“Third Generation Photovoltaics”

Martin A. Green
University of New South Wales
Sydney, Australia

* Supported by the Australian Research Council
First Generation Wafers/Ribbons

**Strengths**
- reliable, durable, etc.

**Weaknesses**
- material intensive
- < US$1/Wp unlikely
- energy payback only 4yr

**BUT**
zero energy if growth > 25%/yr

(Lysen, PV in Europe)
Second Generation (thin-film)

Crystalline Silicon on Glass (CSG)

Pacific Solar >> CSG Solar
first products 2006

Metal
Resin
p⁺
P
p⁺/n⁺

'Silicon'
'Crater'
'Groove'
'Dimple'
'
Textured glass

Light In

Photovoltaics - Electricity from Sunlight
II. Efficiency/cost

![Graph representing efficiency and cost in Photovoltaics]

- Present limit
- Thermodynamic limit

- US$0.10/W
- US$0.20/W
- US$0.50/W
- US$1.00/W
- US$3.50/W
Photovoltaics - Electricity from Sunlight

Efficiency Limits

\[ \eta \leq (1 - \frac{T_A S_s}{E_s}) = 93.3\% \text{ (direct)} = 73.7\% \text{ (global)} \]
III. Efficiency/cost

UNSW

Photovoltaics - Electricity from Sunlight
Third Generation

- thin-film
- high efficiency (> single junction)
- abundant materials
- non-toxic
- stable, durable
Options/Limits

- Circulators
- Tandem (n→∞)
- Hot carrier
- Tandem (n = 6)
- Impurity PV & band, up-converters
- Impact ionisation
- Tandem (n = 3)
- Down-converters
- Single cell
- Thermal, thermoPV, thermionics
- Tandem (n = 2)

Percentages:
- 100%
- 74%
- 68%
- 58%
- 54%
- 49%
- 44%
- 39%
- 31%
- 0%
Hot Carrier Cells

The diagram illustrates the efficiency of hot carrier cells as a function of bandgap energy. The graph shows two curves representing hot carriers and cold carriers, with peak efficiencies at different bandgap values. Materials like InN and Si are indicated, with arrows pointing to their respective bandgap values. The x-axis represents the bandgap in electron volts (eV), while the y-axis represents the efficiency in percentage.
1. Energy relaxation: radiative ~ phonon
2. Energy selective contacts
“Hot Phonons”/Phononic Bandgaps

indium nitride

Silicon

tunneling contact

absorber

Photovoltaics - Electricity from Sunlight
Up-Conversion

Absorption (%)

EQE (%)

\( \lambda \) (nm)

\begin{align*}
\text{absorption 0.8mm EVA:phosphor [7:3]} \\
\text{EQE x~2000 QTH lamp excitation} \\
\text{EQE Laser excitation}
\end{align*}

UNSW

Photovoltaics - Electricity from Sunlight
Tandems

Solar cells

Sunlight

Decreasing band gap

Photovoltaics - Electricity from Sunlight
Photovoltaics - Electricity from Sunlight

2D/3D Silicon

Photoluminescence [a.u.]

Appl. Phys. Lett. 84, 2286, 2004

UNSW
Photovoltaics - Electricity from Sunlight

UNSW

0D/3D Silicon

SiO_x, Si_yN_x, Si_C_x

SiO_2, Si_3N_4, SiC

Photovoltaics - Electricity from Sunlight
Si Quantum Dot Tandem (SQOT)

AM1.5G Efficiency

UNSW
All-Si CSG Tandem

Metal
Resin
'Crater'
'Groove'
'Dimple'
Textured glass

Light In

Photovoltaics - Electricity from Sunlight
Conclusions

- innovation needed for PV to reach full potential

- **hot carrier:**
  
  resonant tunneling, phononic engineering

- **multiple step:**
  
  rear up-converter

- **tandems:**
  
  all c-Si quantum dot tandems (SQOTs)