

# Photovoltaic Research and Development

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**Energy and Processes Competency Area**

**Materials Science and Manufacturing**

**CSIR**

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# Outline

- Introduction to Photovoltaics
- South African PV Research Roadmap
- CSIR PV R&D
- Some Results
- Future Work
- Acknowledgements

# -----INTRODUCTION-----

# Introduction to Photovoltaics

- Photovoltaics (PV) is the direct conversion of sunlight into electrical energy through a solar cell
- Conversion results from the physical photo (or photovoltaic) effect, originally discovered by French physicist Edmund Becquerel in 1839
- Only until the beginning of the semiconductor era in the early 1950s Becquerel's findings were used and in 1954 the first solar cell was developed from crystalline silicon in the USA
- Initially used only for satellite application as a clean source of energy
- First oil crisis in 1973: Realisation that earths' fossil resources are finite and cause for concern → Increased research into PV technologies



Satellite with PV power supply

Source: ESA



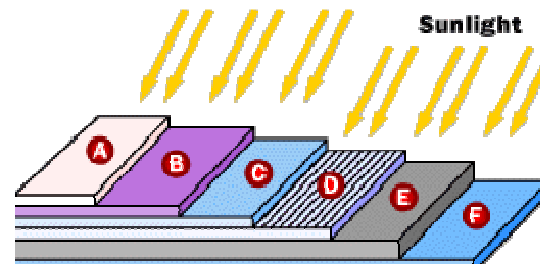
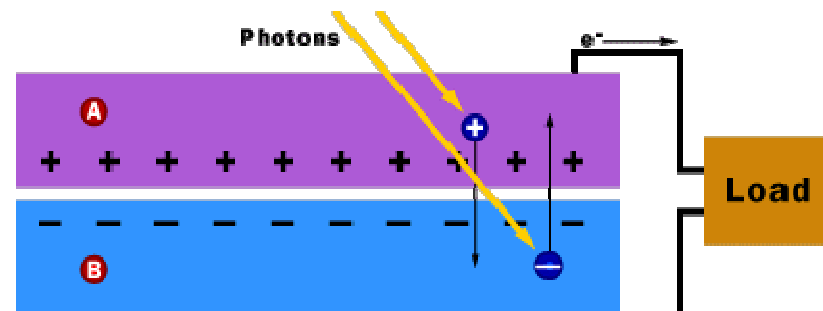
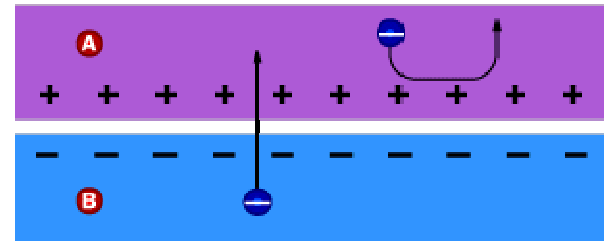
Car park installation (Courtesy: SEI, Italy)



# Introduction to Photovoltaics

Simple explanation of the operating principle: Traditional semiconductor solar cell

- *Photons* in sunlight hit the solar panel (individual solar cells connected in series or parallel) and are absorbed by semiconducting materials, such as silicon
- Electrons (negatively charged) are knocked loose from their atoms, allowing them to flow through the material to produce electricity
- Due to the special composition of solar cells, the electrons are only allowed to move in a single direction.
- The complementary positive charges that are also created (like bubbles) are called holes and flow in the direction opposite of the electrons in a silicon solar panel.
- An array of solar cells converts solar energy into a usable amount of direct current (DC) electricity.



# Introduction to Photovoltaics

## Advantages

- The technological advancements in solar energy systems have made them extremely cost effective.
- Conversion of solar energy into electricity produces no pollution.
- Solar powered lights and other solar powered products are very easy to install. This is because there are few wiring issues and little need to ever dig supporting trenches.
- Most systems do not require any maintenance during their lifespan, which means you never have to put money into them.

## Disadvantages

- Owners of active and passive solar systems need regulations that prevent construction of other structures that block access for a user to solar heat or impact
- The initial costs discourage buyers.
- Outdoor solar lighting will cost you not more than normal lighting, but large solar energy systems for your entire home can run from a minimum of \$5,000 to a more likely figure of \$15,000 to \$20,000
- Low efficiencies and limited lifetime

# Introduction to Photovoltaics

## DIFFERENT TYPES OF SOLAR CELLS:

### (1) Matured Photovoltaic Technologies



Single-crystalline Si Cell



Poly-crystalline Si Cell

Amorphous Si Cell

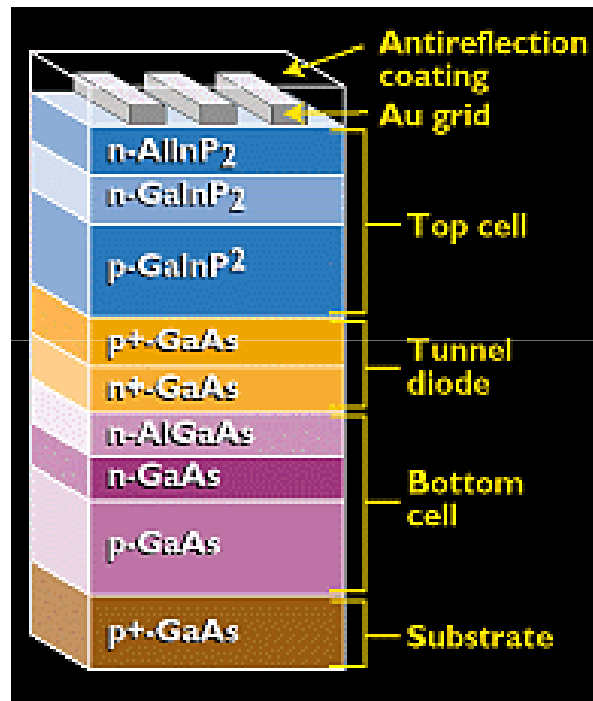


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# Introduction to Photovoltaics

## DIFFERENT TYPES OF SOLAR CELLS:

### (2) High-efficiency Photovoltaic Technologies



Multi-junction (or Tandem) Solar cells

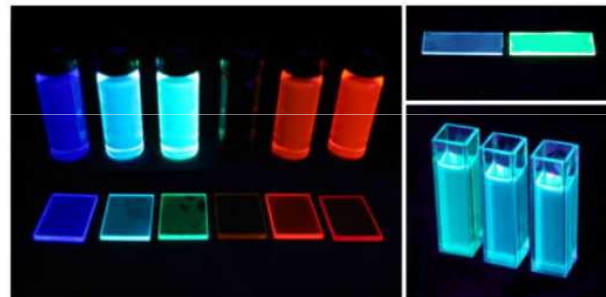
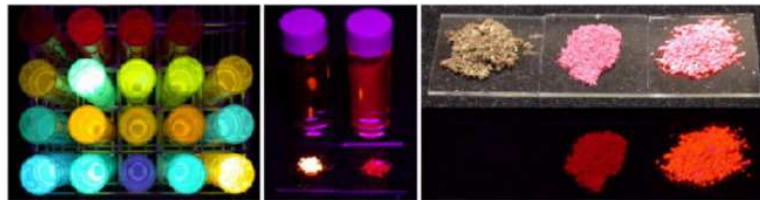
- Individual single-junction cells with different energy band gaps are stacked on top of one another
- Sunlight then falls first on the material with the largest bandgap, and the highest-energy photons are absorbed
- Photons not absorbed in the first cell continue on to the second cell which absorbs the higher-energy portion of the remaining solar radiation while remaining transparent to the lower energy photons.
- Energy efficiencies ~ 50% achieved



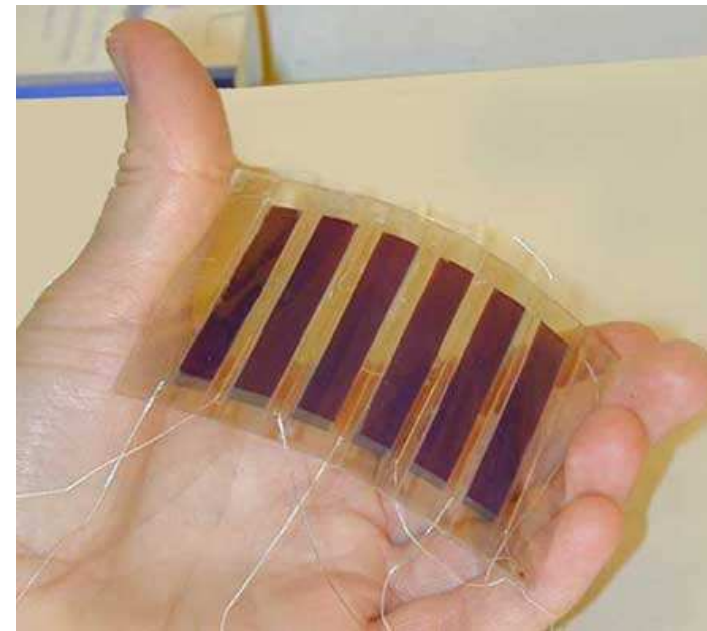
# Introduction to Photovoltaics

## DIFFERENT TYPES OF SOLAR CELLS:

### (3) Low-cost Alternative Photovoltaic Technologies

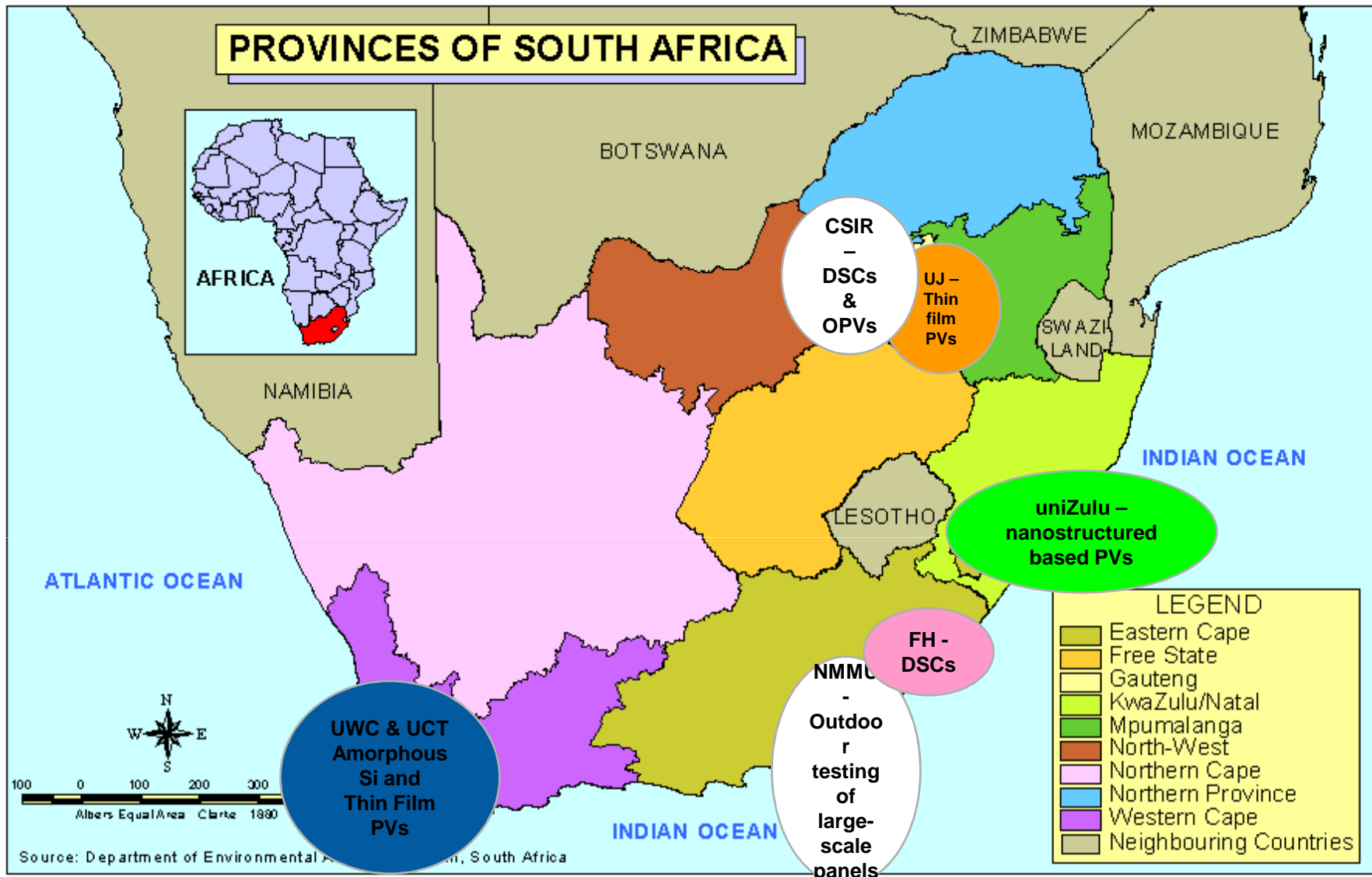


Organic solar cells



Dye-sensitised solar cells

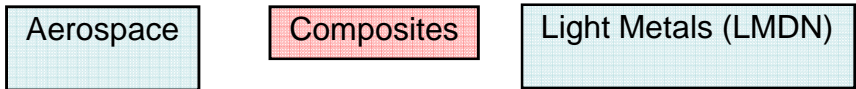
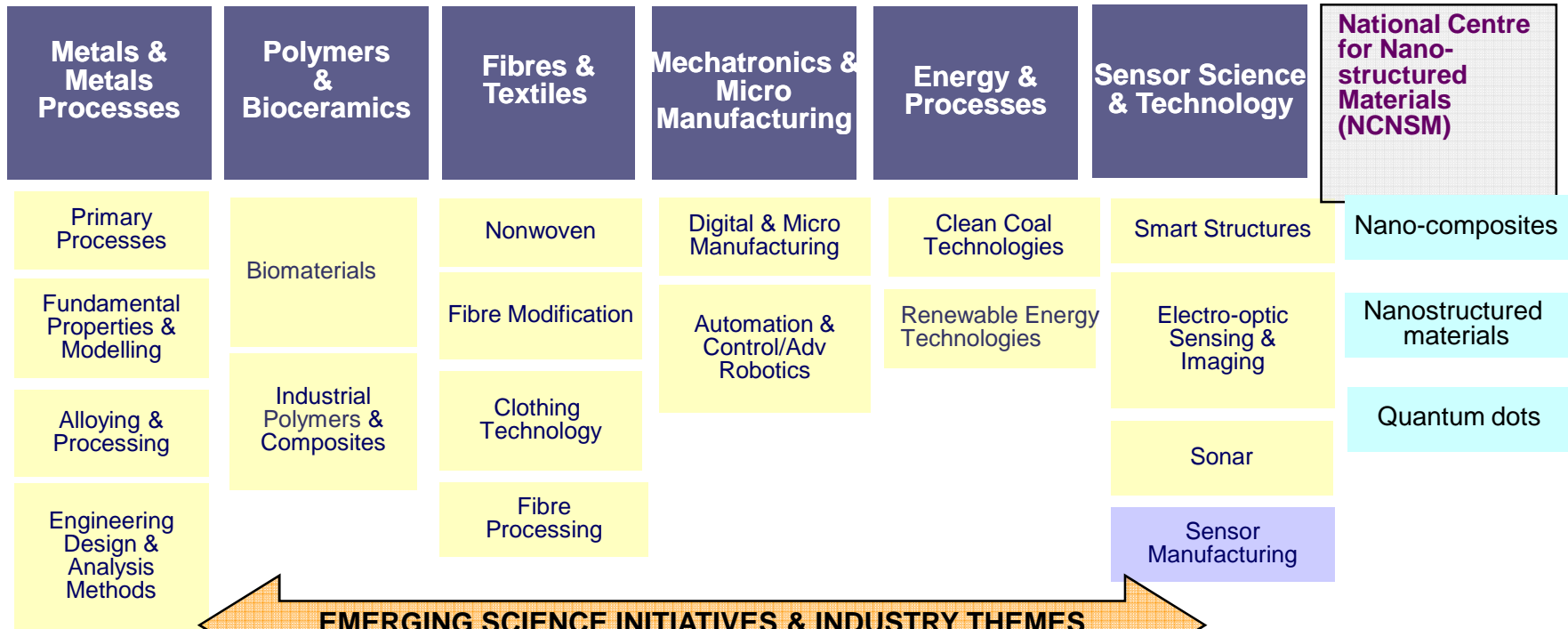
# ----- SA PV RESEARCH ROADMAP-----



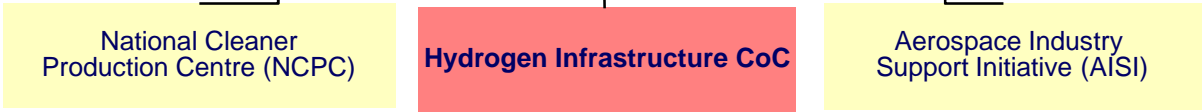
# ----- CSIR PV R&D -----

# MATERIALS SCIENCE & MANUFACTURING (MSM)

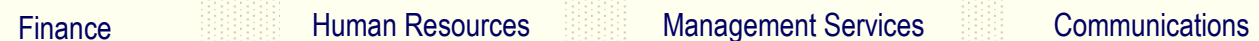
## SET Leadership & Competence Management



### AGENCIES



### SHARED SERVICES



**R&D Outcomes Management**  
**Strategic Contract R&D Management & Strategic Relationship Management**

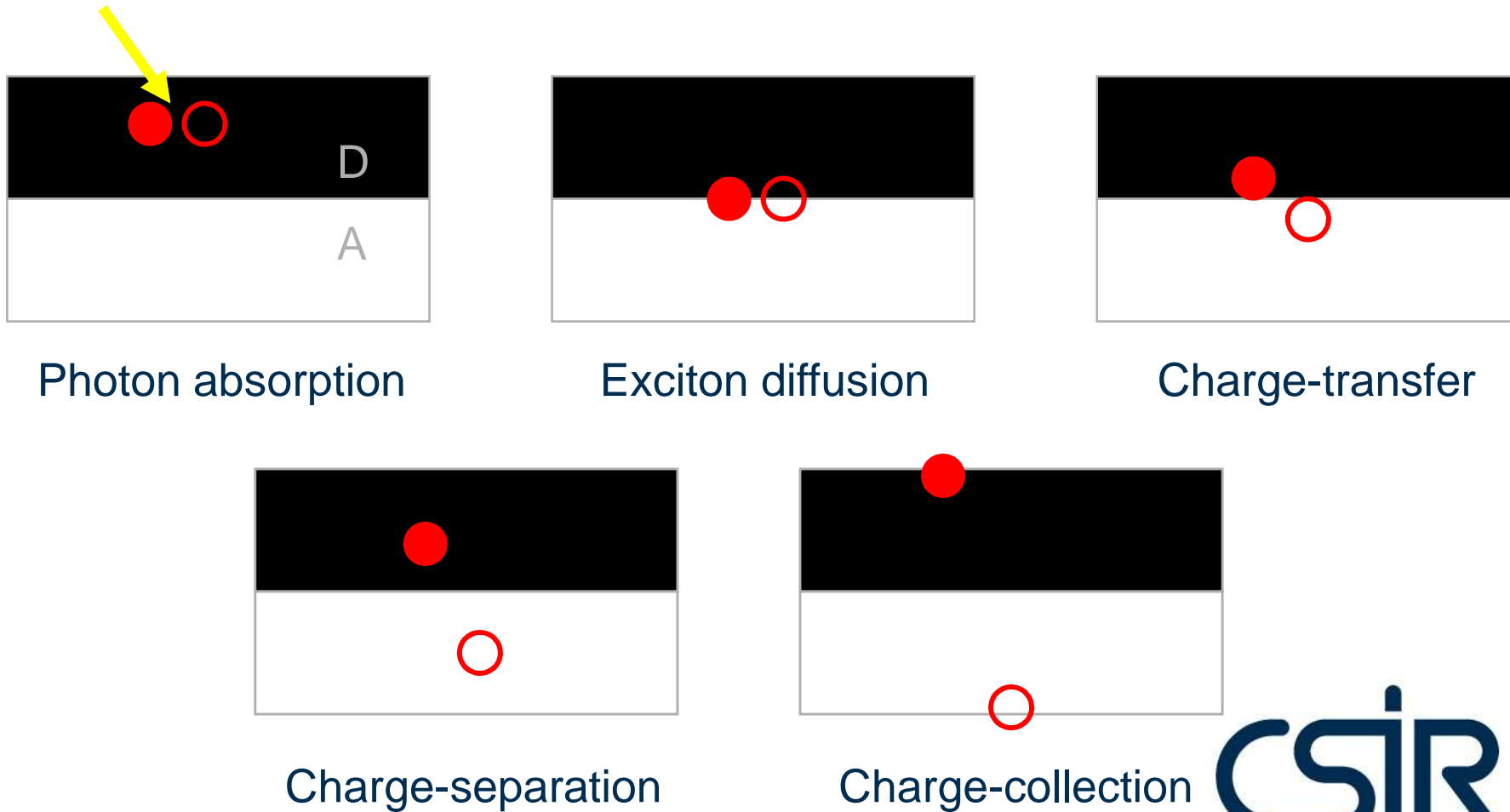
# CSIR Photovoltaic Research and Development

- Two major PV research projects:
  - Dye-sensitised solar cells (DSCs)
  - Organic photovoltaics (OPVs)
  
- Low cost manufacturing of moderate efficient devices
  
- Synthesis of nanomaterials with novel opto-electronic properties for implementation within the above cells – new applications
  - To replace window panes with transparent DSCs thereby replacing air-conditioning systems
  - Manufacturing of OPVs on flexible polymer substrates for miniature device application

# ----- SOME RESULTS -----

# Some Results

## (1) Organic Photovoltaic R&D



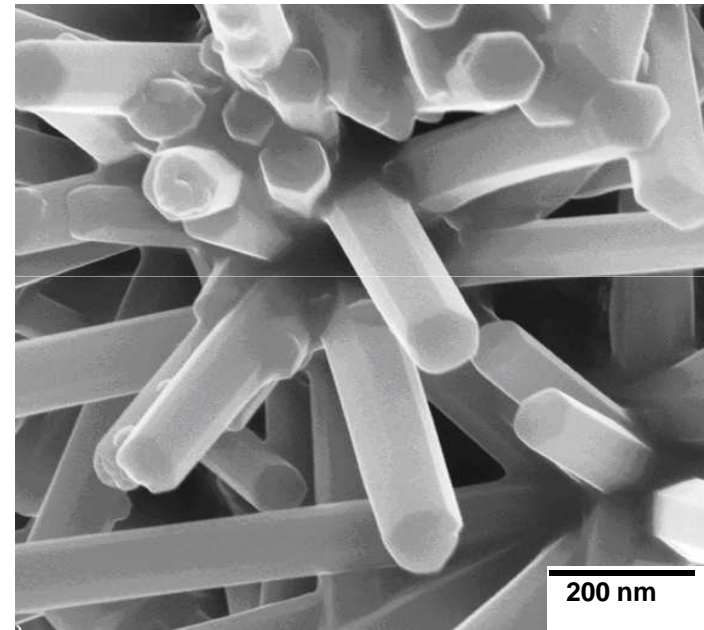


# Some Results

## Synthesis of different organic/inorganic hybrid photovoltaic materials electrochemically or chemically

Structures of polyaniline and polydimethoxyaniline synthesis by an oxidative polymerization process.

By combining two oxidants ammonium per sulphate  $(\text{NH}_4)_2\text{S}_2\text{O}_8$ , and  $\text{FeCl}_3$  give rise to polymers in the pernigraniline state that exhibit hexagonal morphologies.



# Some Results

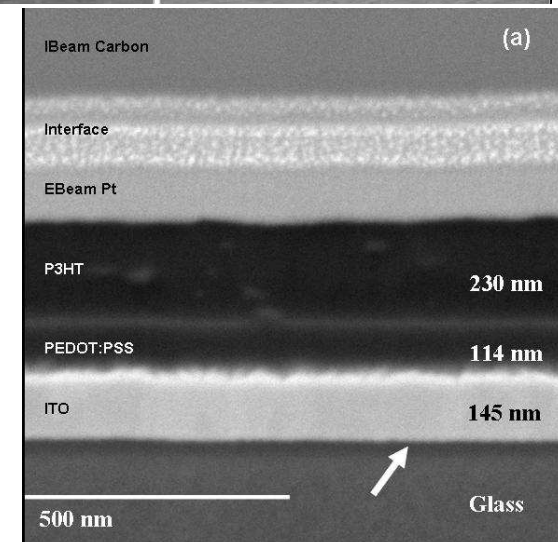
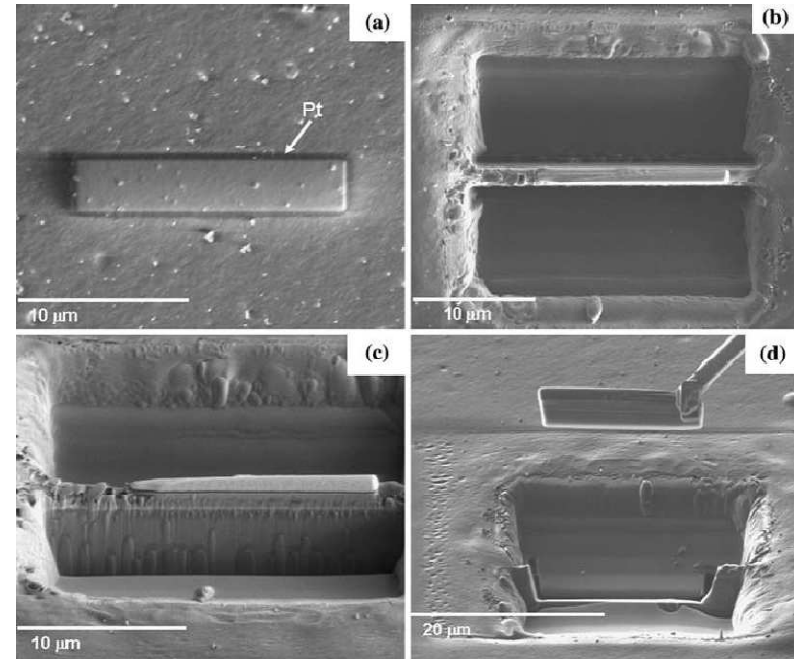
## Construct solar cell and develop an understanding of the interfacial interactions

Preparation of P3HT/PEDOT/ITO/Glass structures

Preparation of TEM/SEM samples for interfacial/cross-sectional analysis by means of ion-beam milling in HELIOS Nanolab 600 (FEI)

Cross sections reveal that a smooth and homogeneous polymer (P3HT and PEDOT:PSS) film is observed on the glass substrate.

The ITO/Glass substrate has an interfacial surface roughness of ~15 nm, while the most sensitive organic layers have sharp and undistorted interfaces.



# Some Results

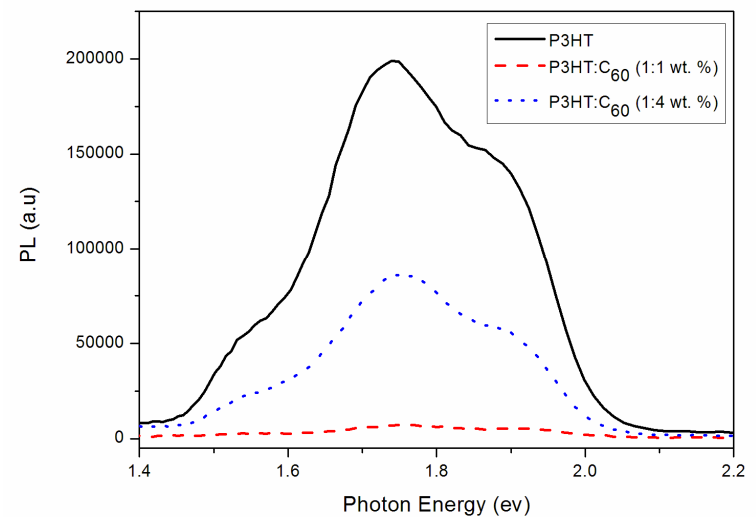
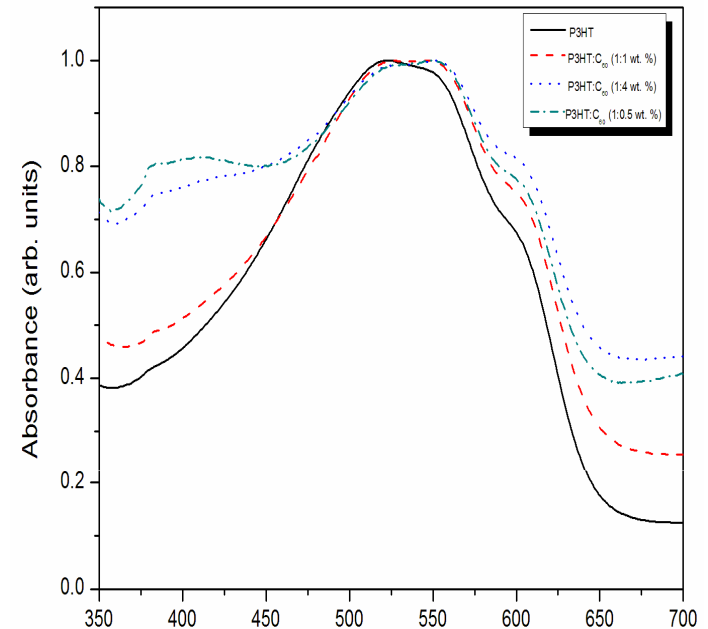
## Study the optical, structural and electrical properties of the synthesized material (UV-Vis, PL, XRD)

The peak wave length of the inter-band transition of the P3HT blended with different fullerene ratios is shifted towards higher wavelength.

Ascribed to the special feature of the applied solvent which induces favourable chain conformations and/or an advantageous inter-chain packaging within the polymer

The P3HT shows PL, which is completely quenched when it is mixed with a 1:1 wt. % of C60.

This implies that the excitons generated on one polymer within the film reached an interface with the other polymer and dissociate before recombining.



# Some Results

## (2) Dye-sensitised Solar Cell R&D

### Major Research Areas:

#### *Improvement in DSC Efficiency*

Implementation of TiO<sub>2</sub> nanotubes in cell  
Al<sub>2</sub>O<sub>3</sub>/TiO<sub>2</sub> nanoparticle composite synthesis and application

#### *Improvement in Long-Term Stability of DSCs*

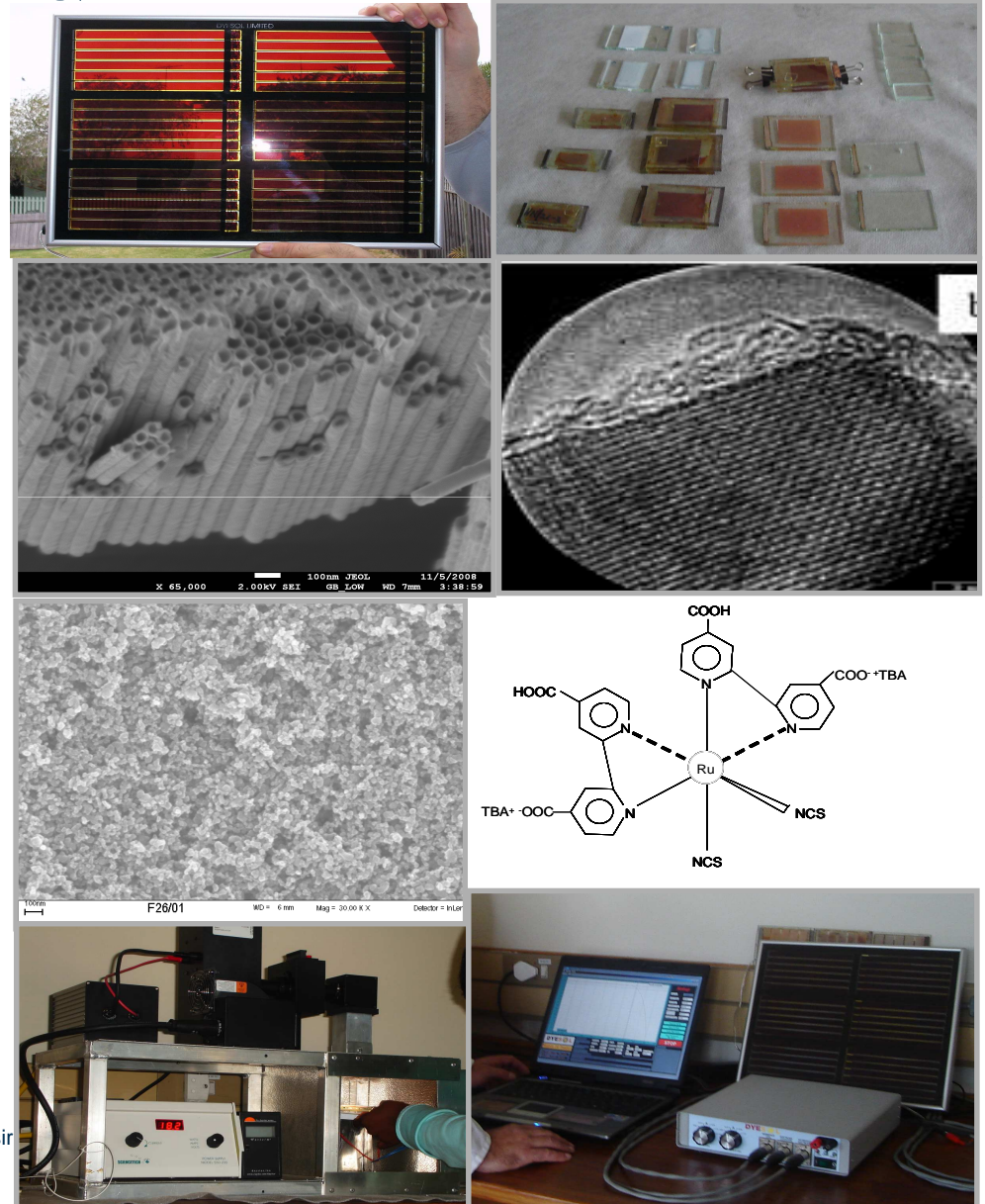
Studying the effect of reverse biased potentials on the stability of the cell  
Outdoor testing: DSC performance vs. a-Si and c-Si cells over extended periods

#### *Cell Cost Reduction*

Novel dye synthesis from CSIR collected Ru waste products

#### *Cell Characterisation Techniques*

Investigation into new techniques for characterisation of closed and open cells



# Some Results

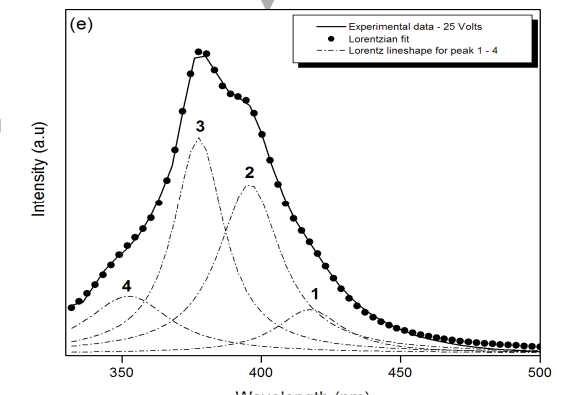
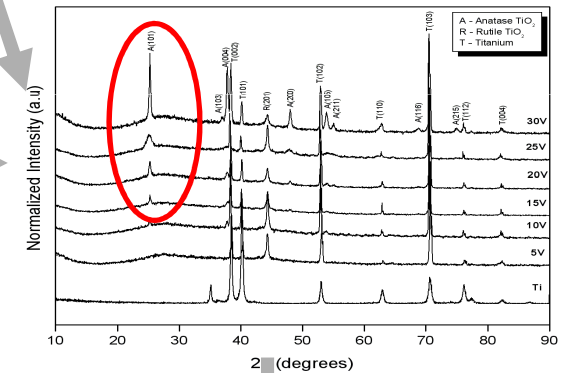
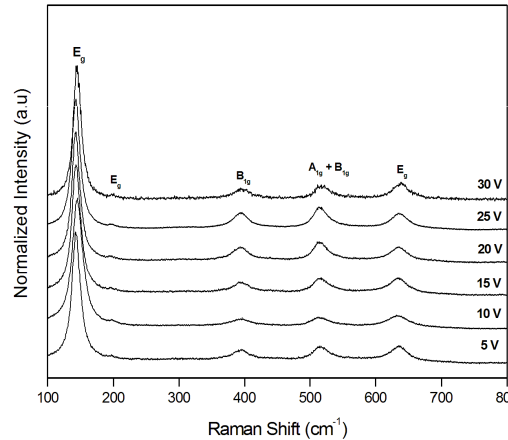
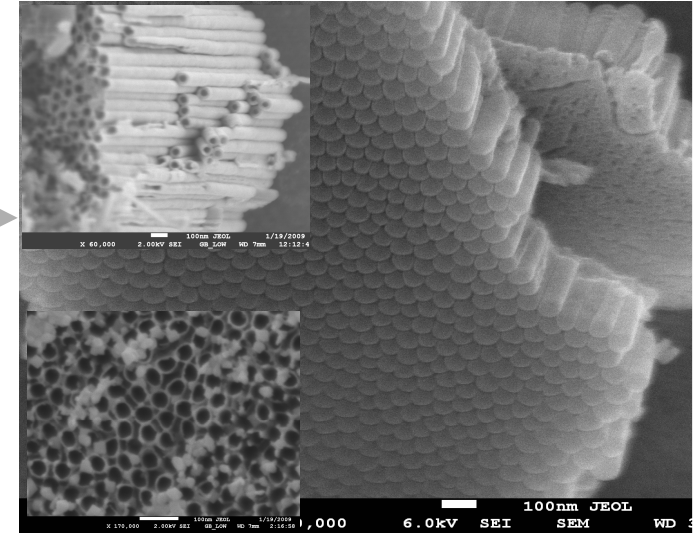
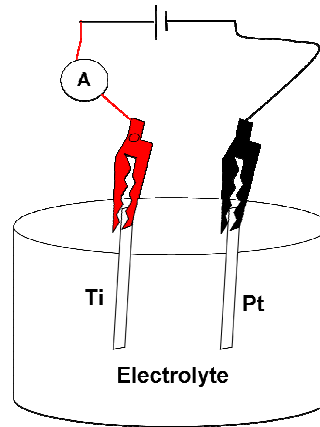
## TiO<sub>2</sub> Nanotubes

**Aim:** Implementation in DSCs for improvement of electron transport and manufacturing of transparent cells

Synthesis by means of anodisation

### Major findings thus far:

- Able to control the physical dimensions of tubes by altering anodization bath conditions
- Nanotube structure influences crystallinity
- Alters optical properties; subsequently able to control optical properties (e.g. band gap) of tubes
- Lead to transparent DSCs, novel applications, e.g. office window panes



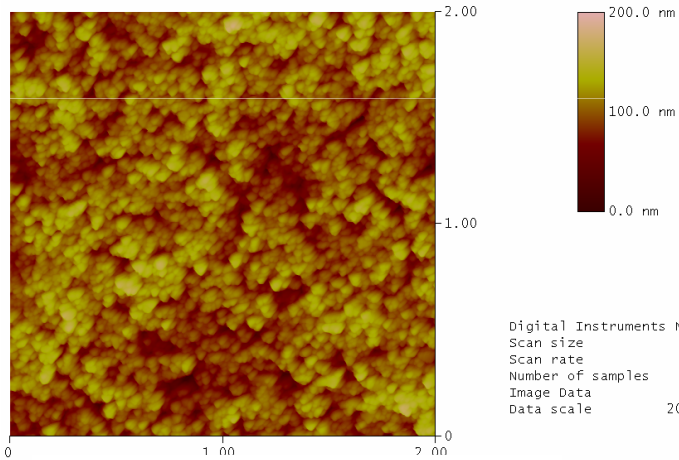
# Some Results

## TiO<sub>2</sub>/Al<sub>2</sub>O<sub>3</sub> Coreshell Nanostructures

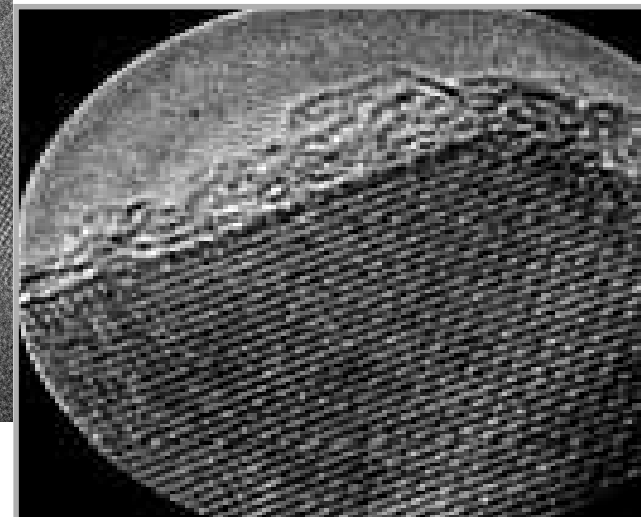
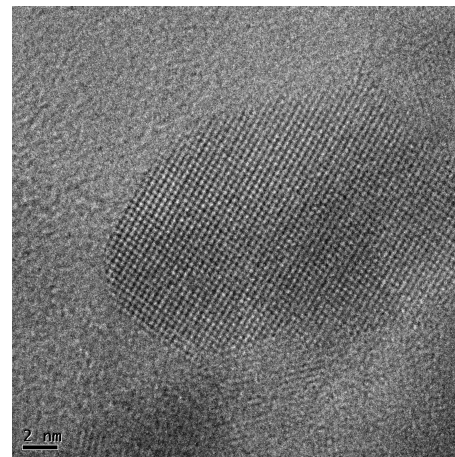
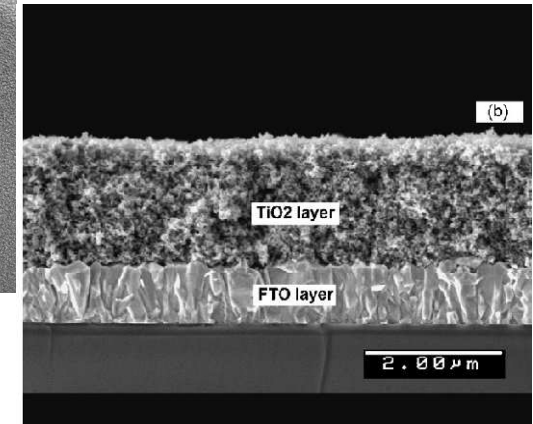
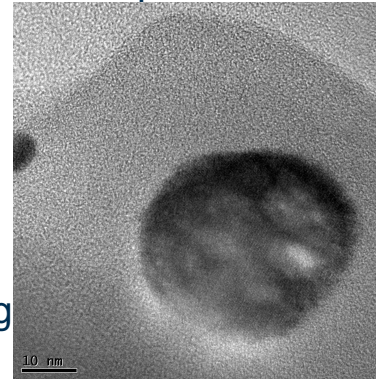
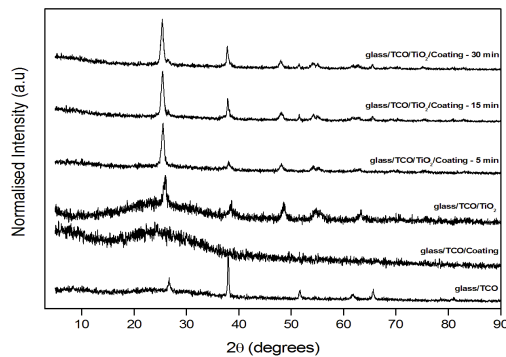
**Aim:** Implementation of Al<sub>2</sub>O<sub>3</sub> coated TiO<sub>2</sub> nanoparticles for implementation in DSCs to reduce interfacial recombination

Synthesis of TiO<sub>2</sub> nanoparticle films via wet-chemical methods

Coating of Al<sub>2</sub>O<sub>3</sub> thin layers onto TiO<sub>2</sub> nanoparticles via dip-coating technique



Digital Instruments NanoScope  
Scan size 2.000  $\mu$ m  
Scan rate 1.002 Hz  
Number of samples 512  
Image Data Height  
Data scale 200.0 nm



## Published/Accepted manuscripts

- (1) “Interfacial analysis and properties of regioregular P3HT spin-coated on an Indium tin oxide coated glass substrate”  
**Journal of Materials Science 43, 5599 (2008)**
- (2) “Synthesis and characterization of novel nanophase hexagonal poly(2,5-dimethoxyaniline)”  
**Electroanalysis 20, 2347 (2008)**
- (3) “Effect of mixture ratios and nitrogen carrier gas flow rates on the morphology of carbon nanotube structures grown by CVD”  
**Journal of Materials Science 43, 1020 (2008)**
- (4) “The influence of thermal annealing on the morphology and structural properties of a conjugated polymer in blends with an organic acceptor material”  
**Journal of Materials Science 44, 3192 (2009)**
- (5) “Structural and photo-physical properties of poly (3-hexylthiophene) thin films prepared using sol-gel techniques” **Materials Chemistry and Physics 116, 279 (2009)**
- (6) “Thermal induced changes on the properties of spin-coated P3HT:C60 thin films for solar cell applications” **Solar Energy Materials & Solar Cells 93, 1674 (2009)**
- (7) “Structure induced optical properties of anodized TiO<sub>2</sub> nanotubes” Submitted, **Materials Chemistry and Physics**

# ----- FUTURE WORK -----



# Future Work

Further optimization of low-cost donor and acceptor materials for application in OPVs

Manufacturing of OPVs on flexible substrates

Modelling of physical properties of photovoltaic materials used in solar cells

Implementation of cost-effective  $\text{Al}_2\text{O}_3$ -modified  $\text{TiO}_2$  NTs in DSCs

Further optimization of coreshell  $\text{Al}_2\text{O}_3$ - $\text{TiO}_2$  nanoparticle materials

Modelling of opto-electronic materials used in DSCs

# Acknowledgements

- Funding sources – DST and CSIR
- Dr. Gerald Malgas – NCNSM for providing some of his major findings for this presentation
- Collaborators – UWC, NMMU, FU
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**Thank You**

**CSIR**

*our future through science*