Advances in Thin Film PV: CIGS & CdTe
Towards high efficiency and cost reduction concepts

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Different technologies
Several options available
Different opportunities and levels of maturity

- Si wafer
- Thin film Si
- CdTe
- CIGS
- III-V on wafers
- a-Si
- DSC
- OPV
- CZTS
Thin film solar cells based on compound semiconductor absorbers: CIGS and CdTe

- High efficiency potential to 30%
- Long term performance stability
- Cost effective process and materials
- Low cost solar modules
Towards cost effective solar electricity with thin film PV
Dead-end or progress in right direction?

Integration and implementation

Low Capex factories

Low BOS cost

High efficiency and stability

Low production cost of solar modules
CIGS and CdTe thin film photovoltaics

✓ High efficiency: 19.6% - 20.4% cells
               15.7% - 16.1% champion modules

✓ Low cost: Inherent advantages of thin film technology for large area high speed coating and monolithic interconnections
               Already proven by First Solar (CdTe)

➢ Solar module cost < $0.50/Wp and fully installed system cost < $1/Wp seem feasible

✓ Advantages on integration on system level and provisions of added functionalities (e.g. BIPV)

Excellent progress made and it continues....
20.4% flexible CIGS solar cell record by Empa

Best Research-Cell Efficiencies

Source: http://www.nrel.gov/ncpv/images/efficiency_chart.jpg
Key issues in high efficiency CIGS solar cells

Cu-poor composition below stoichiometry point

- Morphology (surfaces and interfaces)
- Microstructure and defects
- Stress
- Composition gradients
- Doping with Na
CIGS on glass substrate gaining maturity for large volume industrial production

News of success from Solar Frontier:

... achieves 19.7% efficiency solar cell (0.5 cm²)
... completed a new 900MW module factory producing 13% efficiency solar panels
... posted revenue of $833 million in 2012 and recorded its first positive quarterly income in the fourth quarter
... achieves 14.6% efficiency champion solar module (1257mm x 977mm) at 179.8W (June 2013)

CIGS technology on glass substrates has progressed to industrial scale production

(Several papers presented during the conference)

Flexible CIGS technology is in early stage of development (pilot-scale production)
Flexible and lightweight solar modules offer several advantages and paradigm shift.
Companies in development stage (pilo-scale)...
Progress: 20.4% efficiency

Improvement in record efficiency of flexible solar cells

CIGS optimisation for composition grading, Na doping and microstructure

Post-deposition Na

Optimised buffer layer, TCO and AR-coating

Lift-off process
Spin-coated PI and NaCl

Excellent potential to bring a paradigm shift as efficiency equals to Poly-Si wafer and CIGS/glass record values

source: Empa
20.4% efficiency of CIGS solar cells on glass and flexible polymer matches to poly-silicon wafer solar cell

Prospects of 25% efficiency CIGS solar cells are bright!
Higher efficiency with tandem and concentration concepts
Technology status: Industrial manufacturing
Selected examples (disclaimer: not a complete or updated list, discretion is used)

Vacuum-based (Co-evaporation)

- Glass
- 17.4% submodule
- Monolithic

- Stainless steel
- 13.2%
- Stringing

- Glass
- 15.9% module
- Monolithic

See also:
- Solarion
- Ascent Solar
- Flisom
- XsunX, etc…

Champion efficiencies

- Large size modules: 15.5% - 15.9%

- Sub-modules: 17.4% - 17.8%

Continuous trend of remarkable progress in average efficiency of modules in industrial production is reported

- 18% module efficiency in near future….

More details: P. Reinhard et al., Technological status of Cu(In,Ga)(Se,S)2-based photovoltaics, SOLMAT (2013), http://dx.doi.org/10.1016/j.solmat.2013.08.030
CdTe device structure

19.6% cell efficiency (GE)
Green et al., PiP 21, 827 (2013)

19.0% cell efficiency (FSLR)
Gloeckler et al., IEEE J. PV 3, 1389 (2013)

16.1% module efficiency (FSLR)

17-18% projected module efficiency (FSLR)
Gloeckler et al., IEEE J. PV 3, 1389 (2013)

Costs: 0.68 $/Wp (FSLR)

Conventional configuration
~ 2000 publications

FSLR = First Solar; GE = GE Global Research
Conclusions on CdTe

• **Superstrate configuration**
  • 19.6%* efficiency on glass by GE (comparable to 20.4% of p-Si)
  • 16.1% module efficiency on glass by First Solar
  • 15.6% efficiency on glass with low temperature (<450 °C) process
  • 13.8% efficiency on polyimide

• **Substrate configuration (emerging concept)**
  • 13.5%* efficiency on glass
  • 11.5%* efficiency on flexible metal foil
  • Similar $V_{OC}$ and FF as in superstrate configuration
  • New opportunities

* Certified efficiency

What more can be achieved?

Very low manufacturing cost and high efficiency technology
Conclusions on CIGS

- 20.4% flexible CIGS efficiency comparable to p-Si wafer cell efficiency
- 16% efficiency large area modules (several champions on glass and flexible foils)
- 17.4%-17.8% sub-modules show prospects of >18% large area modules
- CIGS production technologies are gaining maturity and next phase of industrial plants will provide higher average efficiencies
- Projection of <$0.38/Wp production cost from 1 GW factory was announced in industrial session (3AO4.4)
- Future R&D targets: 25% CIGS solar cells seem feasible
- CIS with (1 eV band gap) is an excellent candidate for large area tandem solar cells
Thin Film PV on fast track to progress

Multiple advantages for enabling low cost solar electricity

High efficiency cells and modules comparable to p-Si wafer

- Lower module cost (€/Wp)
- Lower BOS cost (€/Wp)
- Lower cost of fully installed systems
- Integration opportunities provide additional values and functions in applications