UNSW THE UNIVERSITY OF NEW SOUTH WALES } ENGINEERING

School of Photovoltaic and Renewable Energy Engineering

Australia-based Education and Research for Photovoltaics Industry Expansion in the Asia-Pacific Region

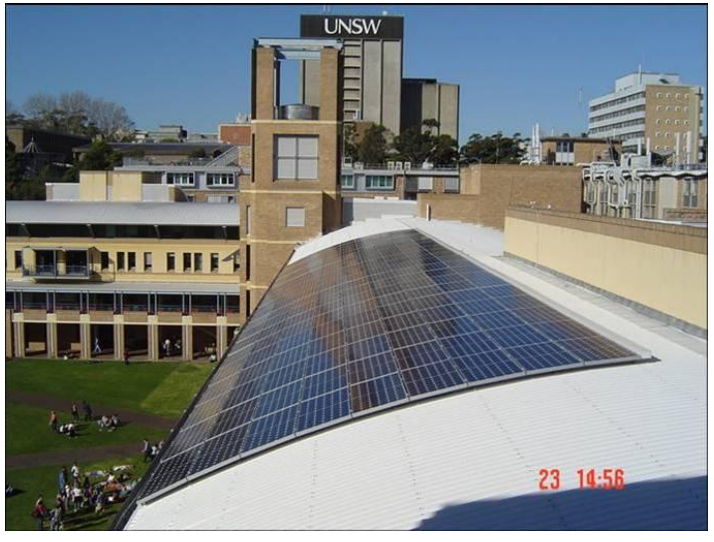
R. Corkish, Head of School

r.corkish@unsw.edu.au

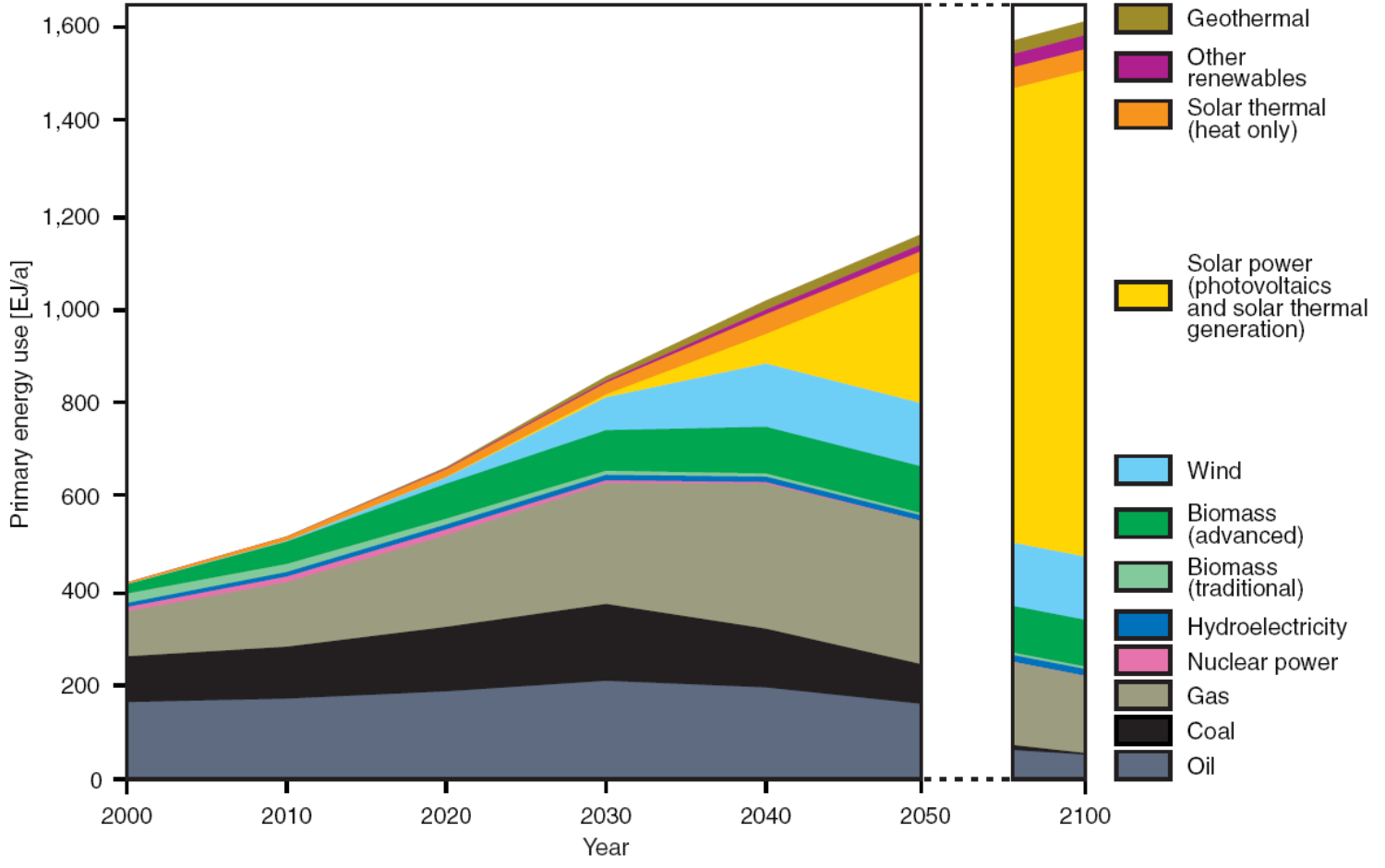
www.pv.unsw.edu.au

UNSW

- Established 1949
- Member Group of Eight best Australian research universities
- Member Universitas21 - leading research intensive universities in 13 countries
- Focus on environmental sustainability
- 46,630 Students in 2009
  - 69% undergraduate
  - 24% postgraduate coursework
  - 7% higher degree research
  - 25% international
- 2,497 Academic Staff
- 2,779 Professional & Technical Staff
- 200,847 alumni in 2008
- 8 faculties; 56 schools
- Kensington site is 38 ha

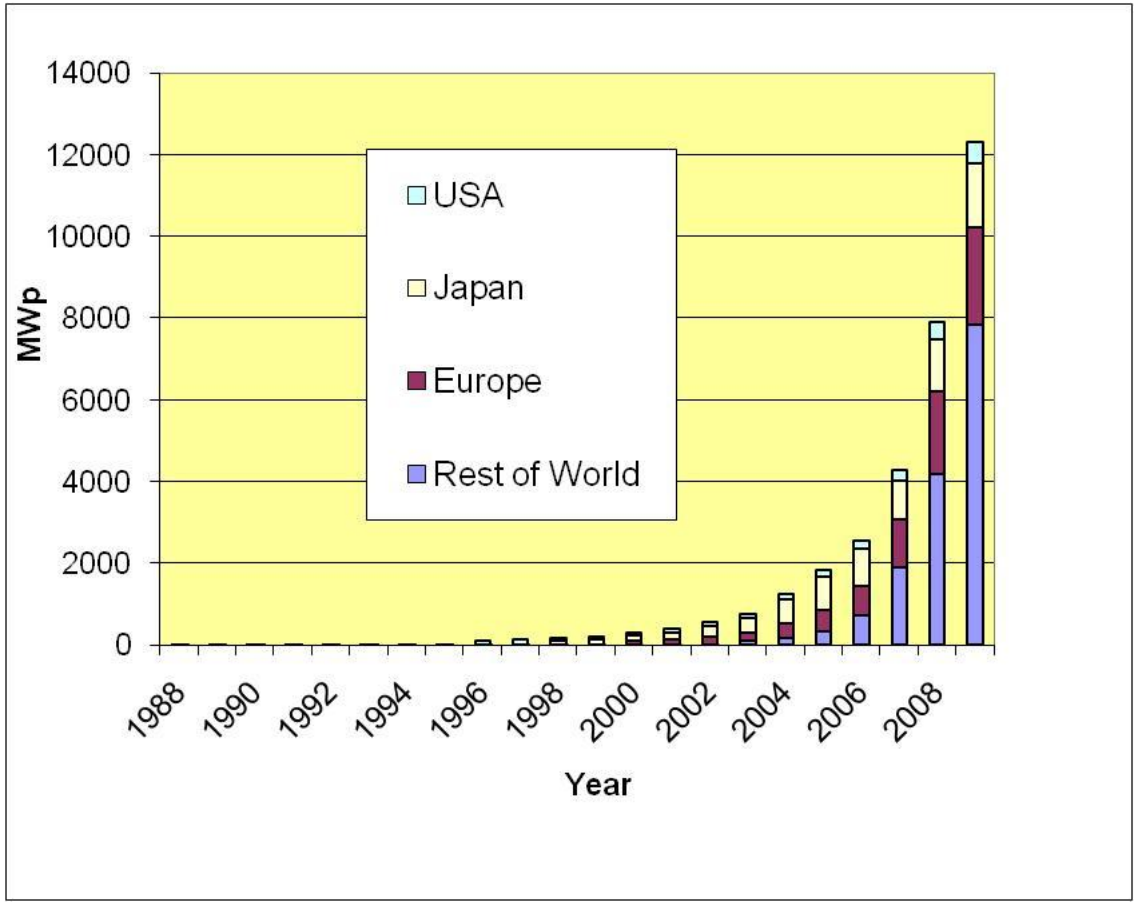


Context: The exemplary path until 2050/ 2100

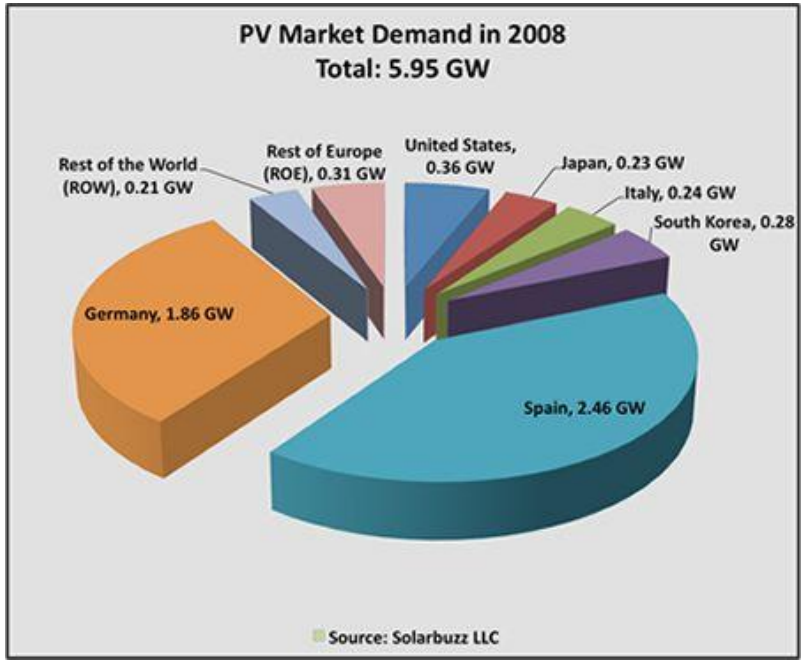


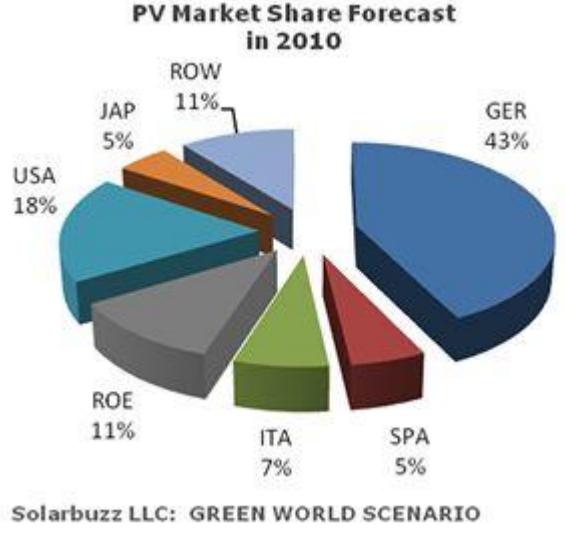
Reference: "World in Transition: Turning Energy Systems Towards Sustainability (Summary for Policy Makers)," German Advisory Council on Global Change, Berlin 2003.
www.wbgu.de

Context: Booming Photovoltaics



By region of manufacture

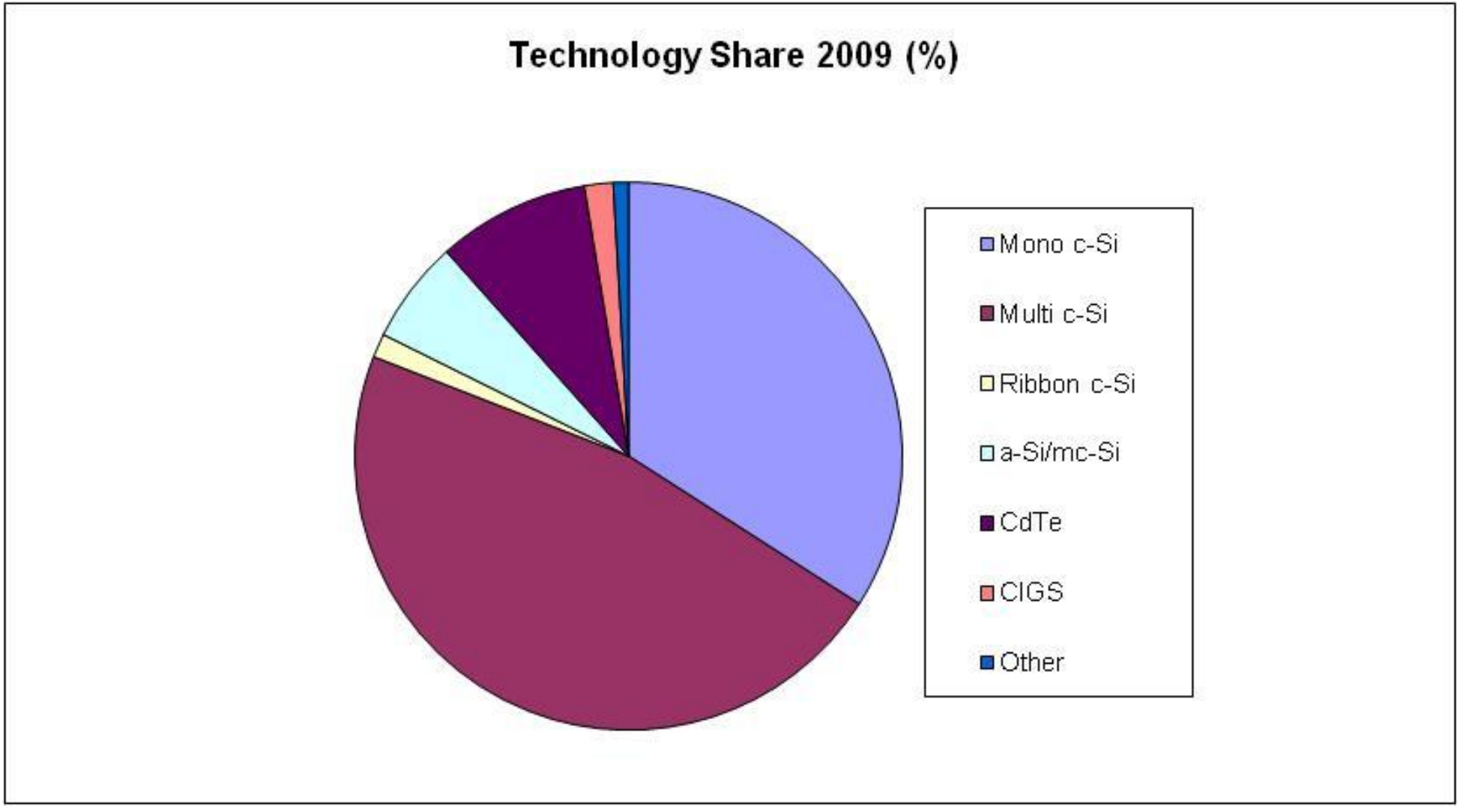




PV production in 2009

- 56% production growth in 2009
- Photon Int. predicts further 76% growth in 2010
- Asia dominating cell production (63%)
- Mainland China grew 81%
- Taiwan grew 64%
- India grew 152%
- Korea grew 141%

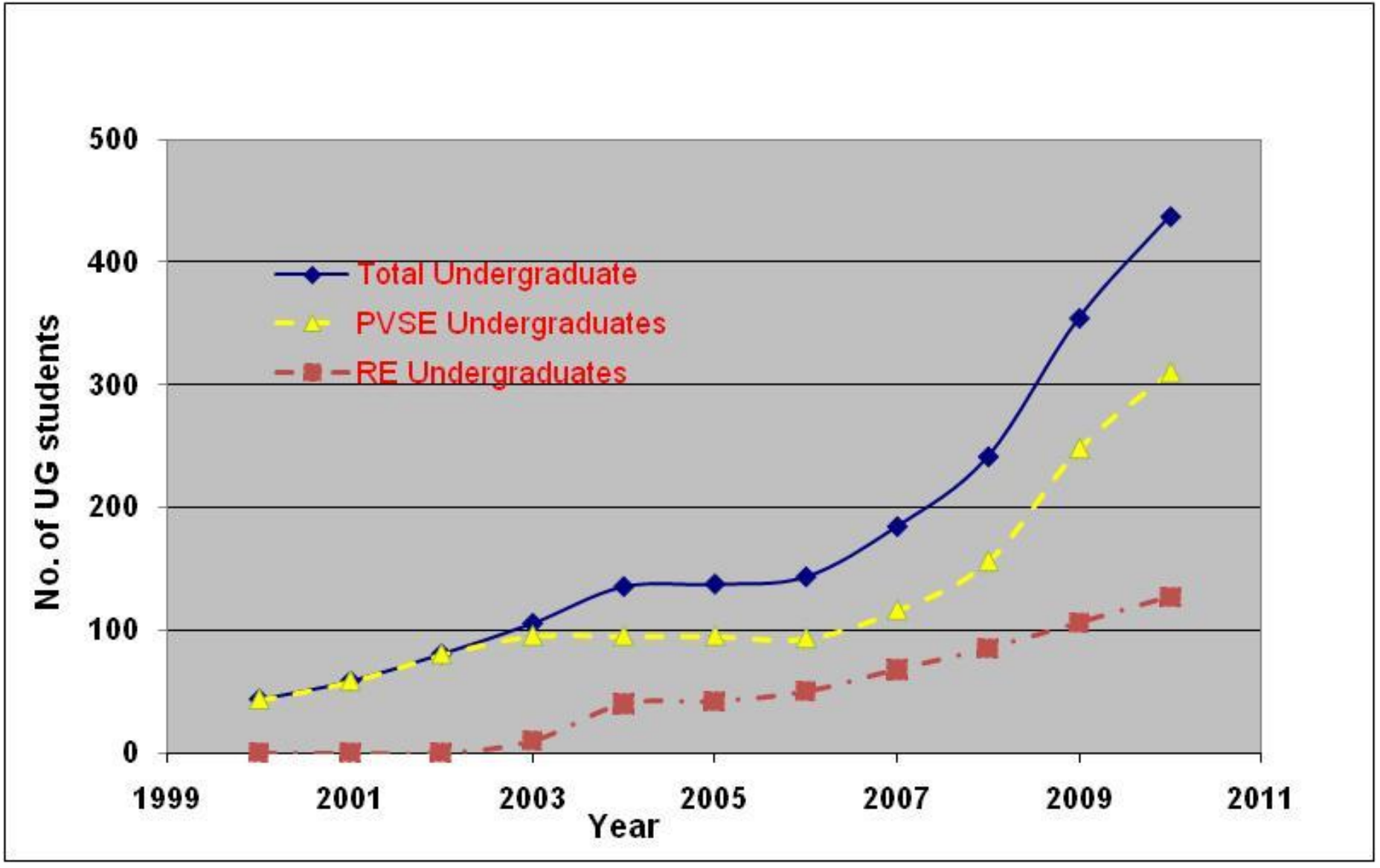
Technology Share



School History

- PV research within UNSW Electrical Eng. 1974 – 1998
- Separate Centre 1999 – 2005
- Pioneering UG photovoltaics engineering program 2000
- PG coursework program 2001
- Second UG program 2003
- New School declared 2006

Undergraduate Education



Session 2, numbers

Undergraduate Education

Two 4-year Engineering programs (439 students):

- Photovoltaics and Solar Energy (2000)
- Renewable Energy (2003)
- 24% growth 2009-10

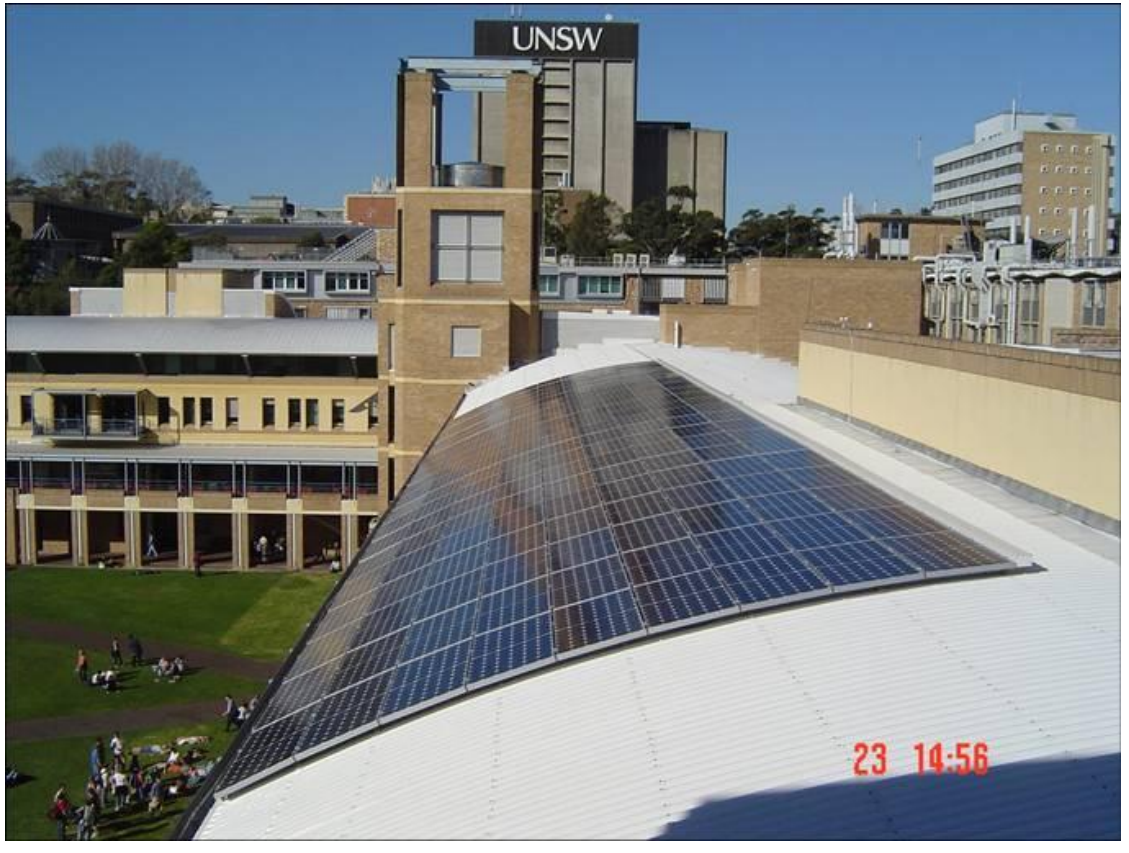
- 158 graduates
  - 108 PVSE
  - 8 PVSE + Science
  - 9 PVSE + Arts
  - 3 PVSE + Commerce
  - 28 RE
  - 2 RE + Science

(Session 2, 2010 figures)

Photovoltaics and Solar Energy

First such specialist degree globally

- Technology development
- Manufacturing
- Systems engineering
- Maintenance
- Reliability and lifecycle analysis
- Marketing
- Policy



Renewable Energy Eng.

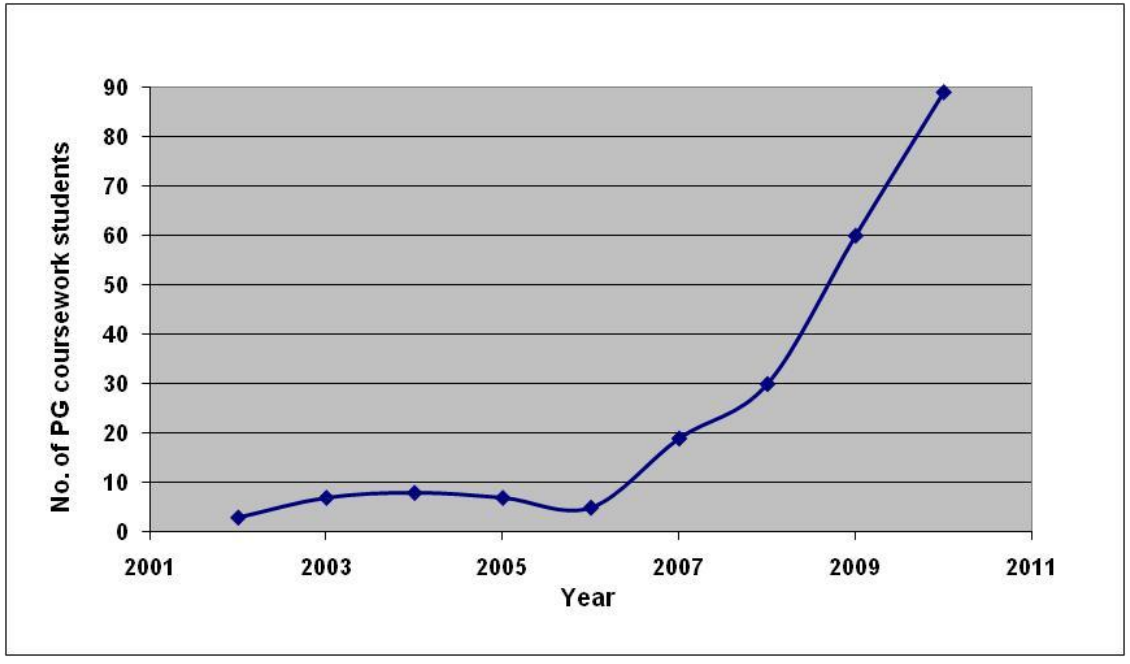
- Begun 2003
- Development shared with Murdoch Univ., Perth
  - Photovoltaics
  - Energy Efficiency
  - Solar thermal
  - Wind
  - Biomass
  - Solar architecture

Postgraduate Education

- **Master of Engineering Science in Photovoltaics and Solar Energy (82 students)**
  - 37% growth 2009-10
  - 1.5 year addition to 4-year BEng. or BSc;
  - 94 graduates
- **Research degrees**
  - PhD **(57 students),**
  - Masters **(10 students)**

(S2, 2010 figures)

Postgraduate Coursework Enrolments

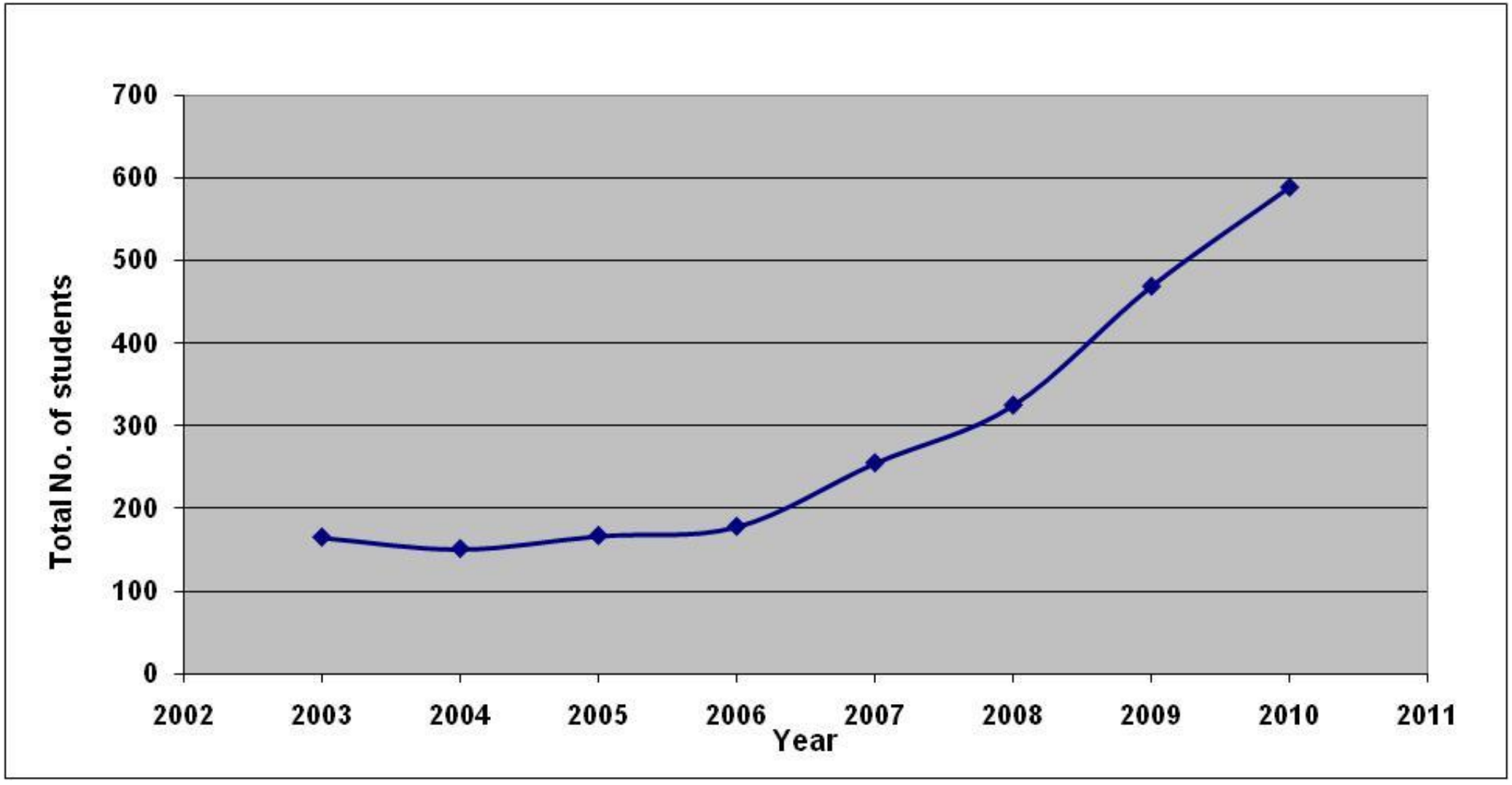


- Significant international fraction
- Low numbers until 2007
- Mood change in Australian community in late 2006
- Rapid recent growth

Session 2, numbers

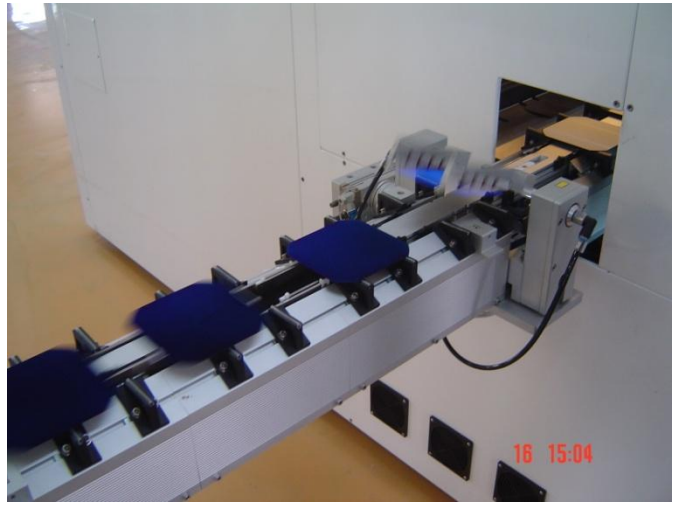
Graduate Certificate of Engineering Science (7338)
Graduate Diploma of Engineering Science (5338)
Master of Engineering Science (8538)

Total Student Population 2003 - 10



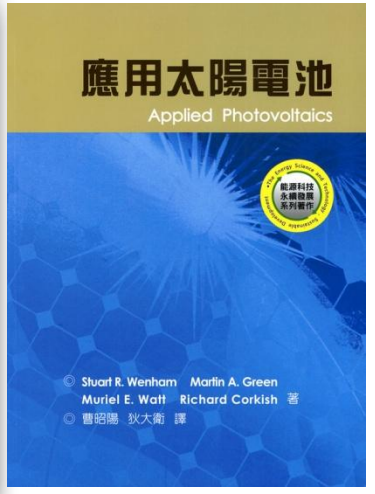
Major (Asia-Pacific) Collaborations

- Toyota Central R&D Labs.
- Several Asian PV manufacturers
  - R&D collaborations
  - Intellectual property licenses
- Asia-Pacific Partnership for Clean Energy & Climate (Australia, Canada, China, India, Japan, Korea, India, USA)
- Chinese publications
- Stanford U. Global Climate & Energy Project (1)
- Stanford U. Global Climate & Energy Project (2)

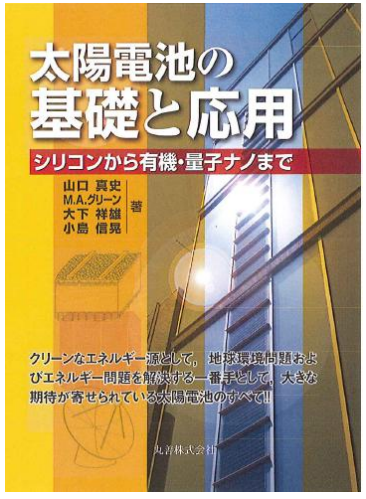


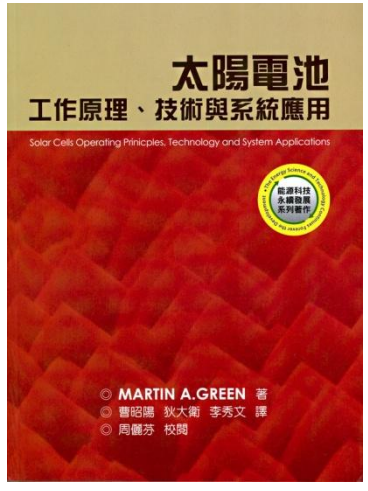
Translated Texts

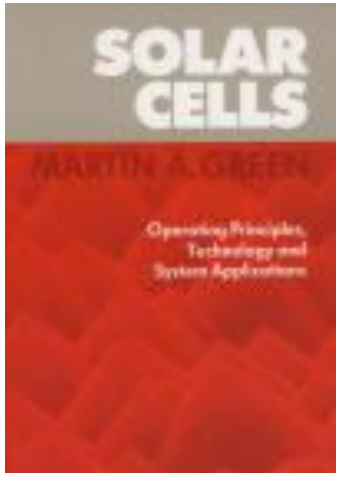
- "Applied Photovoltaics"
  - Simplified Chinese (2008)
  - Traditional Chinese (2009)
  - Korean (in progress)



- "Solar Cells"
  - Simplified Chinese (2010)
  - Traditional Chinese (2010)
  - Japanese (2010)





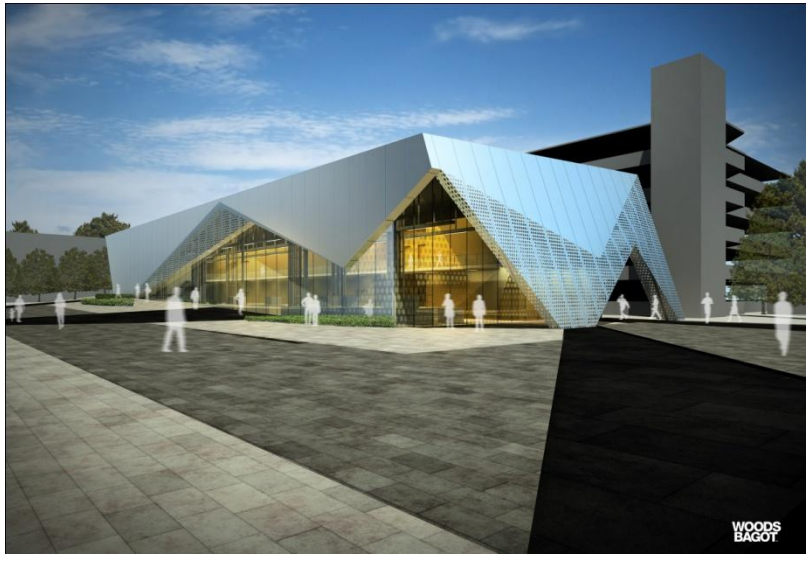


Asia-Pacific Partnership

- Asia-Pacific Partnership on Clean Development and Climate
  (Renewable Energy and Distributed Generation Task Force)
- PhD sponsorships (fees) – now filled
- MEngSc sponsorships (half fees) – now filled
- BEng (2+2) sponsorships (fees, China only) – now filled
  - Nankai University
  - Sun Yat-Sen University
  - Tianjin University
  - Zhejiang University
  - Nanchang University
  - Beijing Jiao Tong University
  - South China University of Technology

Funding & Infrastructure Initiatives

- Australian Solar Institute (ASI)
  - **A$100M** / 4 years (€51M), PV / Solar Thermal
  - Foundation Member Institutions, A$5M initial grant
    - University of NSW (UNSW)
    - Australian National University (ANU)
    - Commonwealth Scientific & Industrial Research Organisation (CSIRO)



- Solar Industrial Research Facility (2011)
  - **A$10M** UNSW campus-located building
    - Roth & Rau pilot line

- Tyree Energy Technologies Building (2012)
  - **A$155M** (€79M) UNSW campus-located showcase building

Technical

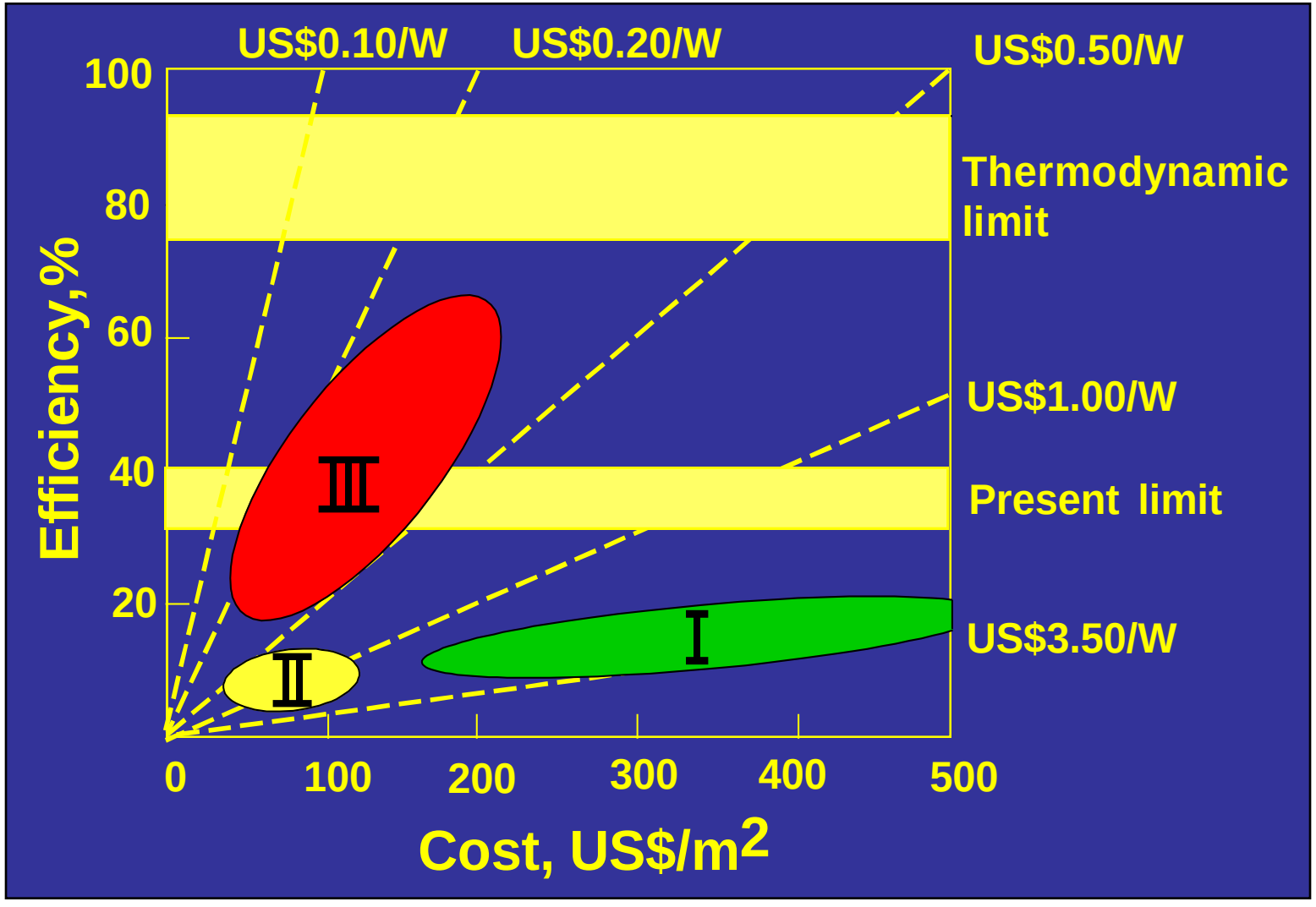
- **System & Installer accreditation:**
  - **Motivator for education & training**
  - **www.cleanenergycouncil.org.au/cec/accreditation/findaninstaller.html**
- **Training organisations list maintained by Clean Energy Council**
  - **www.cleanenergycouncil.org.au/cec/accreditation/accreditationprocess/required-training.html**
- **Accredited inverters and modules**
  - **www.cleanenergycouncil.org.au/cec/accreditation/approvedproducts.html**

Standards

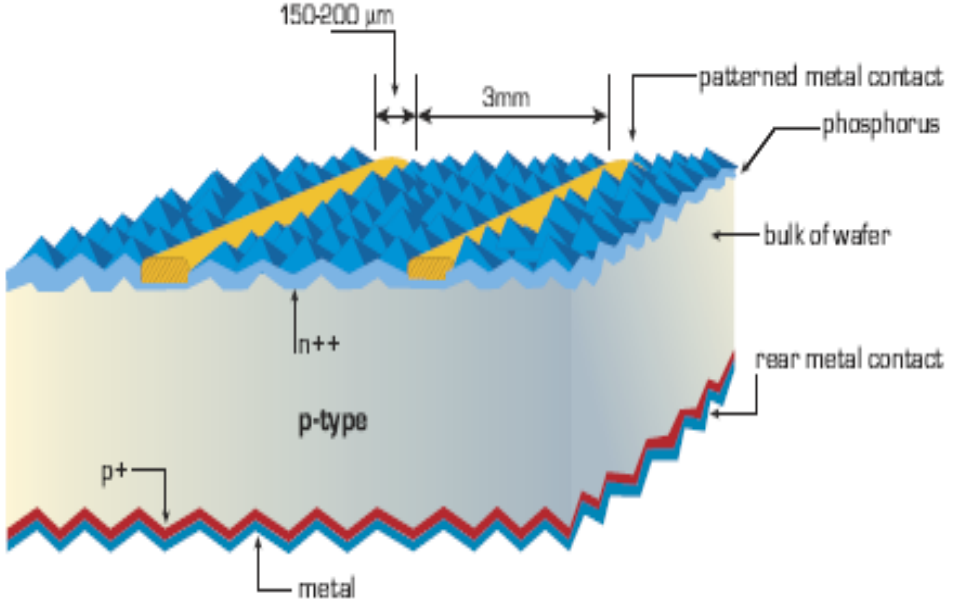
- *www.standards.org.au*

- AS 4509 - Stand-alone power systems
- AS 4777 - Grid connection of energy systems via inverters
- AS/NZS 5033 - Installation of photovoltaic (PV) arrays

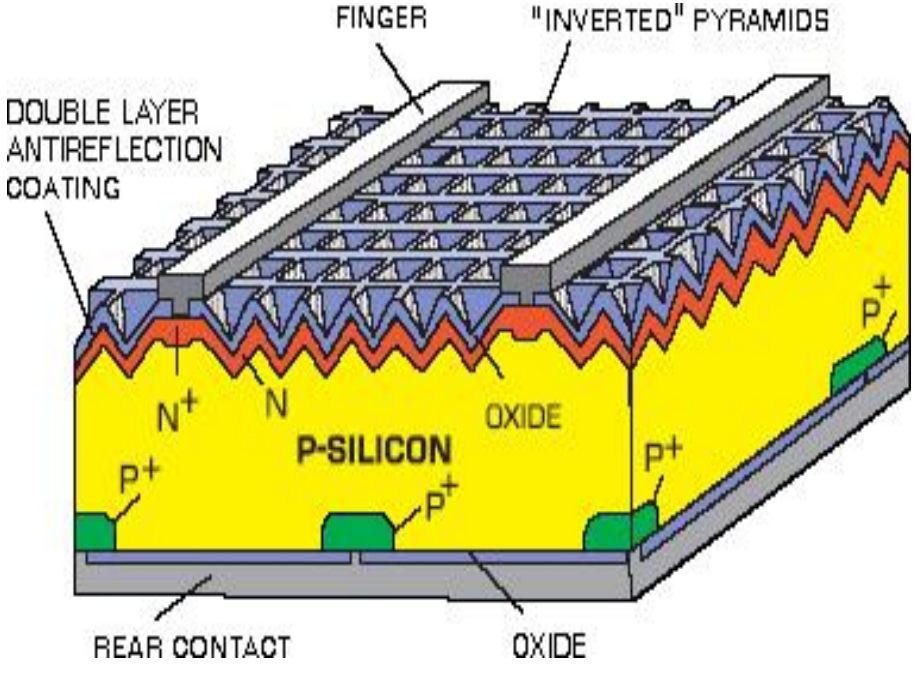
Generations of Photovoltaics



First Generation: Wafers/Ribbons



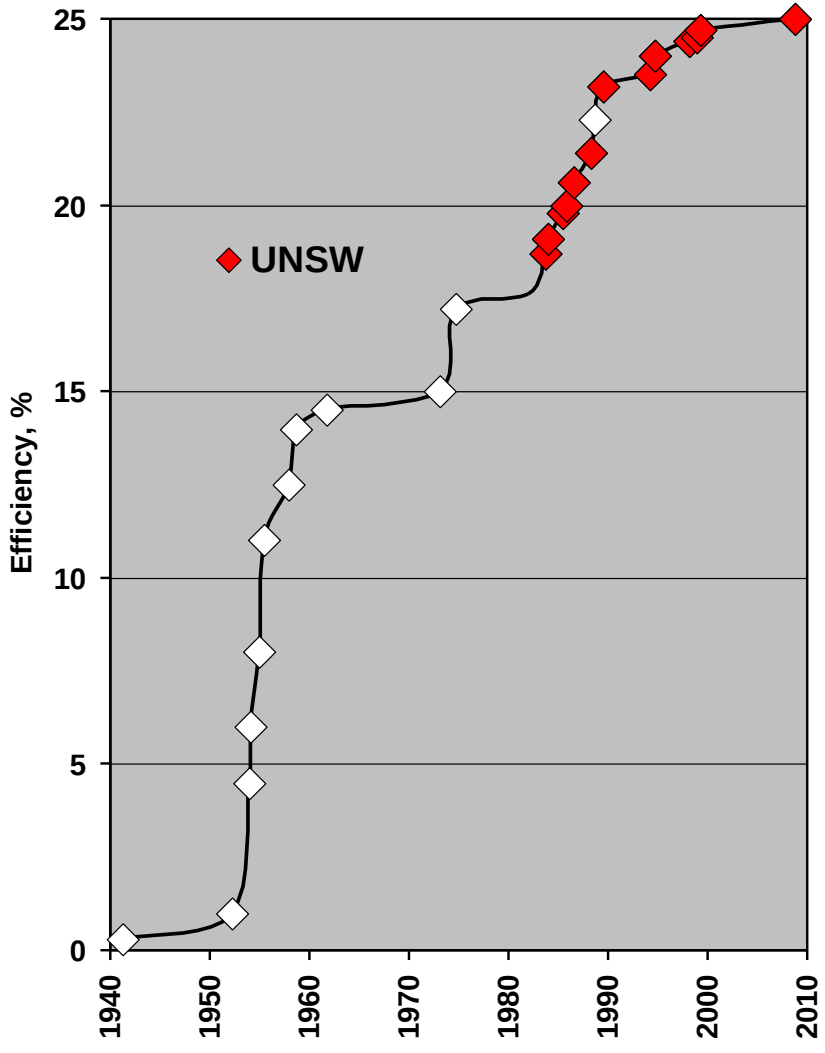
17% Industrial Screen Print Solar Cell



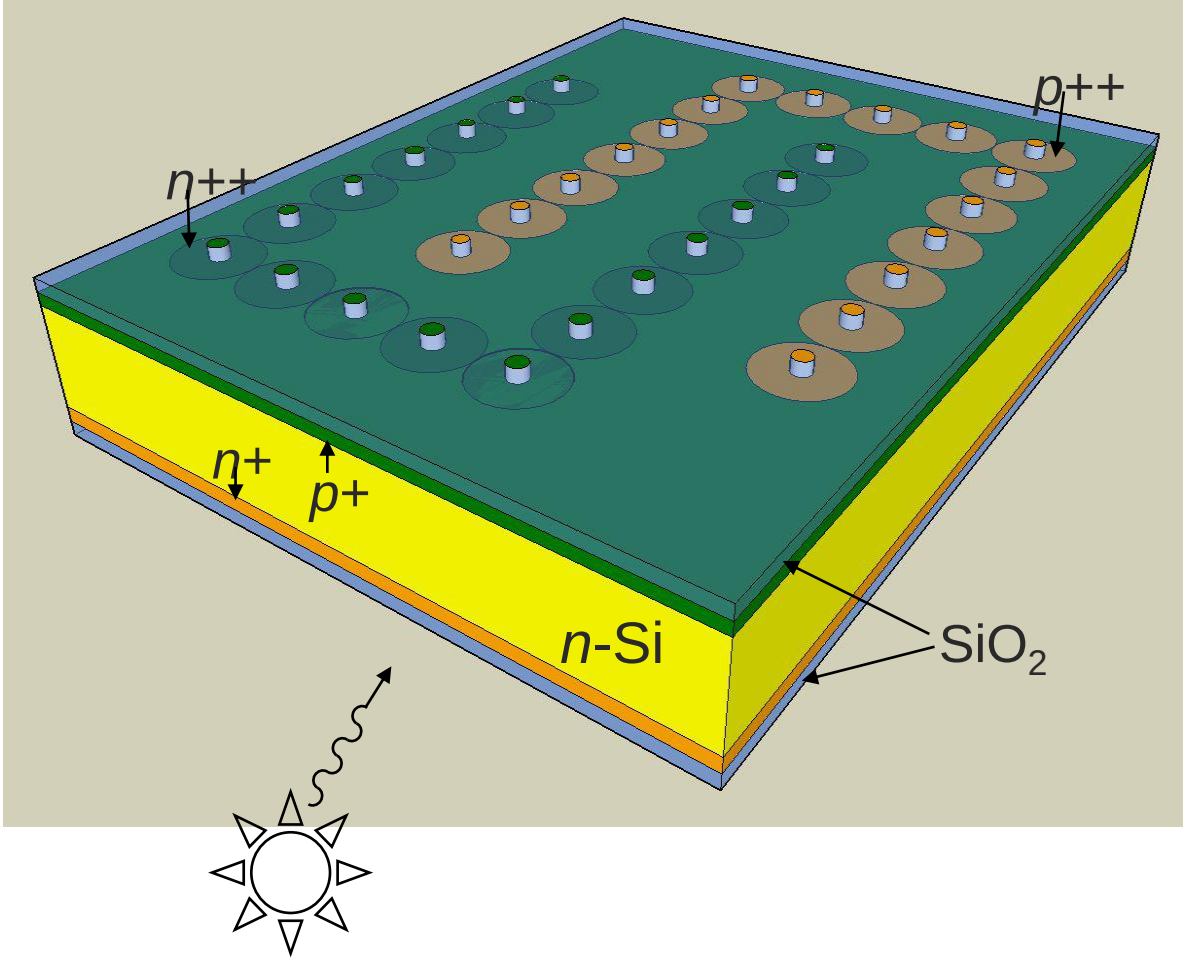
25% Efficient PERL Solar Cell

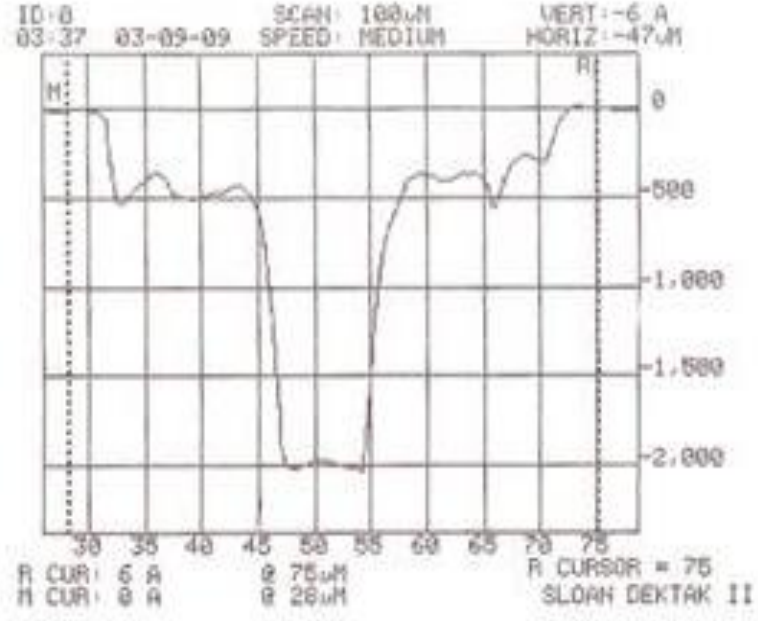
World Records for Device Performance

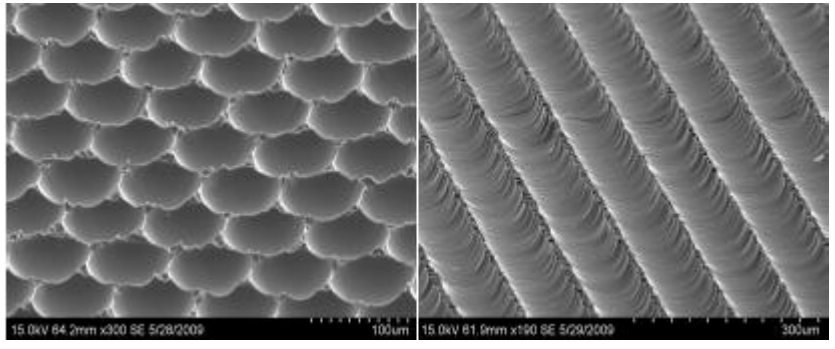
- Highest efficiency Si solar cells
- Highest efficiency PV modules
- Equal highest efficiency n-type Si solar cells



Inkjet Printing

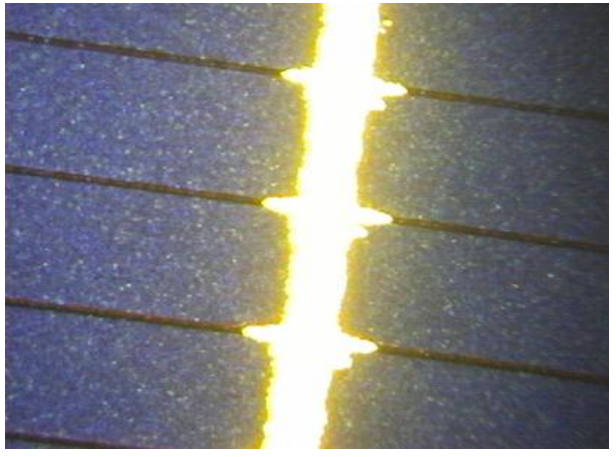


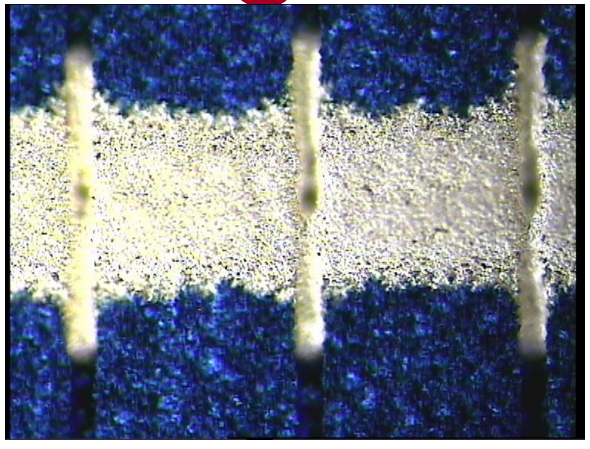




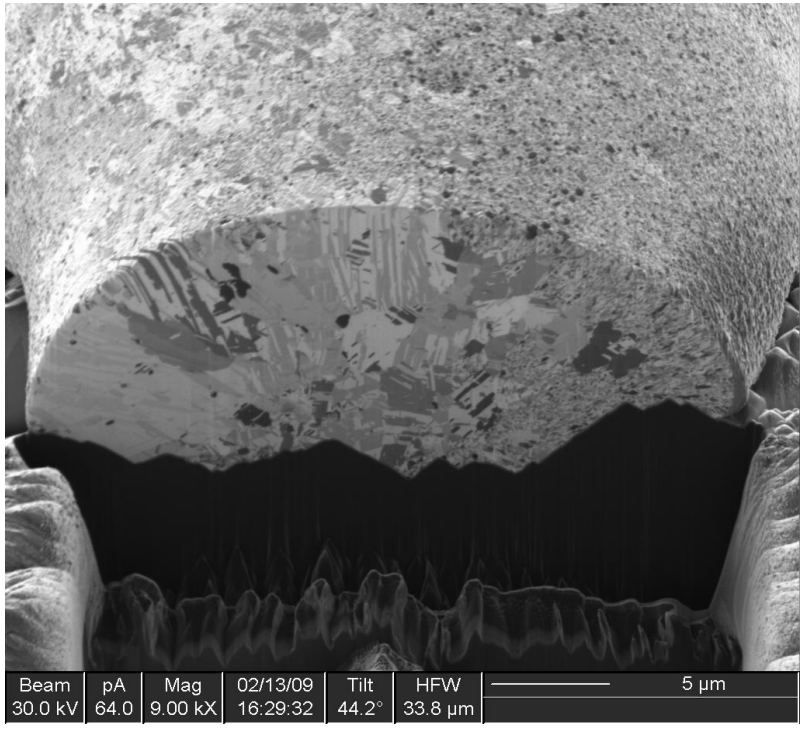
Selective Emitter – 3 Technologies

- Semiconductor Fingers:
  - Laser doped lines replace doped grooves
  - Screen-printed metal fingers run perpendicular to diffused lines



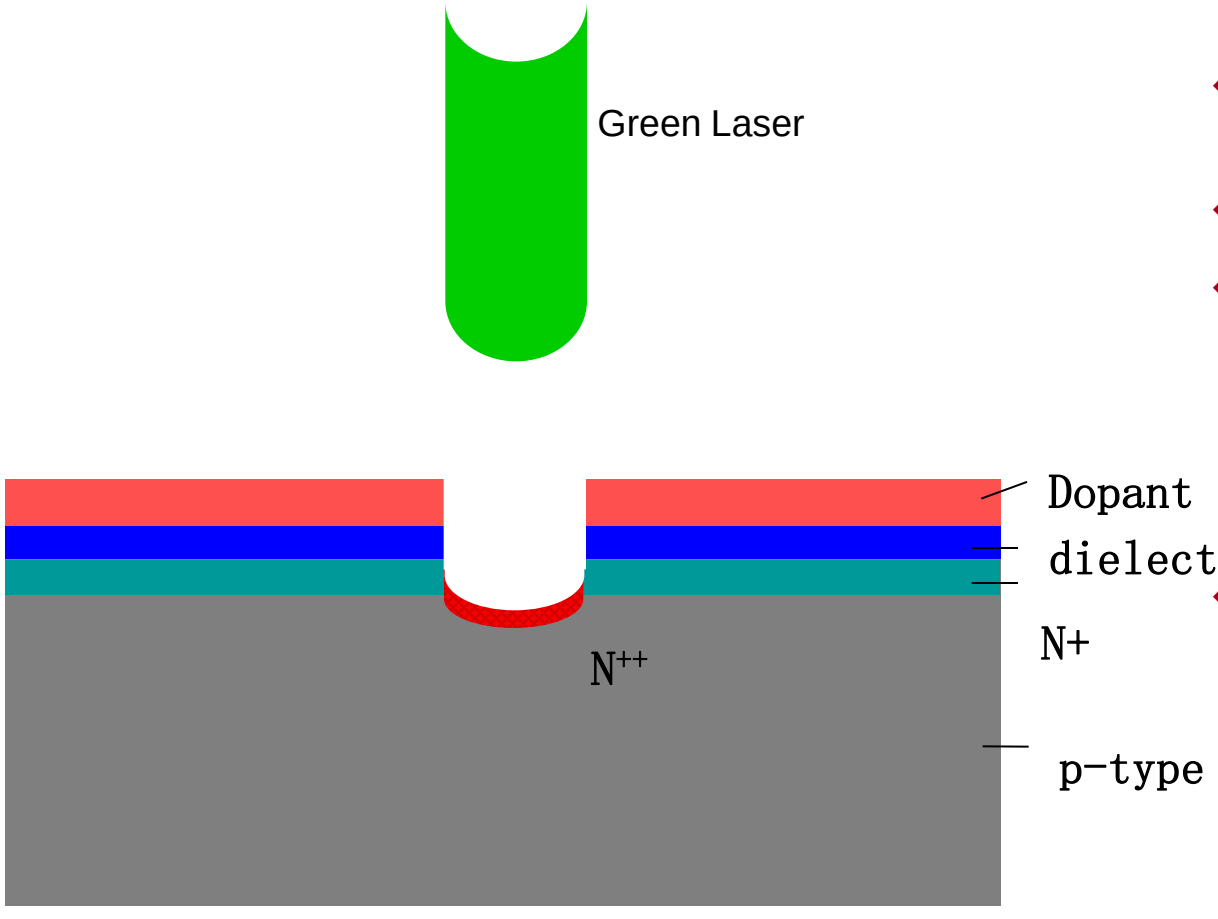


- Laser Doped Selective Emitter
  - Laser doping through/from dielectric layer
  - Dielectric doubles as ARC and plating mask
  - Laser doping gives heavily doped surface ideal for self aligned plating and selective emitter



- Transparent Fingers
  - Semiconductor Fingers with laser doped lines

Laser Doped Selective Emitter



- Green laser selectively removes ARC dielectric and melts the silicon underneath
- Molten Si freezing simultaneously incorporates heavy N-type Phos doping
- High temperature at localised regions only
- Self aligned base metal plating into laser pattern –
  - low cost materials,
  - in line process flow,
  - fast LIP plating,
  - zero contact
- **Performance > 19% LDSE, >> 20% D-LDSE**

Current Status

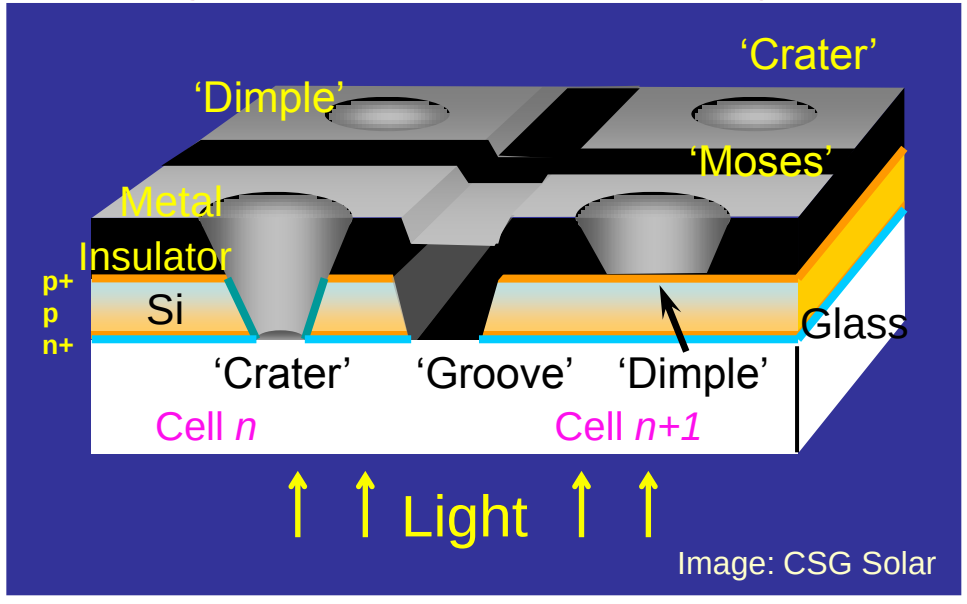
	Now	2011	2012
SP semiconductor finger cells CZ	18.3%		
SP semiconductor finger technology multi	16.0%		
SP transparent conductors CZ	17.8%	18.5%	
SP transparent conductors multi	16.5%	17.0%	
LDSE p-type CZ	19.0%	>20%	
LDSE n-type CZ	19.1%	>20%	21.0%
LDSE p-type-multi	17.4%		18.0%
LDSE n-type multi	16.0%		
Injet/Aerosol technology p-type CZ		18.0%	>20%
Inkjet/Aerosol technology n-type CZ		19.0%	>20%

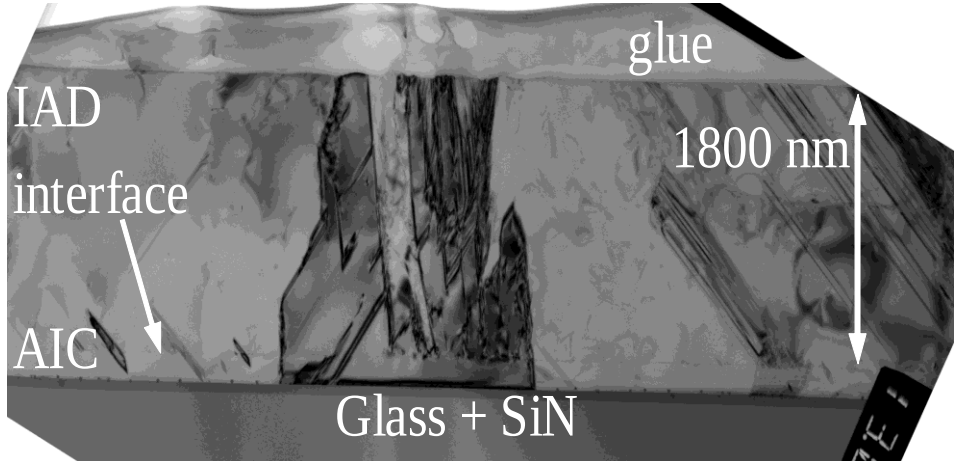
Acronyms	
LDSE:	Laser doping Selective Emitter
SP:	Screen Print
CZ:	Czochralski-method (Cz-Si) - mono

Large-scale production on full-sized wafers

Second Generation (Thin Films)

- Thin films on supporting substrate
  - Amorphous/ microcrystalline Si
  - CIGS
  - CdTe
  - Crystalline Si
- Lower efficiency but lower cost
- Large manufacturing unit
- Fully integrated modules
- Aesthetics





Crystalline Silicon on Glass

SI WAFER TECHNOLOGY

- Technological base
- Electronic properties
- Proven long-term stability
- Nontoxic & abundant materials

+

THIN-FILM TECHNOLOGY

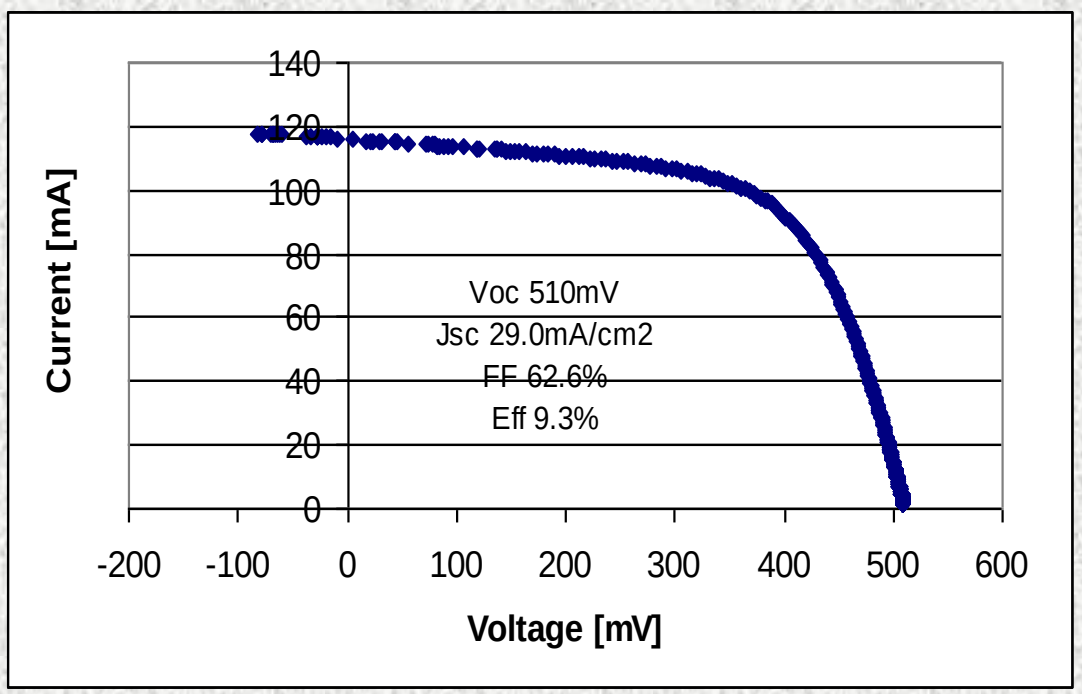
- Large-area monolithic construction
- Low materials consumption
- Cheap supporting material (glass)

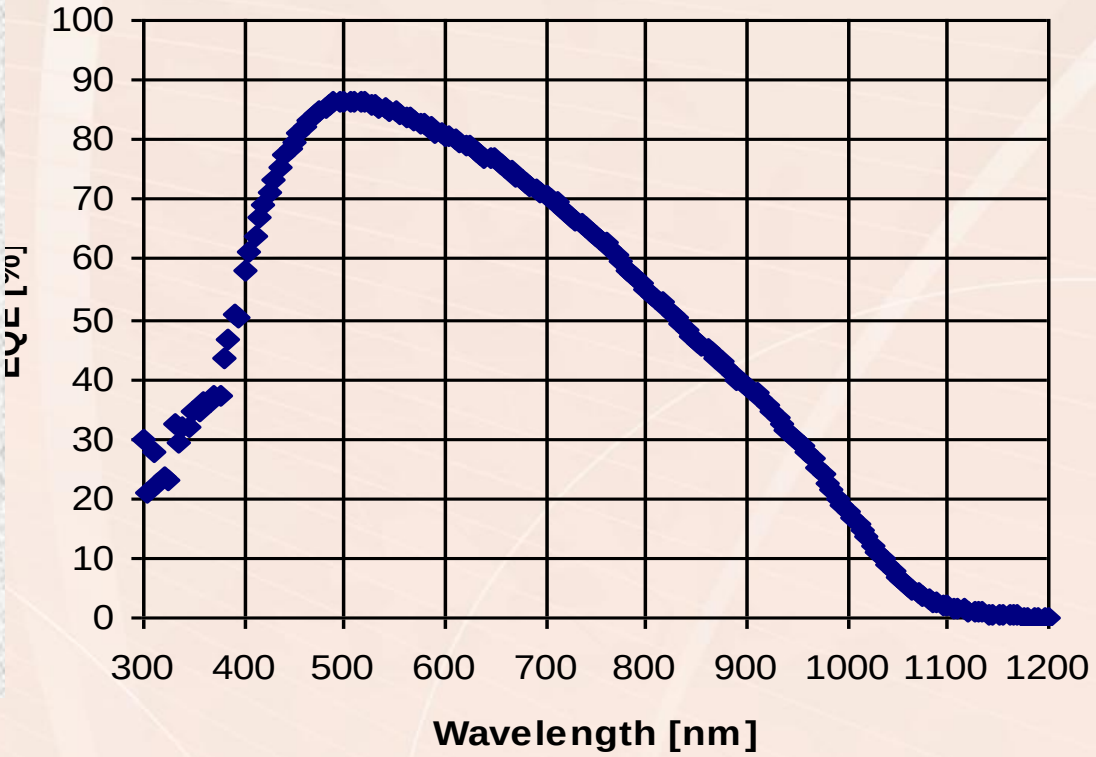
CHALLENGES

- Thermal stability of glass ➢ Limit processing temperature
- Grain boundaries & bulk defects ➢ Large, thin grains
- Semitransparent ➢ Light trapping scheme (texturing)
- Individual cells need to be metallised & interconnected.

Image: CSG Solar

Plasma Cells





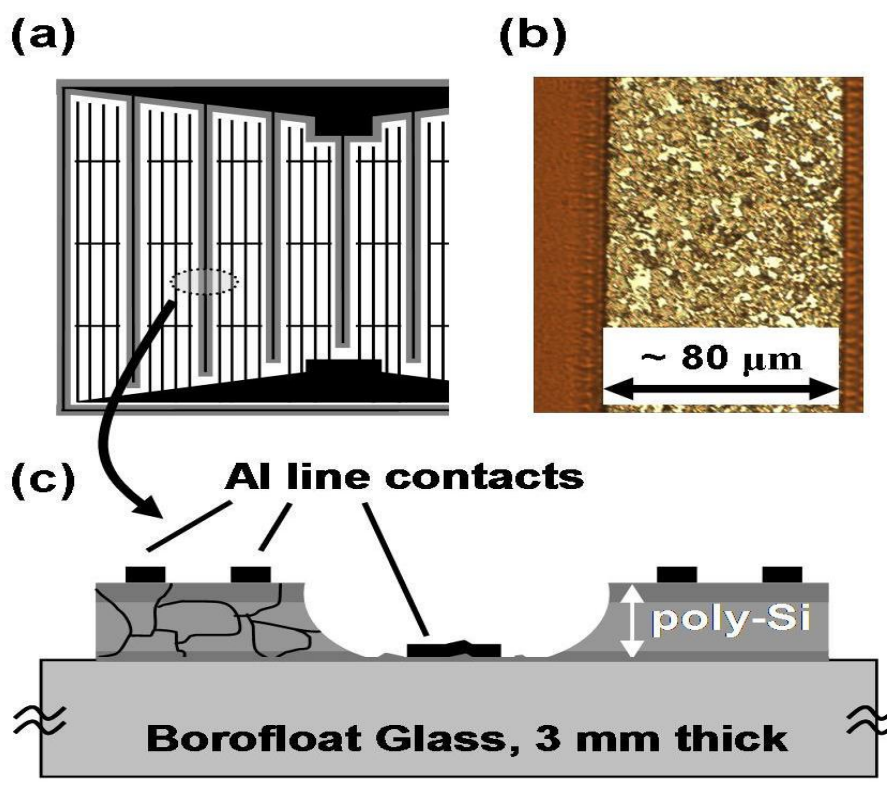
Evaporated Cells

Efficiency development :

May 2007 **1.72%** → November 2008 **5.2%** (planar cells)

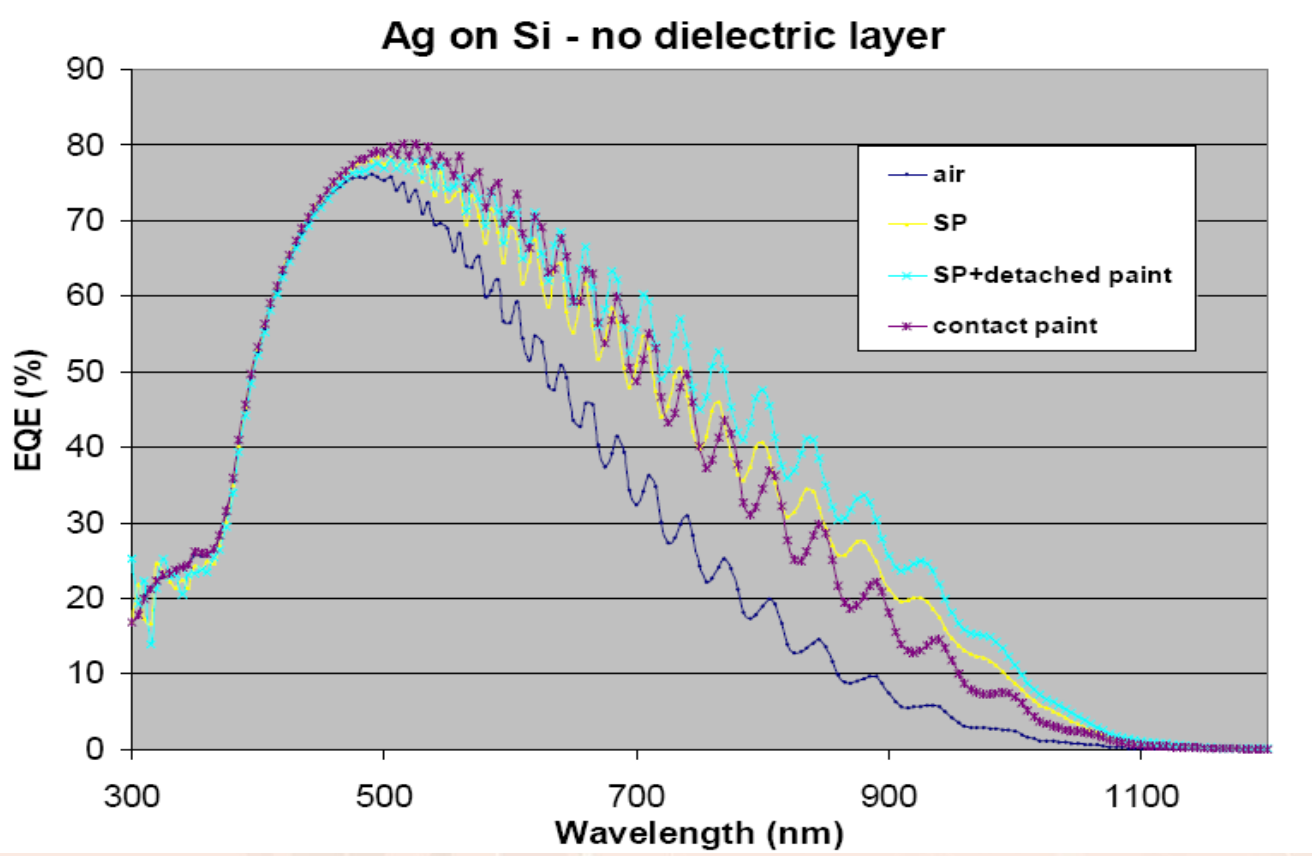
Main advances in evaporated cell technology:

- Improved Rsh due to sub-µm pinhole shunt elimination.
- Aligned bifacial metallisation avoiding non-linear (Schottky) shunting.
- Enhanced current due to diffuse white paint back reflector and absorber doping optimisation.



Plasmonic Evaporated Cells

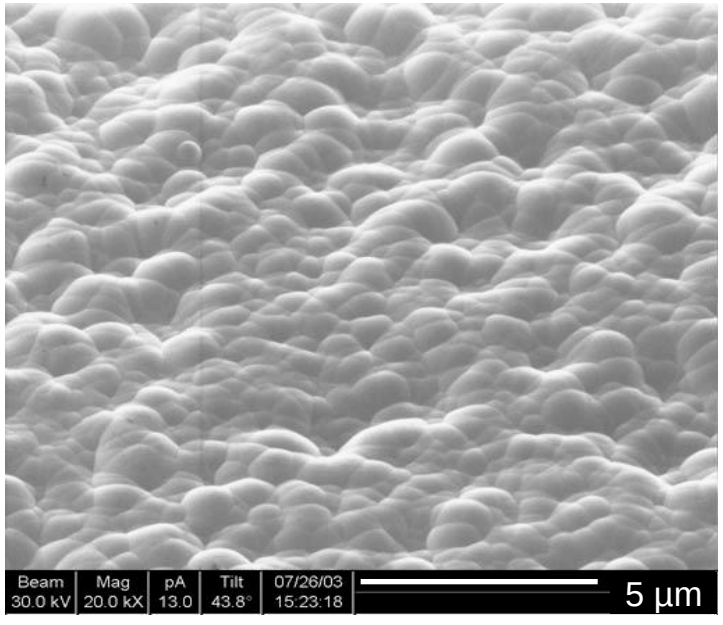
Surface plasmon enhanced light-trapping (planar glass)



Jsc enhancement:

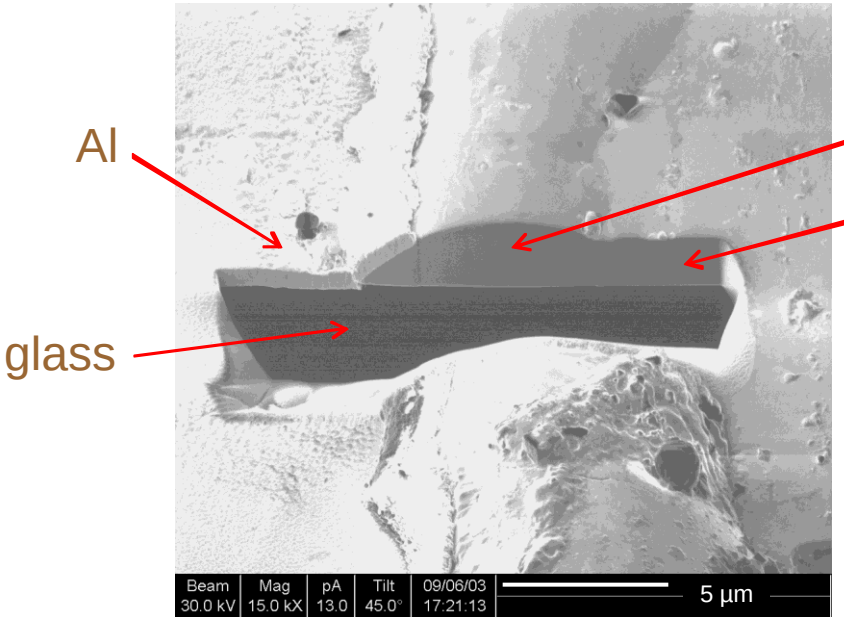
SP only	29%
SP+detached R	38%

Texture & Interconnection



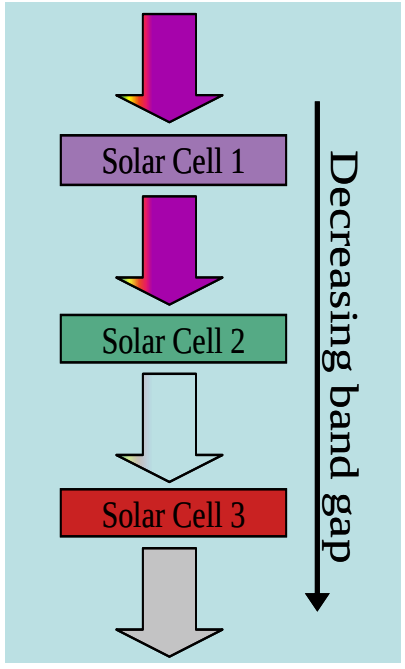
EVA film on 1:20 AIT glass.

Aluminium induced texture

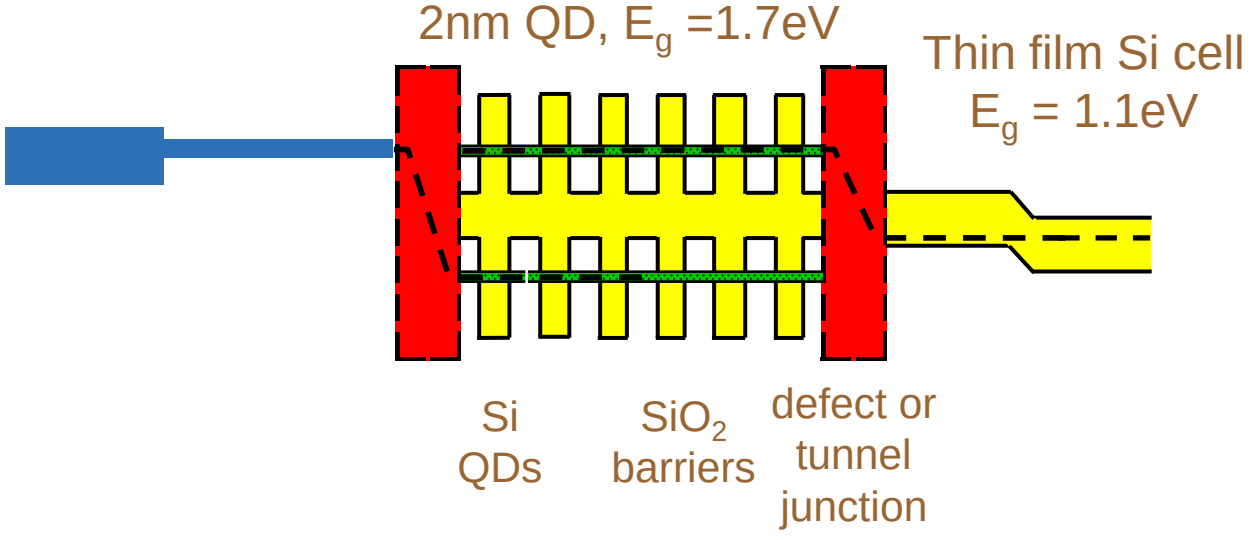


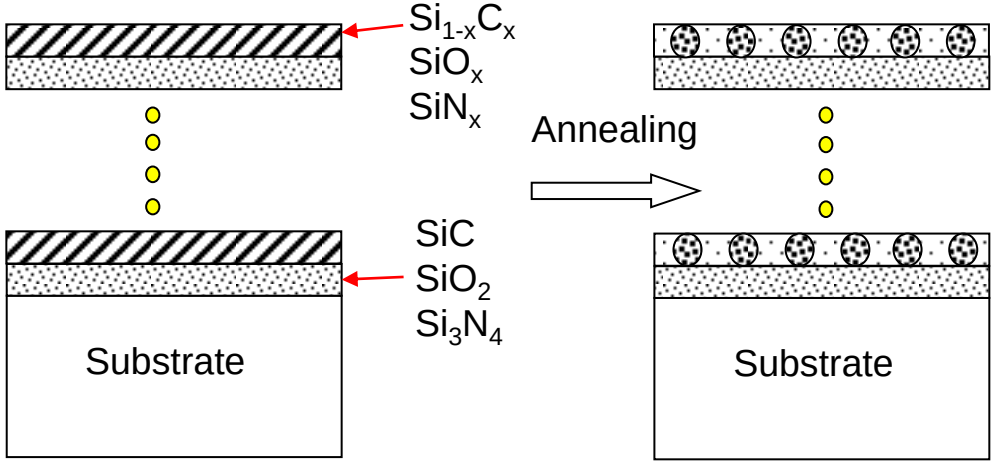
Interconnection

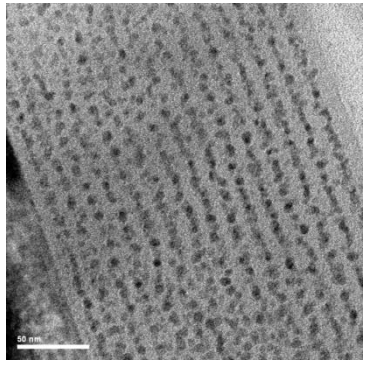
Silicon based Tandem Cell



Engineer a wider band gap – Si QDs





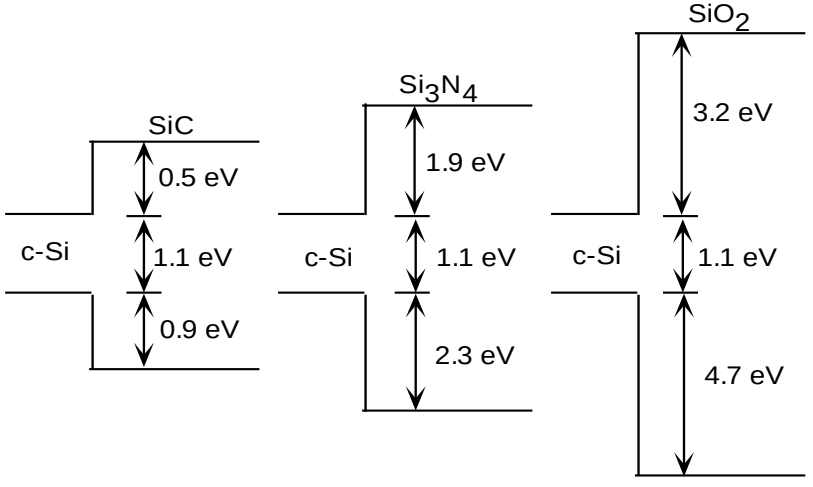


Silicon based Tandem Cell

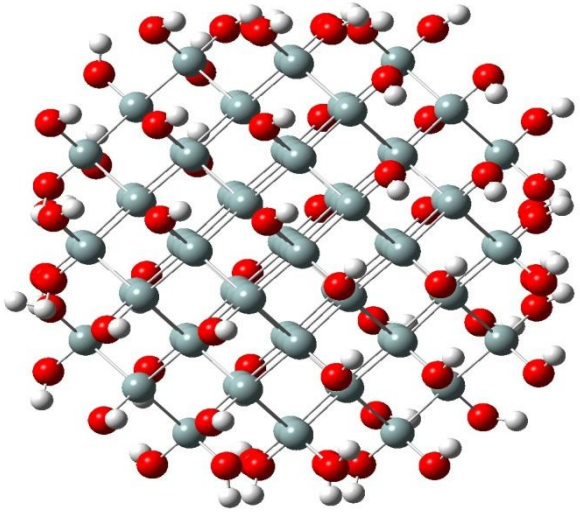
Deposition

- Si-rich Si (O,N,C) & Si precipitation
  - RF reactive sputtering
  - PECVD
- Direct Gas phase QD - PECVD

Alternative matrices



$Si_{72}(OH)_{64}$, d_{QD} = 14 Å



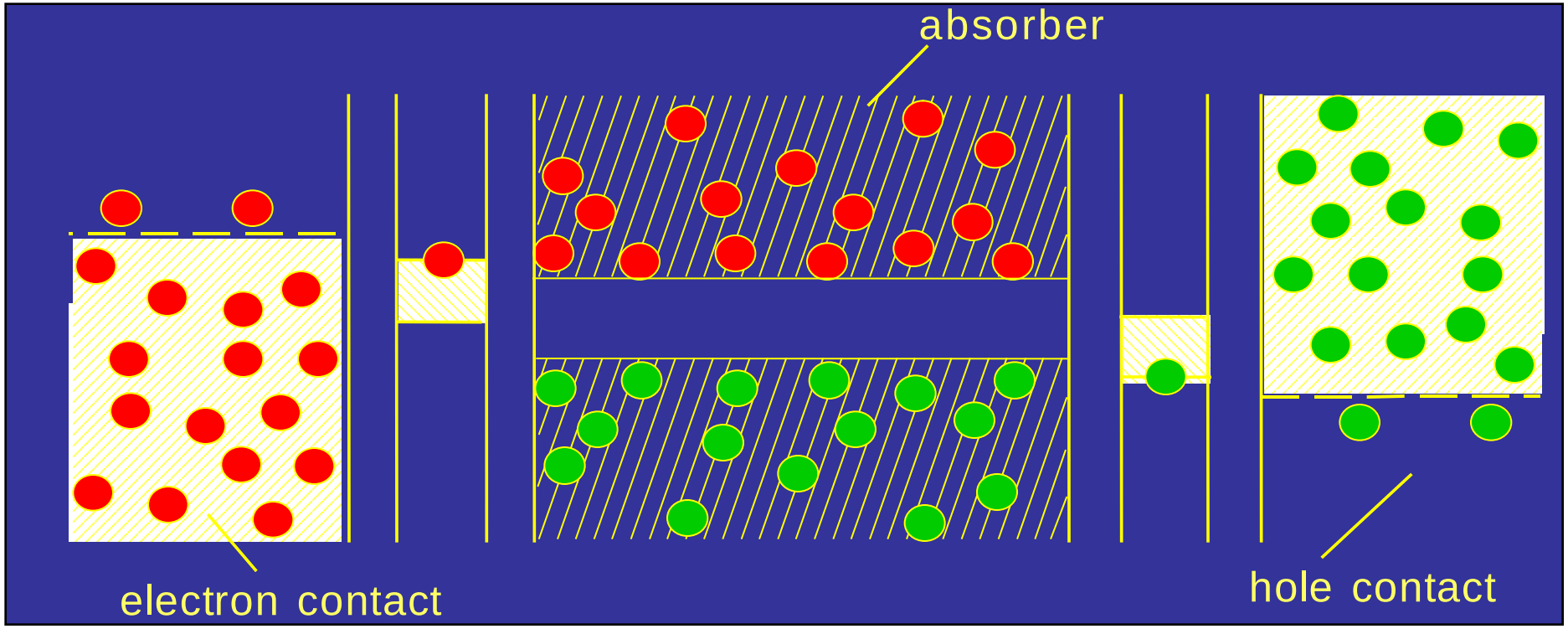
Next Phase

- Ge & Sn QDs – lower temp and/or low E_g
- Doping – p & n or modulation - two dielectrics
- Modelling of these and other structures

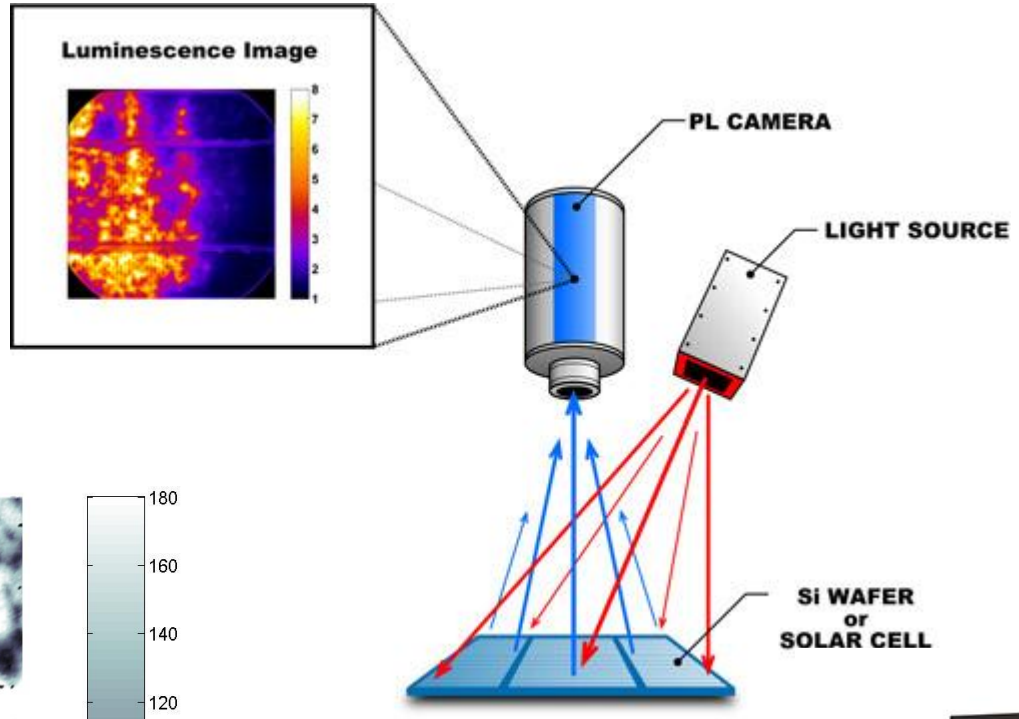
Hot Carrier Cell

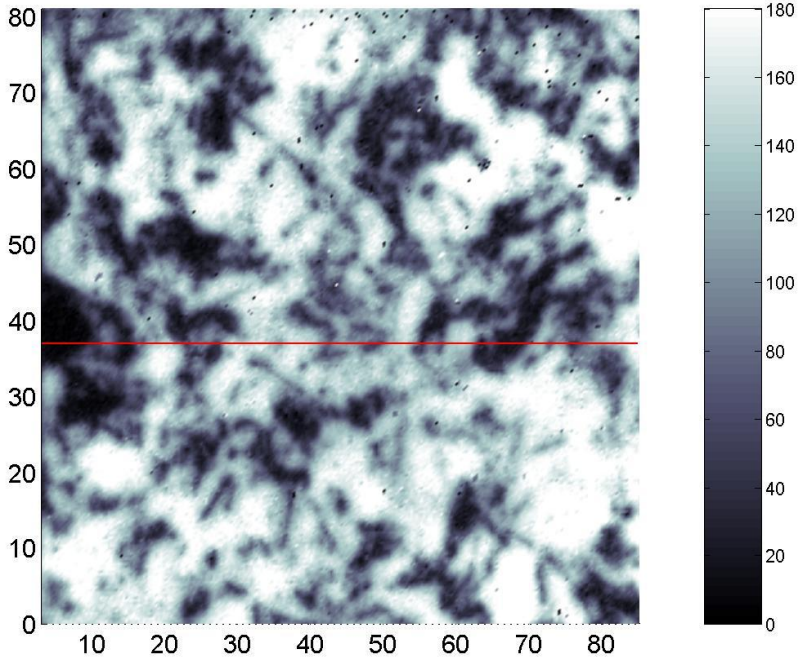
Extract hot carriers before they can thermalise:

1. need to slow carrier cooling
2. need energy selective, thermally insulating contacts



Photoluminescence Imaging





Images courtesy of BT Imaging

Thanks for your attention!