

Optical Properties of Aligned Zinc Oxide Nanorods

For use in Extremely Thin Absorber Solar Cells

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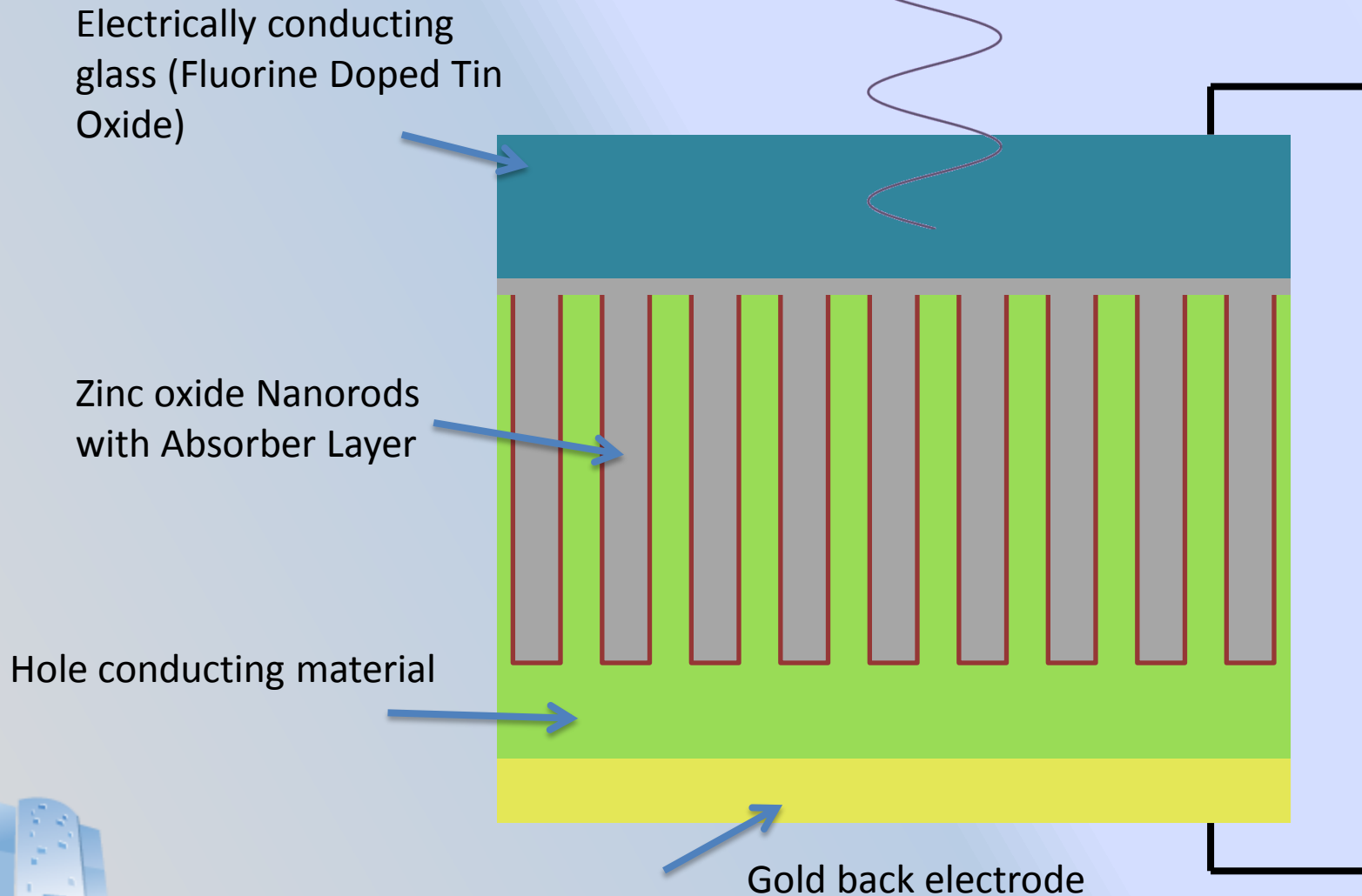
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Project Aims

- To be able to grow zinc oxide nanorods with controllable dimensions
- To characterise the electrical and optical properties of zinc oxide nanorods
- To computationally model nanorods in order to predict optical and electronic properties
- To find a way to improve efficiency in extremely thin absorber solar cells

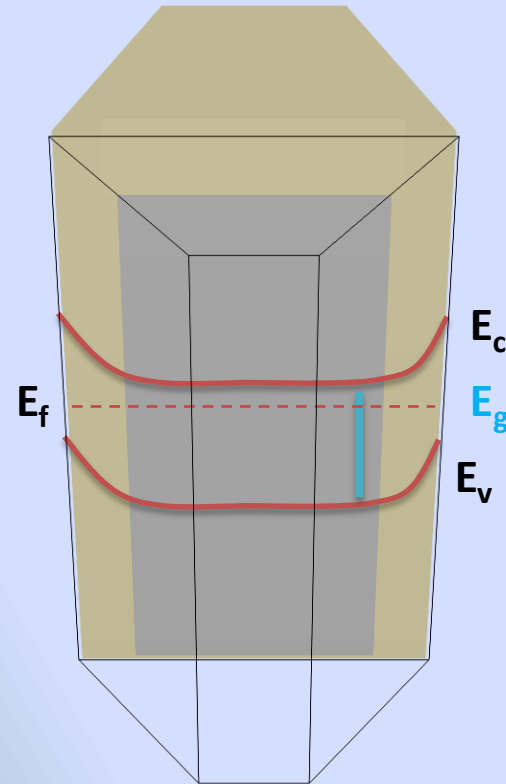


Extremely Thin Absorber Solar Cell



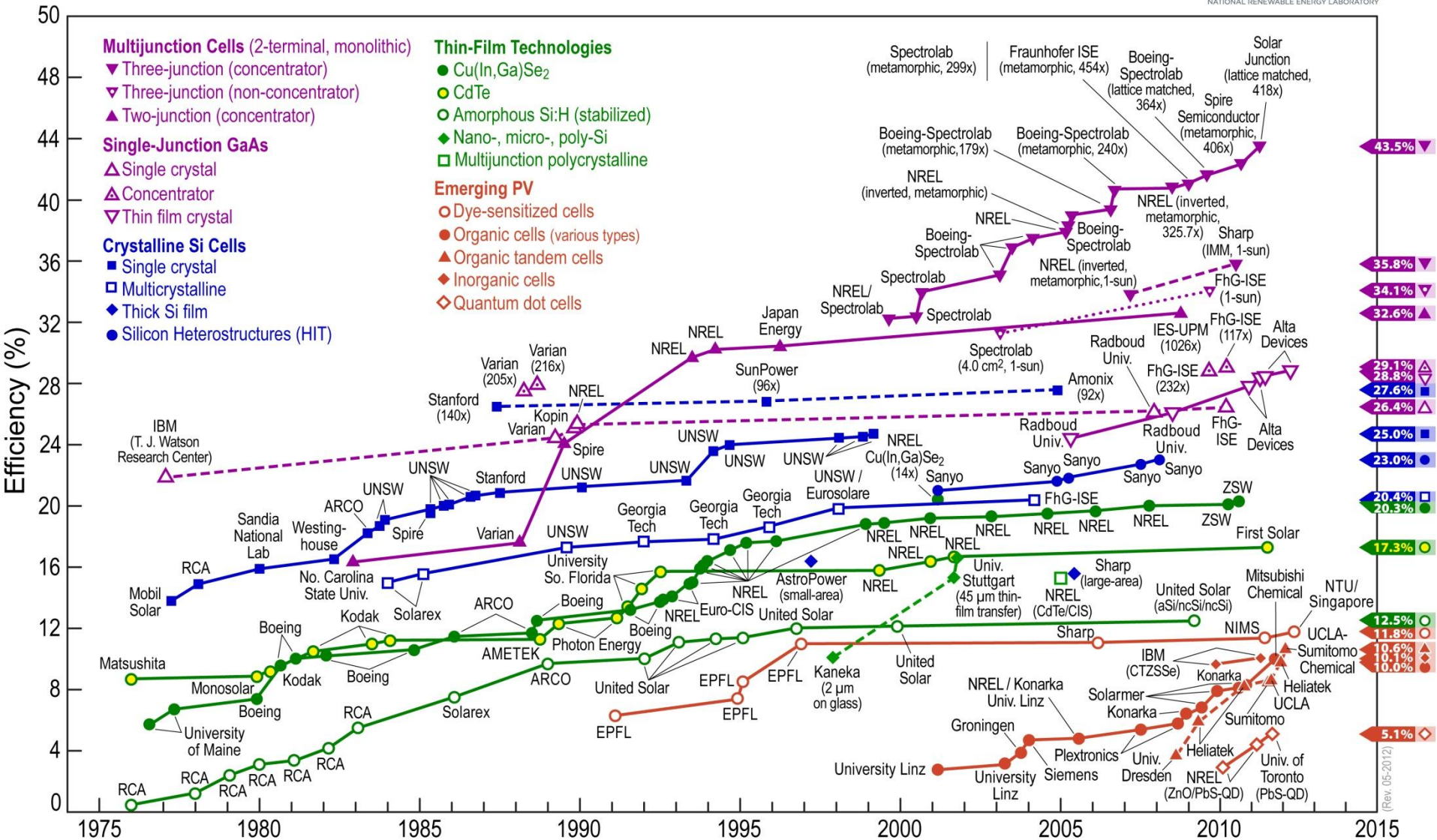
Electrical Properties of ZnO

- ZnO nanorods are n-type semiconductors due to oxygen vacancies
- At interfaces they can create a space charge layer
- A space charge layer will separate electrons and holes



Solar Cell Efficiencies

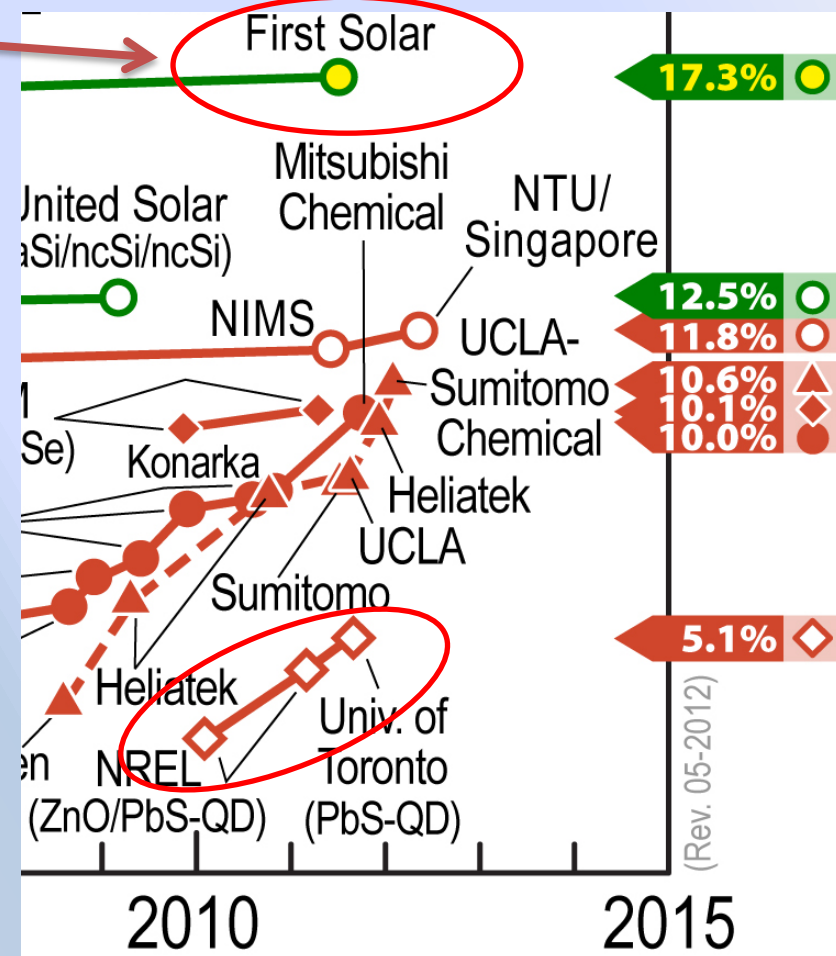
Best Research-Cell Efficiencies



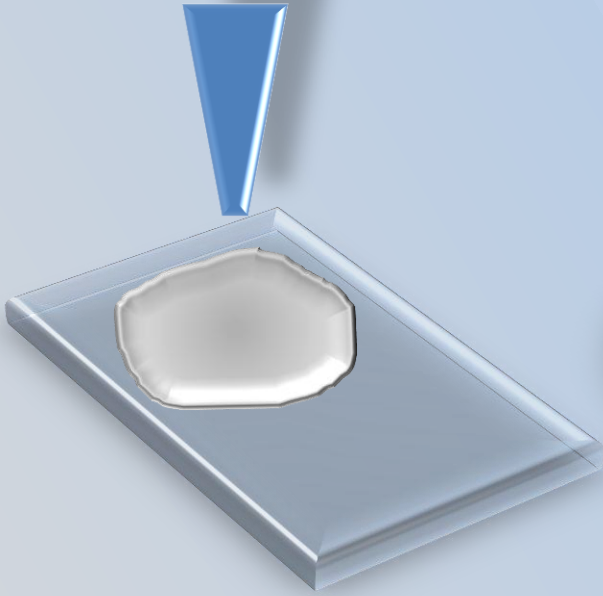
A More Efficient ETA Cell

- CdTe cells now have reasonably high efficiency
- CdTe is expensive and scarce, whereas zinc is cheap
- An ETA cell can reduce the amount of CdTe/CdSe required
- ETA cells only showing 5.1% efficiency
- Control over cell geometry → control over electrical & optical properties → more efficient cell

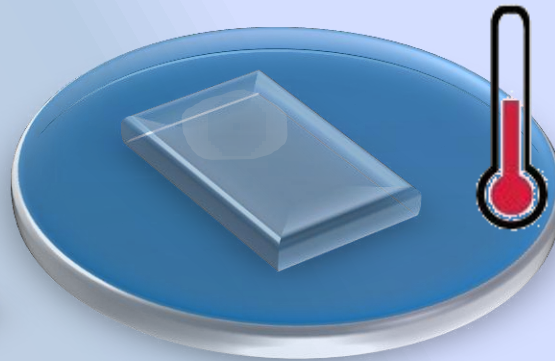
Efficiency vs. time – for major types of photovoltaic cell



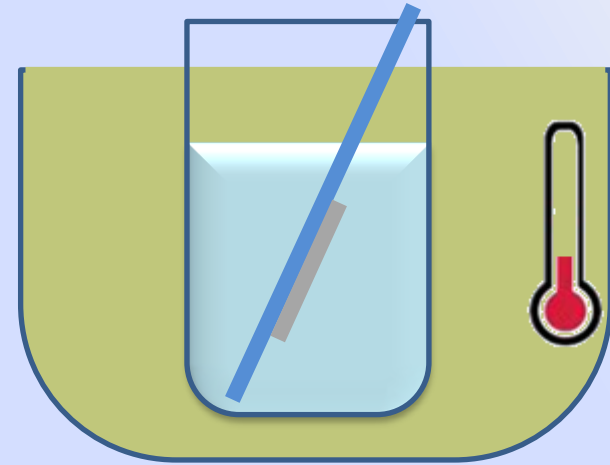
ZnO Nanorod Growth



Drop (5 mM) Zinc Acetate in Ethanol onto FTO, leave for 10 s, wash with ethanol, dry with argon – $\times 5$



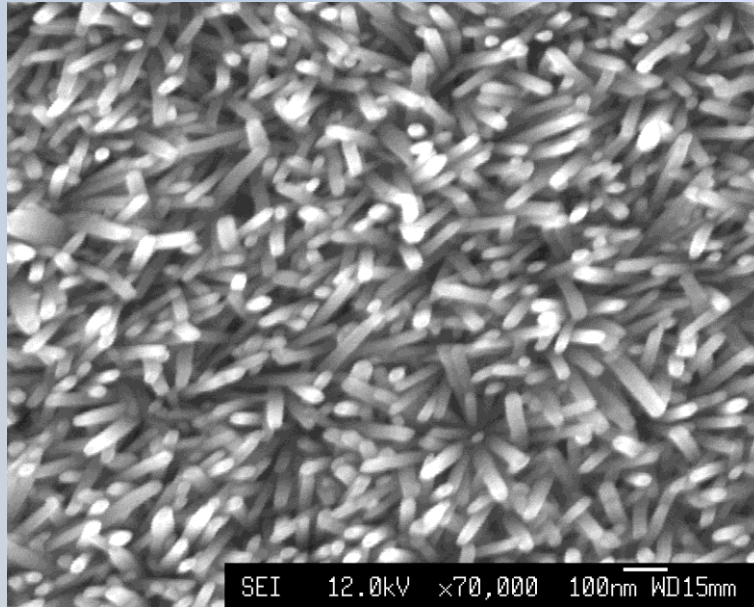
Heat on hot plate at 350 °C for 20 minutes



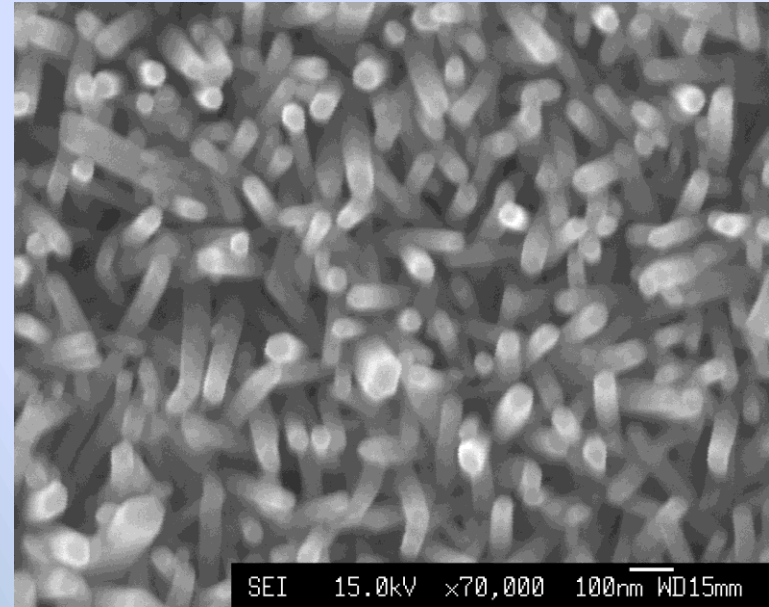
Sample selotaped onto a glass slide, placed into zinc nitrate solution (in an oil bath) at 90 °C for between 1 and 4 hours

$\times 2$

ZnO Nanorods Grown on FTO



2hr Growth



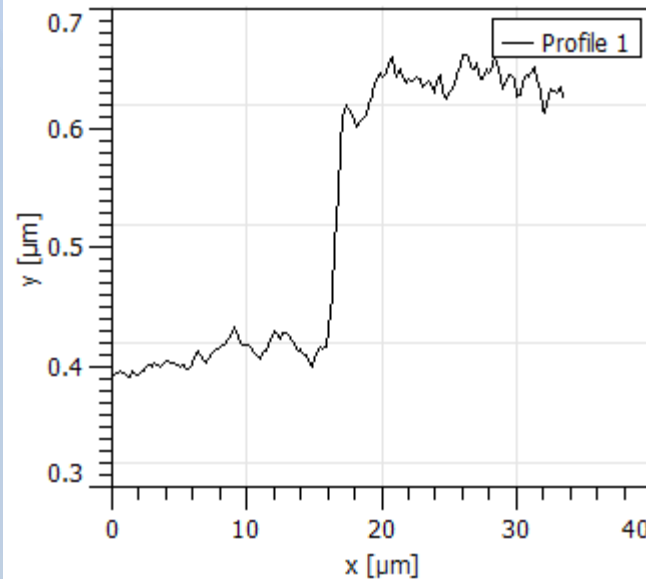
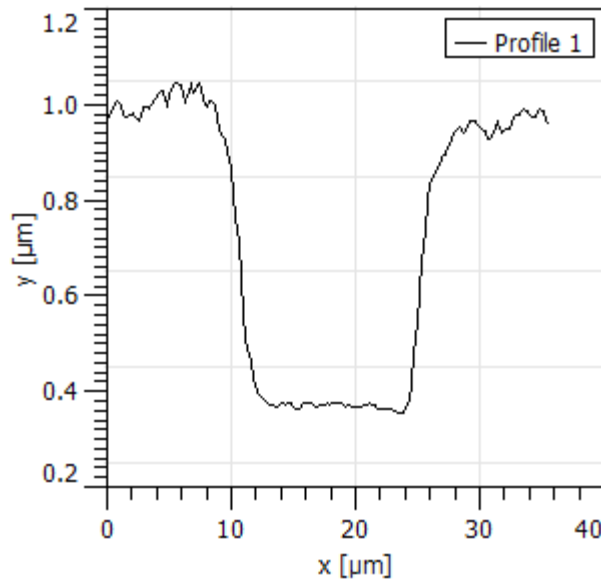
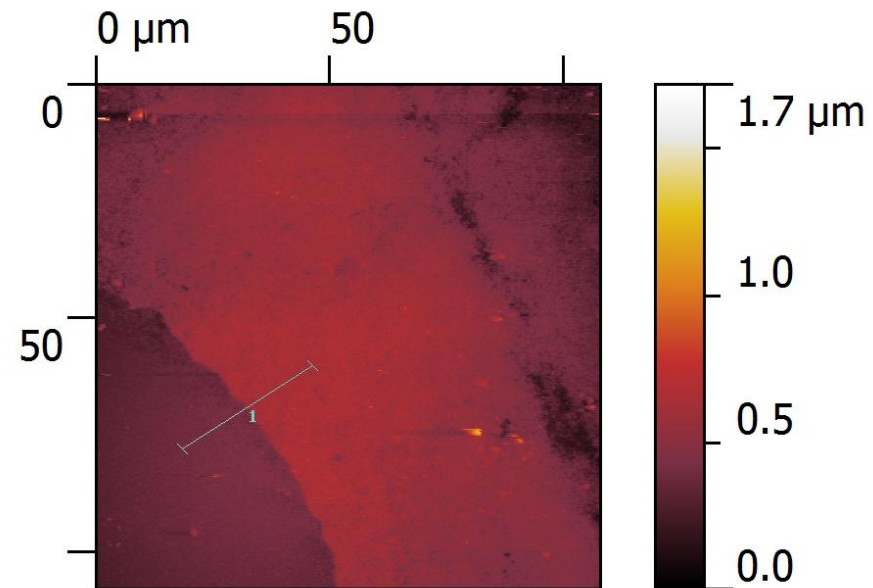
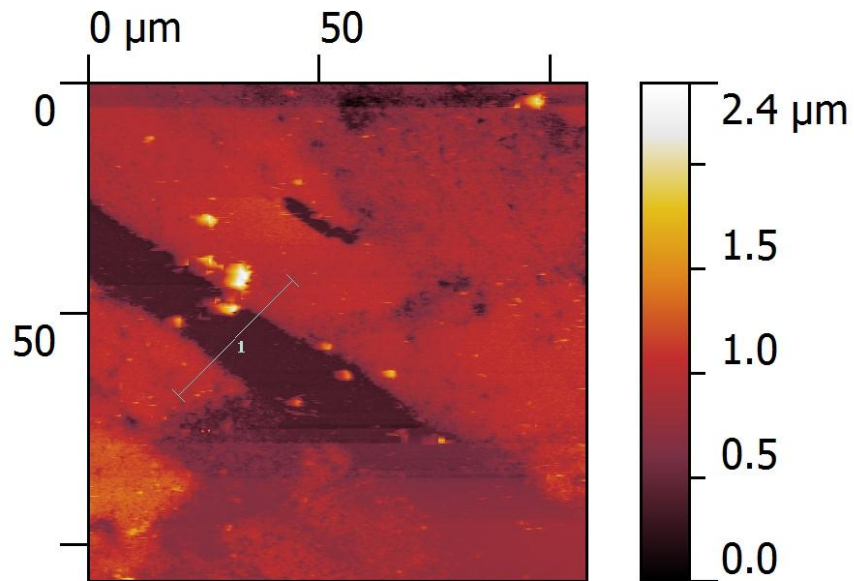
4hr Growth

- Rods are not well aligned
- Longer growth times appear to show charging effects.: lower conductivity

Layer Thickness

4hr - ~600 nm

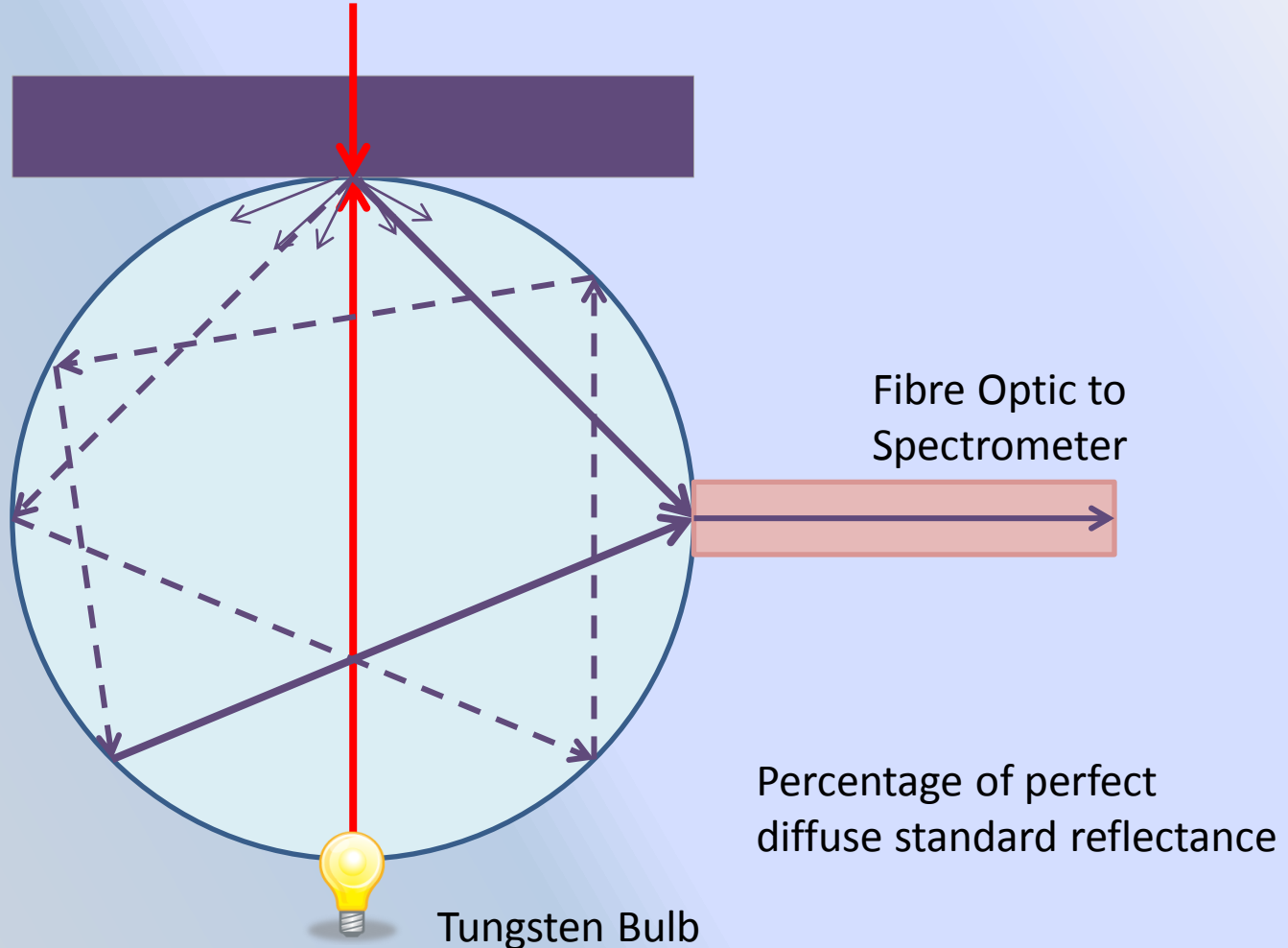
2hr - ~250 nm



% Absorptance Measurement

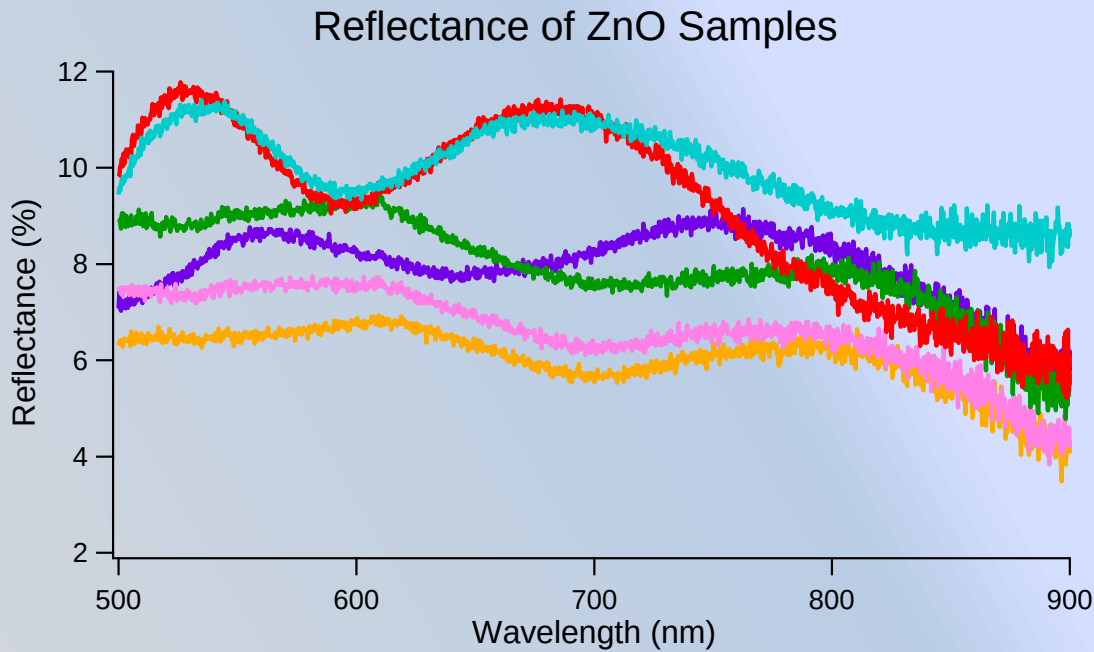
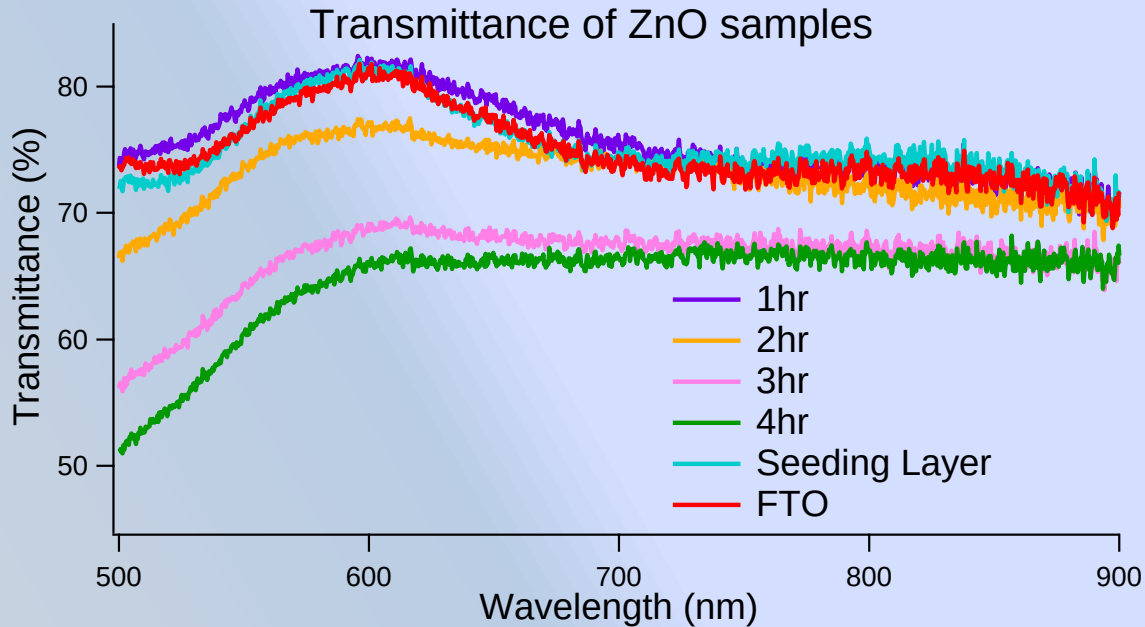
Sample

Integrating Sphere –
Mirrored sphere with inlet
from sample and outlet to
spectrometer

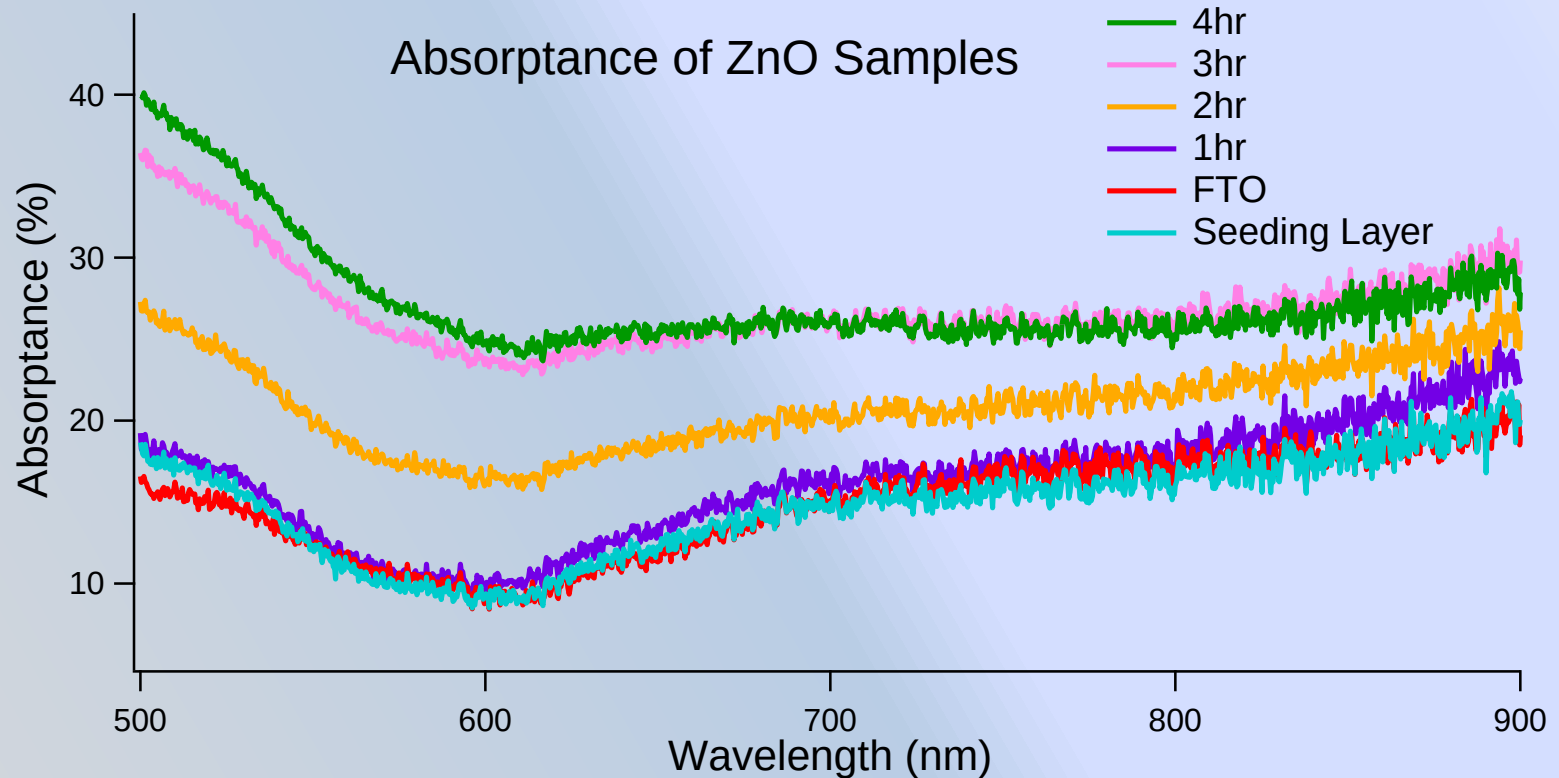


$$\% \text{ Absorptance} = 100\% - \% \text{ Transmittance} - \% \text{ Reflectance}$$

Transmittance and Reflectance



Absorptance Results



Sub Band-Gap Absorption

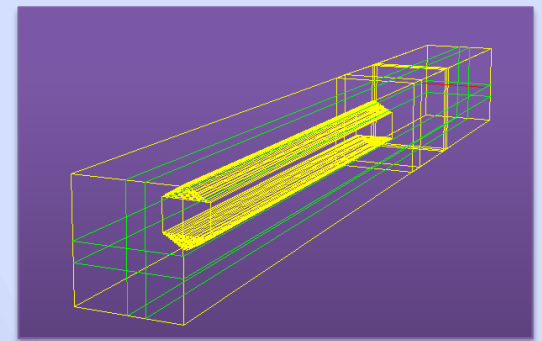
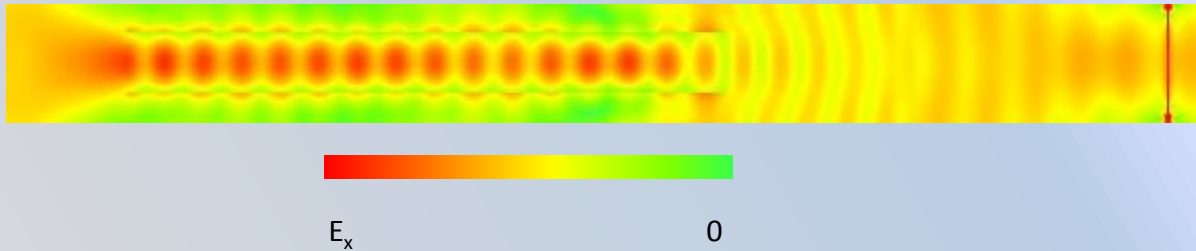
- ZnO nanorod band-gaps have been measured to be 3.2 eV (387 nm)¹
- Light is being absorbed well above this wavelength
- Detrimental effect on solar cell devices
- Likely cause is defect energy levels
- Correlation between defects and growth rate²
- Characterisation of defects may be necessary

1: Brunzli, C. Photoelectrochemical Properties of Nanostructured ZnO Electrodes, University of Bristol, 2011.

2: Akhavan, O.; Mehrabian, M.; Mirabbaszadeh, K.; Azimirad, R. *Journal of Physics D: Applied Physics* **2009**, 42, 225305.

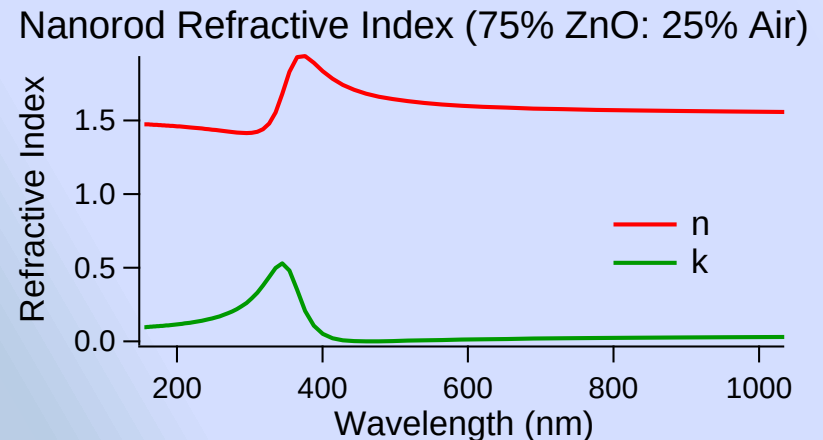
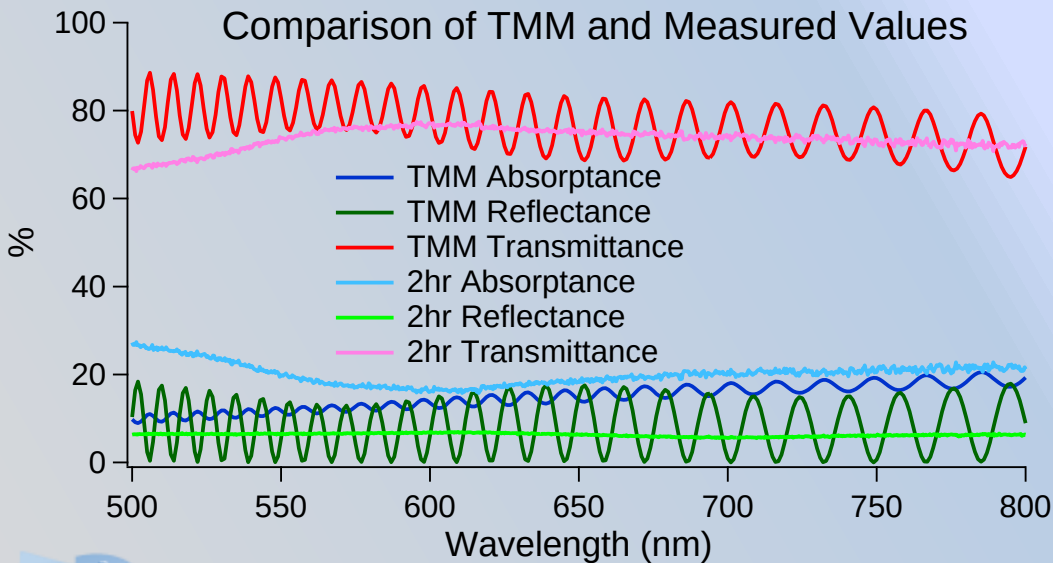
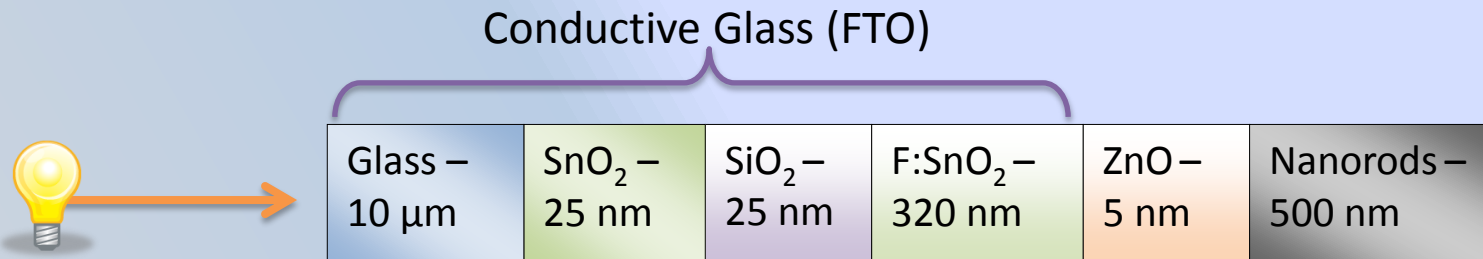
Optical Modelling

- Currently looking into two models
 - 1D Transfer Matrix Method – Reflectance and transmittance
 - 2D/3D Finite Difference Time Domain (FDTD) – Field intensities within structures



Transfer Matrix Method

- Matrix solution of electromagnetic boundary conditions allowing for a calculation of reflectance and transmittance coefficients



Future Work

- Fine tune parameters of ZnO nanorod growth to improve alignment and dimensional control
- Accurate measurement nanorod layer depths using cross section SEM or FIB
- SEM imaging suggests differing conductivity – Characterisation with conductive AFM
- Absorptance to be carried out down to UV
- Photocurrent measurements on varying dimension nanorods
- FDTD – large arrays, absorptance and modifications to allow electronic properties

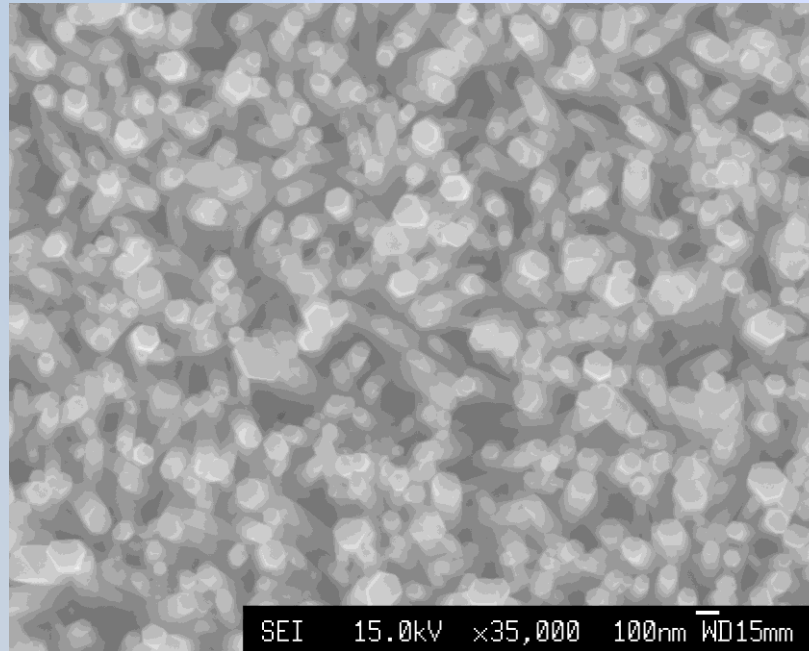


ZnO Nanorod Growth Parameters

- Hydrothermal growth is a versatile method:
 - Seeding layer thickness↑ - Diameter↑, Density↑ & Length↓
 - Seeding Layer Grain Size↑ - Diameter↑
 - Substrate Temperature (25-120°C)↑ - Alignment↑
 - Post Anneal Temperature (100-350°C)↑ - Alignment↑
 - Precursor concentration↑ - Diameter↑, Length↑, Density↑
 - Growth Time↑ - Diameter↑, Length↑
 - Initial PH↑ - Diameter↑, Growth Rate↑, Optical Band Gap↓
 - Polyethyleneimine Concentration↑ - Diameter↓, Length↓

Controlling Alignment

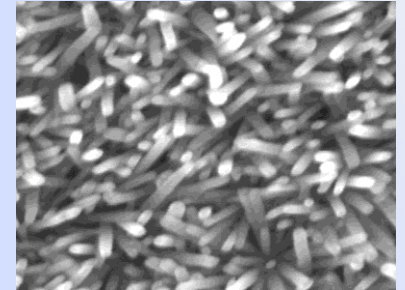
- Preheating the glass before zinc acetate deposition creates better alignment



- Further refinement planned to measure optical properties as a function of alignment

Summary

- Growth of zinc oxide nanorods
- Visible absorptance characterisation
- Transfer Matrix Method simulations
- Further work planned with many avenues of research available



Thank You

- Supervisors: Prof. Dave Cherns, Dr. David Fermin and Dr. Martin Cryan
- The Bristol Electrochemistry Group
- The Bristol Centre for Functional Nanomaterials
- Thank you all for listening

