Application of TiO_2 nanotubes in dye-sensitised solar cells for improved charge transport

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Energy and Processes
Materials Science and Manufacturing

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Outline of the Presentation

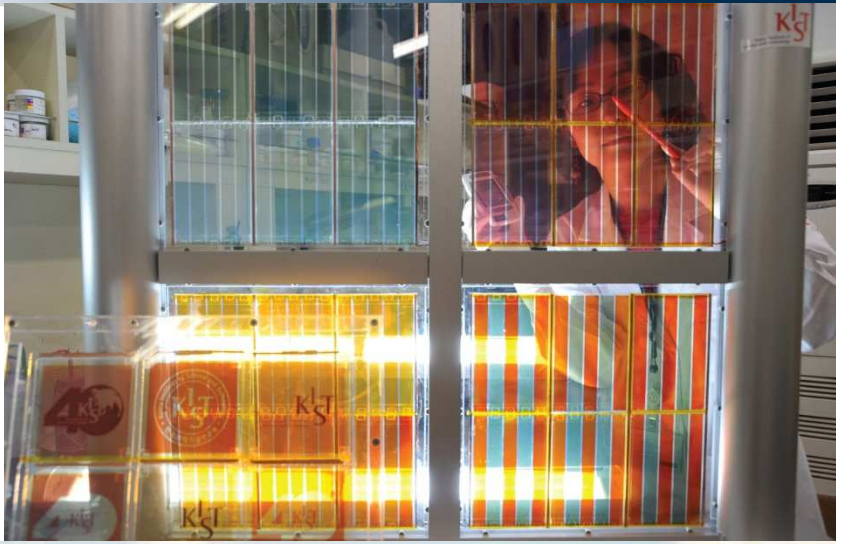
- Background
- Problem Statement
- TiO_2 Nanotube Synthesis and Characterisation
- Manufacturing of Dye-sensitised Solar Cells with TiO_2 Nanotubes
- Device Performance
- Conclusions
- References

Background

- Major breakthrough in reduction of cost of photovoltaics realised in 1991 – first report of a functioning photoelectrochemical cell (*O'Regan & Grätzel, 1991*)

- Big interest from industry and science community:
  - Industry – promise of low cost PVs with moderate efficiency; potentially at a cost of less than 1 US$/peak watt (Grätzel, 2009) vs. 4.8 US$/peak watt for c-Si (*www.solarbuzz.com*)
  - Science – raised important questions around the processes governing their operation

- 20 years onwards and big strides have been made, however
  - Efficiency of best manufactured DSCs ~ 11% mark and 7% for DSC panels



Background

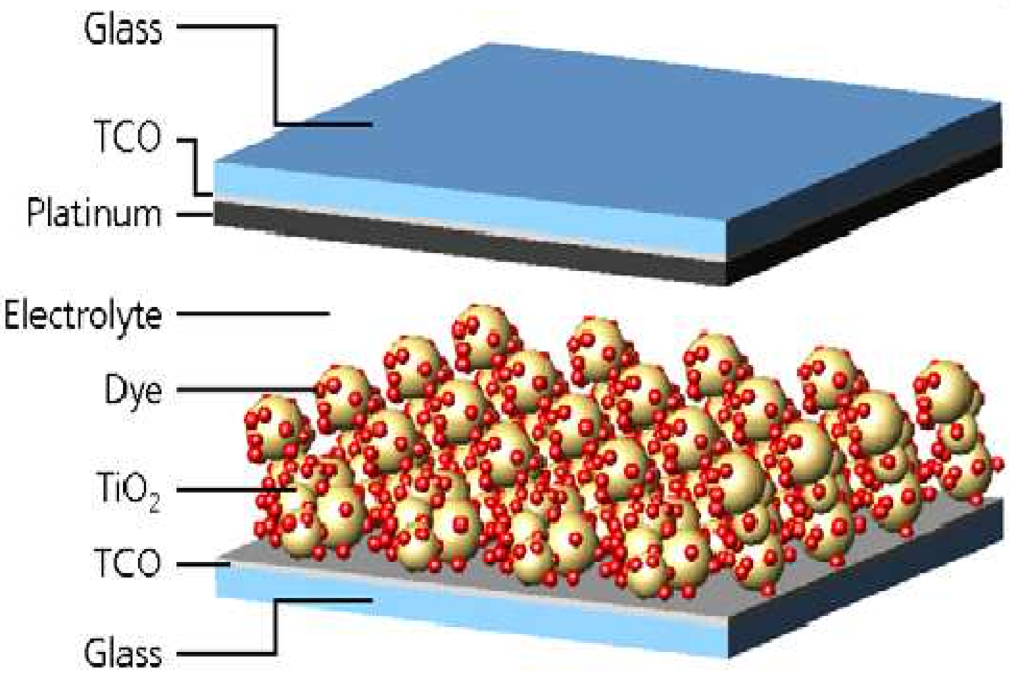
Dye-sensitised Solar Cells

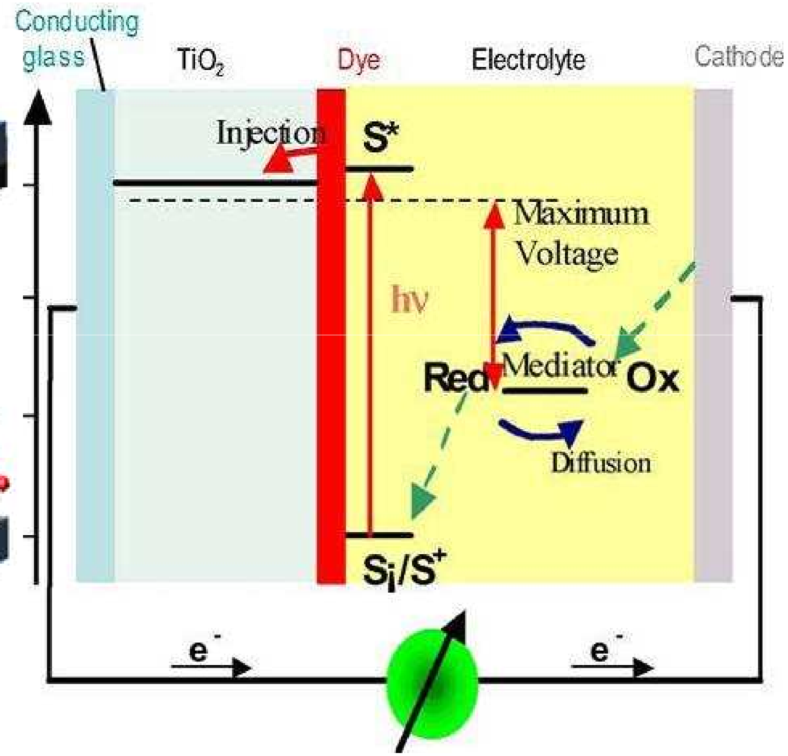
- **Relatively inexpensive**
  - Made in non-vacuum setting
  - Simple manufacturing process with inexpensive materials
- **Short return on investment**
  - Takes approx 3 months to produce energy savings equivalent to cost of production
  - Lightweight, semi-transparent and robust
- **Performance less affected by environmental conditions, e.g. light intensity**
  - Been shown that DSCs outperform traditional Si solar cells by 20% over 6 month period

Traditional Solar Cells

- **Expensive**
  - High vacuum and heat systems required to manufacture device quality materials
- **Long return on investment**
  - Takes approx 4 years to produce energy savings equivalent to cost of production
  - Heavy, big and rigid
- **Performs poor in low sunlight**
  - Known that solid state cells perform poor in days of low sunlight, through the night

Background





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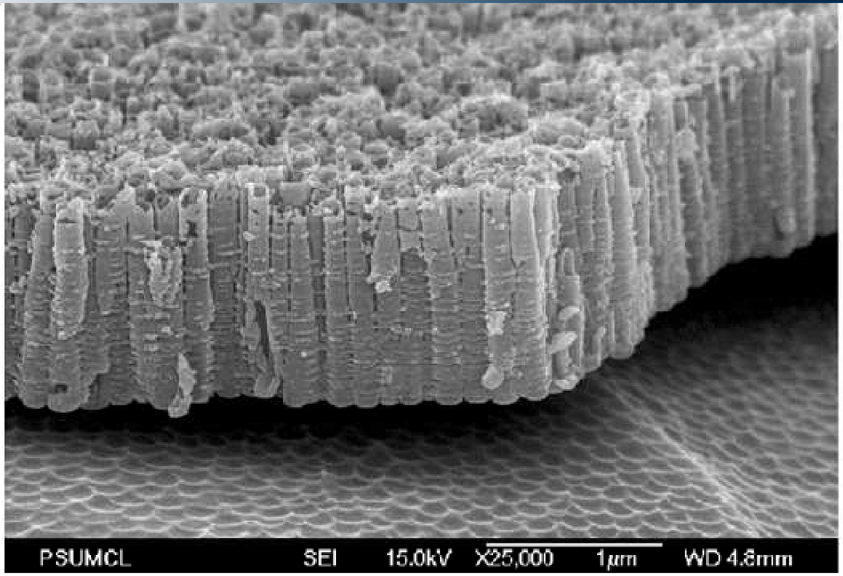
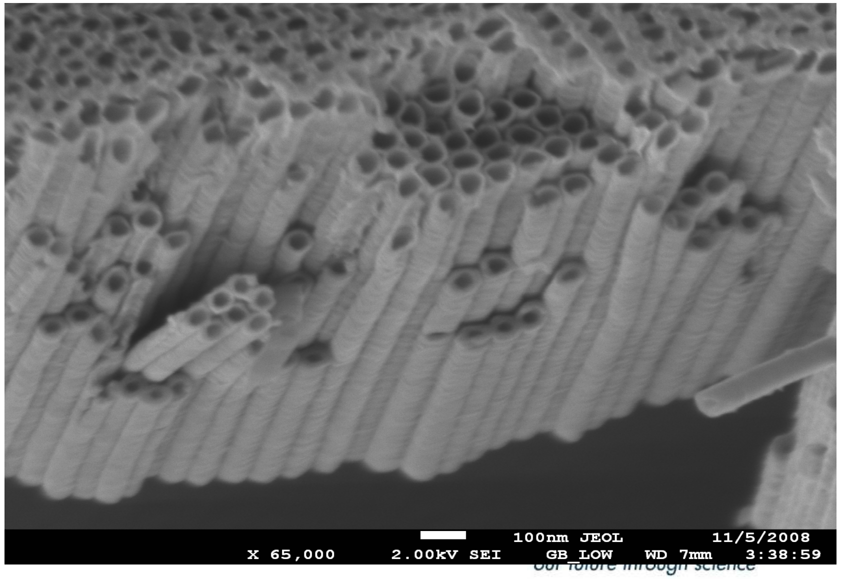
Problem Statement

- Complex TiO_2/dye/electrolyte interface - electrons & holes in close proximity
- TiO_2 nanoparticles experience scattering of photo-generated electrons at crystal grain boundary of two nanoparticles (*Paulose et al., 2006*)
- Leads to enhanced recombination of electrons and holes at the TiO_2/dye/electrolyte interface
- Major contributing factor to the low cell efficiency of the DSC

TiO_2 Nanotubes Synthesis and Characterisation

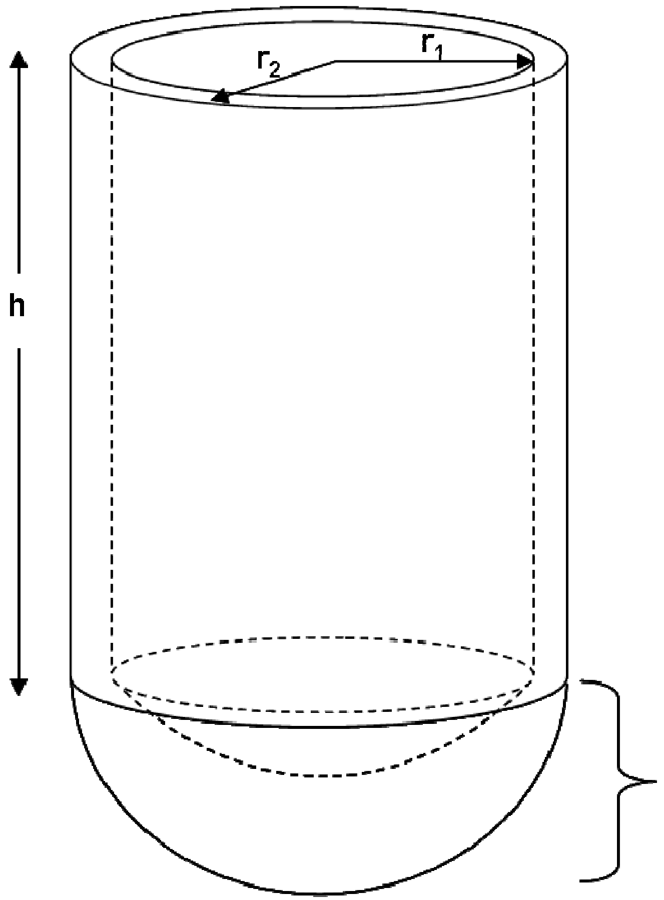
- Breakthrough in TiO_2 nanostructured synthesis in 2001 (*Gong et al.)* – self-organised TiO_2 nanotubes via anodisation
- First tested in DSCs in 2003/4 (*Mor et al.)*
- Shows potential to enhance electron transport through the TiO_2 layer
- However…
    - ➢ Suffers from low surface area compared to a layer of TiO_2 nanoparticles, implies low photocurrent in DSC
    - ➢ Ti layer at bottom prevents light absorption through the working electrode
- Hence…
    - ➢ Improve anodisation synthesis





TiO_2 Nanotubes Synthesis and Characterisation

Part A: Improvement in nanotube surface area

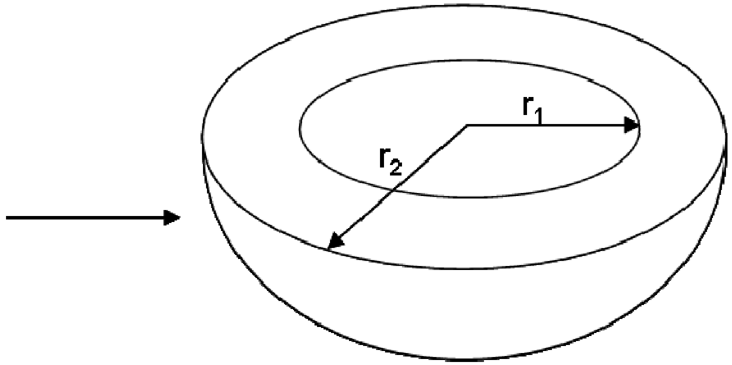


$$S_{tube} = \pi\left[(r_2 - r_1)^2 + h(r_2 + r_1)\right] + 2\pi\left[r_1^2 + r_2^2\right]$$

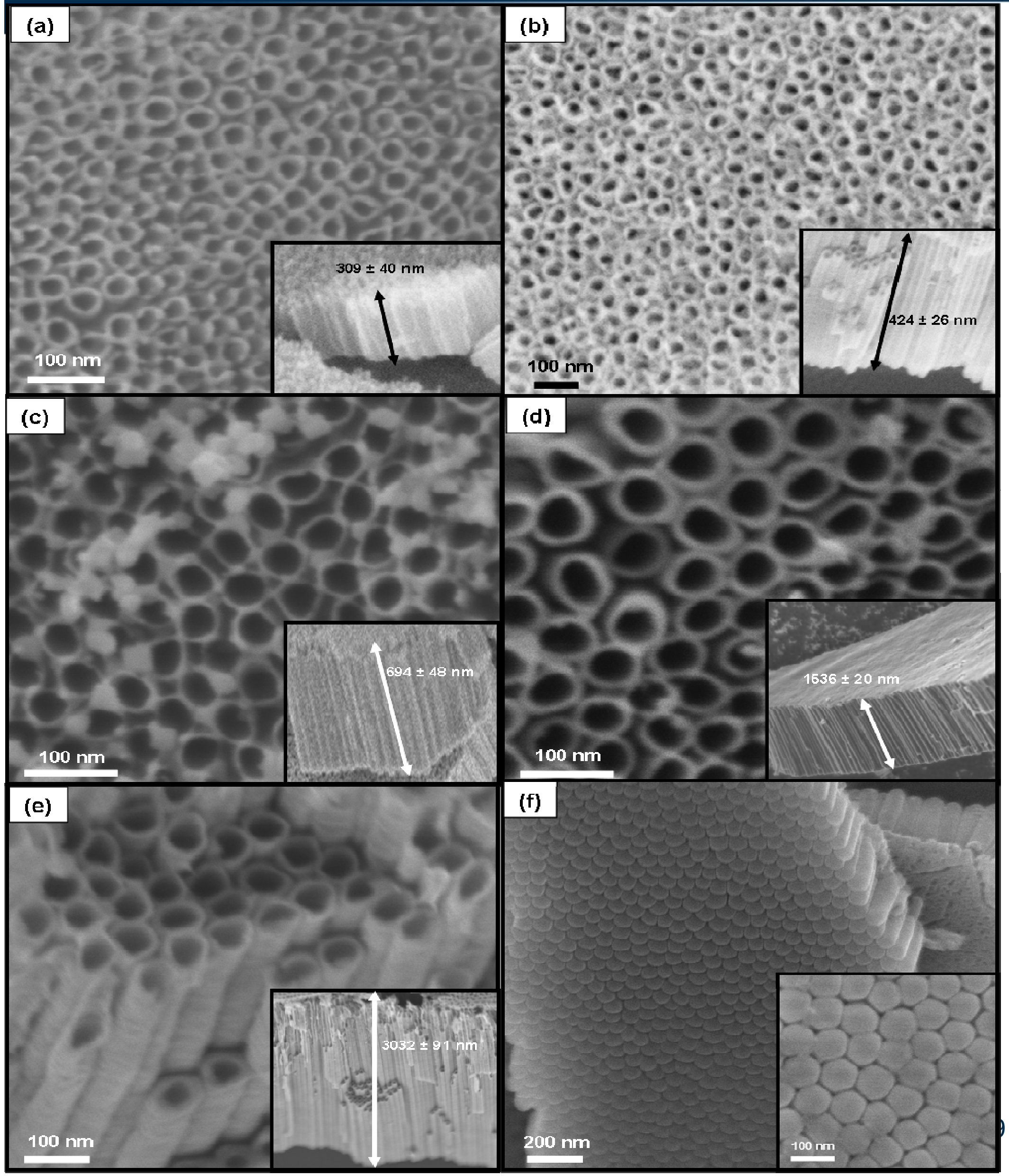
NB: $r_2 - r_1$ = wall thickness

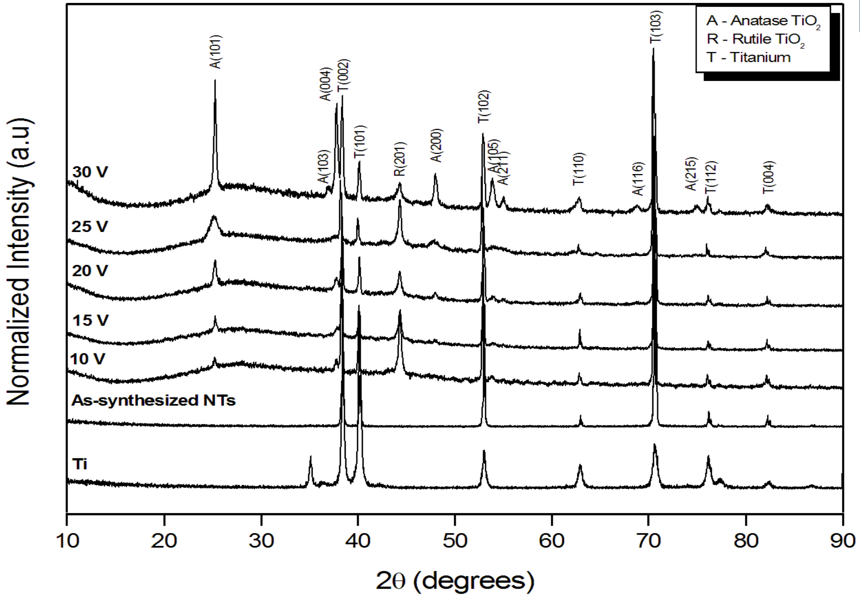
Hence to improve S_{tube}:

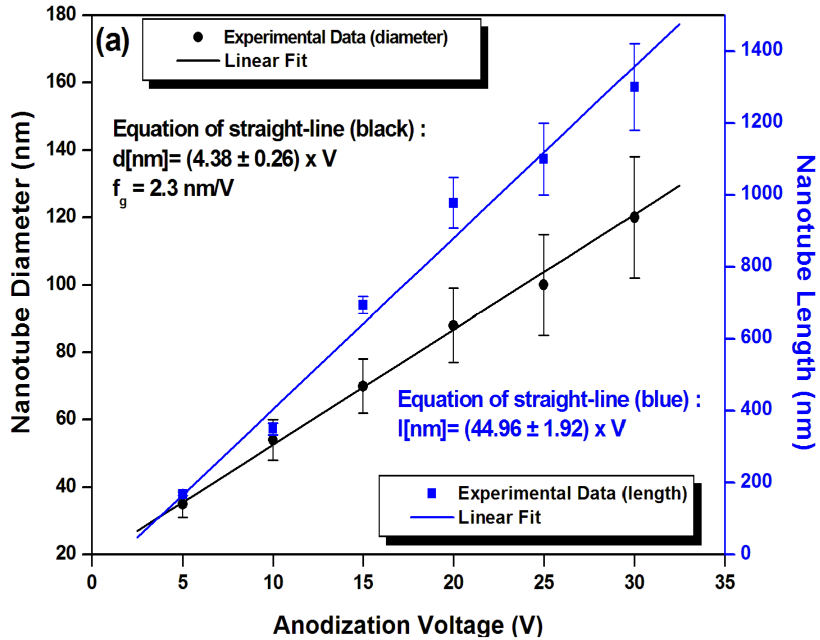
- Increase wall thickness, $(r_2 - r_1)$
- Increase height, h
- Increase diameter



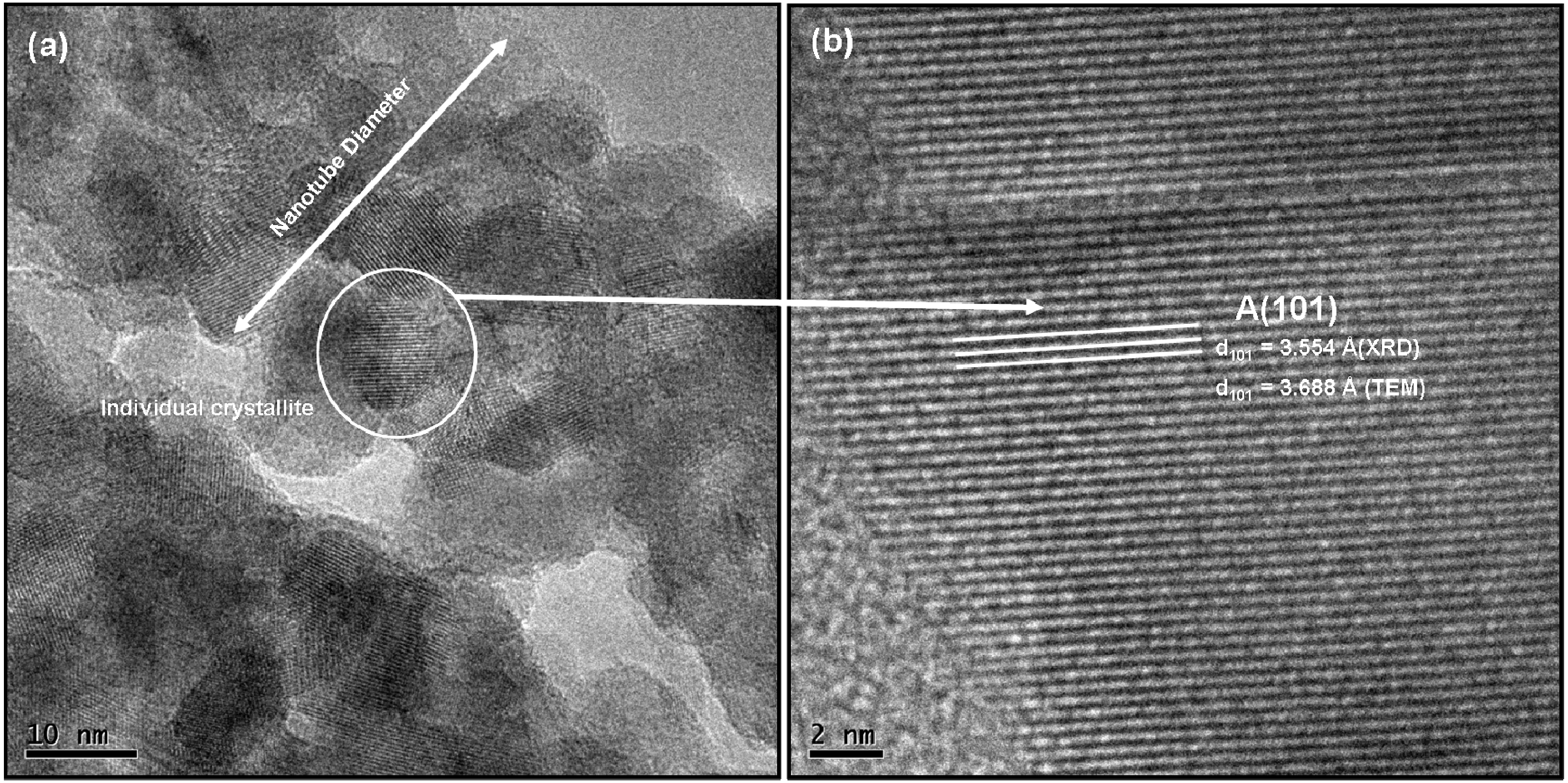
TiO$_2$ Nanotubes Synthesis and Characterisation





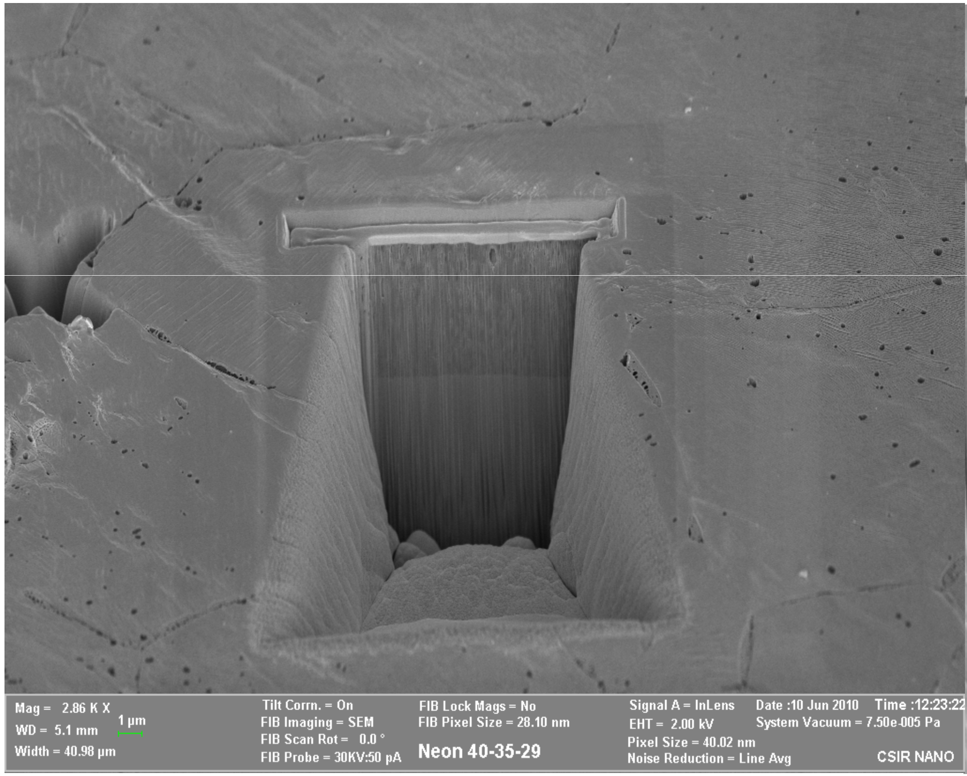


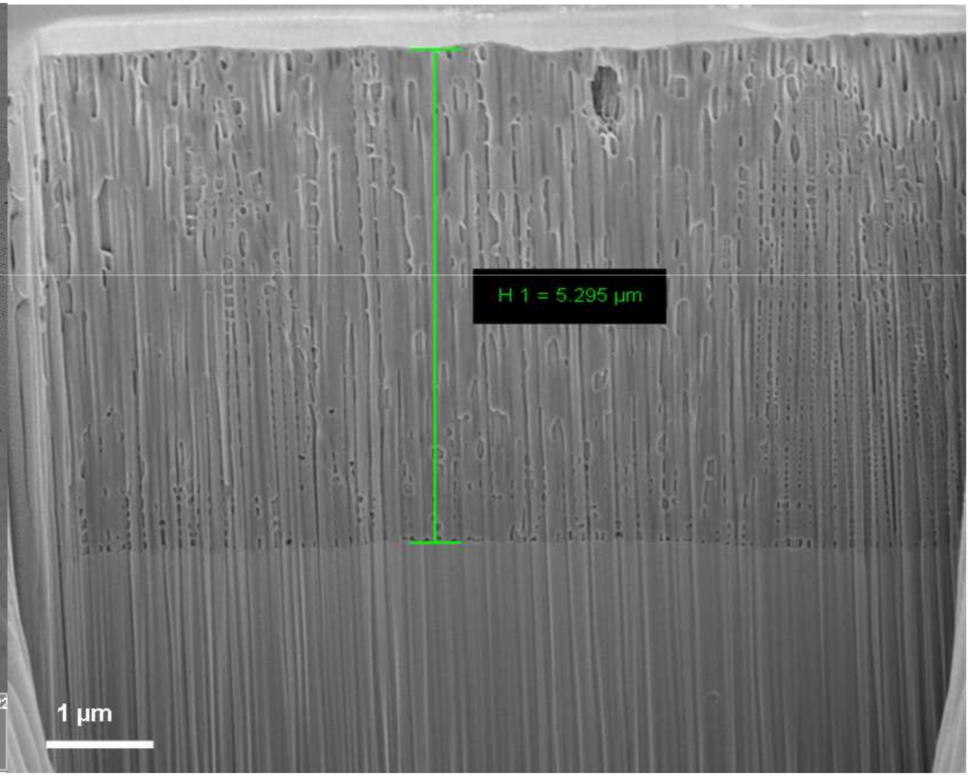
TiO_2 Nanotubes Synthesis and Characterisation



TiO_2 Nanotubes Synthesis and Characterisation

Part B: Improvement in nanotube morphology





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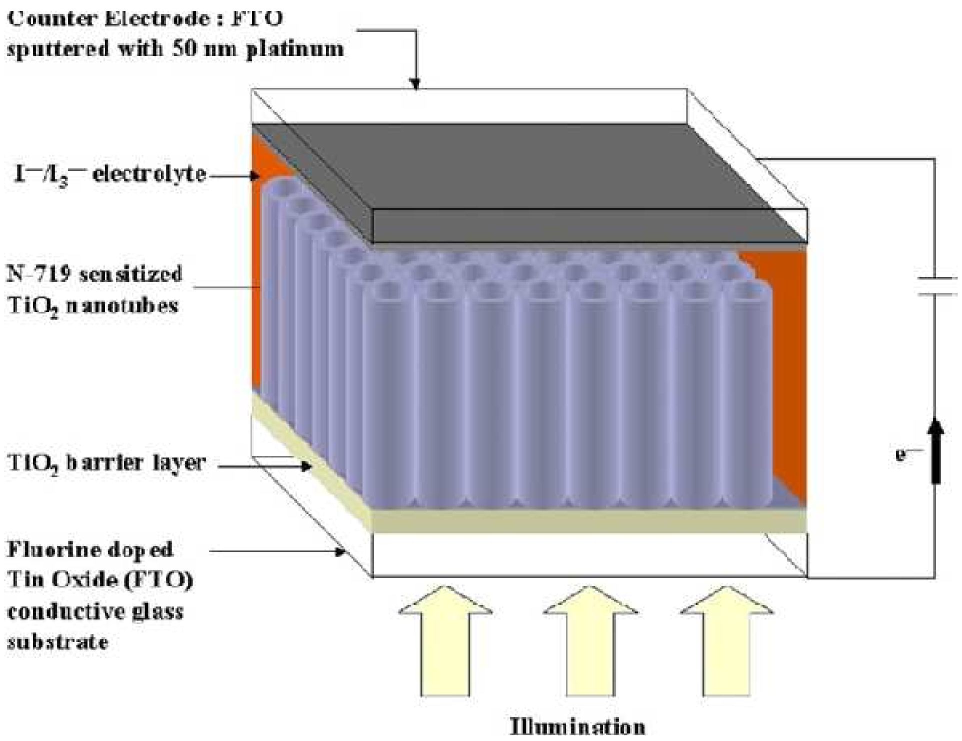
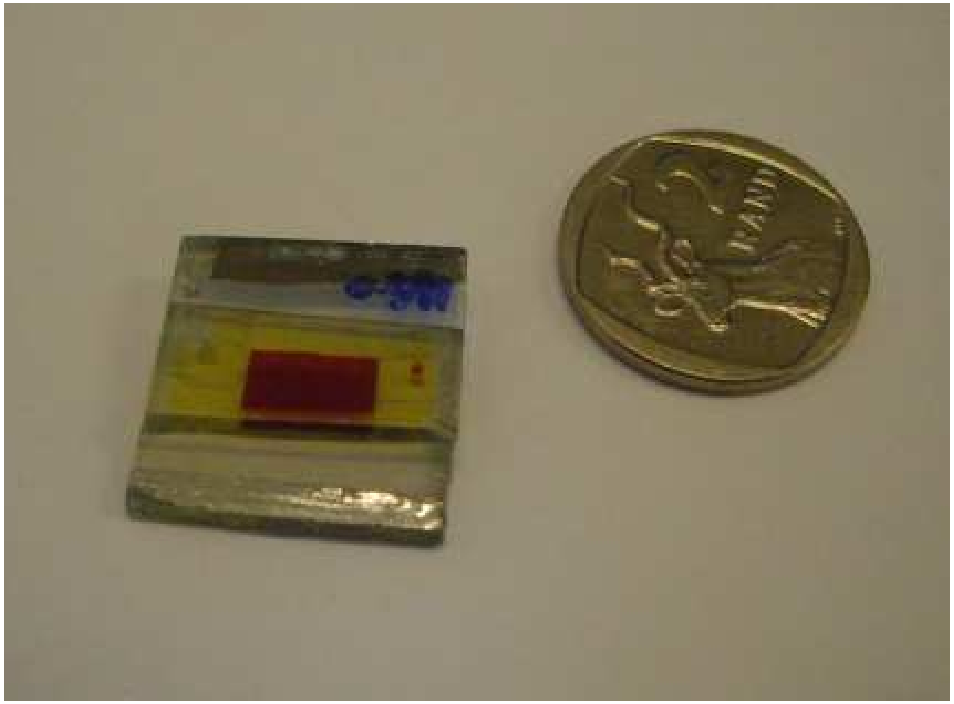
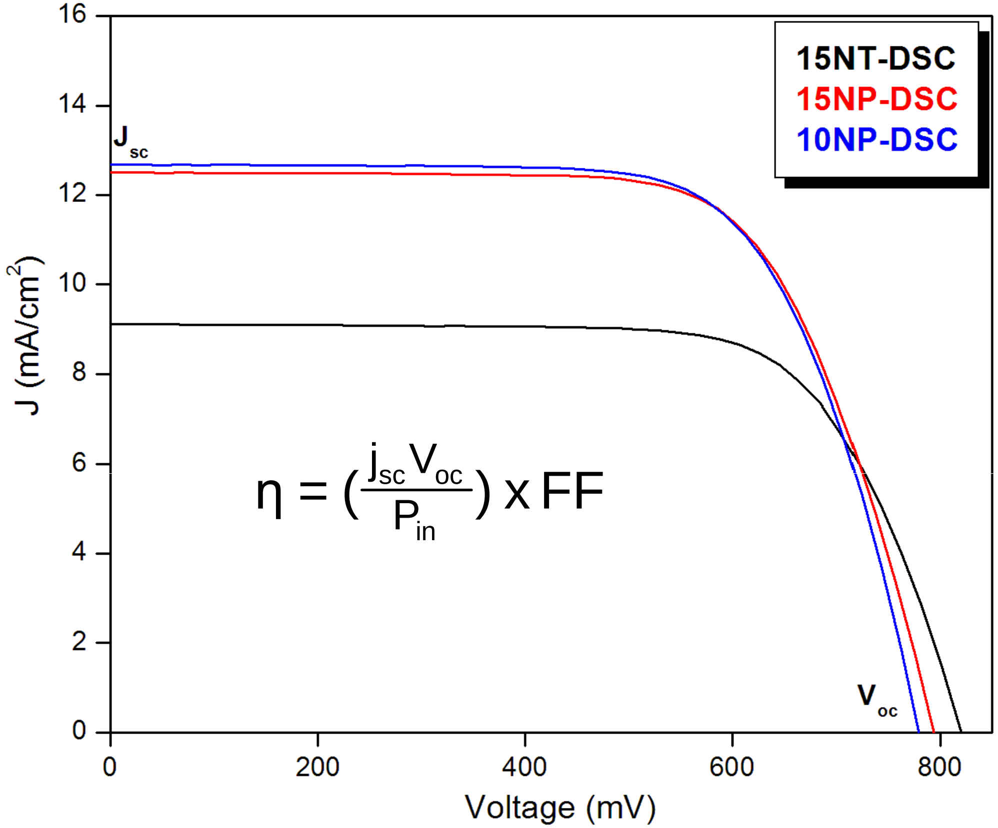
Manufacturing of Dye-sensitised Solar Cells with TiO_2 Nanotubes





Device Performance



$$\eta = \left(\frac{j_{sc} V_{oc}}{P_{in}}\right) \times FF$$

Idealistic Diode Equation - 1 Diode Model

$$j = j_{sat}\left(\exp\frac{e_0 V}{kT} - 1\right) + j_{sc}$$

where

j_{sat} = diode saturation current density

Real-life solar cells - 1 Diode model modified

$$j = j_{sat}\left(\exp\frac{e_0 V - e_0 R_s j}{m_D kT} - 1\right) + j_{sc} + \frac{V - R_s j}{R_{sh}}$$

where

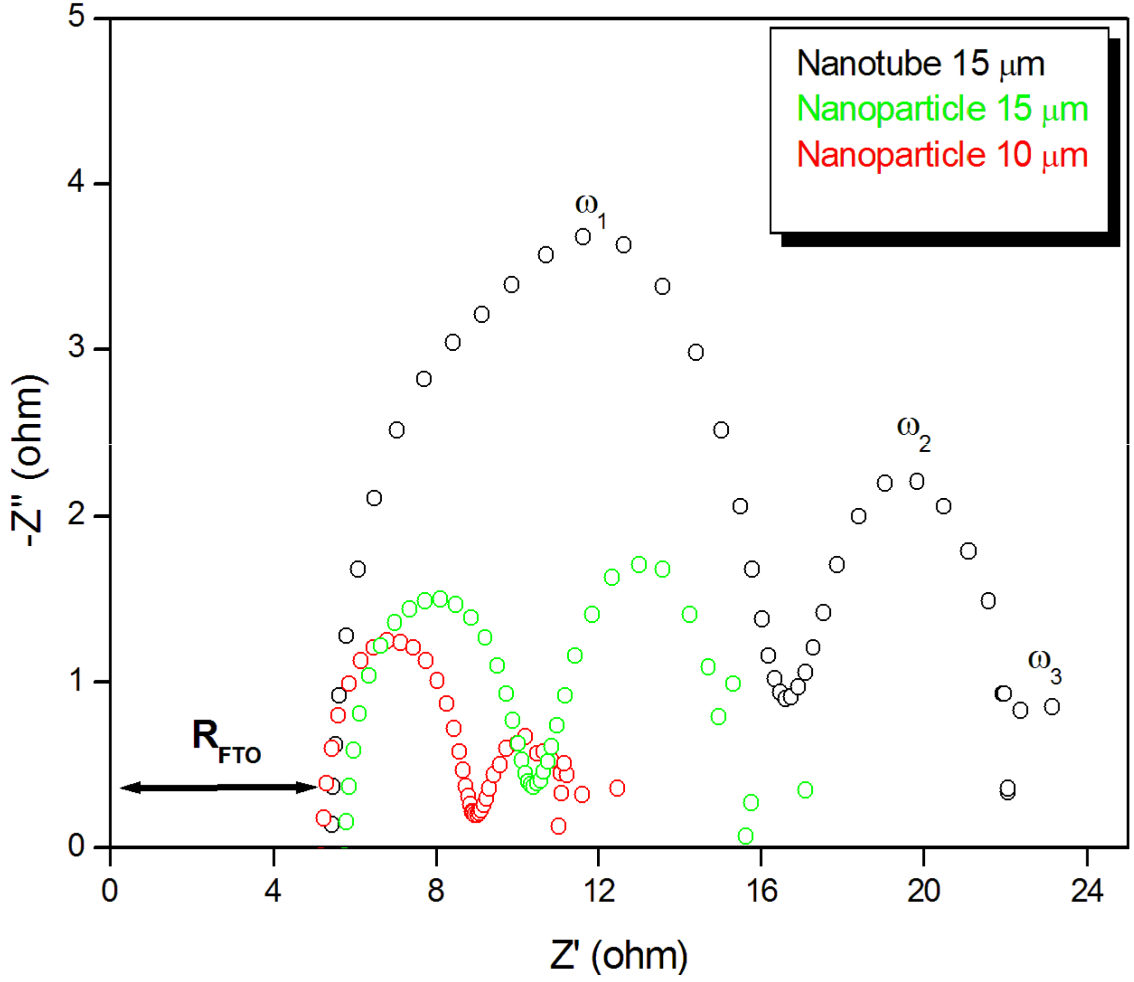
R_s = series resistance

R_{sh} = shunt resistance

m_D = ideality factor

Cells	V_{oc} (mV)	J_{sc} (mA/cm^2)	FF (%)	R_{series} (Ω)	R_{shunt} (kΩ)	eff (%)
15NT-DSC	820.05	9.11	66.90	30.25	9.97	5.01
10NP-DSC	793.43	12.51	69.32	26.65	7.64	6.88
15NP-DSC	779.01	12.68	70.46	20.95	6.30	6.94

Device Performance



- EIS – 3 semicircular arcs noticed
- Of interest middle arc, ω_2 associated with the recombination and charge transfer at the TiO_2/dye/electrolyte interface
- Shift in ω_2 towards lower frequency range
- Indicates retardation in recombination rate of electrons with holes at interface

Conclusions

- TiO_2 nanotubes synthesised via anodisation and tested in DSCs
- Morphology of the nanotubes – showed ability to synthesise nanotubes with lengths in excess of 10 µm
- DSCs employing TiO_2 nanotubes showed lower photocurrent values due to poor dye absorption compared to TiO_2 nanoparticle film
- However, an increase in open-circuit voltage was observed, which indicates an decrease in the recombination of charge carriers within the cell
- Confirmed with EIS
- Future work – treatment of TiO_2 nanotube film with $TiCl_4$ for improved dye absorption
- – further synthesis of TiO_2 nanotube films with improved morphologies
- – further device characterisation

References

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Thank You

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