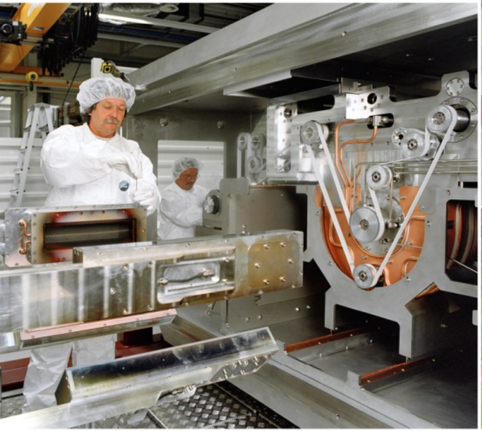

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Investigation of multilayer ZnO:Al/Ag/ZnO:Al transparent conductive films prepared by magnetron sputtering for solar applications

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AIMCAL R2R Conference

Roll to Roll Web Coating and Finishing
AIMCAL R2R Conference USA 2017
Naples, Florida - October 15th - 18th

SPE FlexPackCon

FHR Anlagenbau GmbH

Headquarter near the city of Dresden, Germany
Office rooms and more than 6,000 sqm assembling spaces for thin film deposition equipment

Outline

- Introduction
    - TCO for solar cells
- Experiment
    - Magnetron sputtering of AZO/Ag/AZO layer stack
    - Optical and electrical properties
    - Adhesion improvement
    - Morphological studies
    - Themal stability
- FHR tools for thin film deposition
- Conclusions

Introduction

- PV - technologies

Silicon Wafer Technologies

Monocrystaline Silicon

16-21%

Polycrystalline Silicon

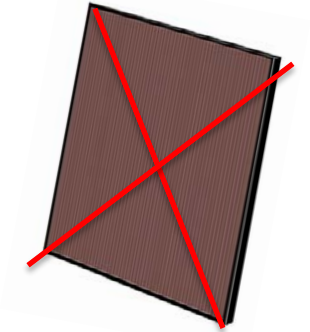
14 -17%

Thin Film Technologies

CI(G)S, CdTe

13 -16%

Thin Film Silicon



8-10%

- No market potential due to low efficiency

Introduction

- PV - technologies

Silicon Wafer Technologies

Monocrystaline Silicon

16-21%

Polycrystalline Silicon

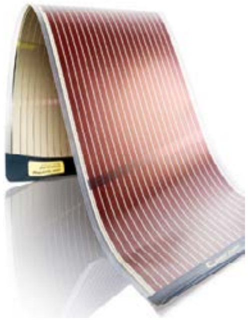
14 -17%

Thin Film Technologies

CI(G)S, CdTe

13 -16%

OPV & Perovskites



7-10%

- Flexible foil
- Building Integrated PV applications
- Require high performing TCOs

PV-TCO: Electrode requirements

- Electrical properties: Low Sheet resistance (Rsh < 10 ohm/sq)
- Optical properties
  - High transmittance (TL>80%)
  - Aesthetic colours (Neutral colour for BIPV)
- Mechanical properties
  - Good adhesion on glass, foil etc
- Compatibility with solar cell fabrication process
  - Temperature (up to 200 ºC)
  - No delamination / Long term durability
- Low cost potential
  - Simple manufacturing
  - Easily available materials

PV-TCO: Deposition methods

- Wide range of choices for TCO deposition

TCO process

- CVD
  - SnO_2: Off line
  - SnO_2: Online
- ALD
- Magnetron coatings
  - ITO / ZnO:Al
  - Metal/Dielectric structures

PV-TCO: Deposition methods

- Wide range of choices for TCO deposition

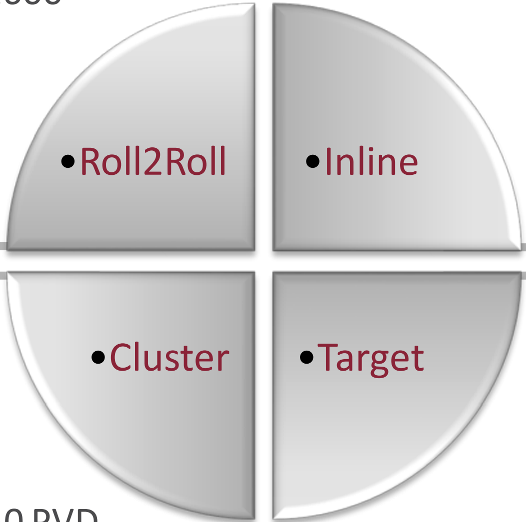
Material	Method	Advantages	Disadvantage
SnO_2: F (FTO)	APCVD	• Inexpensive	• Durability against Hydrogen plasma • Chemical etching
In_2O_3: SnO_2 (ITO)	Sputter	• Electrical and Optical properties	• Most successful / But Expensive coating material
ZnO:Al (AZO)	LPCVD Sputter	• Easy Chemical etching • Good durability against Hydrogen plasma	• Degradation in atmosphere • Post annealing treatment (cold sputtering)
New TCOs	Sputter	• No degradation in atmosphere • Non toxic (Cd like materials / ~~Ex: $CdSnO_4$~~) • No or very little In (cost related) • Good durability (Cell fabrication, in-build stress etc related)	

FHR product focus
Vacuum coating equipment & Sputtering targets

See also - Dr. Reinhard Fendler: Session 3.2.2 Room 3812/3 Wednesday, 26 October 11:45

"Large area deposition of contact films by magnetron sputtering"

FHR.Roll.1600-PVD



FHR.Line.2500-TCO

FHR.Star.150-PVD

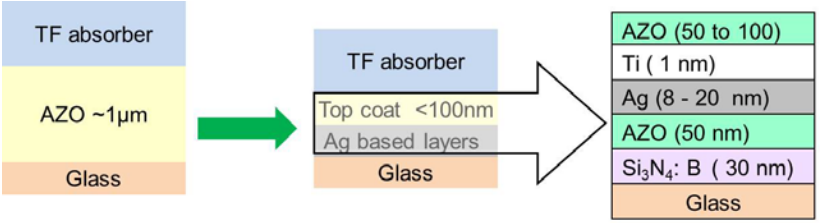
Experiment

- AZO and Ag deposition by magnetron sputtering
- In-line magnetron sputtering machine at SERIS –NUS (FHR Line 540)

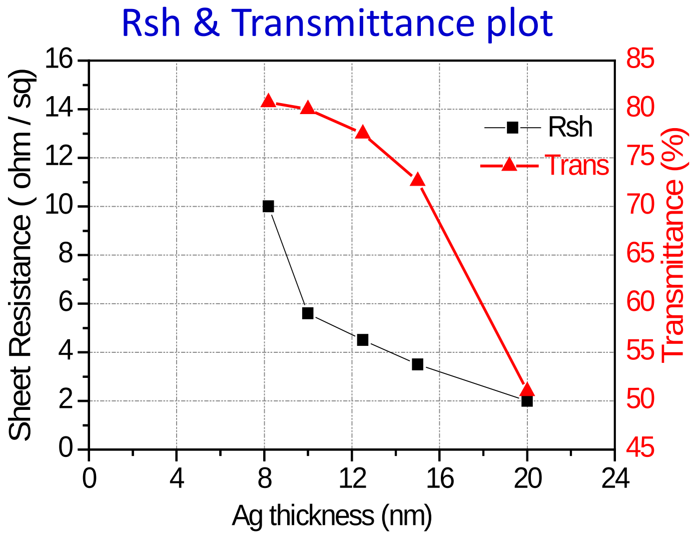
- Equipment capabilities
  - Two process chambers
  - Number of sputter sources: 6 (Planar, Cylindrical targets / DC and DC+ sources)
  - Maximum substrate temperature: 300 °C
  - Substrate size: 30 cm x 40 cm
  - Complete in-line process

Experiment (cont'd)

- AZO/Ag/AZO development

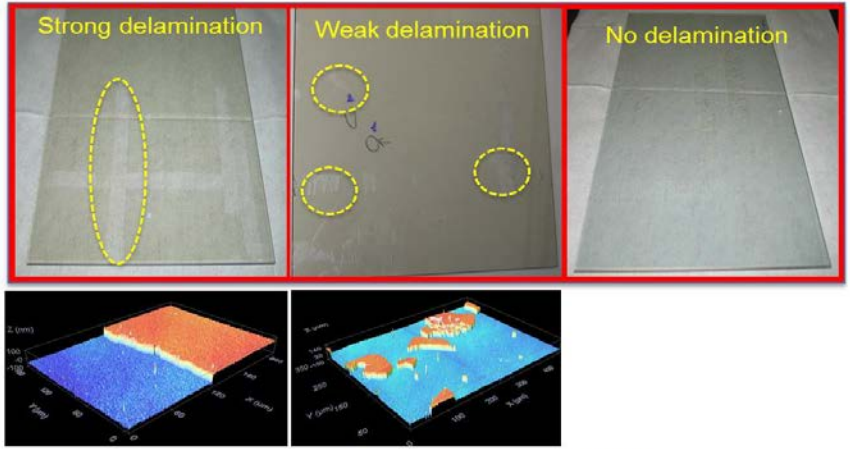


- With increasing Ag thickness
  - Sheet resistance decrease
  - Transmittance decrease
  - Optimum Ag thickness: 8 to 10 nm → TL ~ 80%



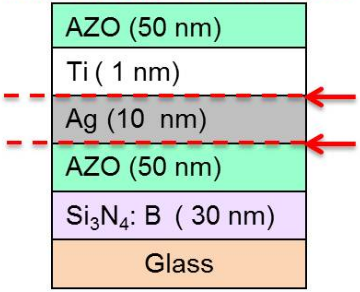
Experiment (cont'd)

- Adhesion improvement
  - AZO deposition pressure influence the adhesion
  - Adhesion test → standard scotch tape test



Ag & AZO removed   Partial removal of Ag & AZO

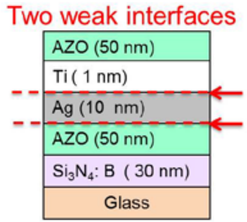
Two weak interfaces

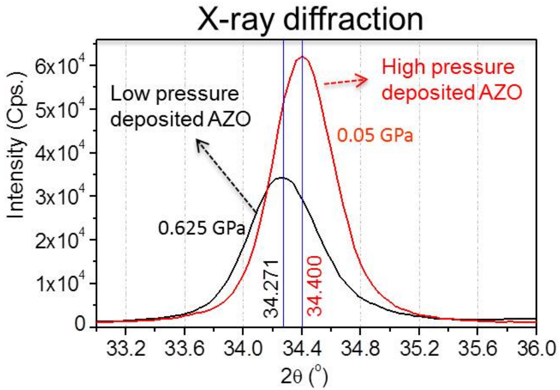


- High pressure deposited AZO retains good adhesion

Experiment (cont'd)

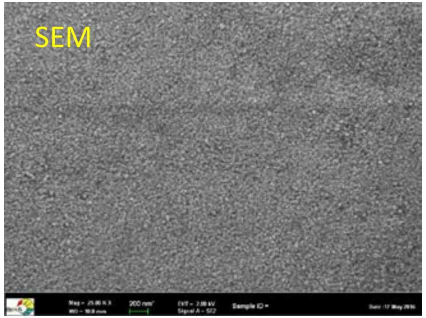
- Adhesion improvement
  - AZO deposition pressure influence the adhesion
  - Adhesion test → standard scotch tape test
- Sample with delamination
  - XRD peak shifted towards lower angle
  - Indication of compressive stress
  - Estimated stress value: 0.625 Gpa
- Sample with GOOD adhesion
  - XRD peak observed at 34.4º
  - Nearly stress free films
  - Estimated stress value 0.05 Gpa
- High pressure deposited AZO retains good adhesion

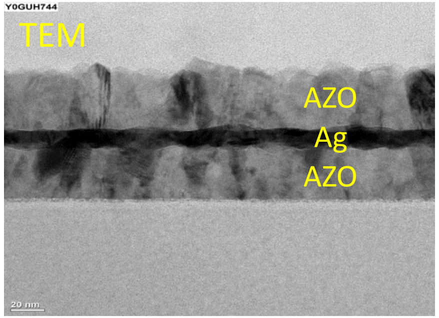




Experiment (cont'd)

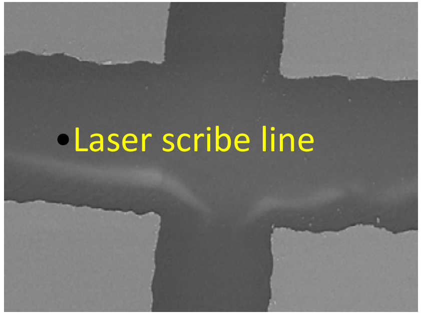
- Morphology (SEM & TEM)
  - Smooth surface → suited for further layer deposition & solar cell processing





- ➢ Smooth surface
- ➢ Thin & continuous Ag layer

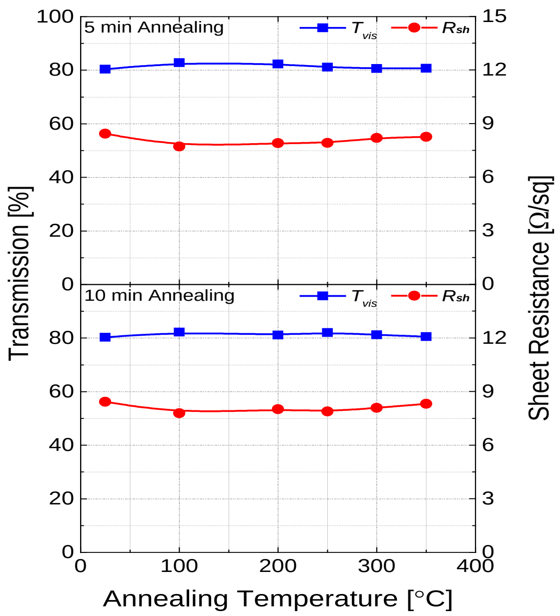
- Module making
  - compatibility for laser processing

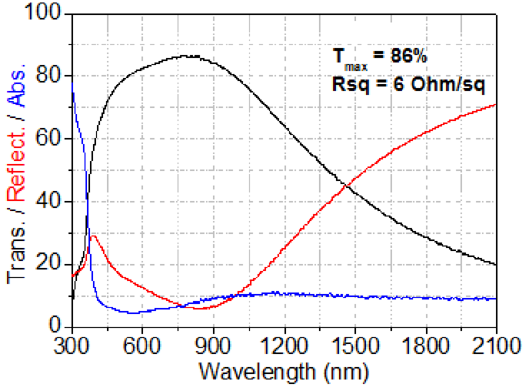


- ➢ No difficulties for laser scribing/patterning

Experiment (cont’d)

- Thermal stability & Annealing studies





- Layer stack is suitable for high temperature cell fabrication process
- Annealing does not affect optical and electrical properties

Summary

- AZO/Ag/AZO can be an alternative material for electrode application for making thin film solar cells → high performing and low cost potential
- Adhesion issue can be solved by adjusting the AZO deposition conditions
- Stack is more suitable for newly emerging OPV and perovskite technologies for BIPV application
    - Low-E functionality is an added advantage for smart building concepts
- Stack can be easily produced in existing production lines without huge investments
- Next step: Fabrication of solar cells

Research collaboration

Professor Armin ABERLE (left), CEO of the Solar Energy Research Institute of Singapore (SERIS) at the National University of Singapore, and Dr Reinhard FENDLER, CEO of FHR Anlagenbau GmbH. © FHR/SERIS 2013

- FHR is closely working with the Solar Energy Research Institute of Singapore (SERIS-NUS) for the development of next generation TCOs

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