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Nanowire Solar Cells

Andrew Foster
dtp09apf@sheffield.ac.uk

Supervisor: Dr L. Wilson

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Overview

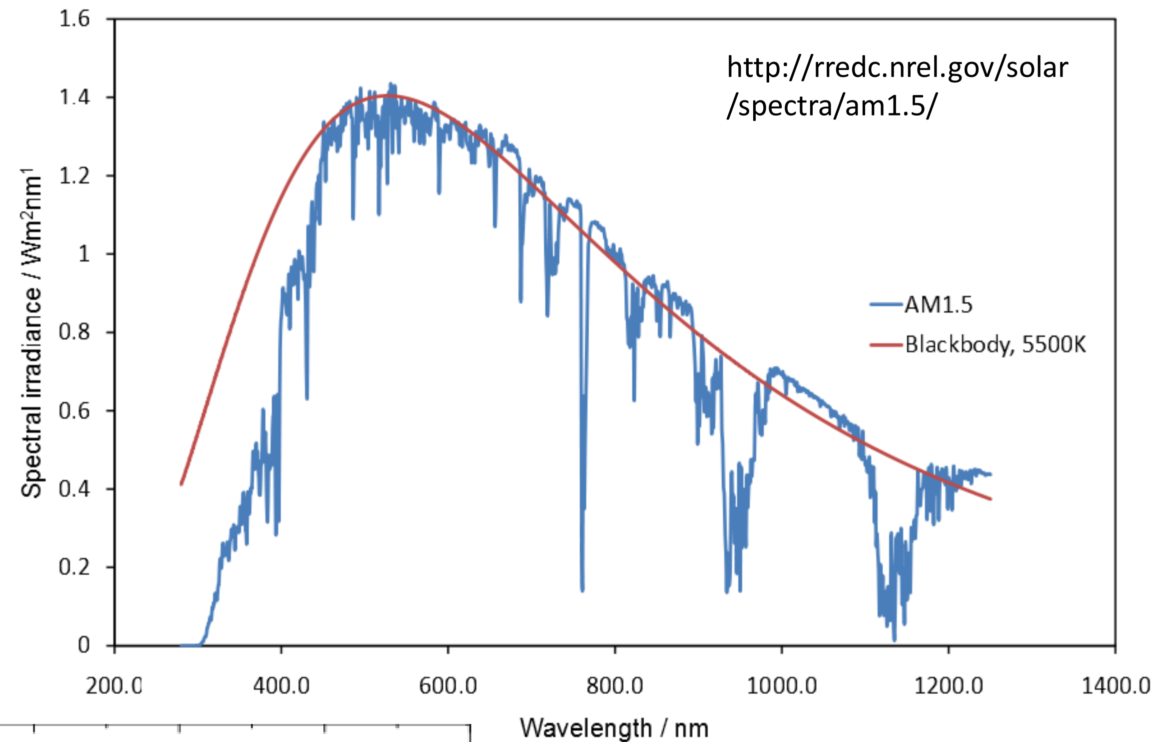
- Background for nanowires, tandem solar cells and their efficiency
- Why we might want to make PV devices from nanowires
- Development of models for tandem nanowire solar cells
- Further development of models and possible experimental work

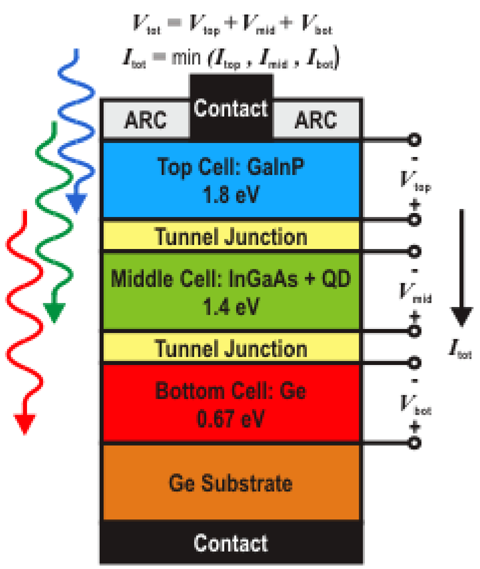
Nanowires - background

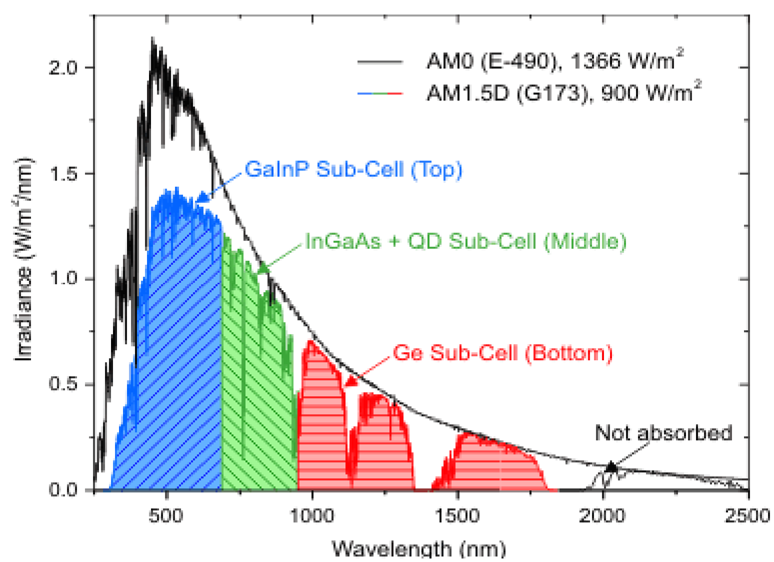
- A nanowire has two dimensions which are small enough that quantum confinement effects are observed, altering the bulk material properties.
- Growth of III-V semiconductor alloys on one another requires lattice constant and thermal expansion coefficient matching.
- If an alloy is not lattice matched to the substrate, during growth dislocations are produced to relieve strain build-up – can be overcome by growing very thin layers, or used to form e.g. quantum dots.
- Nanowires may be grown using the same principle and have been shown to accommodate greater strain than planar structures [1]

Theory – tandem cells and the solar spectrum

Solar incidence at ground level usually described by AM1.5 spectrum – can be approximately modelled as a blackbody at 5500K







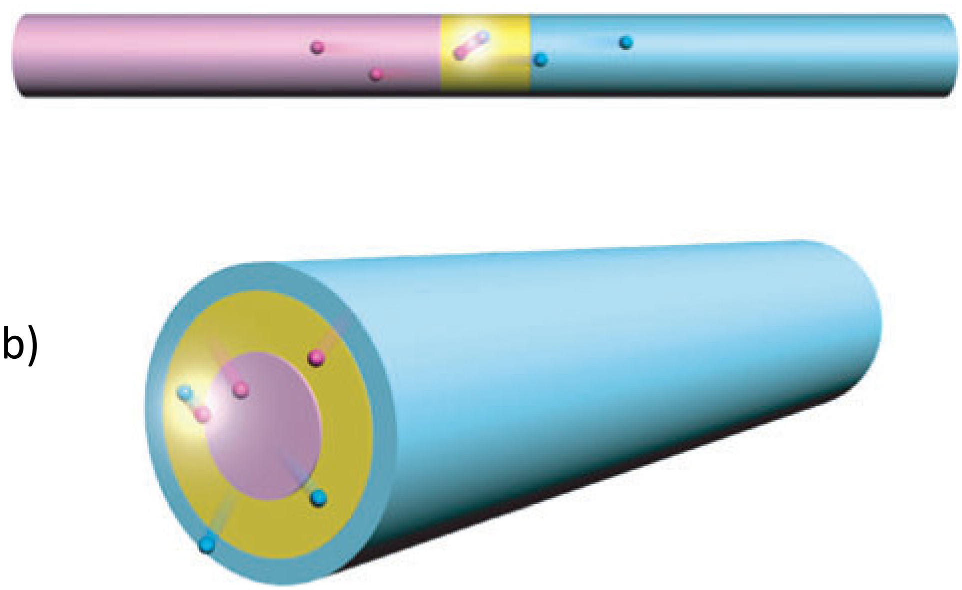
Example of current tandem cell technology: InGaP/GaInAs/Ge - Used in space or concentrator systems due to high material cost.

SUNLab: sunlab.site.uottawa.ca/research/Content/MjCellSpectra.gif

Nanowires – PV

Nanowires can be grown on silicon substrates to produce tandem cells, taking advantage of the expertise in producing high purity silicon within industry, combined with greater efficiency than planar silicon devices

a)
b)



Idealised a) axial p-i-n junction and b) radial p-i-n junction nanowires. The latter allows orthogonal separation of light absorption and carrier extraction pathways.

Figures: Tian, B et al. (2009) ‘Single nanowire photovoltaics’ ChemSocRev 38(1) pp. 16-24

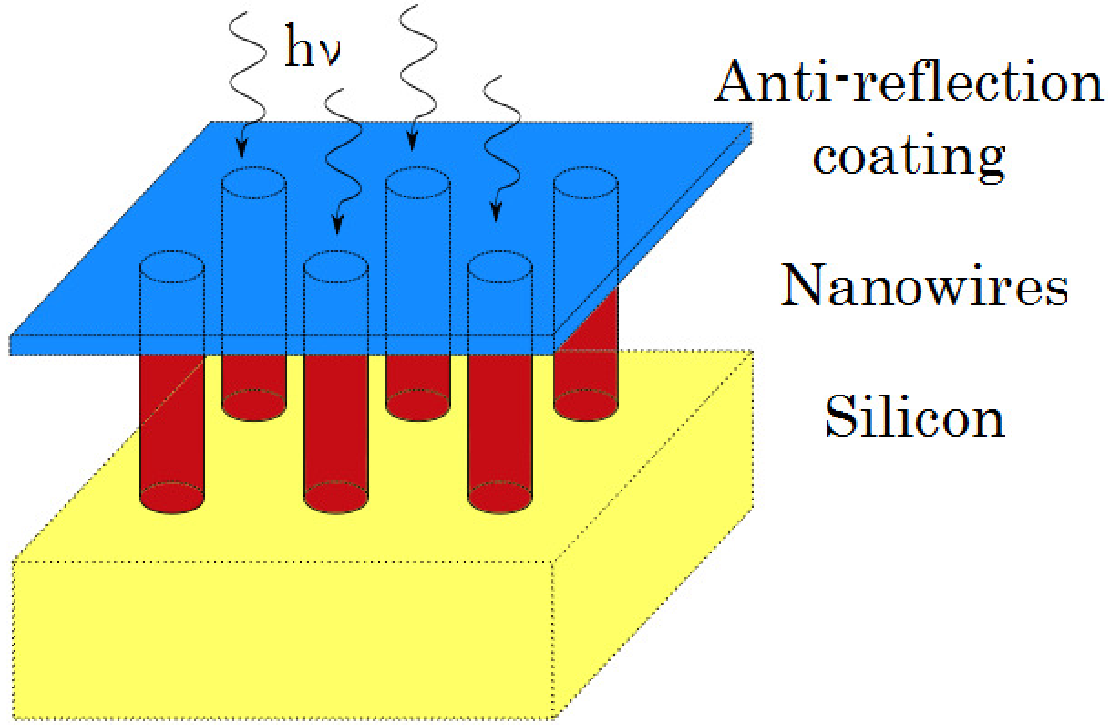
Models

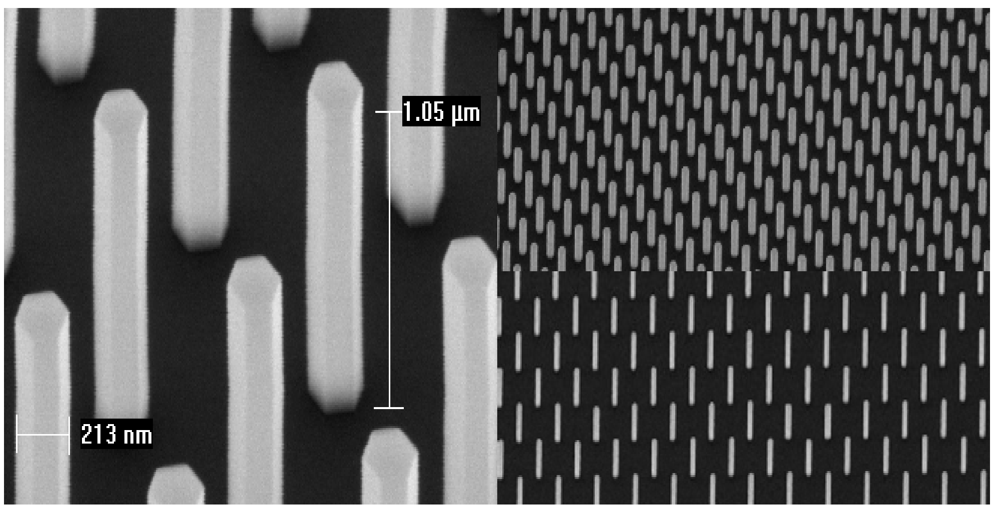
- Efficiency determined for three models:
  - absolute limit
  - limit with reflection
  - limit with an anti-reflection coating
- Assumed normal incidence, as (approximately) observed in concentrator systems
- First approximation used for effective medium of region containing nanowires in air:

$$n_{eff} = fn_{wire} + (1 - f)n_{air}$$

where f is the packing fraction of nanowires and the refractive indexes n_{eff} and n_{wire} are complex, $n_{air}=1$

Model of nanowire tandem cell with anti-reflection coating used in this work (not to scale). AR coating is of the order 50-100nm deep

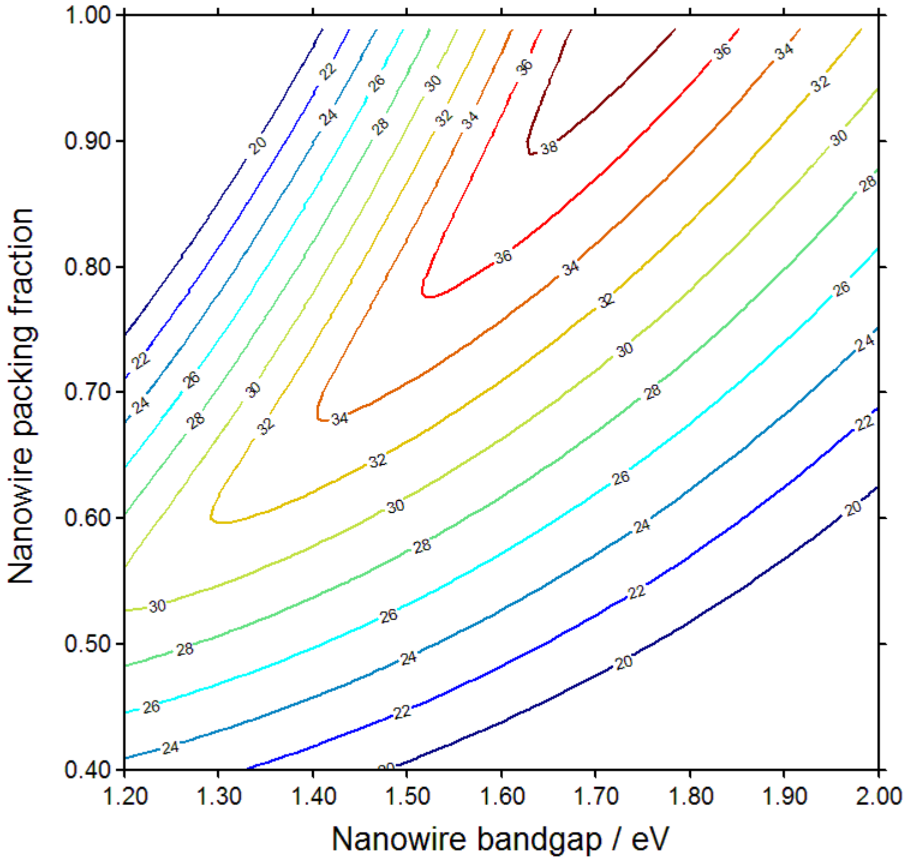




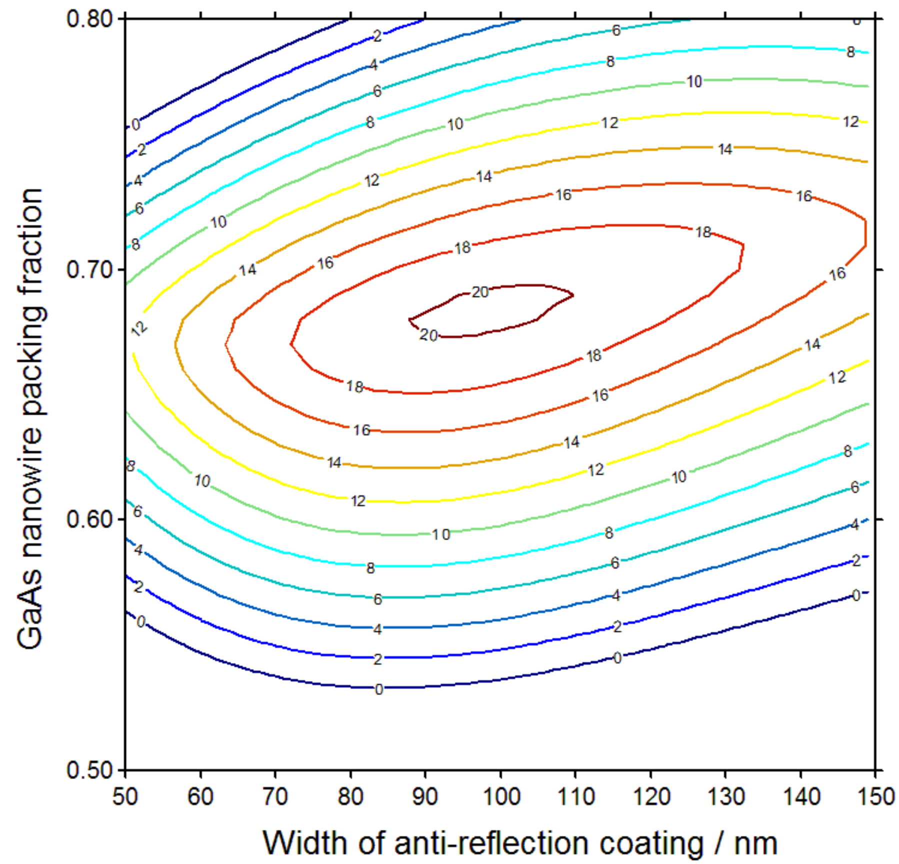
Hexagonal cross-section nanowires as produced in Sheffield, viewed via SEM.

Results

Ultimate efficiency in detailed balance limit



Relative improvement in efficiency over silicon cell for GaAs nanowires with ideal single AR coat



Conclusions from the models

- InP-Si cell shows modest efficiency limit improvement over planar silicon, with GaAs-Si slightly better again
- Ideal material for nanowires would have a bandgap of around 1.55eV – possibly $In_xGa_{(1-x)}P$
- Choice of anti-reflection coating is more involved than for planar silicon, and will depend critically on the effective refractive index of the nanowire array, if this is indeed valid

Analysis – model improvements

- The effective cross-section of the nanowires was assumed to be the physical cross-section, whereas in reality it may differ due to the sub-wavelength diameter of the nanowires.

- A crude 'effective medium' approach was used to model the effect of air within the nanowire layer – this is not strictly correct and even an approach such as Maxwell-Garnett is inaccurate [2]

- The above could potentially be overcome using computational modelling such as the Finite Difference Time Domain method.

Summary

- Greater range of possible material combinations
- Fewer electrons/holes lost before reaching external circuit
- Potential intrinsic anti-reflection properties

References

1. Ertekin, E et al. (2005) ‘Equilibrium limits of coherency in strained nanowire heterostructures’ J.App.Phys 97(11) pp.1-10
2. Rahachou, A.I and Zozoulenko, I.V (2007) ‘Light propagation in nanowire arrays’ Journal of Optics A: Pure and Applied Optics 9 pp.265-270