## 1. Temperature Effects

$V_{oc}$ decreases (approx 0.33% per °C for monocrystalline Si PV) as the temperature increases

∴ PV's have a negative temperature coefficient

→ show Fig 2.12

$I_{sc}$ changes much less with temperature

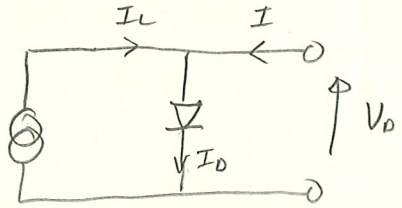
→ ∴ Power output decreases as temperature increases

→ Winter in northern latitudes with snow reflecting light onto a PV array is a good application for PV

→ In hot climates, PV cells may reach 70°C → techniques for cooling them are important

## 2. Modelling Resistive Losses in the PV cell

a. More on the PV circuit model




$$I = I_D - I_L = I_0\left(e^{V_D/V_T} - 1\right) - I_L$$

for $I_{sc} \rightarrow V_D = 0$ : $I_D = 0$

$$\therefore I = -I_L = -I_{sc}$$

$$\therefore I_L = I_{sc}$$

for $V_{oc} \rightarrow I = 0$

$$\therefore I_{sc} = I_D = I_0\left(e^{V_{oc}/V_T} - 1\right)$$

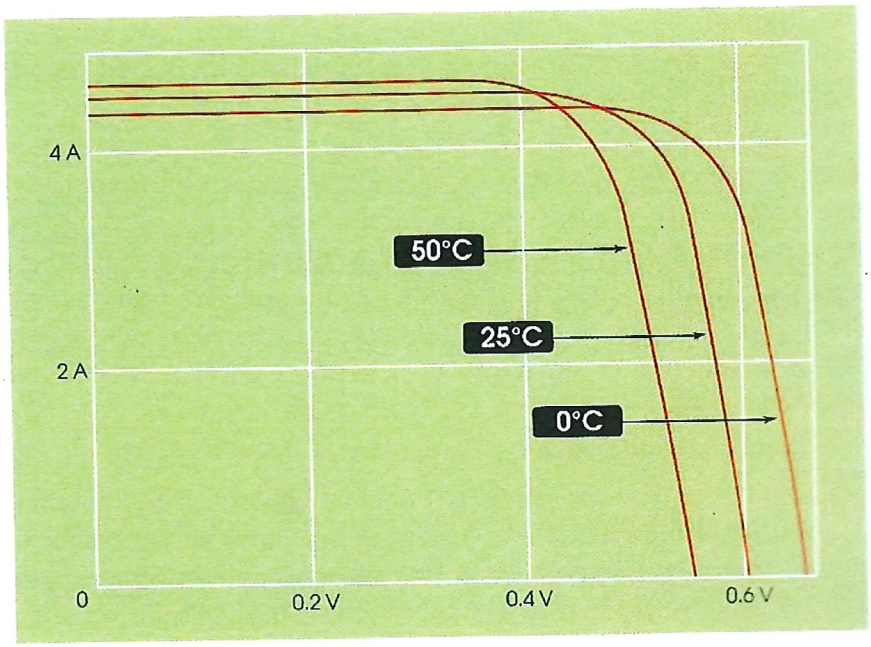



**Figure 2.12** Effects of temperature on the *I–V* characteristic.

or $V_{oc} = V_T \ln\left(\frac{I_{sc}}{I_0} + 1\right)$

$I_{sc}$ = "light current"

$I_0$ = "dark current"

$\therefore$ $V_{oc}$ = function of light and dark currents

If we include the diode nonideality factor, n

$\therefore$ $V_{oc} = nV_T \ln\left(\frac{I_{sc}}{I_0} + 1\right)$, but n is close to 1

<u>Note</u>: $V_T = \frac{kT}{q}$

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

This indicates $V_{oc}$ increases with temperature!

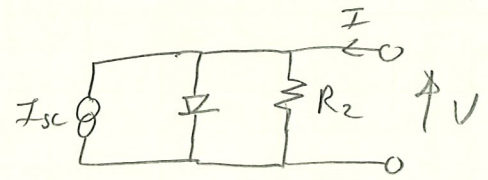
It Does Not!

The dark current, $I_0$, <u>increases</u> with temperature, enough to offset increasing T, so that $V_{oc}$ decreases as temperature increases

b. <u>Modeling Losses</u>

① recombination and other "shorting losses"

→ can be modeled as a shunt resistor, $R_2$, in parallel with the PV




$R_2$ effect: small decrease in $V_{oc}$, larger decrease in the fill factor

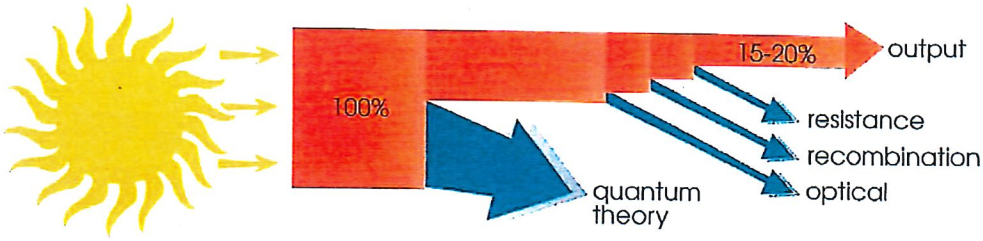



**Figure 2.14** Solar cell losses.



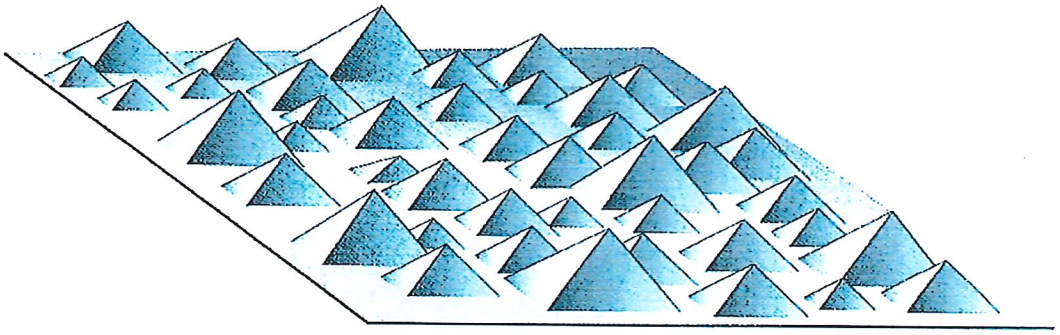


**Figure 2.18** Texturisation by raised pyramids.

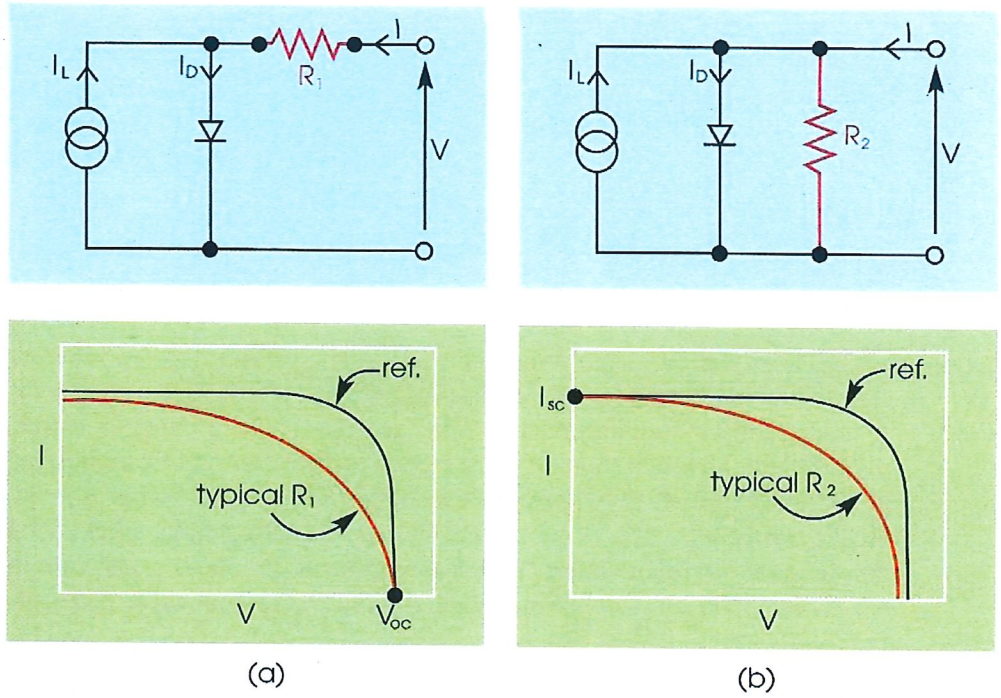
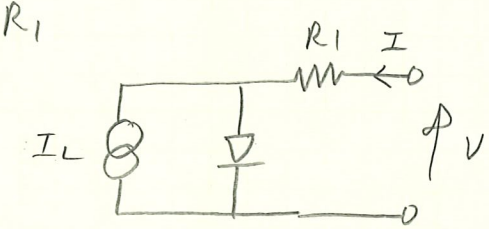



**Figure 2.21** Equivalent circuits and *I–V* characteristics of a solar cell that includes: (a) series resistance; (b) shunt resistance.

② Resistive losses (resistance in contacts, bus bars, fingers and the bulk semiconductor material)

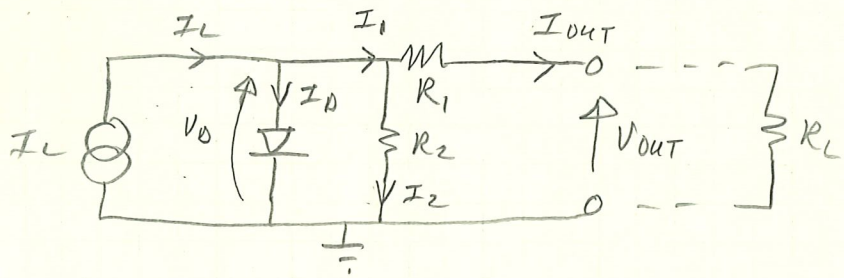
→ can be modeled as a resistor in series with the PV, $R_1$




$R_1$ effect: small decrease in $I_{sc}$, but a larger decrease in the fill factor

→ Show Fig 2.21

③ Circuit model with $R_1$ and $R_2$




$$I_1 = I_L - I_D$$

$$I_D = I_0 \left(e^{V_D/V_T} - 1\right)$$

$$V_D = V_{OUT} + I_{OUT} R_1$$

$$I_{OUT} = I_1 - I_2$$

$$I_2 = \frac{V_D}{R_2} = \frac{V_{OUT} + I_{OUT} R_1}{R_2}$$

$$\therefore I_{OUT} = I_L - I_0 \left(e^{\frac{V_{OUT} + I_{OUT} R_1}{V_T}} - 1\right) - \frac{V_{OUT} + I_{OUT} R_1}{R_2}$$

## 2. Poly- or Multicrystallin Si PV

→ Similar to the Single or Monocrystalline PV cells

→ Different manufacturing process

Monocrystalline Si →

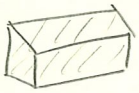
CZ or Czochralski process ⟹

single xtal ingot

→ saw to wafer

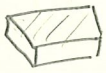
→ finely polished

Multicrystalline Si →

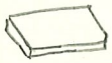


cast multicrystalline block

→ cut to smaller block →



→ waferized



Poly Si PV are about 1% less efficient than Single-Xtal Si PV
↳ 10% to 16% eff

But: (1) Poly Si PV are lower cost

(2) are made rectangular → more densely packed than ~ rounded single crystal Si PV

→ Poly Si PV cells have a scaly, shimmering blue distinctive apperance
↓
antireflective coatings

Poly Si grain boundaries → present unwelcome sites for $e^-$-hole recombination → hence lower efficiency than single crystal PV

3. Amorphous Si (a-Si) PV

→ 1st "thin-film" PV technology.

→ easy to manufacture and low-cost

→ a-Si PV has lower efficiency: 6-8% → about half the efficiency of single-crystal Si PV

→ But a-Si is better than single-crystal Si PV in weak or diffuse light (indoor aps like powering a calculator)

→ a-Si PV is less adversely affected by temp than SC Si PV

a. a-Si

→ a better light absorber the SC-Si

∴ very thin films can be used for PV → ~1μm

→ no regular lattice structure → random structure

→ incomplete bonds and many defects

→ results in energy stepping stones between valence and conduction bands → promotes recombination

→ low charge carrier mobility

⇒ Techniques have been developed to overcome these issues.