Development and Exploitation of Processes For Thin Flexible Glass

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Thin flexible glass as a substrate for PV panels

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- **36 month project (March 2013-April 2016)**
- **The Engineering and Physical Sciences Research Council**

- **Centre for Solar Energy Research, Glyndŵr University**
- **Faculty of Engineering & Physical Sciences, University of Surrey**
- **Surrey Satellite Technology Ltd**
- **Qioptiq Space Technology Ltd**

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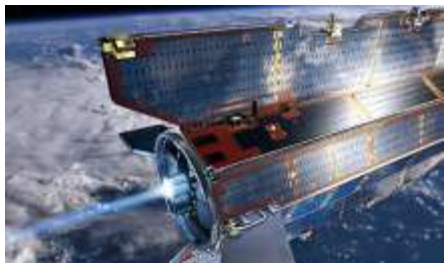
Space Application

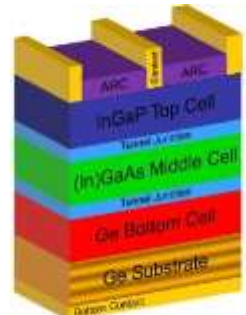
- ❑ Solar Electric Propulsion
  - >100's KW
- ❑ Space Based Solar Power
  - > MW
- ❑ Lunar and Martian bases
  - > MW

Space PV

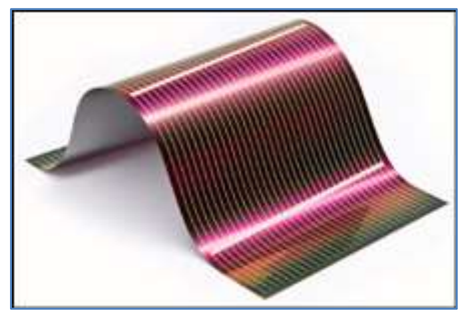
❑ Space PV dominated by III/V technology

- Azur, NeXt and Spectrolab Triple Junction (XTJ) Solar Cells. GaInP/GaAs/Ge solar cell on 140 µm Ge substrate 29.5 %





❑ Thin film technologies on flexible substrates for Space application are receiving more attention

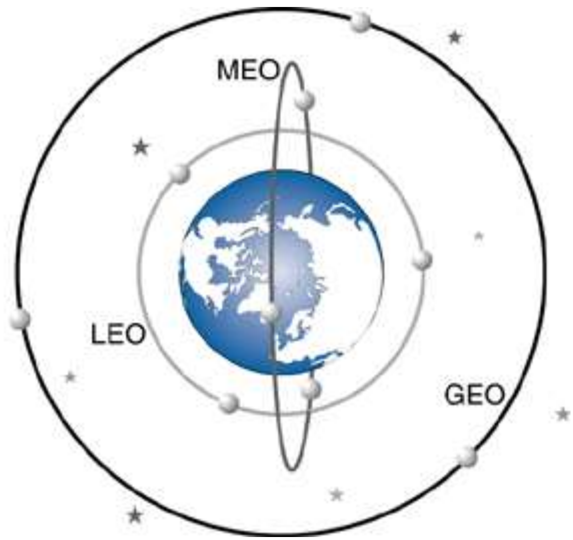


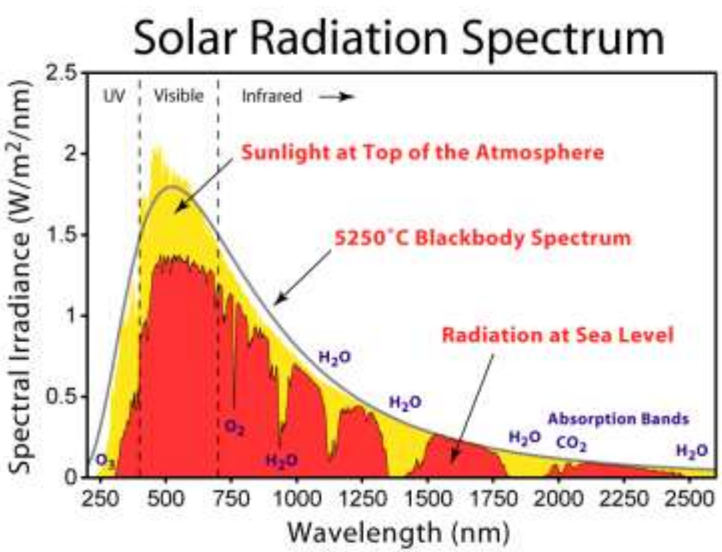
Technology	Efficiency (%)	Cell weight (kg/m^2)	Cell weight with CMG (kg/m^2)	Power (kW/m^2)	Specific Power (kW/kg)
Triple junction	30	0.86*	1.06	0.41	0.38
Silicon	16.9	0.32*	0.52	0.23	0.44
CdTe	12**	0.03***	0.24	0.16	0.67

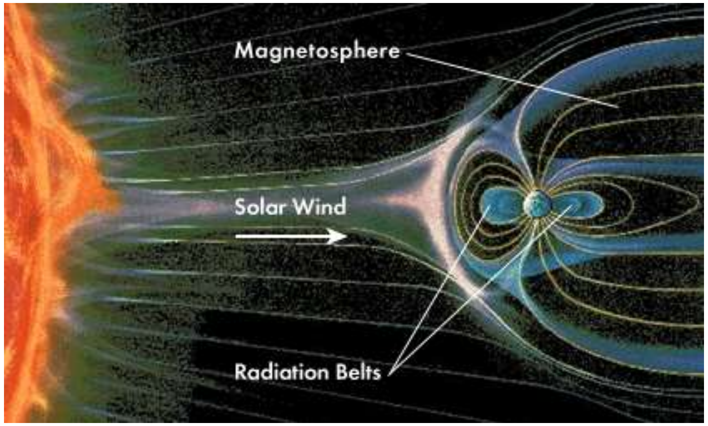
Manufacturers values for cell and substrate. **Projected efficiency.*Theoretical value for cell without substrate.(80 microns of CMG 0.204 kg/m²).*

Space Environment

- ❑ Space PV environment
- ❑ ultra-violet, electron and proton irradiation
- ❑ Level of radiation protection depends on orbit
- ❑ Thermal shock, cycling
- ❑ Delamination
- ❑ ESD
- ❑ Storage, stowage, launch and deployment







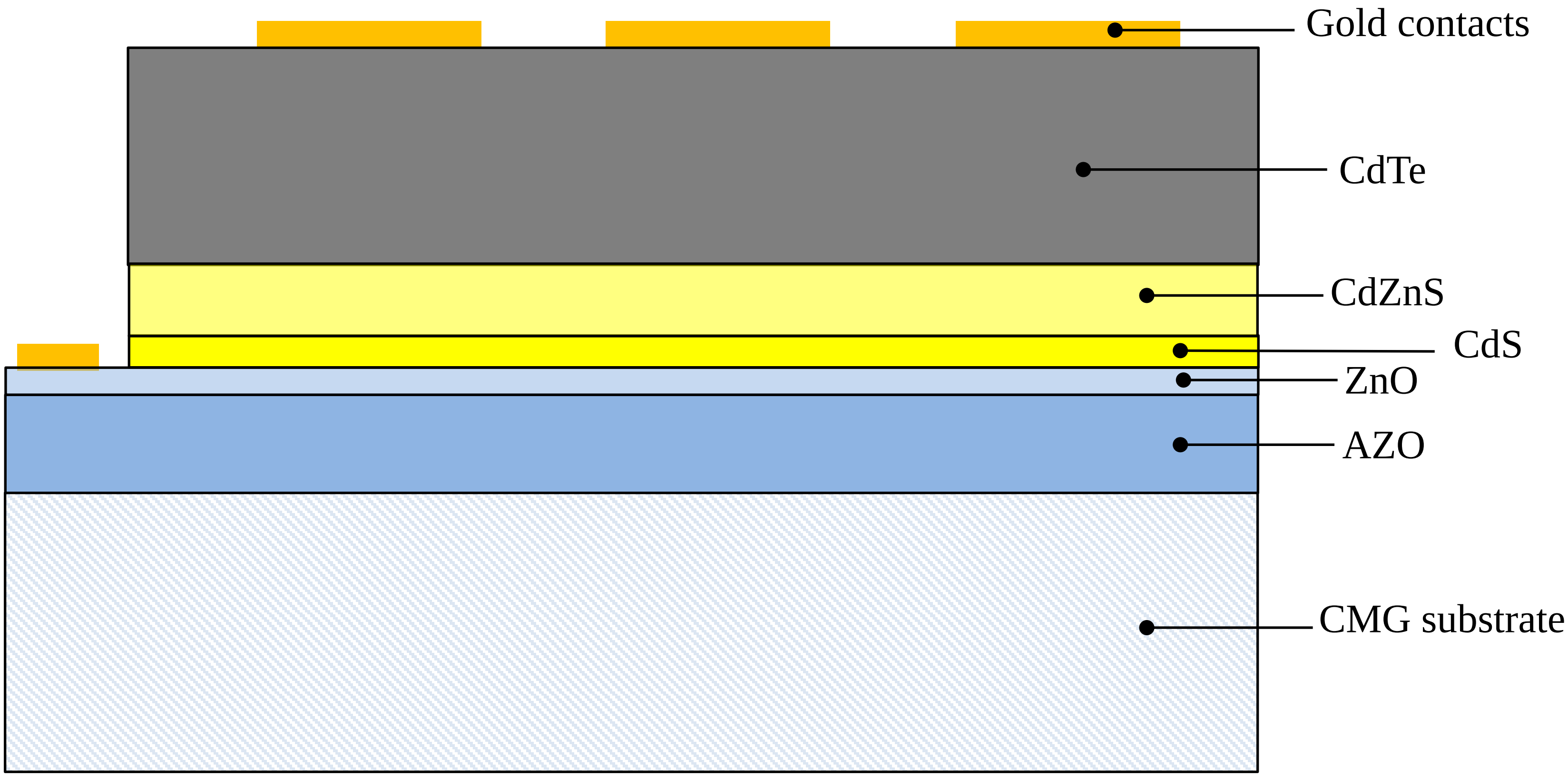
Novel Substrate

- 1970 as Pilkington Space Technology
- Cover glass is used to protect solar cells from damage which would otherwise occur due to ultra-violet, electron and proton irradiation
- Innovative step PV directly onto cover glass
- This ultra thin glass is cerium doped.
- A chemical toughening process is carried out on the substrates for our research

$$Ce^{3+} \xrightarrow{UV} Ce^{4+}$$

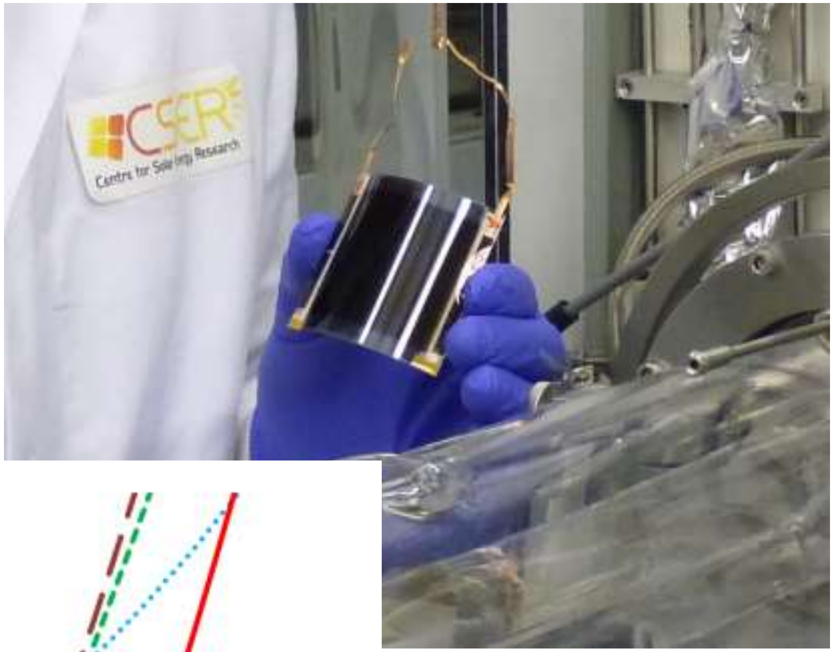
Thin film CdTe

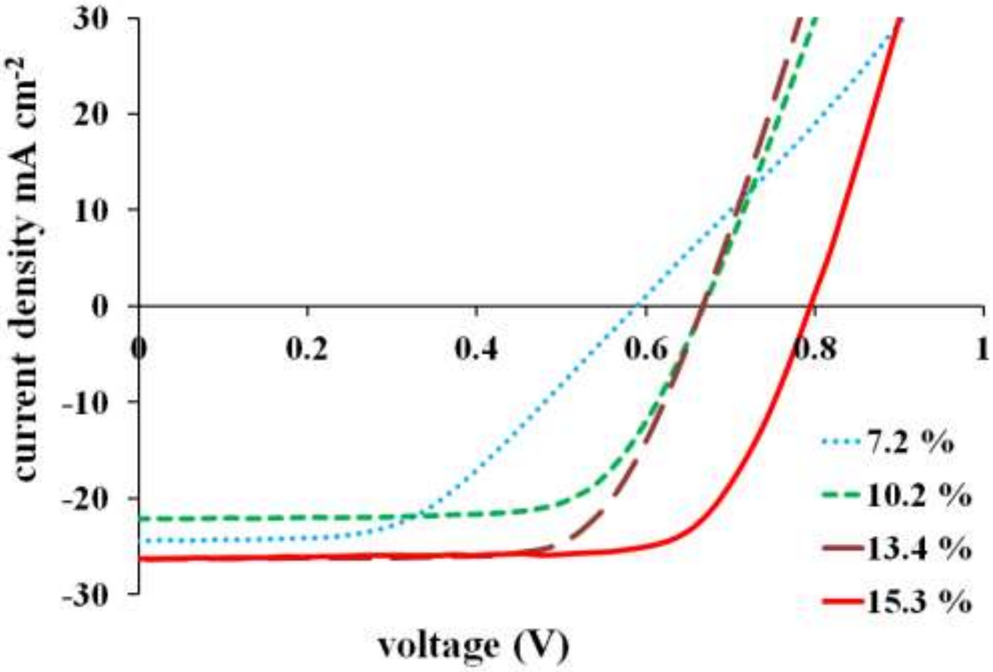
- Thin film CdTe on Space PV glass



Device performance

- 12 month project duration
- D. A. Lamb et. al. Proceedings of the 28th European Photovoltaic Solar Energy Conference, Paris, 2012, 546–548.
- S.J.C. Irvine et. al. Journal of Electronic Materials DOI: 10.1007/s11664-014-3090-9 2014 TMS





Device improvements

[illegible]	7.2	10.2	13.4	15.3
	24.3	22.1	25.1	26.3
	586	667	707	788
FF (%)	50.6	69.4	75.3	74.0
R_s (Ω cm^2)	11.2	4.2	3.6	3.3

Adhesion to substrate

- Instron 5500R pull Test
- At 3 of the 4 points, a tensile strength of between 12 and 14 MPa
- In each case, a cohesive failure had occurred within the adhesive rather than at the AZO/glass interface.
- Minimum cohesive failure 6 Mpa

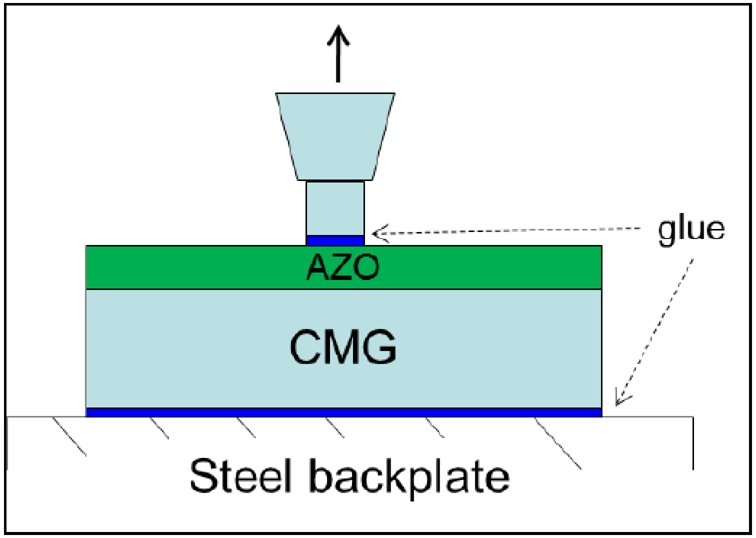
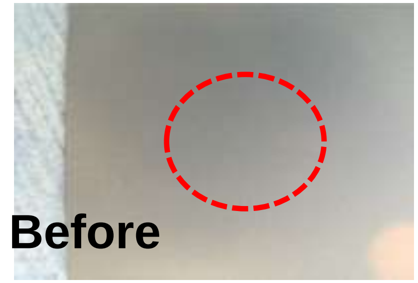


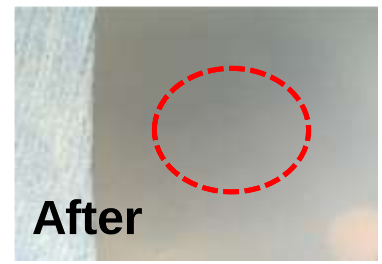
Figure 2.1: Pull-off test arrangement.

Load	317-1	317-2	317-3	317-4
MPa	12	14	13	6

Thermal shock testing

- AZO/CMG and full device structure
- Thermal shock test
- +80 °C to –196 °C
- Cycle was repeated 20 times
- Scotch Tape Test
- 10 X magnification
- The TCO structure evaluated for a deterioration of sheet resistance.

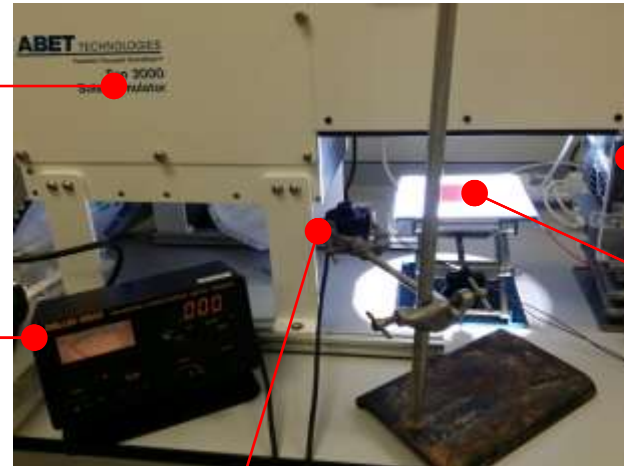


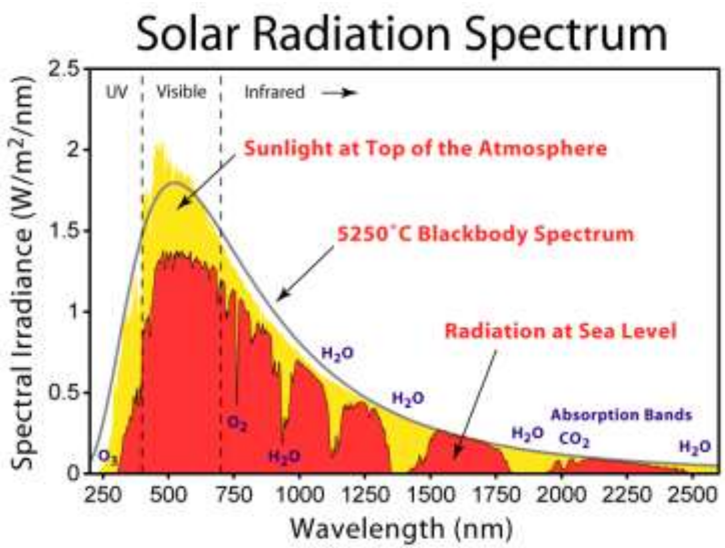


J/V parameters	B4 TST	After TST	3 weeks after TST
η %	14.8	14.8	14.9
Jsc mA cm^{-2}	25.2	25.5	25.9
Voc mV	788	788	788
FF %	74.6	73.7	73.1
R_s Ω cm^2	2.2	3.2	3.1
R_{sh} Ω cm^2	2190	3454	2554

AM0

- 1336.1 W/m²
- Power meter
- Checked with GaAs calibration standard





J/V	AM1.5 Mean	AM0 Mean
η %	13.8	13.20
Jsc mA cm^{-2}	24.4	31.6
Voc mV	788	788
FF %	71.9	72
Rs Ω cm^2	4.3	3.2
Rsh Ω cm^2	2445	1605

Scale-up

- Inline, AP < 450 °C
- 10 x 20 cm^2
- AZO through to $CdCl_2$ anneal
- cm/min

Summary

- Application
- Environmental considerations
- From first reported thin film PV directly onto space glass (7.2 %) to latest best 15.3 %
- Multiple improvements to thin film structure
- Excellent adherence of the semiconductor to glass (>6MPa)
- Early indication of good stability to thermal shock

- Future work will include: radiation testing, module demonstration, scale-up and array and deployment design considerations