IN-LINE DEPOSITION OF TIO_{2-X} ELECTRON TRANSPORT LAYERS FOR LARGE AREA PEROVSKITE SOLAR CELLS

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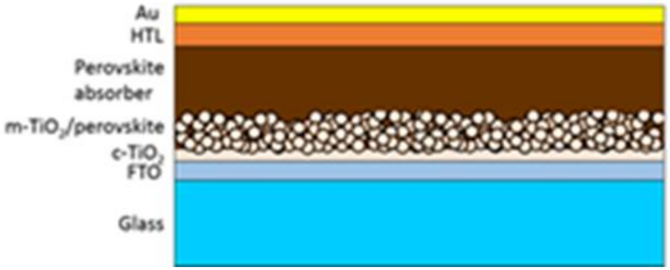
Motivation for Work



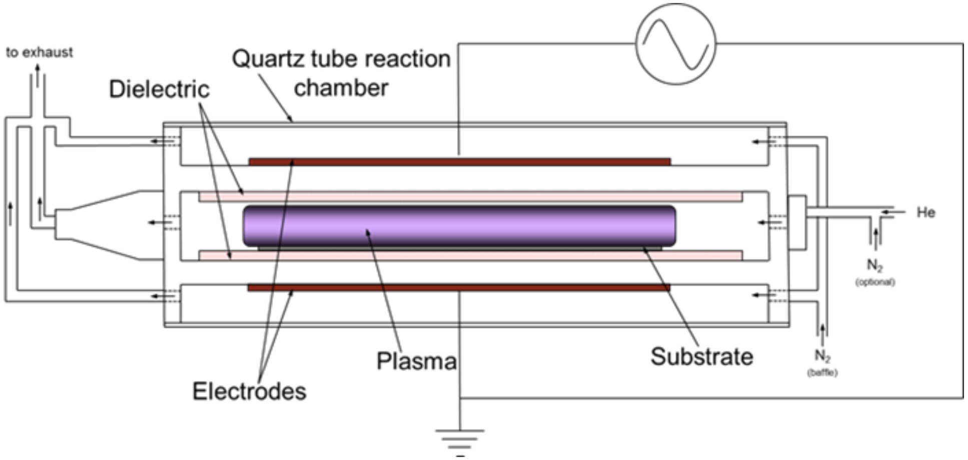
- Perovskite solar cells have shown considerable promise as architecture for the next generation of solar modules
- Challenge – cost effective large scale production
  - Typically spin coating / vacuum based technologies
  - Salford CVD optimise FTO / perovskite absorber
- In-Line deposition of compact TiO_{2-x} ETL via AP PECVD
  - Advancement of this AP technology to achieve film properties and uniformity down to ~ 40 nm
  - Compatible with the online production of TCO
- Mesoporous cells constructed to evaluate ETL performance compared to a reference sputtered ETL

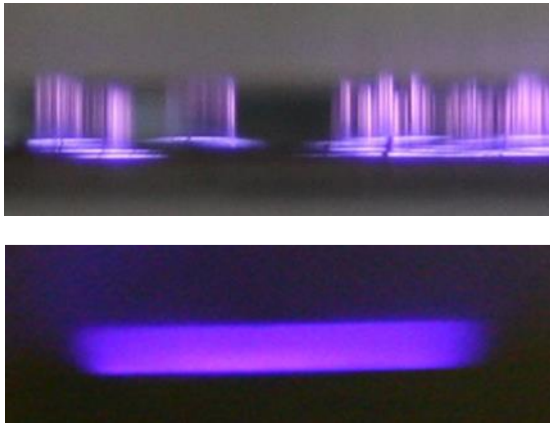
Technical Approach

- APCVD is a cost effective industrial process
  - Continuous film growth on large area substrates
  - Deposit FTO on-line
  - Advantage for ETL process
- CVD provides control of film properties
  - Crystallinity
  - Topography
  - Stoichiometry
- Activated processes allow reduced substrate temperatures
  - Plasma (PECVD), Flame, Hotwire etc
  - Further opportunities for control
- PECVD typically operates under vacuum
  - Stable low temperature ‘glow discharge’
  - Diffusion driven processes give conformal high quality films

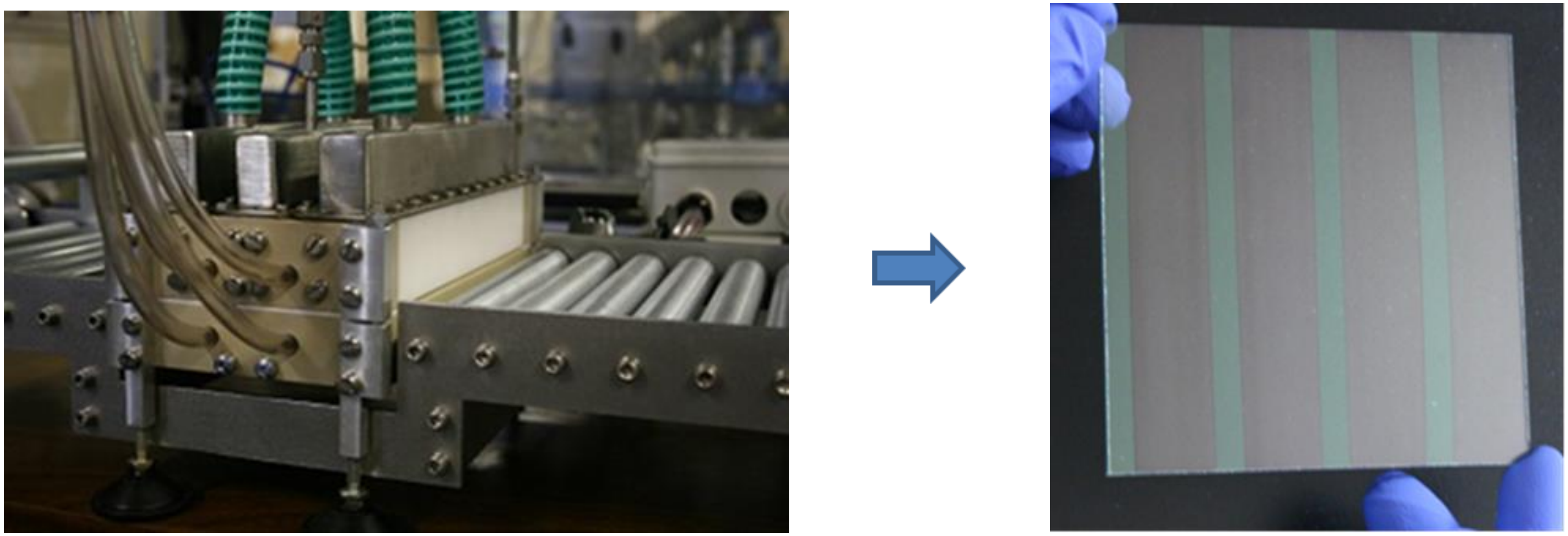
Atmospheric Pressure Plasma Enhanced CVD

- AP plasmas typically operate close to thermal equilibrium
  - E.g. RF ICP, metal cutting, arc-jet plasma spray
- Barrier discharge systems provide non thermal plasma at AP
  - Controlled reaction of precursors for film growth
  - Deposition on thermally sensitive substrates
- Development can produce diffuse discharges & CVD
- Typically used for surface treatment & polymers due to reduced plasma stability and film quality
- Optimised system can provide device quality films at AP & RT!



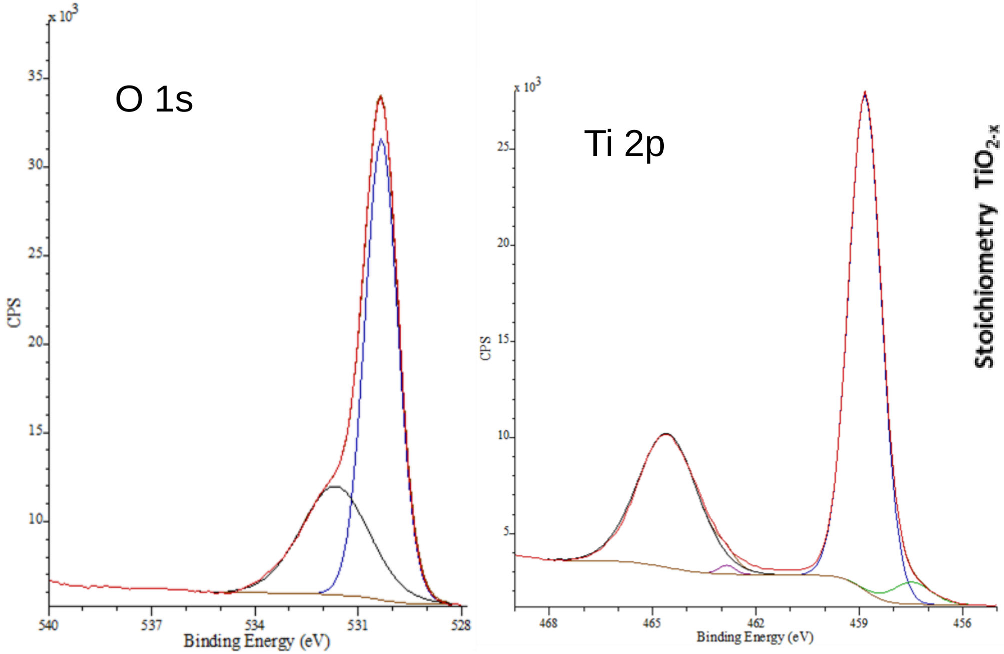


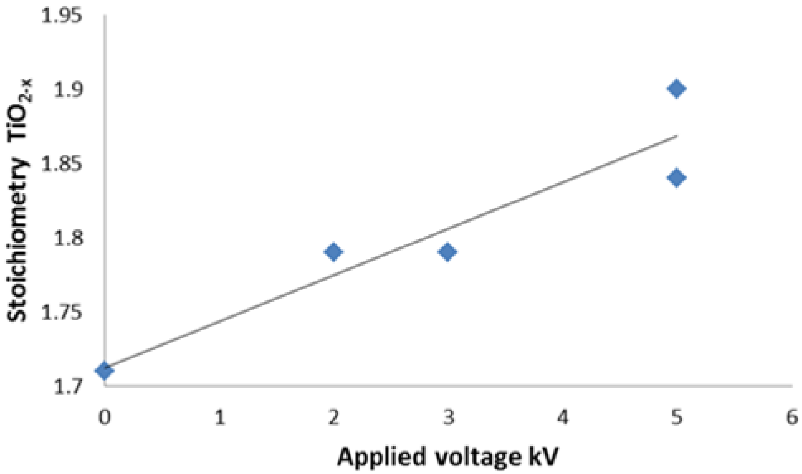
Process Demonstrator



- Dual flow AP PECVD roll to roll system
- Convey solid substrates up to 20 x 20 cm
- Continuous film growth with high uniformity
- TiO_{2-x} deposited from TTIP on 10 x 10 cm Solaronix TCO22-15, 10.7 m.hr^{-1}
- 4, 6 & 8 passes resulted in 40 nm, 55 nm & 85 nm films
- Argon plasma, nitrogen under investigation

Control of Film Properties

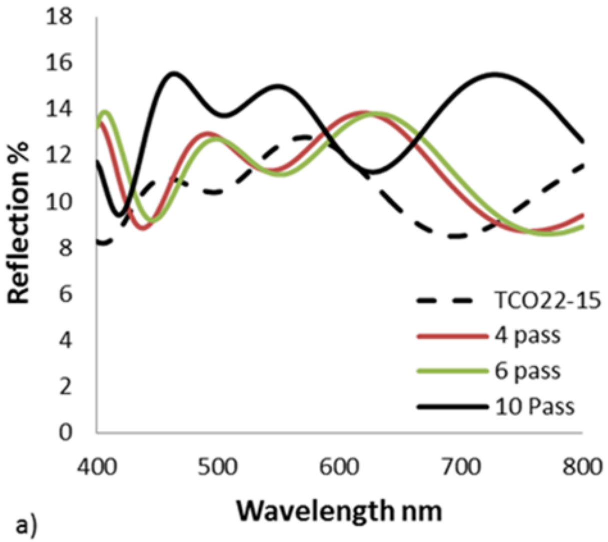




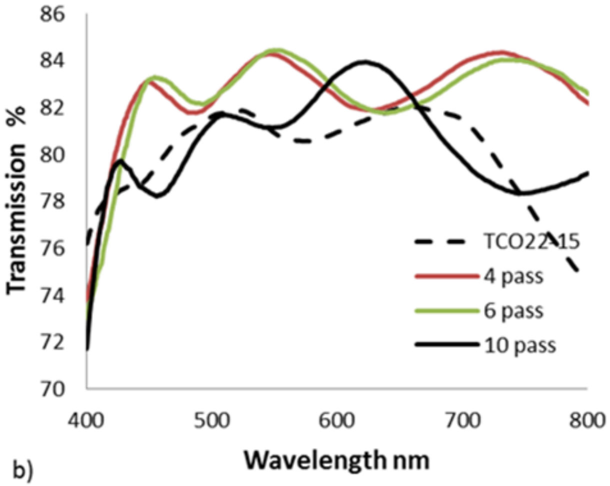
- XPS shows sub-stoichiometric titania
- Strong correlation between voltage and Ti:O ratio
- Films could be soft, hard or powdery dependant on plasma conditions
- Conditions chosen to provide dense, adherent powder free films

Optical Properties

- TiO_{2-x} increased mean reflection from 10 to 14 %
- Transmission increase from 80.0 % to 82 ±1 %
- Explained by a reduction in haze and hence net reduction in reflection due to smoother surface (14 to 4 nm RMS)



a)



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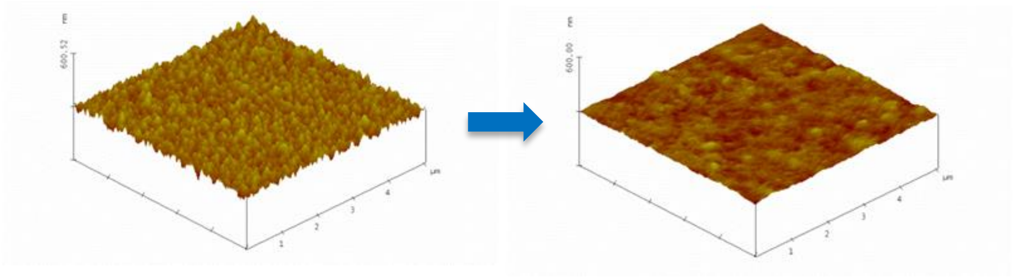
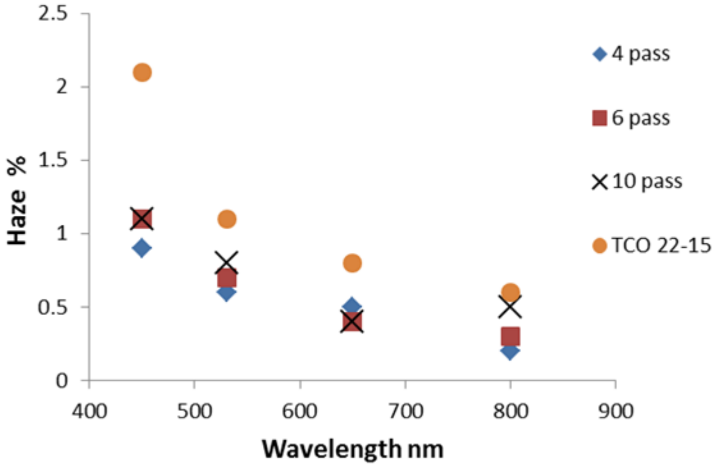
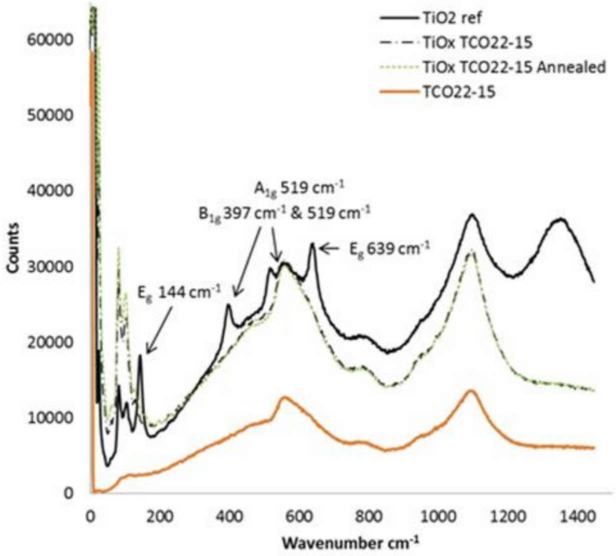
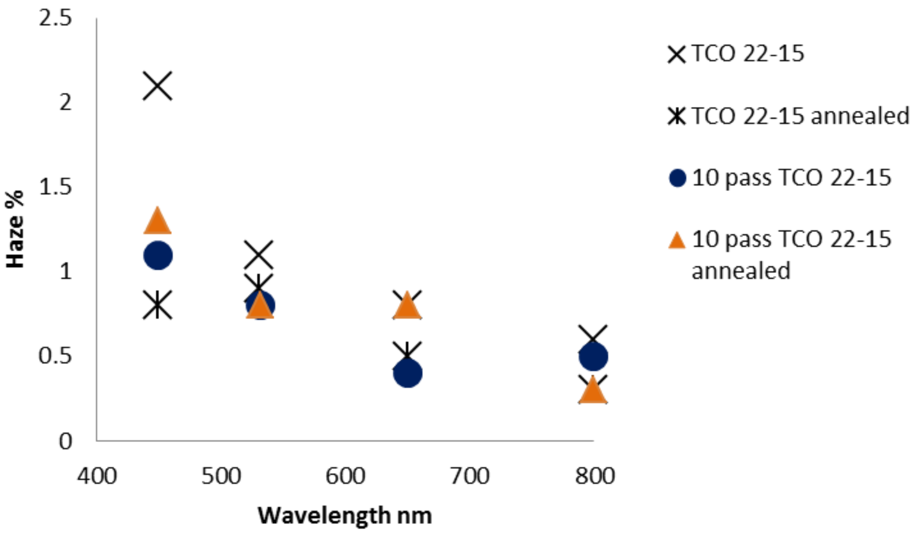
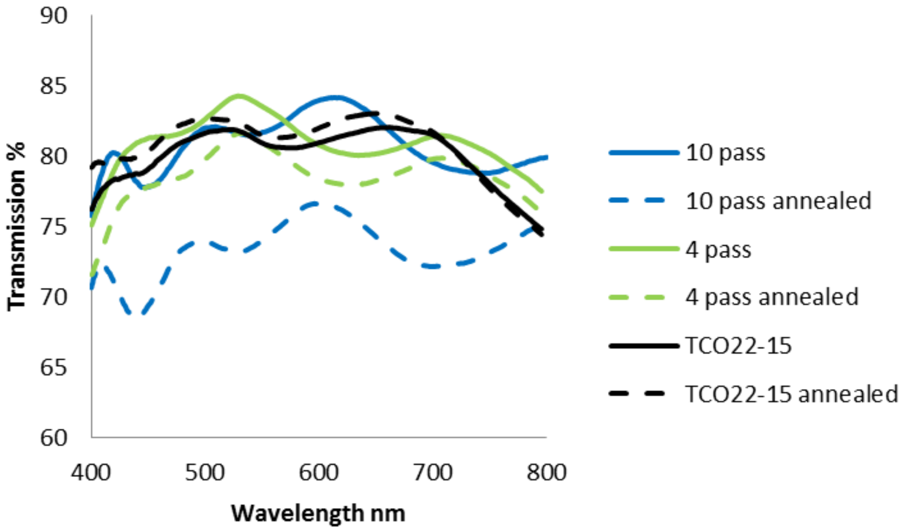


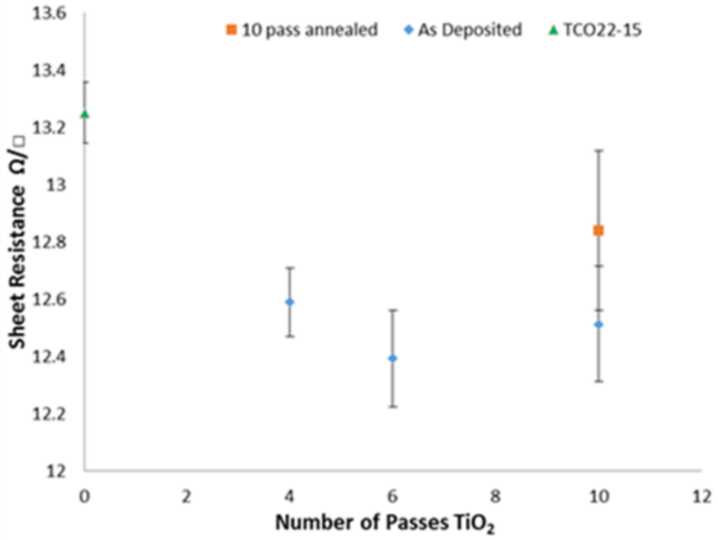


Annealing Behaviour

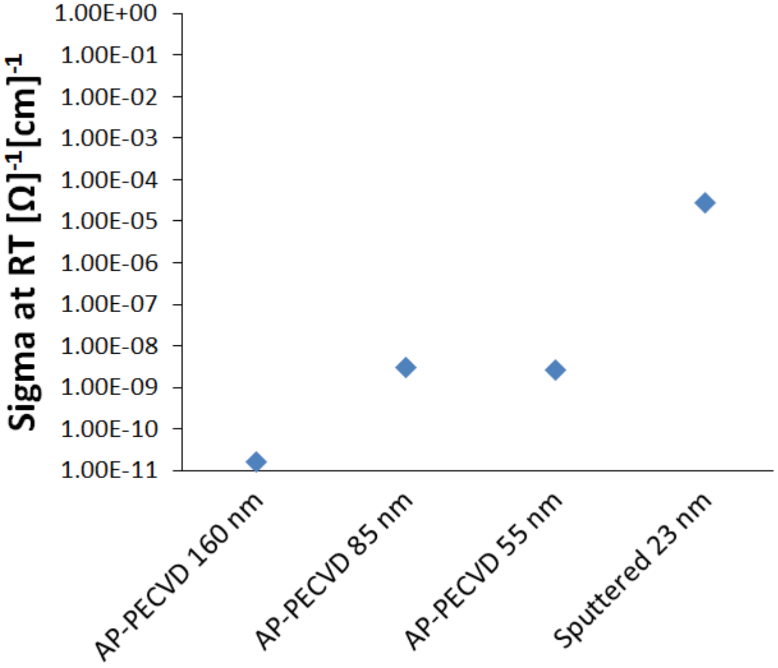


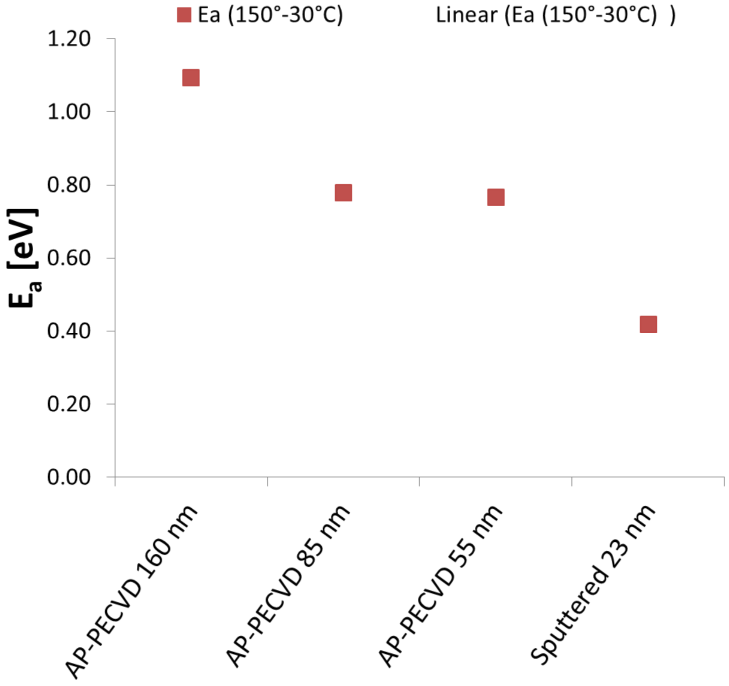






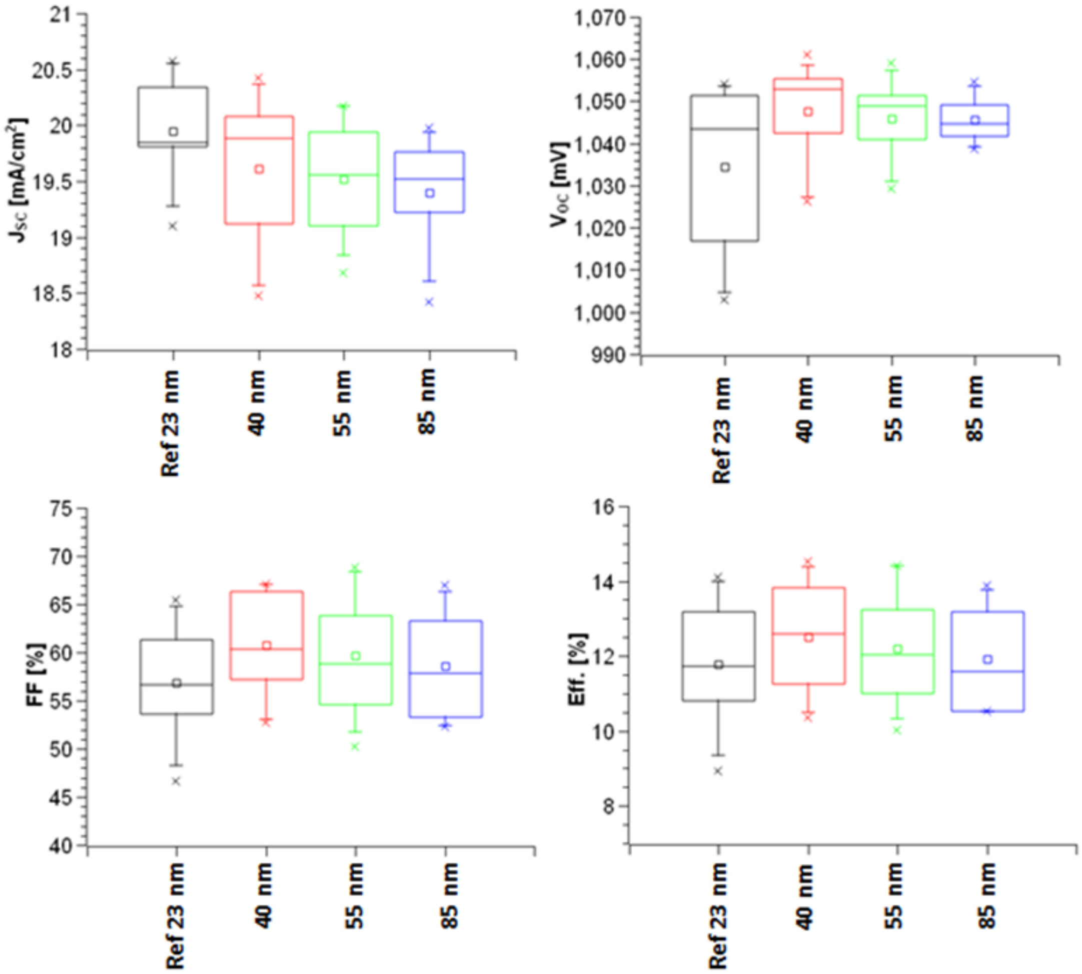
Dark Conductivity





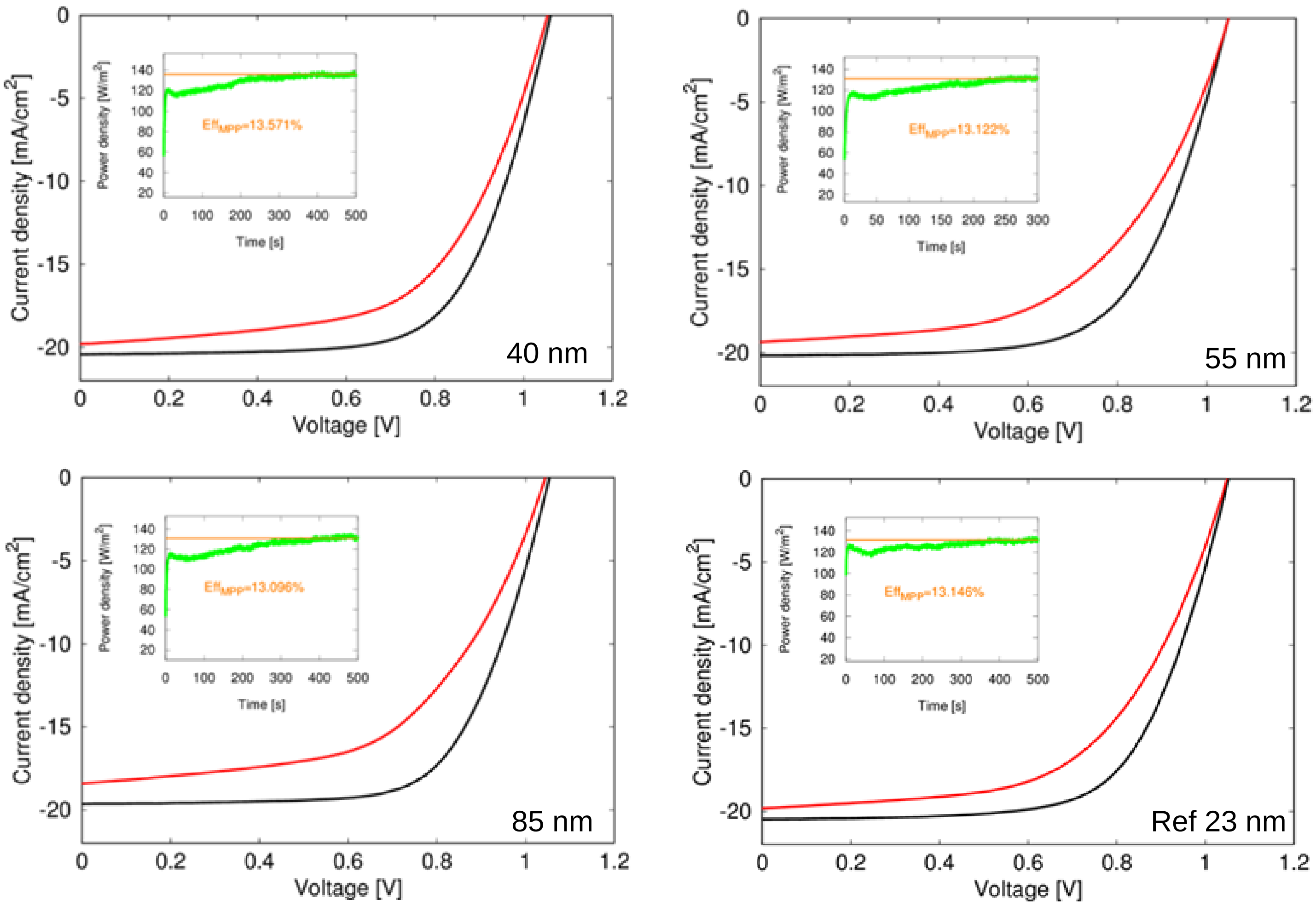
- σ Dark & E_a measurements conducted for a range of TiO_{2-x} thicknesses on float glass
- Reduced conductivity compared to the reference
- Higher activation energy suggests less defective than the sputtered film
- Strong correlation with thickness

Cell Results



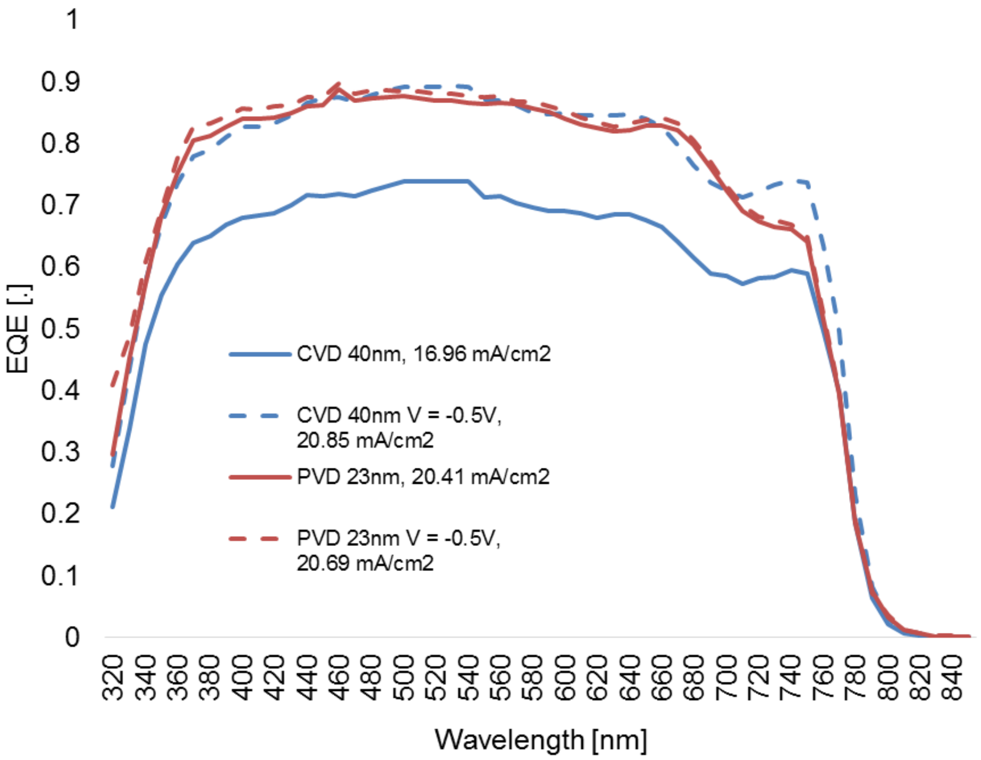
- TiO_{2-x} / TCO22-15 1 cm^2 mesoporous $CH_3NH_3PbI_3$ PV cells
- Efficiency greater than the sputtered reference
- 14.53%, 13.57% mpp vs 14.11% 13.15% mpp
- Decrease in V_{oc},FF, J_{sc} and hence efficiency with thickness
- Possibility to further improve efficiency with reduced thickness

Current Density Plots & MMP Tracking



- Increased FF for 40 nm AP PECVD & Sputtered film
- Hysteresis reduced for thinner films – reduced series resistance
- MPP efficiency stable after five minutes

External Quantum Efficiency

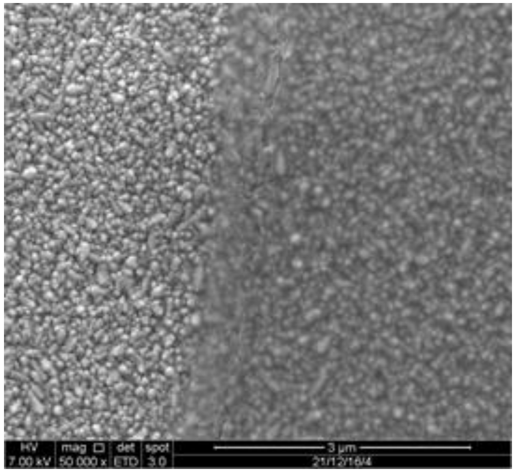


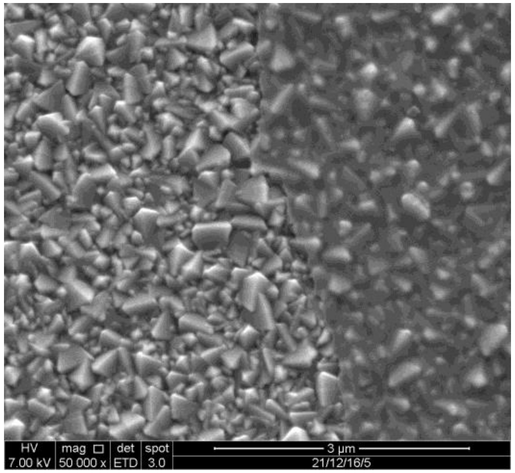
- 40 nm AP PECVD film gave reduced EQE compared to sputtered film
- This deficiency could be completely offset by applying a 0.5 V negative bias
- Collection issue related to an extraction barrier at the interface

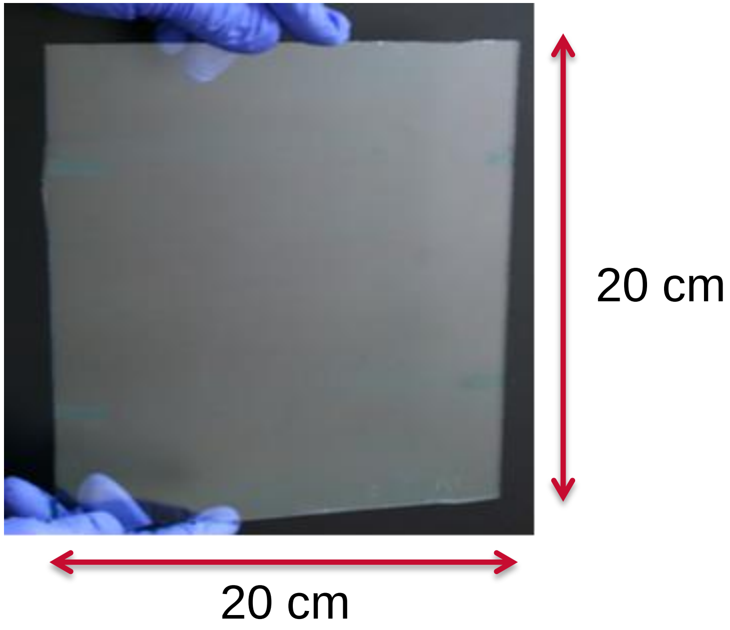
Conclusions and Further work

- TiO_{2-x} deposited via continuous AP PECVD process
- Film properties and uniformity suitable for ETL
- Excellent cell performance demonstrated by non optimised films
    - 14.53%, 13.57% mpp (AP PECVD) vs 14.11% 13.15% mpp (Sputtered)
- Issues generally related to film thickness (40 nm vs 23 nm)
    - Dark conductivity, series resistance, FF
- Significant potential for efficiency gains in conjunction with large area processing
- Further work ongoing to optimise films
    - Repeat characterisation & cell tests with reduced film thickness
    - Compare different substrates – optimal thickness / coverage
    - Explore scale up to 20 x 20 cm
    - Investigate the use of nitrogen plasma

Further Work







- ~20 nm films deposited on Solaronix TCO 22-15 & NSG TEC 7
- Cell evaluation underway
- Deposition on 20 x 20 cm substrate

Acknowledgments

Co Authors / collaborators

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SEVENTH FRAMEWORK PROGRAMME

PLIANT

CHEOPS