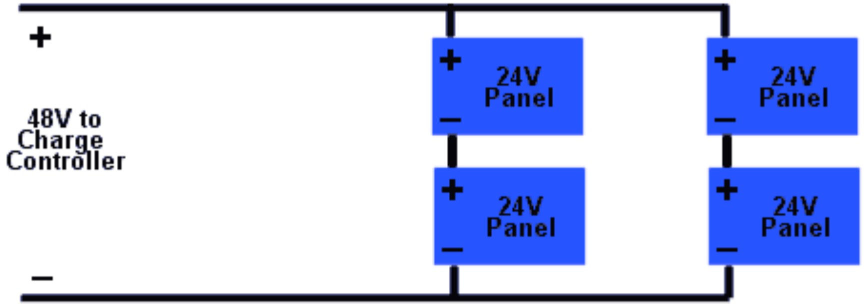
Partial Shading

Solar panels obviously produce less power when they are shaded and should ideally be situated where there will never be any shadows on them. A shadow falling on a small part of a panel can have a surprisingly large effect on output. Not only will the cells that are shaded be producing less power, but as the cells within a panel are normally all wired in series, the shaded cells afffect the current flow of the whole panel. If the affected panel is wired in series (in a string) with other panels, then the output of all those panels will be affected by the partial shading of one panel.

Question number two - do you need to wire the panels in series or parallel?
If your panels are 24 volt and your controller and batteries are 24 volt, then you would need to wire your panels in parallel- you would be connection all the positive connections together and separately connect all the negatives together.

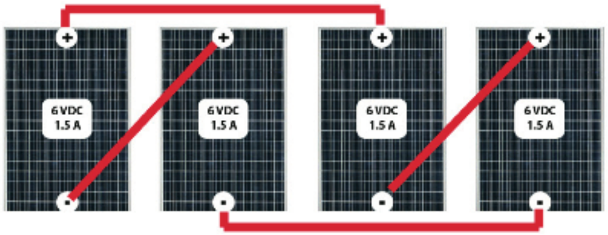


You can connect pairs of panels in series (sometimes referred to as a string), connecting the positive terminal of one panel to the negative of the next, to increase the voltage.
The effects of Partial Shading on overall effeciency should be taken into account when considering series wiring.



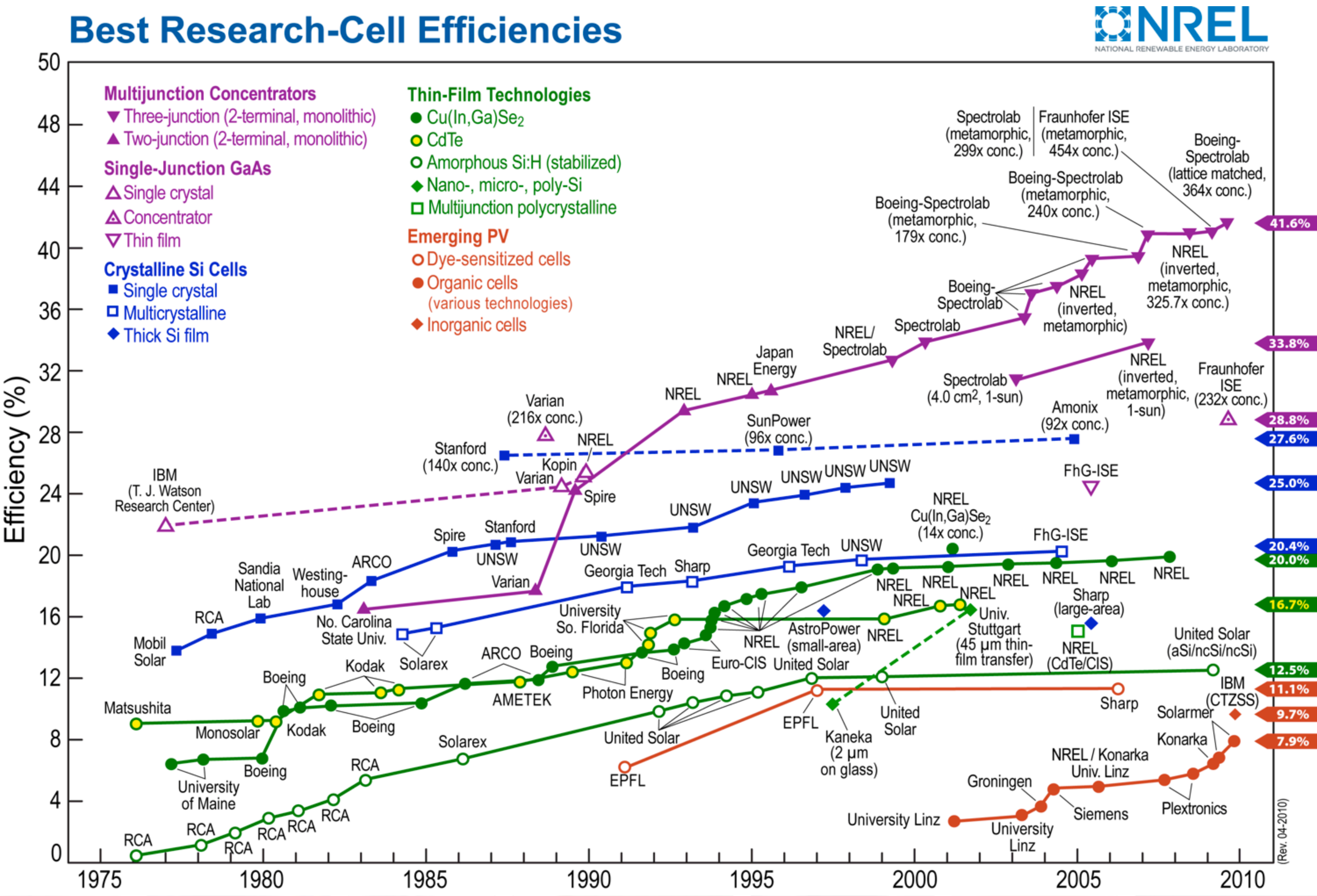
As you don't know how your system may develop in the future, it would be a good idea to buy your panels in even numbers, making it convenient to wire pairs in series if you want to change, say, from a 24 volt to a 48 volt system.

Example: DESIGN A 12V SYSTEM USING FOUR 6V PV



Total Volts = 12

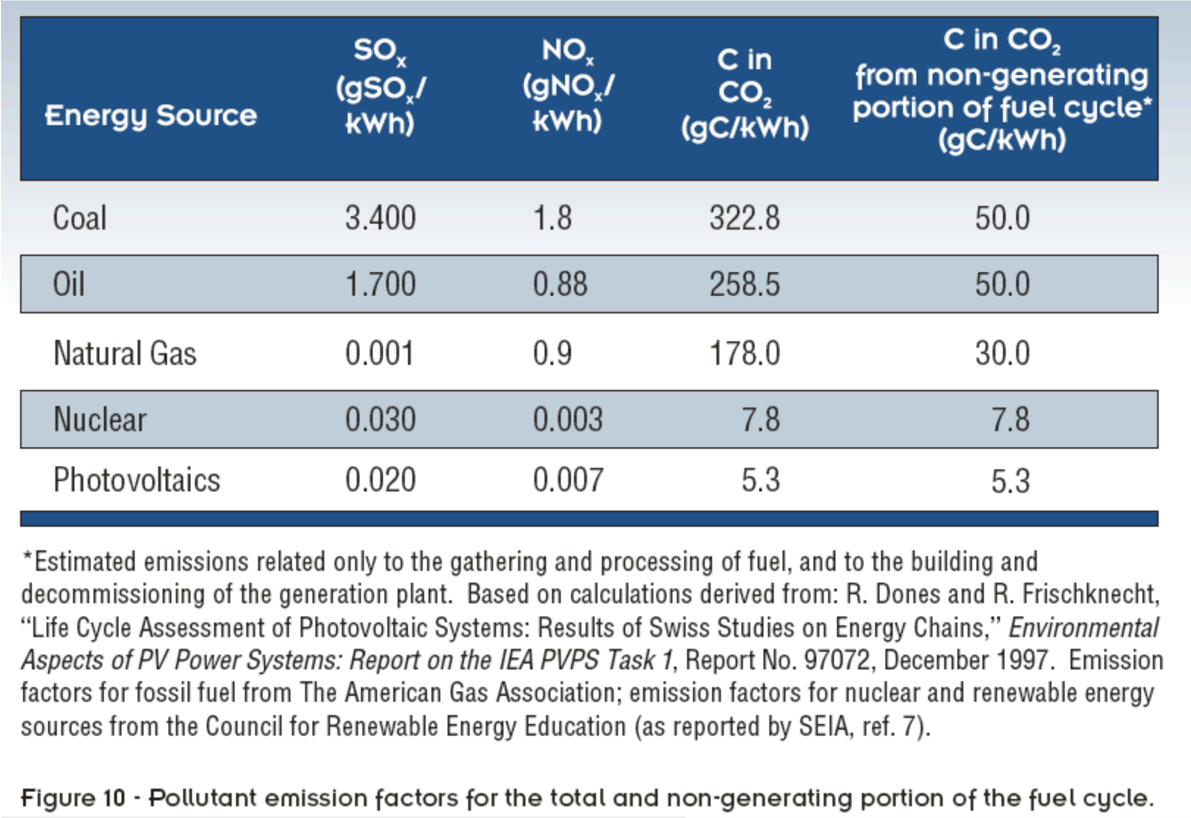
Total Amps = 3


NREL
NATIONAL RENEWABLE ENERGY LABORATORY
Best Research-Cell Efficiencies
Efficiency (%)
50
48
44
40
36
32
28
24
20
16
12
8
4
0
1975
1980
1985
1990
1995
2000
2005
2010
Multijunction Concentrators
▼ Three-junction (2-terminal, monolithic)
▲ Two-junction (2-terminal, monolithic)
Single-Junction GaAs
△ Single crystal
△ Concentrator
▽ Thin film
Crystalline Si Cells
■ Single crystal
□ Multicrystalline
◆ Thick Si film
Thin-Film Technologies
● Cu(In,Ga)Se$_2$
● CdTe
○ Amorphous Si:H (stabilized)
◆ Nano-, micro-, poly-Si
□ Multijunction polycrystalline
Emerging PV
○ Dye-sensitized cells
● Organic cells (various technologies)
◆ Inorganic cells
Spectrolab (metamorphic, 299x conc.)
Fraunhofer ISE (metamorphic, 454x conc.)
Boeing-Spectrolab (lattice matched, 364x conc.)
Boeing-Spectrolab (metamorphic, 240x conc.)
Boeing-Spectrolab (metamorphic, 179x conc.)
NREL (inverted, metamorphic, 325.7x conc.)
Boeing-Spectrolab
NREL (inverted, metamorphic)
Spectrolab
NREL/ Spectrolab
Japan Energy
NREL
NREL
Spectrolab (4.0 cm^2, 1-sun)
NREL (inverted, metamorphic, 1-sun)
Fraunhofer ISE (232x conc.)
Amonix (92x conc.)
SunPower (96x conc.)
Varian (216x conc.)
NREL
Stanford (140x conc.)
Kopin
Varian
Spire
IBM (T. J. Watson Research Center)
UNSW
UNSW
UNSW
UNSW
UNSW
FhG-ISE
NREL Cu(In,Ga)Se$_2$ (14x conc.)
FhG-ISE
Stanford
Spire
UNSW
UNSW
Varian
ARCO
Westing-house
Sandia National Lab
RCA
Mobil Solar
No. Carolina State Univ.
Solarex
Georgia Tech
Sharp
Georgia Tech
UNSW
University So. Florida
NREL
NREL
NREL
NREL
NREL
NREL
NREL
NREL
AstroPower (small-area)
NREL
NREL
Univ. Stuttgart (45 µm thin-film transfer)
Sharp (large-area)
NREL (CdTe/CIS)
United Solar (aSi/ncSi/ncSi)
Euro-CIS
United Solar
Boeing
ARCO
Boeing
Kodak
Solarex
Boeing
AMETEK
Photon Energy
Matsushita
Monosolar
Kodak
Boeing
Boeing
University of Maine
Solarex
RCA
United Solar
EPFL
EPFL
Kaneka (2 µm on glass)
United Solar
Sharp
IBM (CTZSS)
Solarmer
Konarka
NREL / Konarka Univ. Linz
Groningen
Siemens
Plextronics
University Linz
University Linz
RCA
RCA
RCA
RCA
RCA
RCA
RCA
41.6%
33.8%
28.8%
27.6%
25.0%
20.4%
20.0%
16.7%
12.5%
11.1%
9.7%
7.9%
(Rev. 04-2010)

Food for Thought

- Current affordable technology can provide ~10% efficiency which is ~100 W/m^2. Sun -> 100,000 lux, this room, 100-300 lux.

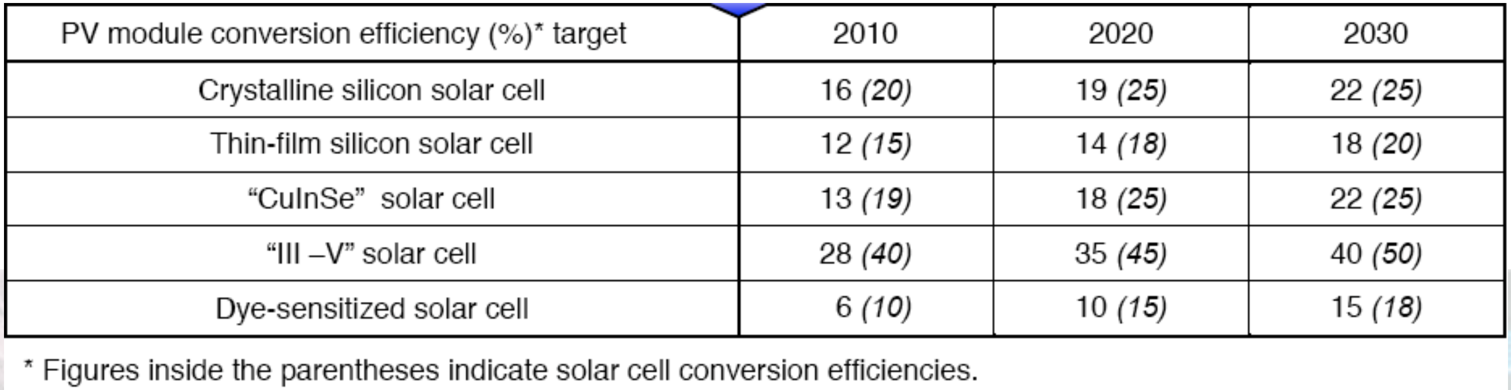
- Homework will include the MATLAB code (from journal article). We give you most of the code…



Energy Source	SO_x (gSO_x/ kWh)	NO_x (gNO_x/ kWh)	C in CO_2 (gC/kWh)	C in CO_2 from non-generating portion of fuel cycle* (gC/kWh)
Coal	3.400	1.8	322.8	50.0
Oil	1.700	0.88	258.5	50.0
Natural Gas	0.001	0.9	178.0	30.0
Nuclear	0.030	0.003	7.8	7.8
Photovoltaics	0.020	0.007	5.3	5.3

*Estimated emissions related only to the gathering and processing of fuel, and to the building and decommissioning of the generation plant. Based on calculations derived from: R. Dones and R. Frischknecht, "Life Cycle Assessment of Photovoltaic Systems: Results of Swiss Studies on Energy Chains," *Environmental Aspects of PV Power Systems: Report on the IEA PVPS Task 1*, Report No. 97072, December 1997. Emission factors for fossil fuel from The American Gas Association; emission factors for nuclear and renewable energy sources from the Council for Renewable Energy Education (as reported by SEIA, ref. 7).

Figure 10 - Pollutant emission factors for the total and non-generating portion of the fuel cycle.



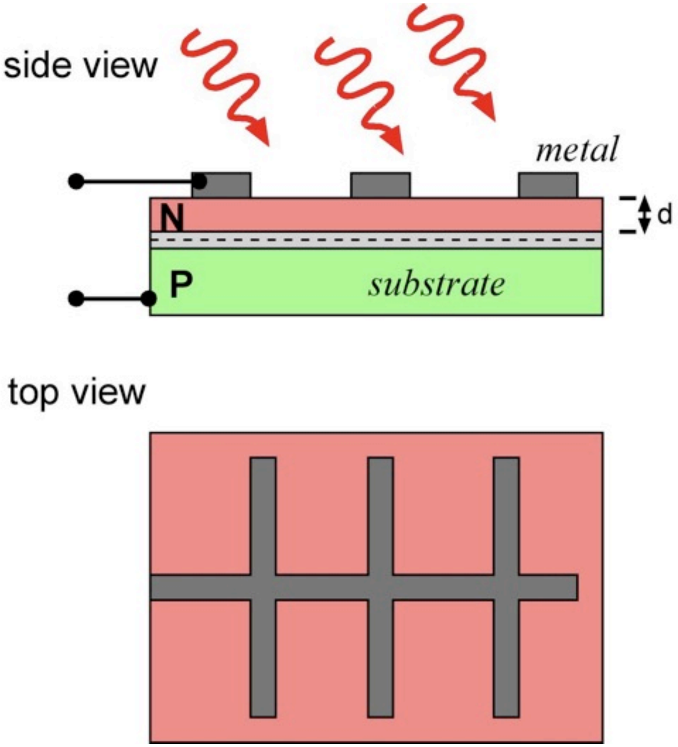
PV module conversion efficiency (%)* target	2010	2020	2030
Crystalline silicon solar cell	16 *(20)*	19 *(25)*	22 *(25)*
Thin-film silicon solar cell	12 *(15)*	14 *(18)*	18 *(20)*
"CuInSe" solar cell	13 *(19)*	18 *(25)*	22 *(25)*
"III –V" solar cell	28 *(40)*	35 *(45)*	40 *(50)*
Dye-sensitized solar cell	6 *(10)*	10 *(15)*	15 *(18)*

* Figures inside the parentheses indicate solar cell conversion efficiencies.

Review! Take a Break!

- In terms of limiting solar cell efficiency, fill in the blank.

Thickness of the top ______layer.
Too much area covered by the ______ contact.
Energy of photons are much ________ than the bandgap energy.



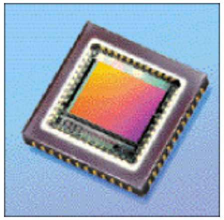
- A typical Si solar cell is how efficient at converting sunlight to electrical power?

(a) 5%
(b) 15%
(c) 25%
(d) 50%

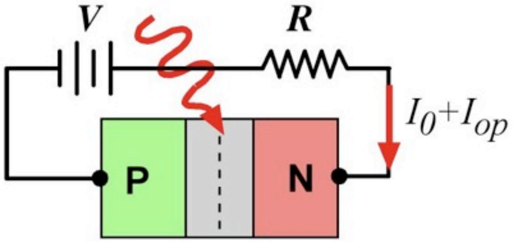
- How are the world's most efficient solar cells constructed?

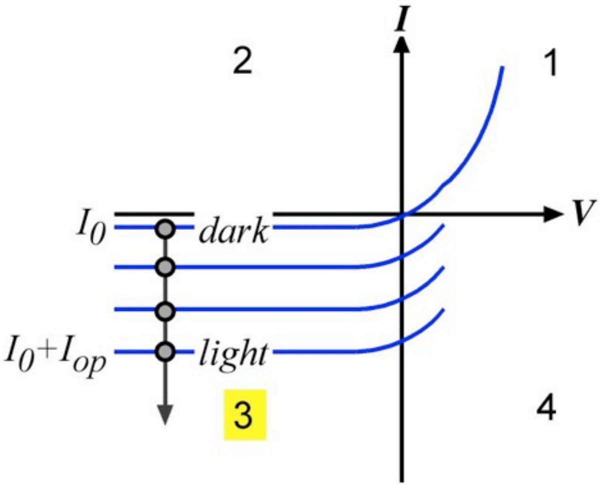
Photodiodes

Oscilloscope?

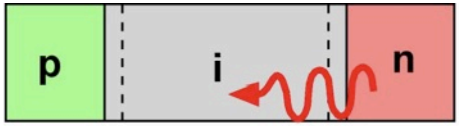


- Photodiode: externally powered, used as a light sensor!

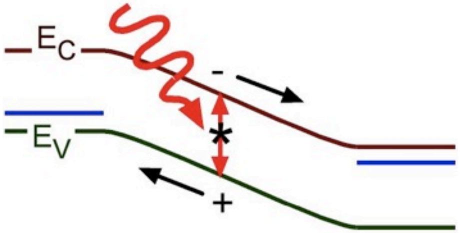




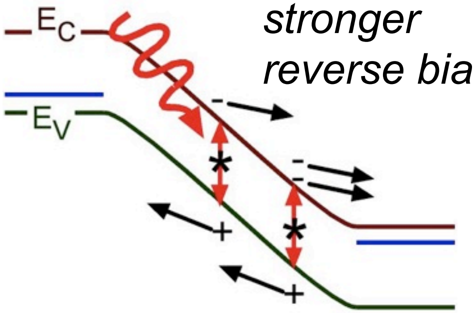
- Photodiode responsivity is A/W ☆ (current out/optical power in)



☆
- PIN PD



☆
- APD

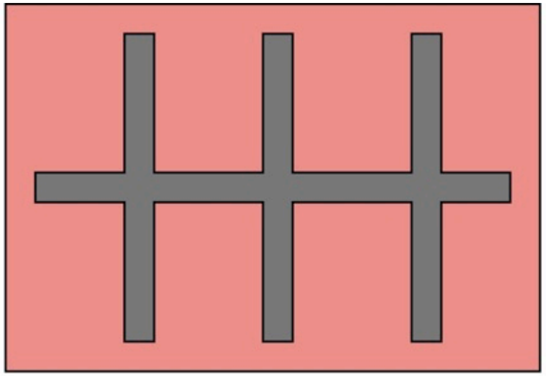


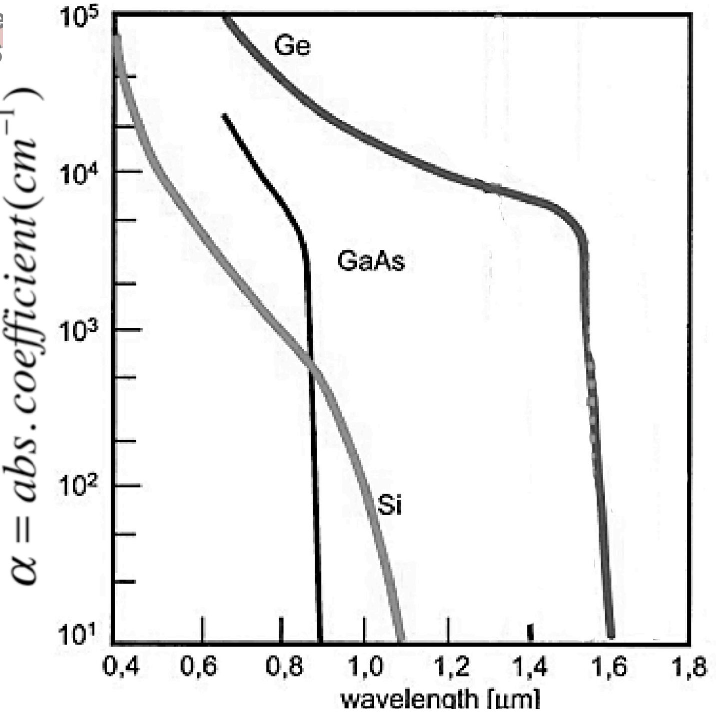
stronger reverse bias

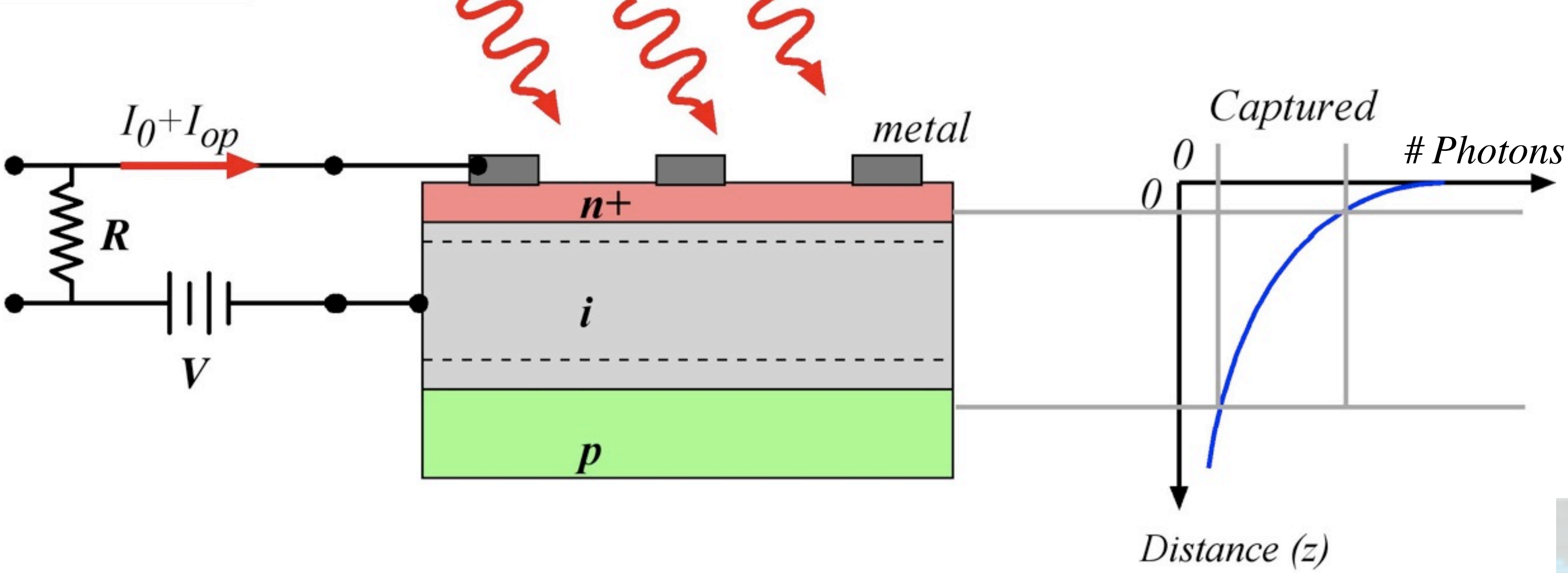
- Avalanche photodiodes (APD) can have large A/W by multiplying number of carriers collected

Photodiodes

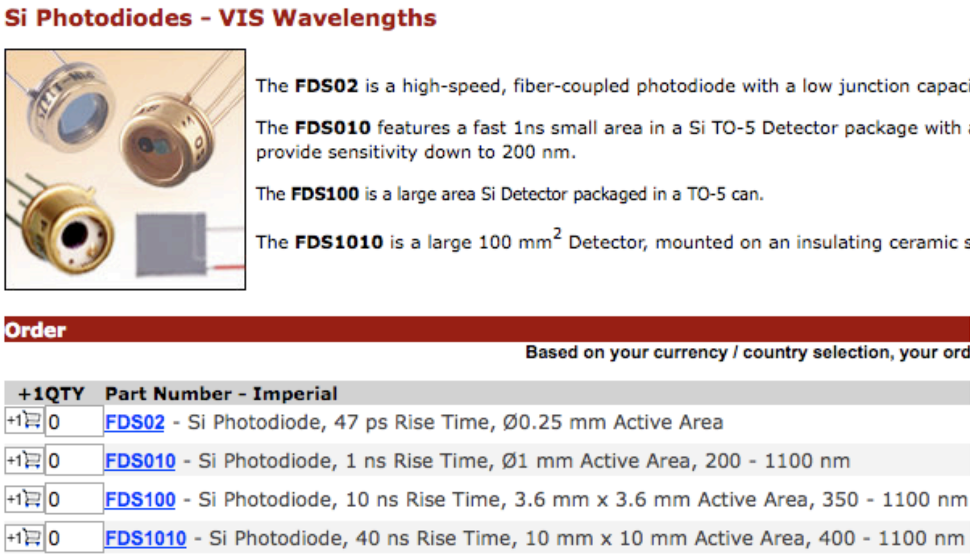
- I want to design a high responsivity (A/W) photodiode… Notice the intrinsic (i, undoped) Si.







Photodiodes



Si Photodiodes - VIS Wavelengths

The **FDS02** is a high-speed, fiber-coupled photodiode with a low junction capaci

The **FDS010** features a fast 1ns small area in a Si TO-5 Detector package with
provide sensitivity down to 200 nm.

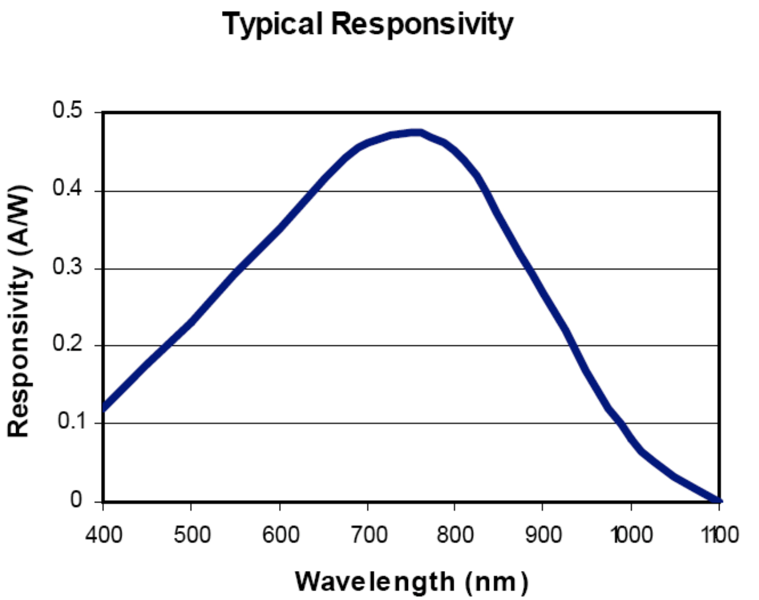
The **FDS100** is a large area Si Detector packaged in a TO-5 can.

The **FDS1010** is a large 100 mm^2 Detector, mounted on an insulating ceramic s

Order

Based on your currency / country selection, your ord

+1QTY	Part Number - Imperial
0	FDS02 - Si Photodiode, 47 ps Rise Time, Ø0.25 mm Active Area
0	FDS010 - Si Photodiode, 1 ns Rise Time, Ø1 mm Active Area, 200 - 1100 nm
0	FDS100 - Si Photodiode, 10 ns Rise Time, 3.6 mm x 3.6 mm Active Area, 350 - 1100 nm
0	FDS1010 - Si Photodiode, 40 ns Rise Time, 10 mm x 10 mm Active Area, 400 - 1100 nm



- FDS02 Si Photodiode.

Active Area Diameter: 250 µm

Capacitance: 0.94 pF at 5V

Peak wavelength – 750 nm / 0.47 A/W

Dark Current (5V): 35 pA

Damage Threshold CW: 18 mW optical power

Question 1: the minimum current is the ‘dark’ current, what does this mean?

Question 2: what is the maximum current?

Question 3: roughly, what is the minimum optical power this could detect?

Key Photodetector Metrics

Dark Current: The DC current that flows through a detector when there is no light present. Usually measured in the nanoamp range.

NEP: The amount of optical input power that produces the same output level as the inherent noise level of the detector/receiver, i.e. a signal-to-noise ratio of one. Usually given in picowatts per root bandwidth. Total noise level is calculated by multiplying the NEP by the square root of the full bandwidth.

Power Bandwidth, -3 dB: The frequency at which the electrical output power of the detector falls to 50% of its value at DC. Same as "electrical" bandwidth. Typically used for specifying analog microwave detector bandwidths.

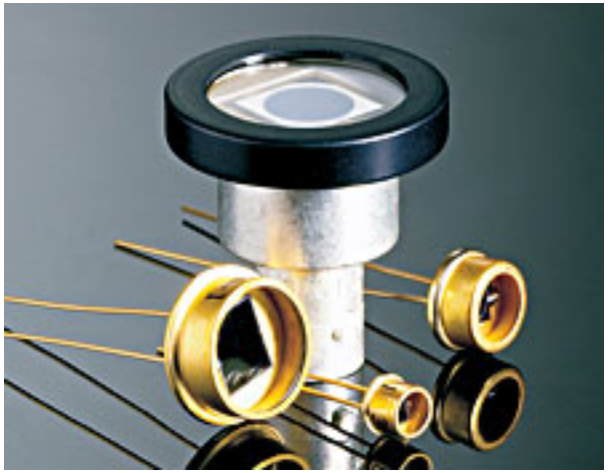
Responsivity, R: The sensitivity of a detector element to light given in amps/watt, independent of load resistance.

$$R = \eta \frac{q}{h\upsilon} = \frac{\# e's}{\# photons} \frac{1.6x10^{-19} C}{6.63x10^{-34}(J \cdot s) f(1/s)} \approx \eta \frac{\lambda(nm)}{1240} \quad A/W \qquad R_{\max} = 2\ A/W \ for\ 2eV$$

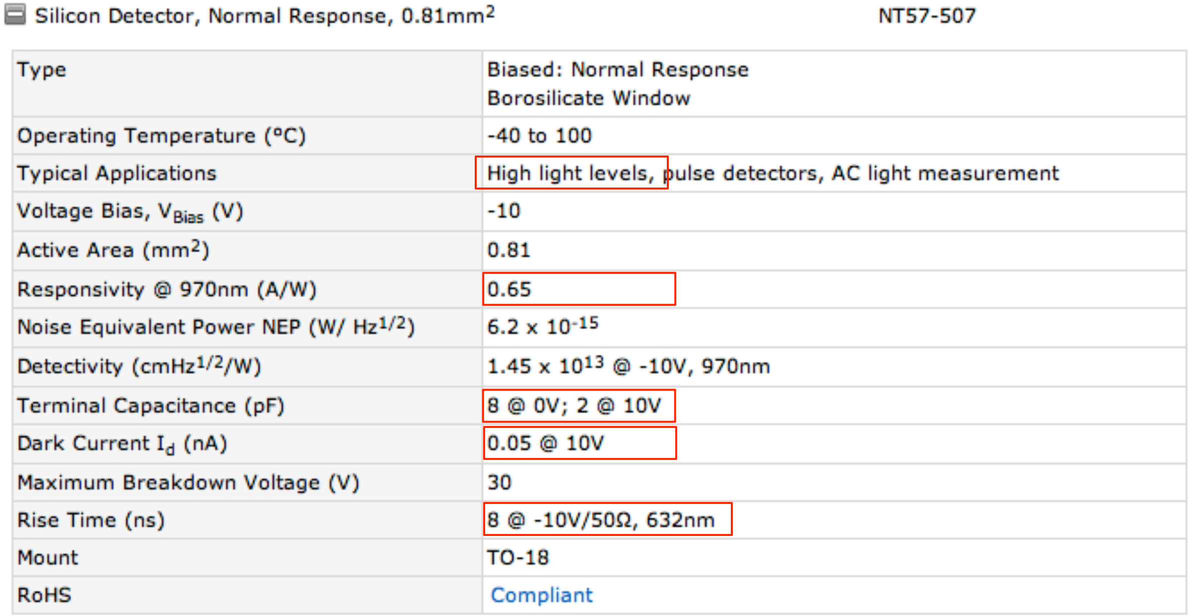
Rise Time: The 10–90% rise time of the output voltage step when the detector is illuminated by a negligibly short optical step function. This is difficult to do in practice, so the measurement is simulated mathematically by integrating the pulse width (see above).

Sensitivity: The optical input power (in dBm) required to achieve a particular Bit Error Rate, BER (or signal to noise ratio) at the output of the detector/receiver. Usually specified for BERs of 10-9 (or a S/N of 6). BERs of 10-12 require a S/N=7.

Si Photodiodes ($22)



Edmund optics | worldwide



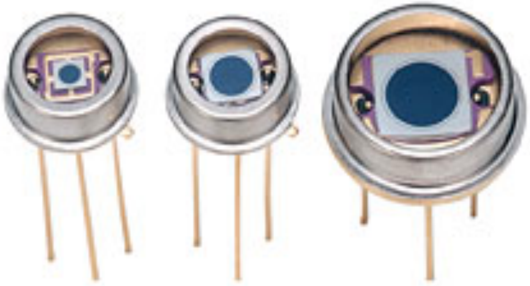
Silicon Detector, Normal Response, 0.81mm^2 NT57-507

Type	Biased: Normal Response Borosilicate Window
Operating Temperature (°C)	-40 to 100
Typical Applications	High light levels, pulse detectors, AC light measurement
Voltage Bias, V_{Bias} (V)	-10
Active Area (mm^2)	0.81
Responsivity @ 970nm (A/W)	0.65
Noise Equivalent Power NEP (W/ Hz$^{1/2}$)	6.2×10^{-15}
Detectivity (cmHz$^{1/2}$/W)	1.45×10^{13} @ -10V, 970nm
Terminal Capacitance (pF)	8 @ 0V; 2 @ 10V
Dark Current I_d (nA)	0.05 @ 10V
Maximum Breakdown Voltage (V)	30
Rise Time (ns)	8 @ -10V/50Ω, 632nm
Mount	TO-18
RoHS	Compliant

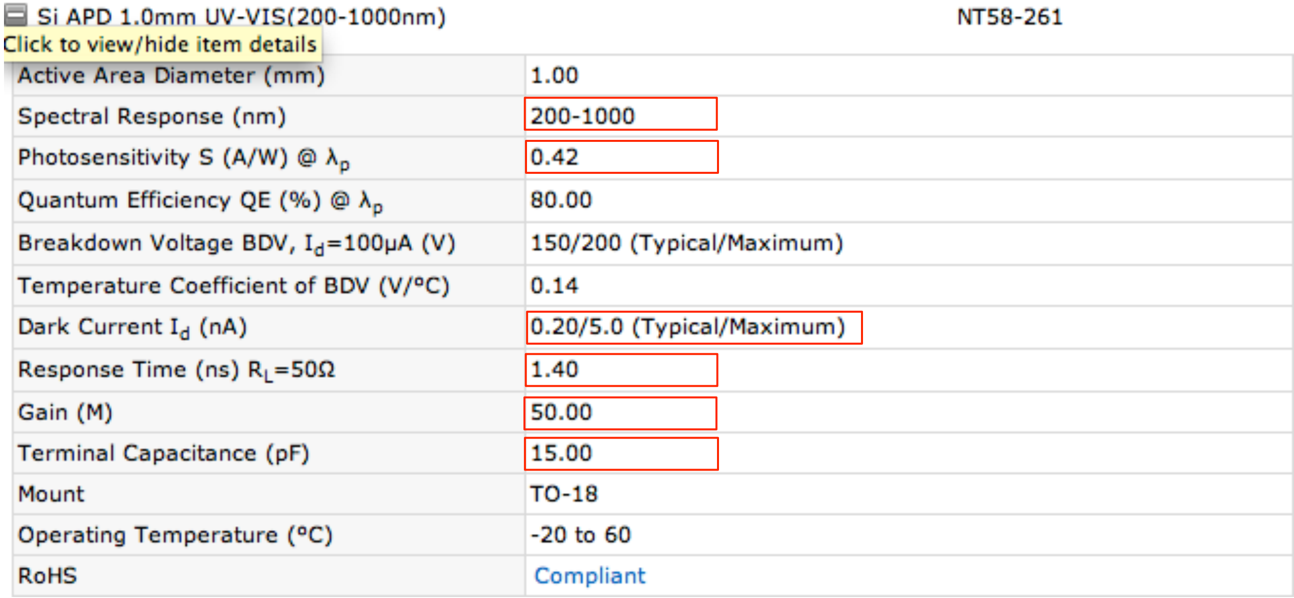
No gain…

When light, with enough energy to excite an electron from the valence to the conduction band, is incident upon the detector, the resulting accumulation of charge leads to a flow of current in an external circuit. Since light is not the only source of energy that can excite an electron, detectors will have some amount of current that is not representative of incident light. For example, fluctuations in thermal energy can easily be mistaken for light intensity changes. A variety of these "non-light" contributions are present and, when summed up, make up the total noise within the detector.

Avalanche Photodiodes ($169)



Gain up to 100…



Si APD 1.0mm UV-VIS(200-1000nm) NT58-261

Active Area Diameter (mm)	1.00
Spectral Response (nm)	200-1000
Photosensitivity S (A/W) @ λ_p	0.42
Quantum Efficiency QE (%) @ λ_p	80.00
Breakdown Voltage BDV, I_d=100μA (V)	150/200 (Typical/Maximum)
Temperature Coefficient of BDV (V/°C)	0.14
Dark Current I_d (nA)	0.20/5.0 (Typical/Maximum)
Response Time (ns) R_L=50Ω	1.40
Gain (M)	50.00
Terminal Capacitance (pF)	15.00
Mount	TO-18
Operating Temperature (°C)	-20 to 60
RoHS	Compliant

As with a conventional photodiode, absorption of incident photons creates electron-hole pairs. A high reverse bias voltage creates a strong internal electric field, which accelerates the electrons through the silicon crystal lattice and produces secondary electrons by impact ionization. The resulting electron avalanche can produce gain factors up to several hundred.

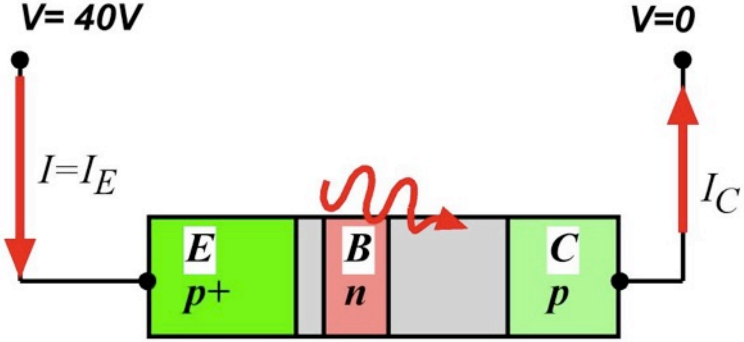
Si APDs are used when light signals are too high for photomultiplier tubes and too low for conventional photodiodes. Si APDs are often used in high-speed applications since the excess noise from the avalanche process is still lower than the noise that would be generated in connecting an external amplifier to a conventional photodiode operated at high frequencies.

HBT Photoreceiver

Your boss asks for an amplified photoreciever for optical communications..

You get a fast photodiode and hook it up to an amplifier… *but the connecting line capacitance and resistance kills your max speed (RC time constant).*

- I am not sure if still used commercially though!



If you are really smart you will use something with internal amplificaiton! But what?

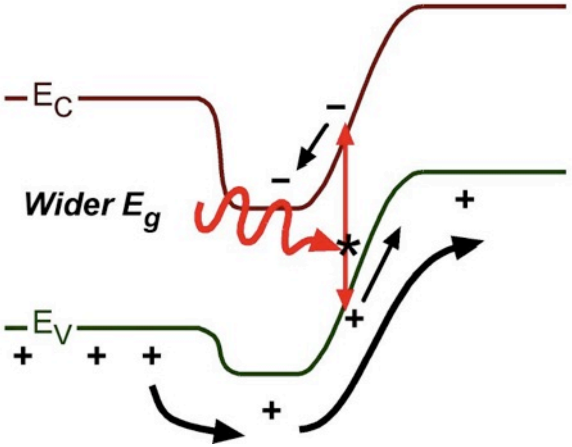
- HBT Photoreciever!

FAST (like a BJT or HBT)
BUILT IN AMPLIFIER!!!!

- If amplification factor is 1000, how many carriers are collected if we hit with one photon?

- Typically emitter is made wider bandgap for two reasons, what are they?

- What will dominate, e-h generation in B, or BC depletion?



Phototransistor

- BJTs used as photodetectors are often called ‘phototransistors’. Here is one from Honeywell. How can it be based on BJT but have only two wires?

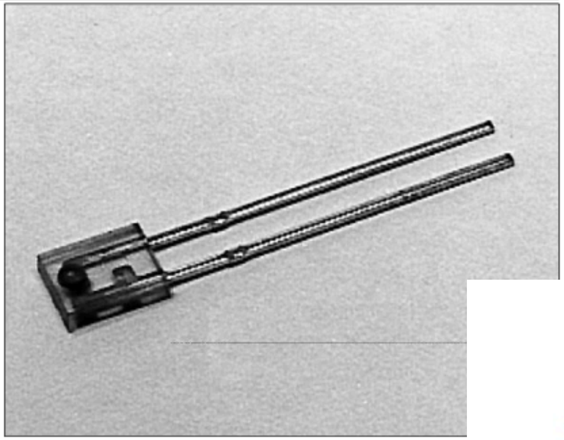
- Careful, some folks also refer to a PIN fed into a MOSFET as a ‘phototransistor’. Always check to see what you are actually buying!

SDP8406

Silicon Phototransistor

FEATURES

- Side-looking plastic package
- 50° (nominal) acceptance angle
- Wide sensitivity ranges
- Mechanically and spectrally matched to SEP8506 and SEP8706 infrared emitting diodes



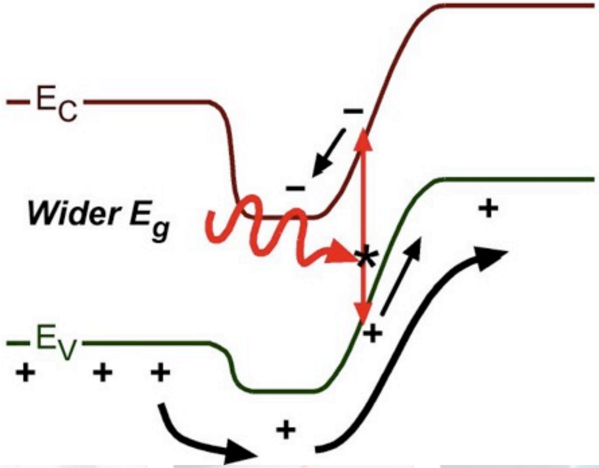
INFRA-21.TIF

DESCRIPTION

The SDP8406 is an NPN silicon phototransistor molded in a side-looking clear plastic package. The chip is positioned to accept radiation through a plastic lens from the side of the package.

OUTLINE DIMENSIONS in inches (mm)

Tolerance	3 plc decimals	±0.005(0.12)
	2 plc decimals	±0.020(0.51)



Review!

- What are the units for responsivity?

- Can I use a heavily doped p+n+ diode as an avalanche photodiode? *Hint, think back to two types of breakdown and how they are effected by doping…*

- What advantage does a PIN photodiode have over a regular PN photodiode?

- For an HBT photoreceiver… what will dominate, e-h generation in B, or BC depletion?

- For an HBT photoreceiver with an amplification factor of 200, if one photon is absorbed in the base-collector depletion region, how many carriers are collected?