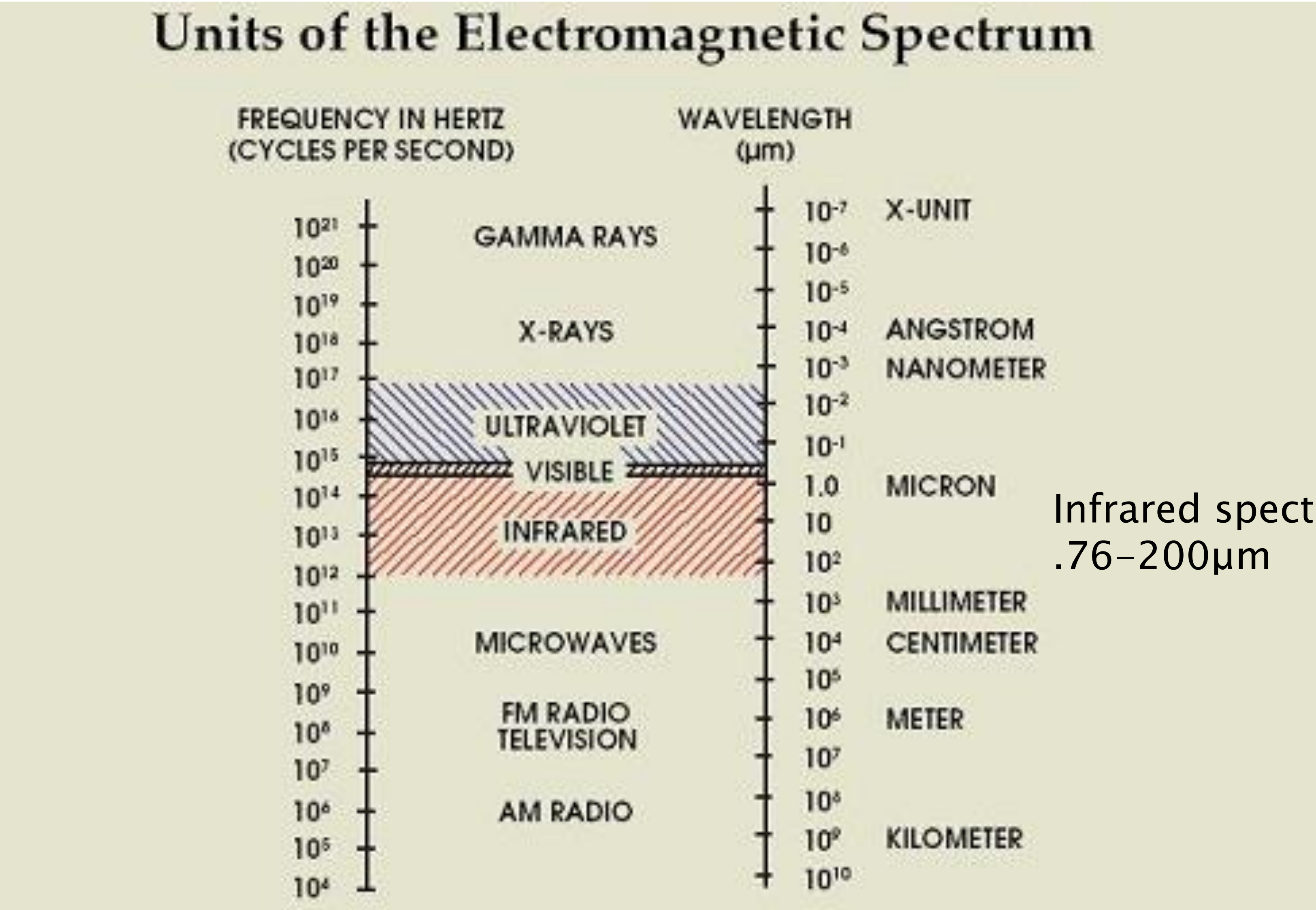
Optical Sensors

Radiation Sensors



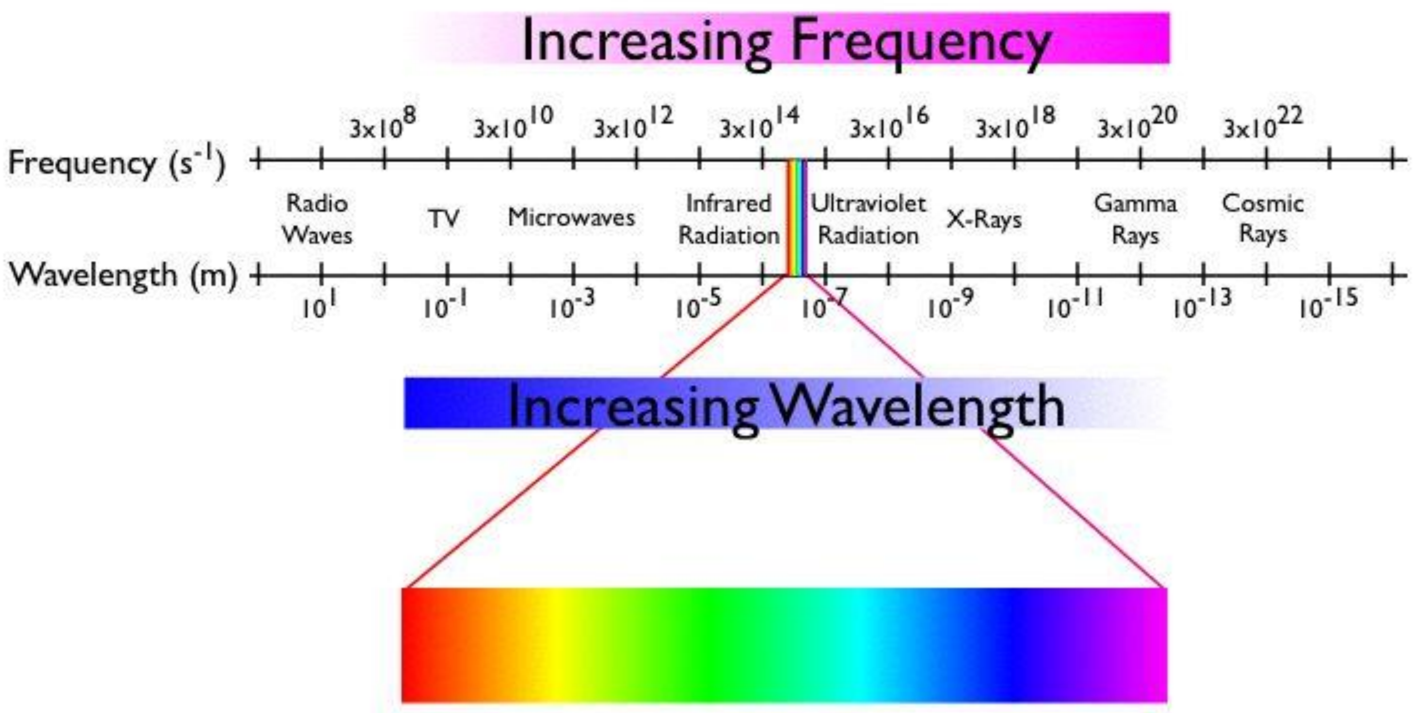
Infrared spectrum
.76-200µm

Visible spectrum 400-760nm

Spectrum

Band	Wavelength	Frequency
MF medium frequency		300-3000 kHz
HF high frequency		3-30 MHz
Radio	20 cm - 20 m	15 MHz - 1.5 GHz
FM	2.5-3.5 m	85-120 MHz
ShortWave	20 cm - 2.5 m	120 MHz - 1.5 GHz
Microwave	0.01-20 cm	1.5-3000 GHz
EHF extremely high frequency		30-300 GHz
Far Infrared	20,000-100,000 nm	3000-15000 GHz
Near Infrared	700-20,000 nm	15000-430,000 GHz
Visible	400-700 nm	430,000-750,000 GHz
Red	620-760 nm	
Orange	570-620 nm	
Yellow	550-570 nm	
Green	470-550 nm	
Blue	440-470 nm	
Violet	380-440 nm	
Ultraviolet	50-190-400 nm	10^{15} - 10^{17} Hz
Soft XRay	1-20 nm	10^{17} - 10^{20} Hz
Hard XRay	0.1-1 nm	
Gamma ray	0.1 - 0.000001 nm	Highest 10^{20} - 10^{24} Hz

Spectrum


Increasing Frequency
3x10^8
3x10^10
3x10^12
3x10^14
3x10^16
3x10^18
3x10^20
3x10^22
Frequency (s^-1)
Radio Waves
TV
Microwaves
Infrared Radiation
Ultraviolet Radiation
X-Rays
Gamma Rays
Cosmic Rays
Wavelength (m)
10^1
10^-1
10^-3
10^-5
10^-7
10^-9
10^-11
10^-13
10^-15
Increasing Wavelength

Basic Optical Phenomena

Refraction governed by Snell's law defining the relationship between incident and transmitted rays at the interface of two media

$n_1 \sin(\varphi_1) = n_2 \sin(\varphi_2)$ Eq. 1 (n_1 and n_2 are indices of refraction

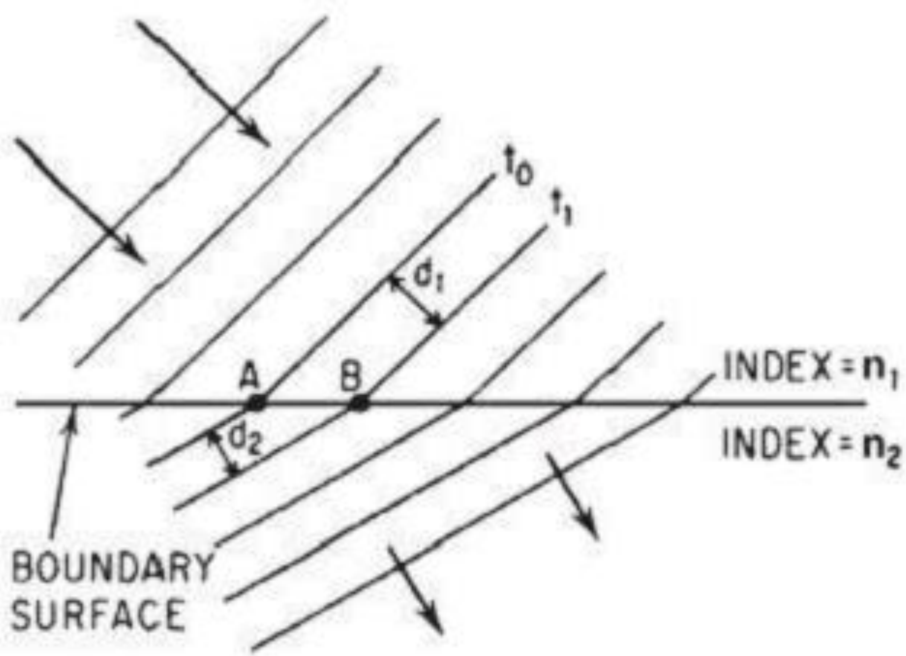


Figure 1.4 A plane wave front passing through the boundary between two media of differing indices of refraction ($n_2 > n_1$).

Review of optical phenomena that might be used in microsensors

Name of effect	Description
Photovoltaic	A voltage is generated by incident radiation at the juction of two dissimilar materials
Photomagnetoelectric	An electrical field is generated by both a magnetic field and incident radiation
Photoconductivity	Electrical conductivity is increased due to incident radiation
Photoelectric	Electrons and holes are generated and separated in a junction area by incident radiation
Photodielectric	The change of a dielectric constant due to incident radiation
Laser	Energy is generated by an optical resonance cavity
Photoluminescence	Radiant energy is emitted by incident radiation with shorter wavelength
Radioluminescence	Visible radiant energy is emitted by incident x- rays or gamma rays
Radiation heating	The increase of temperature of a material by incident radiation

Frequency and Wavelength

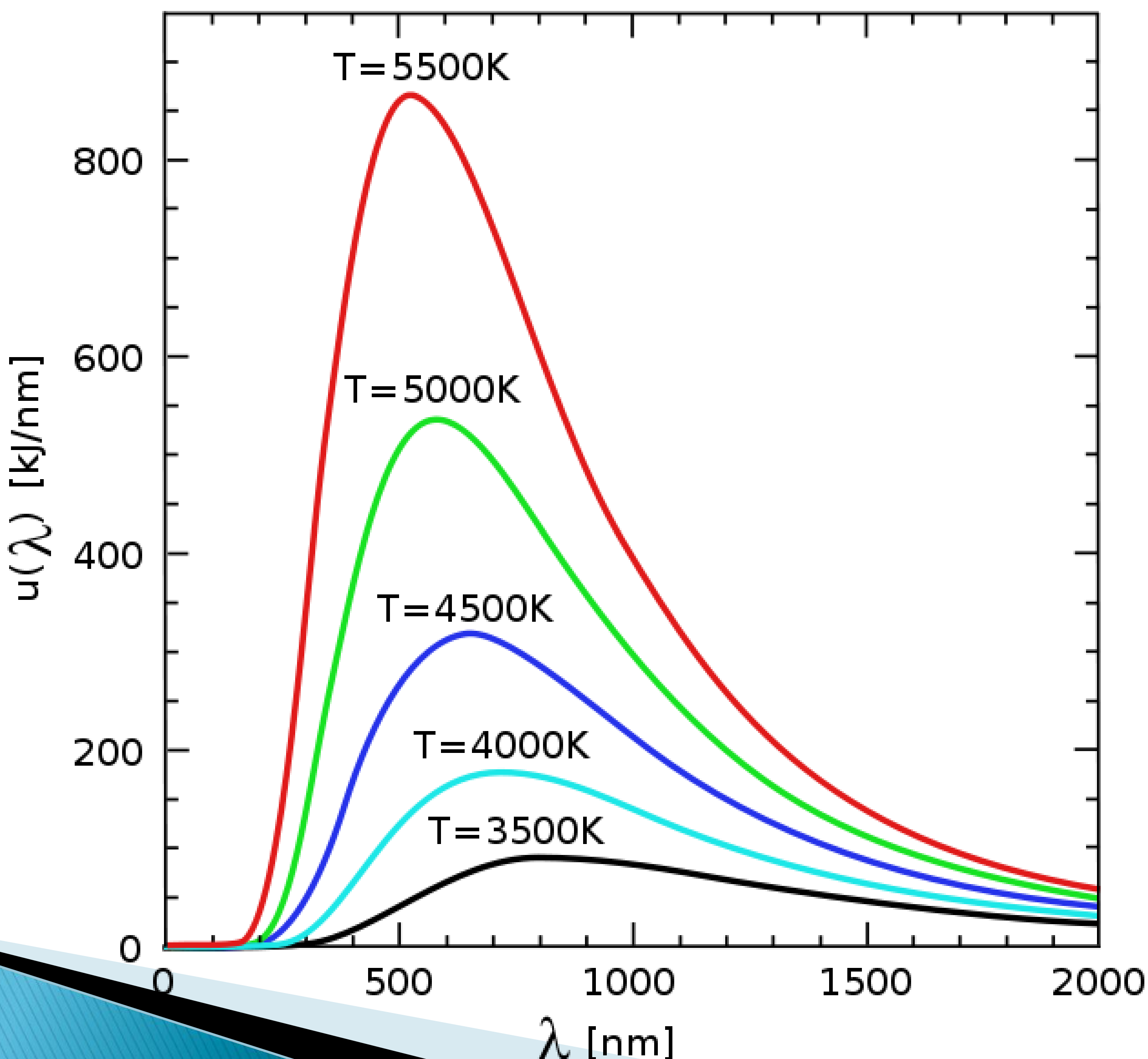
- $C = \lambda.f$
- **λ is wavelength**
- f frequency
- Refractive index $n = c/v$ where v is the velocity of EM radiation
- Photon energy $W = h.f = hc/\lambda$ (Joule)
- Intensity (I)=power in watt/beam cross sectional area in squared meter

Divergence

- Beam Divergence of an electromagnetic beam is an angular measure of the increase in beam diameter or radius with distance from the optical aperture or antenna aperture from which the electromagnetic beam emerges
- The divergence of a beam can be calculated if one knows the beam diameter at two separate points (D_i, D_f), and the distance (l) these points. The beam divergence, Θ, is given by

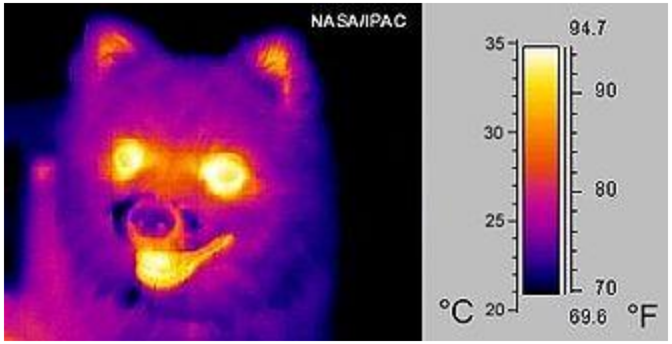
$$\Theta = 2 \arctan\left(\frac{D_f - D_i}{2l}\right).$$

Thermal Radiation

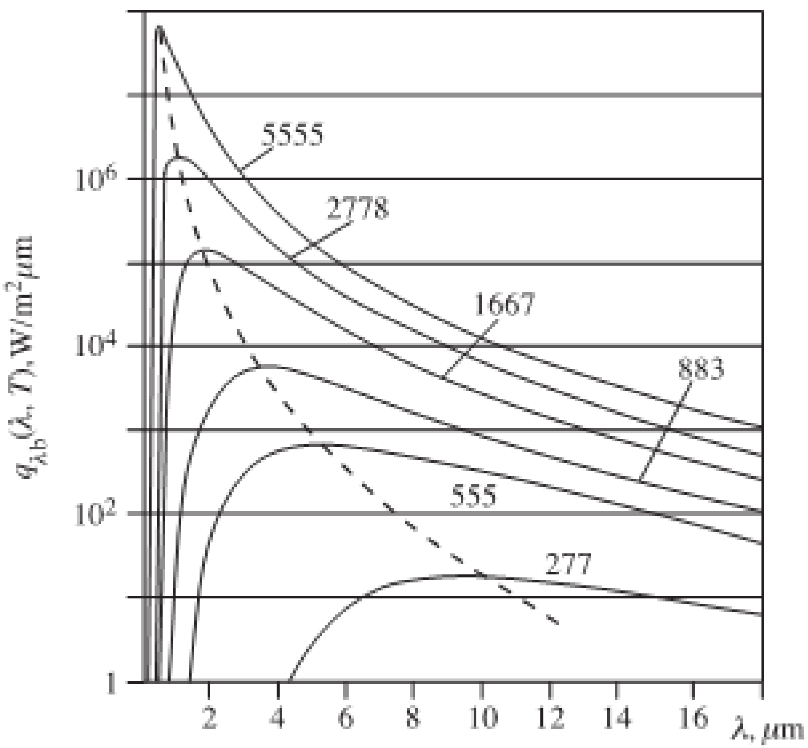


Infrared Camera

- **infrared camera** is a device that forms an image using infrared radiation, similar to a common camera that forms an image using visible light. Instead of the 450–750 nanometer range of the visible light camera, infrared cameras operate in wavelengths as long as 14,000 nm (14 µm).



Thermal Radiation



Application of Wien's Law to human body emission results in a peak wavelength of

$$\lambda_p(\mu m) = \frac{2900}{T}$$

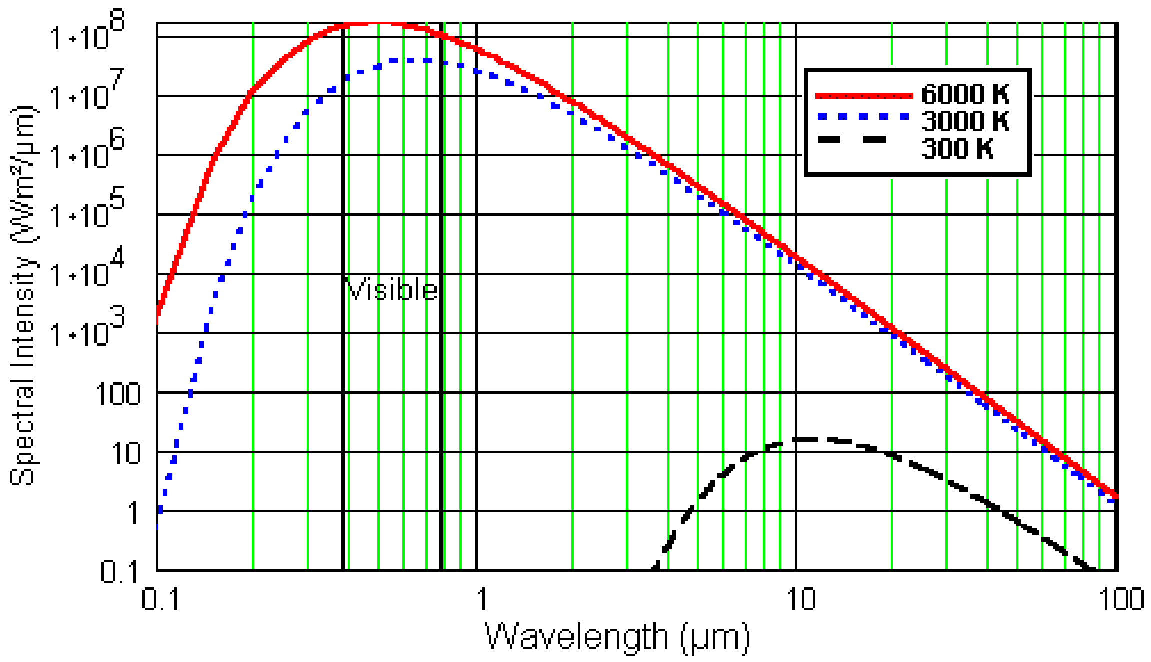
$$\lambda_{\text{peak}} = \frac{2.898 \times 10^6 \text{ K} \cdot \text{nm}}{305 \text{ K}} = 9500 \text{ nm.}$$

$$F(\lambda) = \frac{2\pi h c^2}{\lambda^5\left(\exp\left(\frac{hc}{k\lambda T}\right) - 1\right)}$$

Stefan–Boltzmann law

- **Stefan–Boltzmann law**
- The Stefan–Boltzmann law states that the power emitted per unit area of the surface of a black body is directly proportional to the fourth power of its absolute temperature:
- where P is the total power radiated per unit area, T is the absolute temperature and $\sigma = 5.67\times10^{-8}$ W m^{-2} K^{-4} is the Stefan–Boltzmann constant.

Thermal Radiation



Human Radiation

The net power radiated is the difference between the power emitted and the power absorbed:

$$P_{\text{net}} = P_{\text{emit}} - P_{\text{absorb}}.$$

Applying the Stefan-Boltzmann law,

$$P_{\text{net}} = A\sigma\varepsilon\left(T^4 - T_0^4\right).$$

The total surface area of an adult is about 2 m^2, and the mid- and far-infrared emissivity of skin and most clothing is near unity, as it is for most nonmetallic surfaces. Skin temperature is about 33 °C, but clothing reduces the surface temperature to about 28 °C when the ambient temperature is 20 °C.Hence, the net radiative heat loss is about

$$P_{\text{net}} = 100\ \text{W}.$$

IR imaging

Much of a person's energy is radiated away in the form of infrared light. Some materials are transparent in the infrared, while opaque to visible light, as is the plastic bag in this infrared image (bottom). Other materials are transparent to visible light, while opaque or reflective in the infrared, noticeable by darkness of the man's glasses.

Neon Light

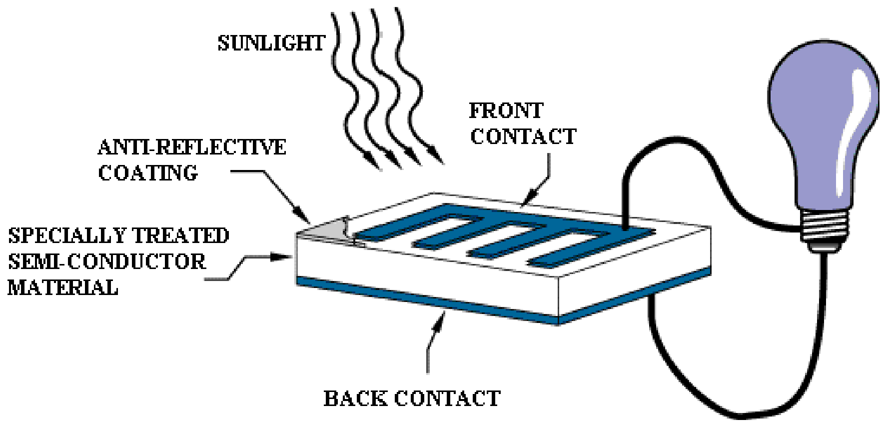
- The idea behind a **neon light** is simple. Inside the glass tube there is a gas like neon, argon or krypton at low pressure. At both ends of the tube there are metal electrodes. When you apply a high voltage to the electrodes, the neon gas ionizes, and electrons flow through the gas. These electrons excite the neon atoms and cause them to emit light that we can see. Neon emits red light when energized in this way. Other gases emit other colors.

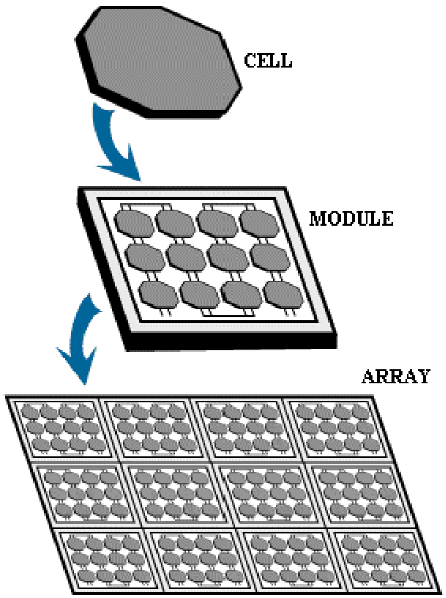
Fluorescent light

- A **fluorescent light** works on a similar idea but it has an extra step. Inside a fluorescent light is low-pressure mercury vapor. When ionized, mercury vapor emits ultraviolet light. Therefore, the inside of a fluorescent light is coated with a **phosphor**. A phosphor is a substance that can accept energy in one form and emit the energy in the form of visible light. In a fluorescent lamp, the phosphor accepts the energy of ultraviolet photons and emits visible photons.
- he light we see from a fluorescent tube is the light given off by the phosphor that coats the inside of the tube (the phosphor **fluoresces** when energized, hence the name). The light of a neon tube is the colored light that the neon atoms give off directly.

Photovoltaic Effect

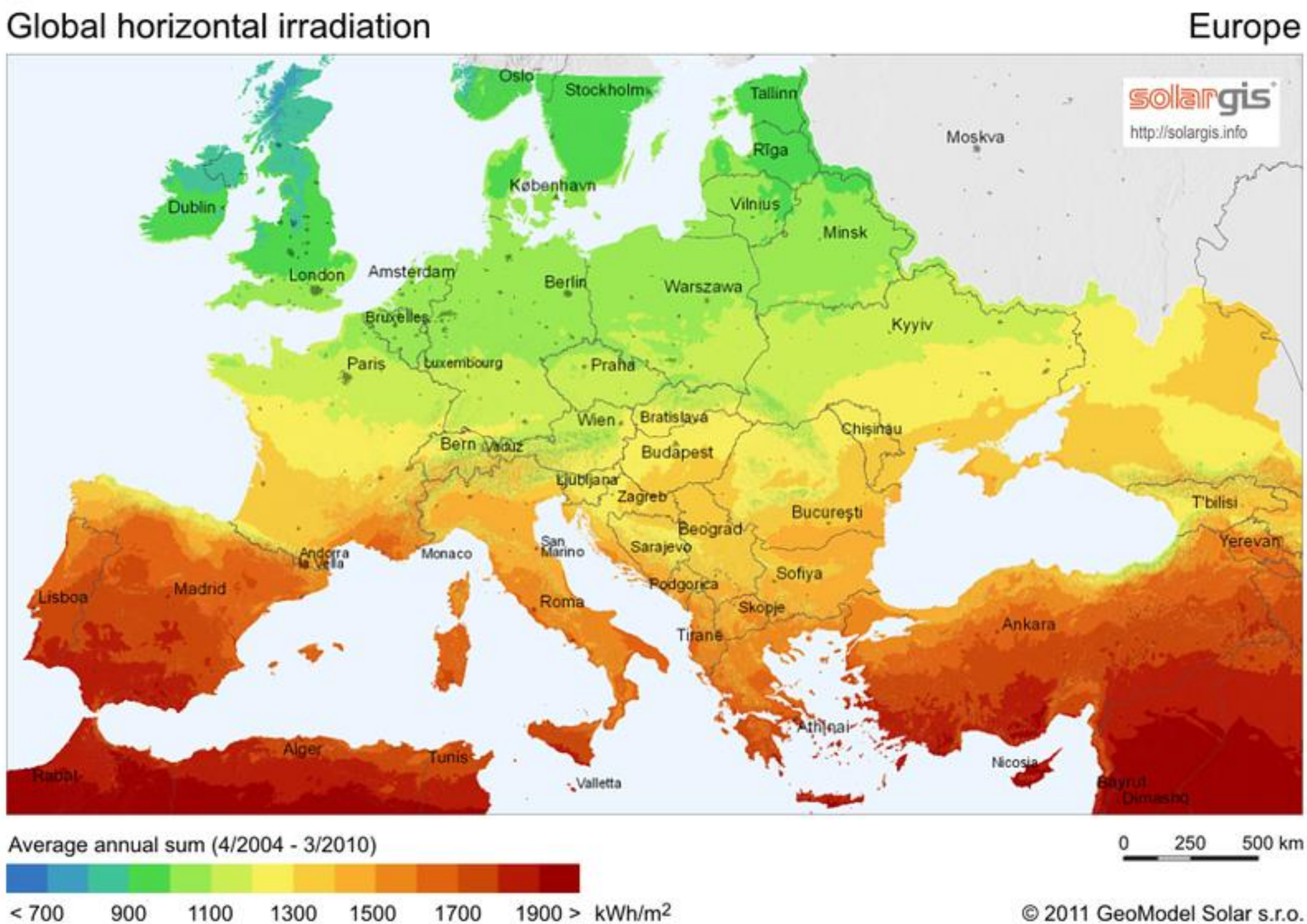
Total global capacity roughly 64 GW





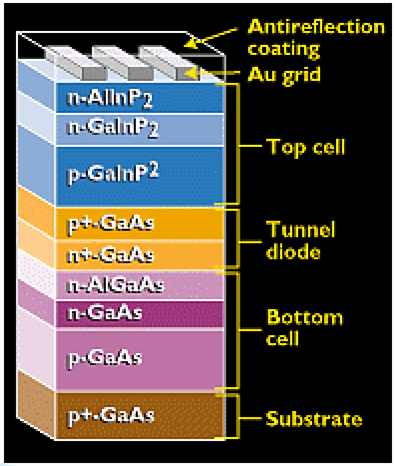
Photovoltaics is the direct conversion of light into electricity at the atomic level. Some materials exhibit a property known as the photoelectric effect that causes them to absorb photons of light and release electrons. When these free electrons are captured, an electric current results that can be used as electricity.

The term photovoltaic denotes the unbiased operating mode of a photodiode in which current through the device is entirely due to the transduced light energy.

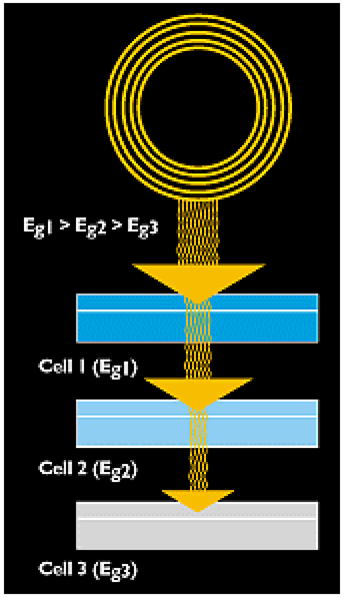

Global horizontal irradiation
Europe
solargis
http://solargis.info
Oslo
Stockholm
Tallinn
Moskva
Riga
København
Dublin
Vilnius
Minsk
London
Amsterdam
Berlin
Warszawa
Bruxelles
Kyyiv
Paris
Luxembourg
Praha
Wien
Bratislava
Chişinău
Bern
Vaduz
Budapest
Ljubljana
Zagreb
T'bilisi
Bucureşti
Beograd
Yerevan
Andorra la Vella
Monaco
San Marino
Sarajevo
Lisboa
Madrid
Sofiya
Podgorica
Roma
Skopje
Ankara
Tirane
Athinai
Alger
Tunis
Nicosia
Rabat
Valletta
Bayrut
Dimashq
Average annual sum (4/2004 - 3/2010)
0 250 500 km
< 700 900 1100 1300 1500 1700 1900 > kWh/m2
© 2011 GeoModel Solar s.r.o.

PV…

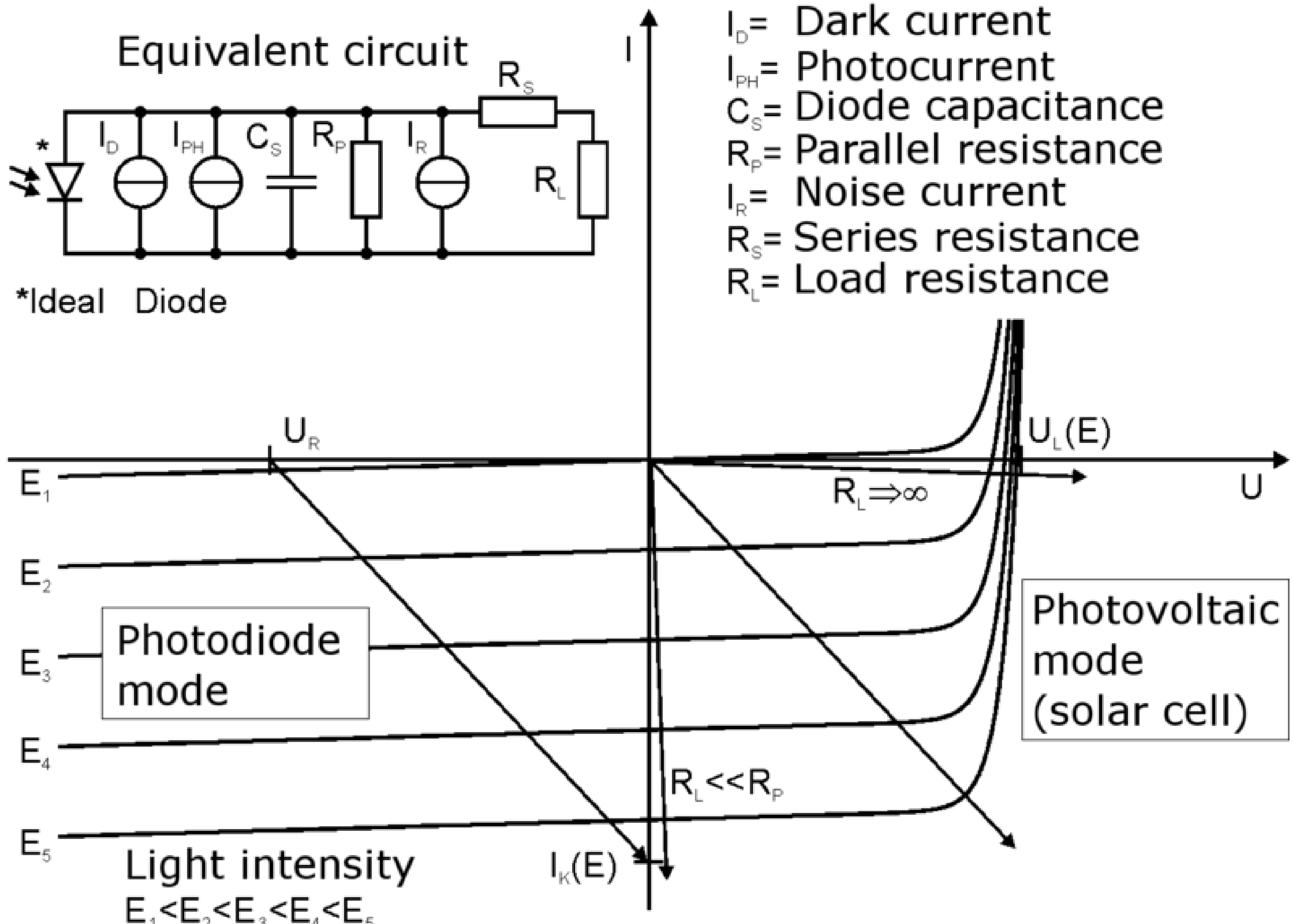
- Today's most common PV devices use a single junction, or interface, to create an electric field within a semiconductor such as a PV cell. In a single-junction PV cell, only photons whose energy is equal to or greater than the band gap of the cell material can free an electron for an electric circuit. In other words, the photovoltaic response of single-junction cells is limited to the portion of the sun's spectrum whose energy is above the band gap of the absorbing material, and lower-energy photons are not used



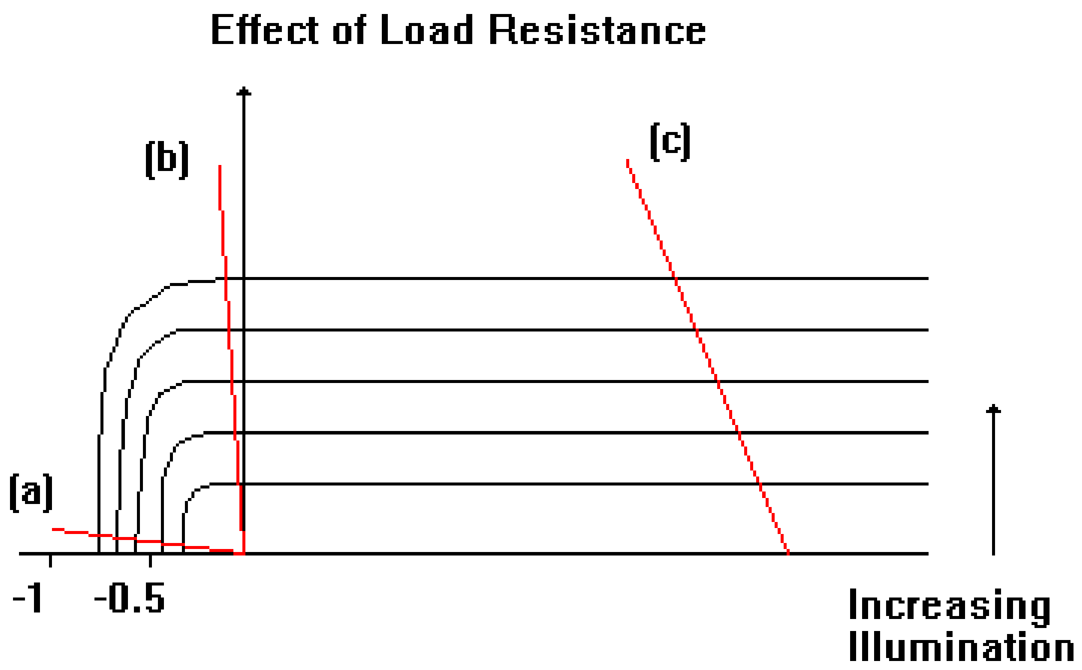
efficiencies of around 35%



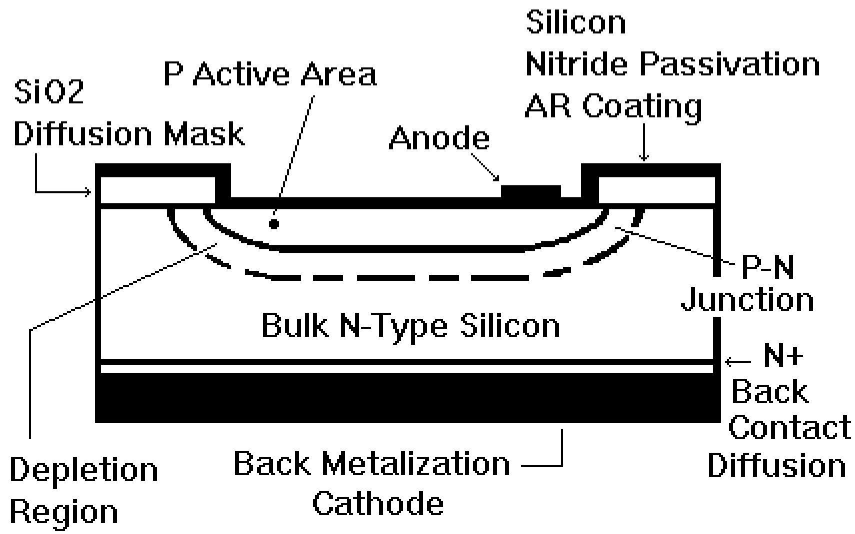
Photodiode Operation

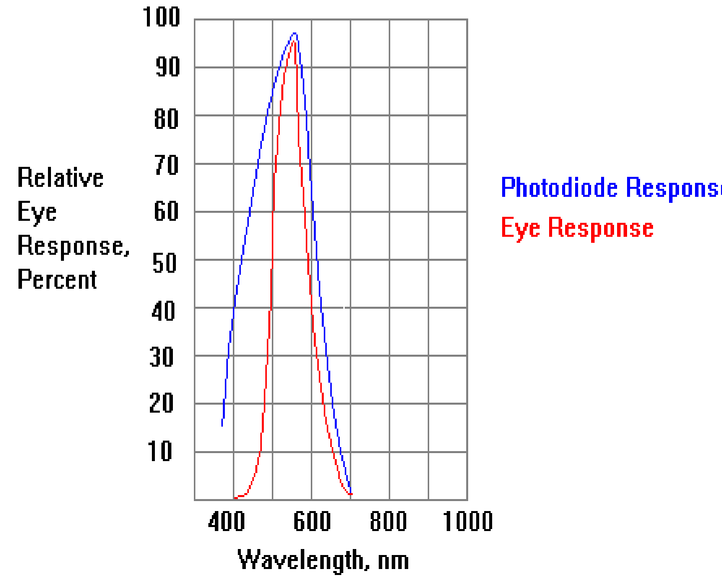


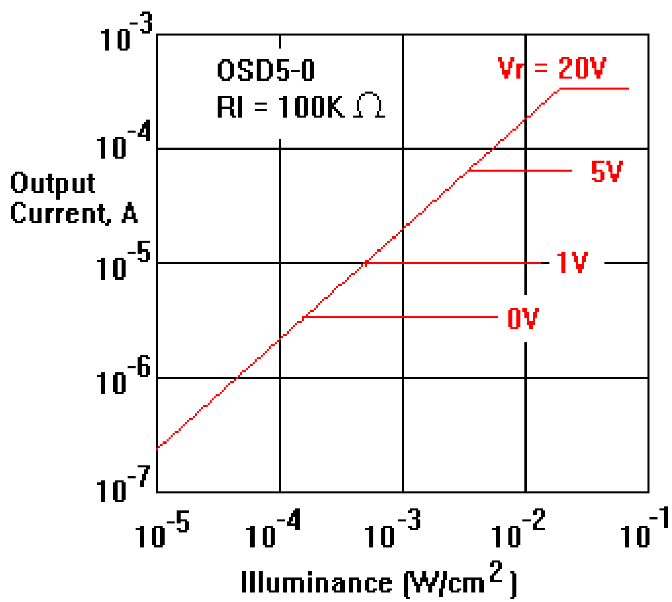
Photodiode Operation

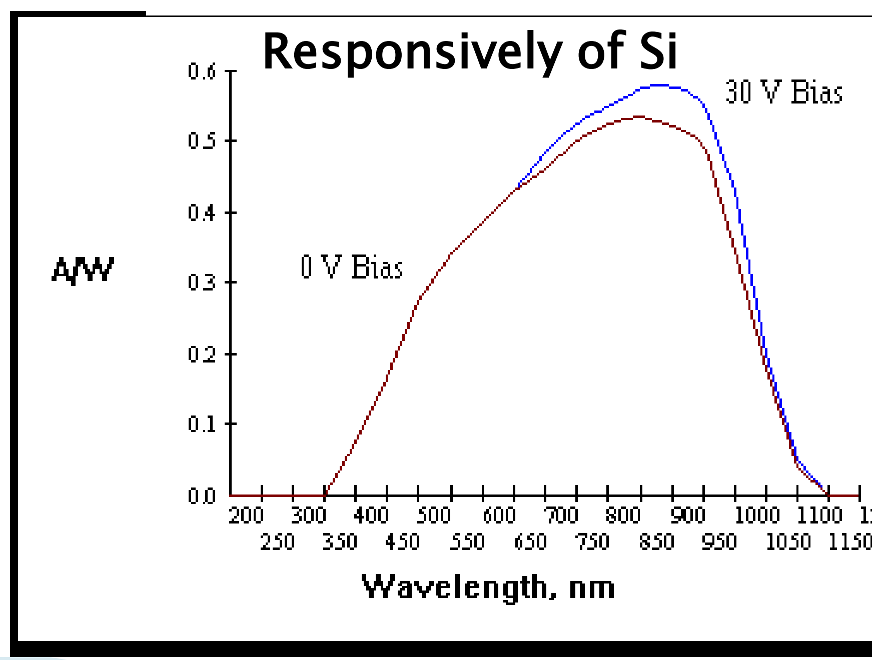


Photodiode


SiO2
Diffusion Mask
P Active Area
Anode
Silicon
Nitride Passivation
AR Coating
P-N
Junction
Bulk N-Type Silicon
N+
Back
Contact
Diffusion
Depletion
Region
Back Metalization
Cathode


Relative
Eye
Response,
Percent
100
90
80
70
60
50
40
30
20
10
400
600
800
1000
Wavelength, nm
Photodiode Response
Eye Response


OSD5-0
Rl = 100K Ω
Vr = 20V
5V
1V
0V
Output
Current, A
10^{-3}
10^{-4}
10^{-5}
10^{-6}
10^{-7}
10^{-5}
10^{-4}
10^{-3}
10^{-2}
10^{-1}
Illuminance (W/cm^2)


Responsively of Si
30 V Bias
0 V Bias
A/W
0.6
0.5
0.4
0.3
0.2
0.1
0.0
200
300
400
500
600
700
800
900
1000
1100
1200
250
350
450
550
650
750
850
950
1050
1150
Wavelength, nm

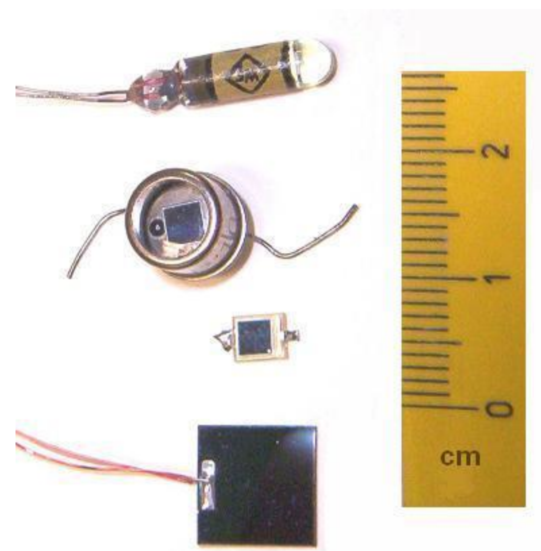
Photodiode Polarity

- IMPORTANT: Normal biased operation of most PD calls for negative biasing the active area of the device which is the anode or positive biasing the backside of the device, which is the cathode.

Fundamentally a photodiode is a current generator. The junction capacitance of the photodiode depends on the depletion layer depth and hence bias voltage. The value of the shunt resistance is usually high (megohms). The series resistance is low.

Quantum Efficiency

$$Q.E.[\%] = \frac{1.24 \times 10^{5} R[A/W]}{\lambda [nm]}$$



Equivalent Operating Circuits