UNIVERSITY OF TECHNOLOGY SYDNEY

Optical Properties of Materials

Angus Gentle

UNSW 10/5/2018

Overview of Talk

- About Me
- Some of our Research at UTS
- Optical Characterisation Facilities at UTS

Most of the topics covered are in collaboration with Geoff Smith, Matt Arnold, Michael Cortie and various students

My Background

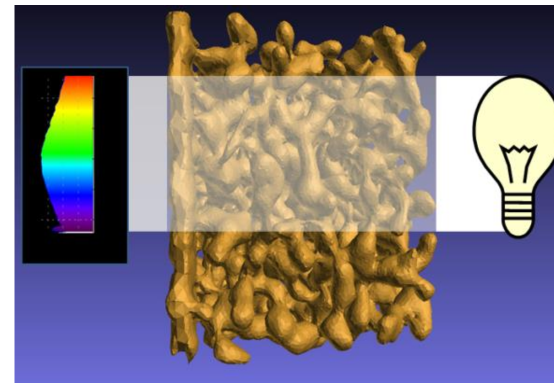
- Applied Physics / Electrical Eng UTS (1998-2004)
- 2000 Started working at UTS as internship (continued part time during undergraduate/honours)
- Physics Honours (2003) + PhD UTS (2005- 2008)
- 1yr Postdoc UNSW (3rdgen PV Group – Si QD solar cells) (2008/9)
- 2.5yr Postdoc UTS (DP: Radiative Cooling) 2009-2012
- 3 Yr Postdoc UTS (Transparent Electrodes for OPV/OLED) (2012-2014)
  CSIRO funded (UQ, UTS and Flinders)
- 2 yr Postdoc UTS (DP: Angular/Spectral control) (2014-2015)
- (2016-) Lecturer UTS School of Mathematical and Physical Sciences
  (currently teach 2nd/3rd year subjects: Applied Electronics and Interfacing/Computational Physics / Measurement and Analysis of Physical Processes)

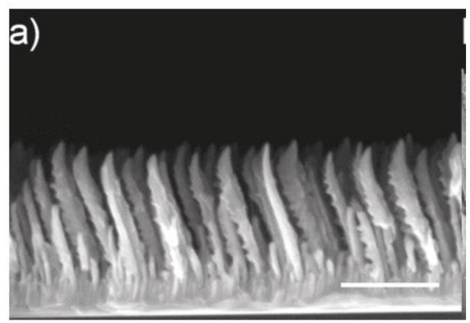
Most of our research relates to:

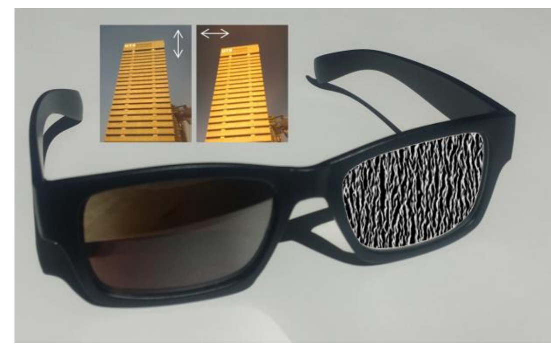
- Nanostructured films
- Spectrally Selective Coatings
- Radiative Cooling
- Paints
- Thermal Performance of Buildings/Surfaces
- Transparent Electrodes
- Optical Characterisation

Optical Properties of materials?
Does it absorb, transmit or reflect?

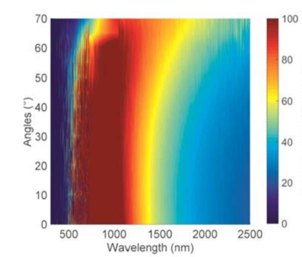
- Measurement
- Analysis
- Characterisation
- Fabrication
- Applications



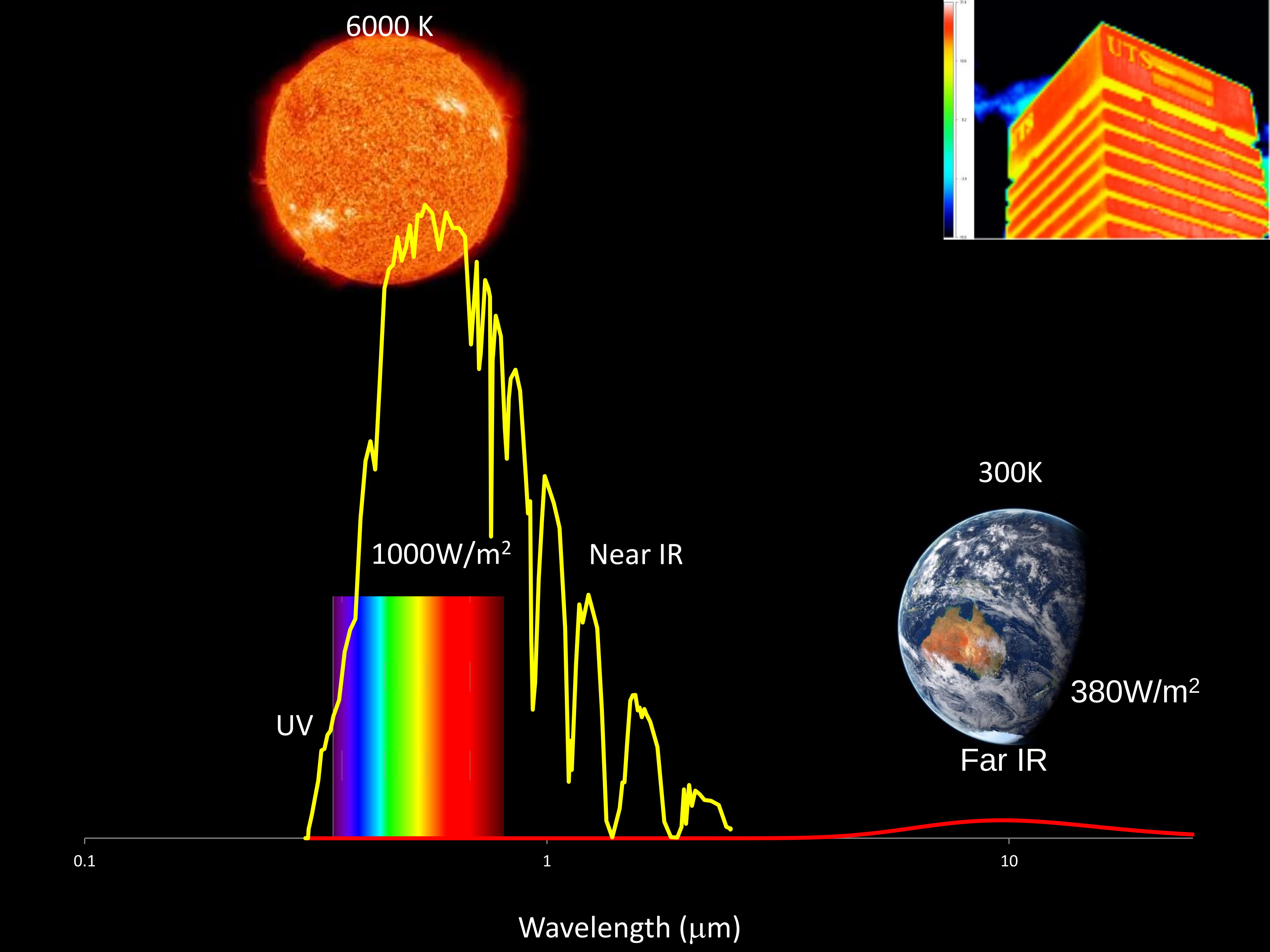




Spontaneous growth of polarizing refractory metal 'nano-fins',
M C Tai et al 2018 Nanotechnology 29 105702



modelling / deposition / characterisation at all scales:
Nano: Materials / Multilayers / plasmonics
Micro: effects of surface structures
Macro: large area applications (building simulation / monitoring / glazing testing)

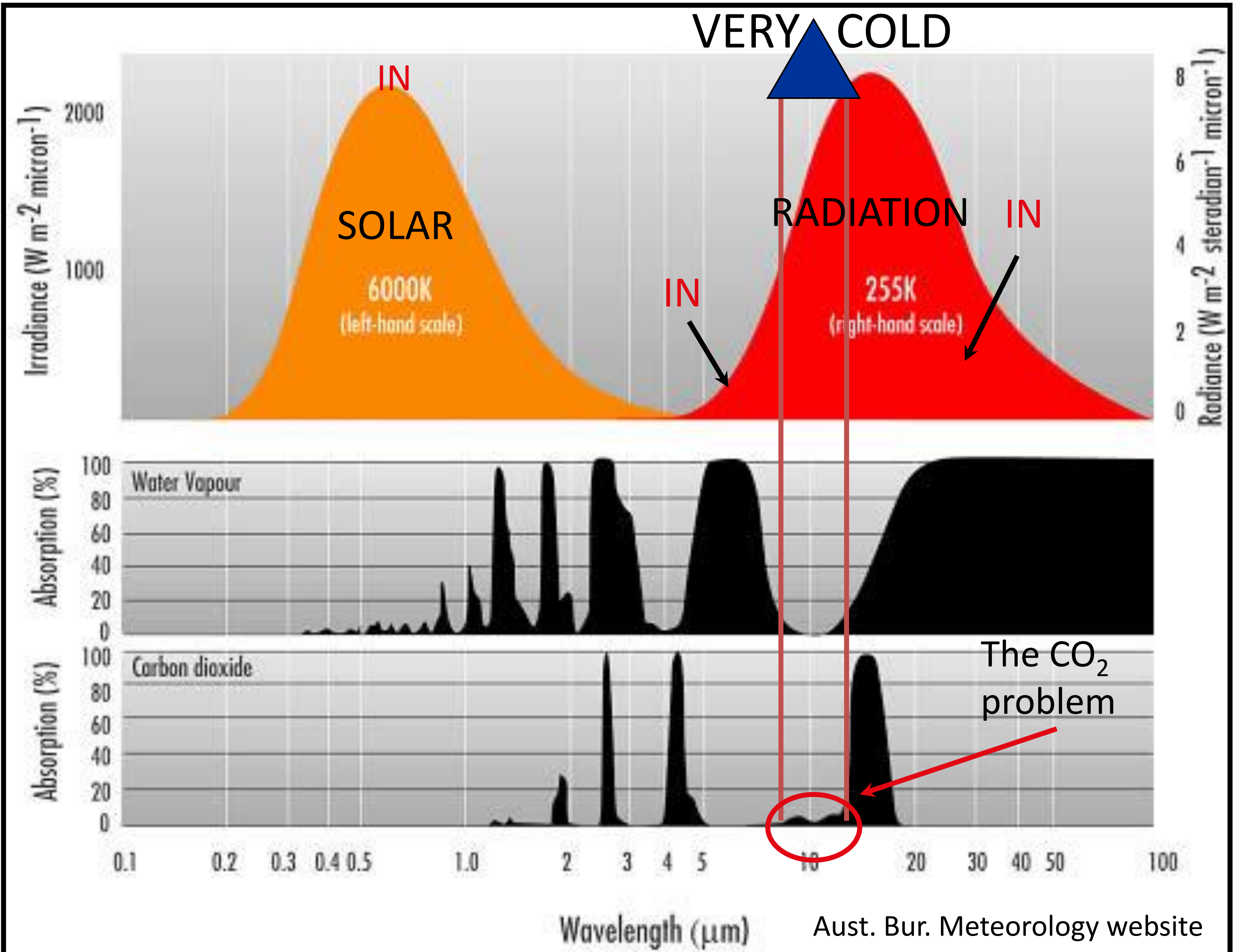

6000 K
1000W/m²
Near IR
UV
300K
380W/m²
Far IR
0.1
1
10
Wavelength (μm)

Manages radiation 3 ways:
solar in /thermal out/atmospheric in

Total Heat flows:
(solar and atmospheric)
<u>in and out</u>
24 hour averages
Infrared:
324 W/m^2 in
390 W/m^2 out

Solar:
~240W/m^2

OUT to outer space



Aust. Bur. Meteorology website

Spectrally Selective Coatings:

- Solar thermal absorber
  - Black in the solar range – “white” in the infrared
- Cool Paints
  - White in the solar range – “black” in the infrared
- Coloured Cool Paints
  - White in the NIR range – “black” in the infrared
- Sky Window Selective Emitter
  - “black” from 7-13um

High Temperature Spectrally Selective Solar Absorbers Using Plasmonic AuAl2: AlN Nanoparticle Composites, M Bilokur, A Gentle, MD Arnold, MB Cortie, GB Smith, Solar RRL 1 (10)

Extending the applicability of the four-flux radiative transfer method, MA Gali, AR Gentle, MD Arnold, GB Smith, Applied Optics 56 (31), 8699-8709

Optimized cool roofs: Integrating albedo and thermal emittance with R-value, AR Gentle, JLC Aguilar, GB Smith, Solar Energy Materials and Solar Cells 95 (12), 3207-3215

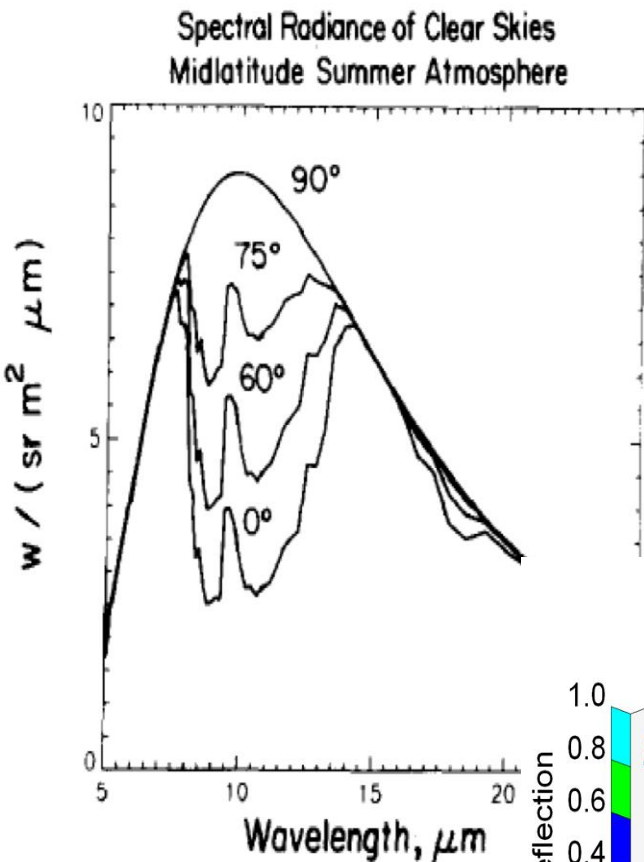
Radiative Cooling: Lumped Equations

- P: Thermal load to pumped away by the system
- Psol: Absorbed Solar irradiance (~0-1000W/m2)
- Ppc: Conduction from sample surrounds (parasitic heat loss/gain) [Ufactor (W/K)]
- Pconv: Convection (will heat or cool depending if T is below or above ambient) (~±400W/m^2)
- PIRout(T) = $\varepsilon_h \sigma T_{surface}^4$ (200-400W/m^2)
- PIRin = $\varepsilon_h \sigma T_{sky}^4$ = ε_h HIR (200-400W/m^2)

- P(T) = Ppc ($T_{surface}$, Ta) + Psol - PIRout($T_{surface}$) + PIRin(Tsky) + Pconv($T_{surface}$, Ta)

Thermal Properties of the Sky?

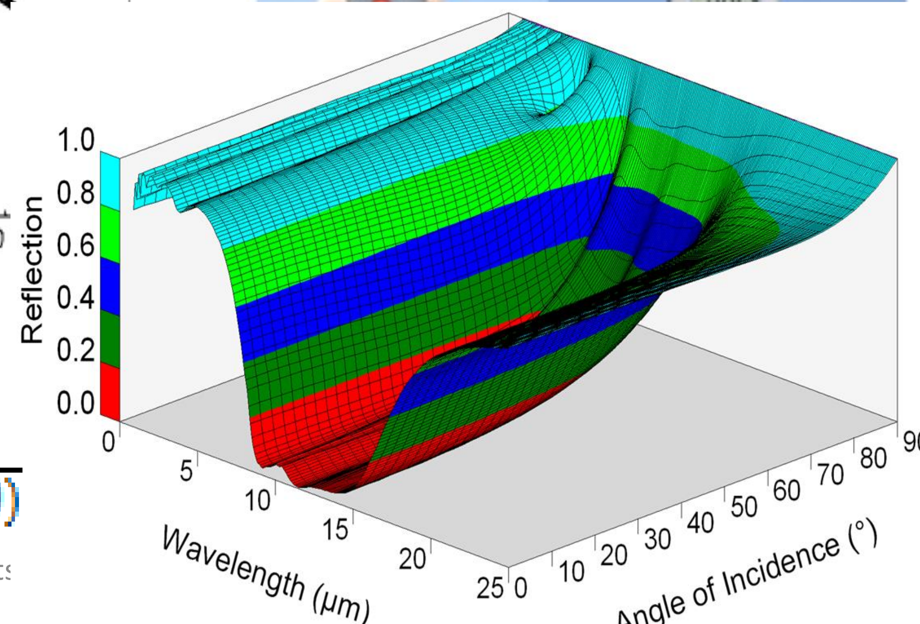
Down-welling sky radiation: ~240-400W/m^2 24h (depending on weather conditions)

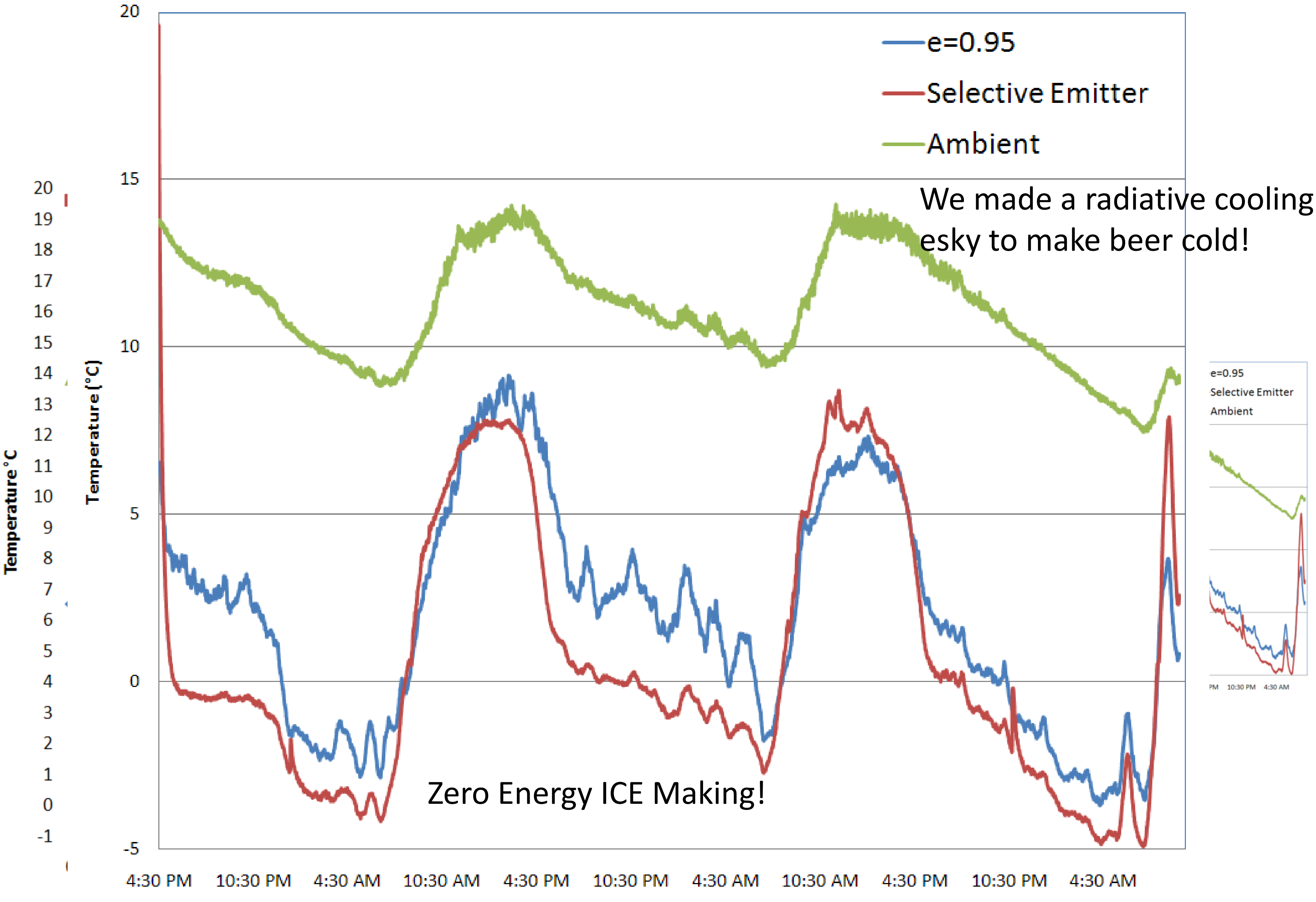


4~50um

$$T(\theta) = T(Zenith)^{\frac{1}{\cos(\theta)}}$$

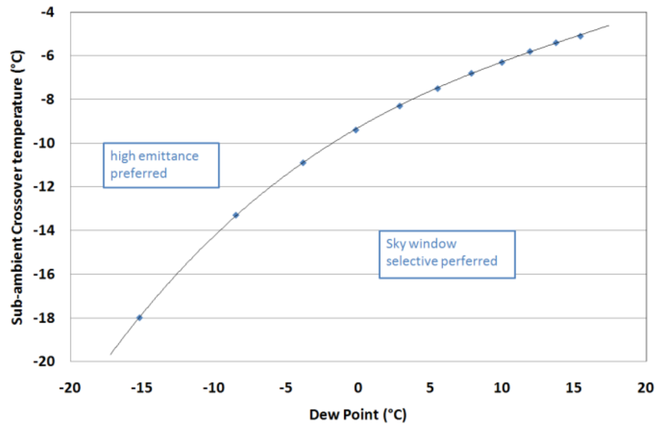
science.uts





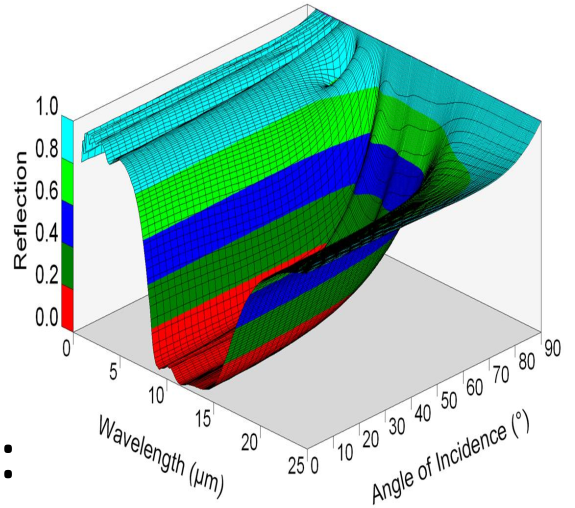
June late afternoon: No direct sun on surfaces
Convection suppression: 10um LDPE film

Performance comparisons of sky window spectral selective and high emittance radiant cooling systems under varying atmospheric conditions, AR Gentle, G Smith - Solar2010, the 48th AuSES Annual Conference, 2010

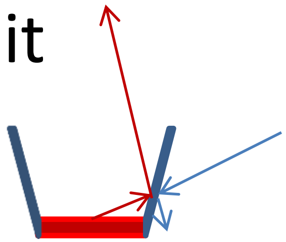


Blackbody or Selective Emitter?

Night Time:



- Depending on the operating temperature:
- Spectrally Selective emitter (Sky window only)
- Angularly-Spectrally Selective emitter
  (Sky window vertically, reflect at high angles)
- Blackbody Emitter (maximise thermal output)
- Blackbody Emitter with heat mirrors to limit skyview to near the zenith



DAY TIME: The same as night while also minimising absorbed sunlight.
Very high solar reflectance ~ ideally higher than 95%.

What about in summer time in the sun?

Passive radiative cooling below ambient air temperature under direct sunlight
Aaswath P. Raman, Marc Abou Anoma, Linxiao Zhu, Eden Rephaeli & Shanhui Fan
Nature volume 515, pages 540–544 (27 November 2014)
•850W/m2, with glad wrap "convection suppressant"

A Subambient Open Roof Surface under the Mid-Summer Sun , Angus R. Gentle and Geoff B. Smith, *Advanced Science, Vol 2, Issue 9,* 1500119, May 2015
•1060W/m2, wind exposed

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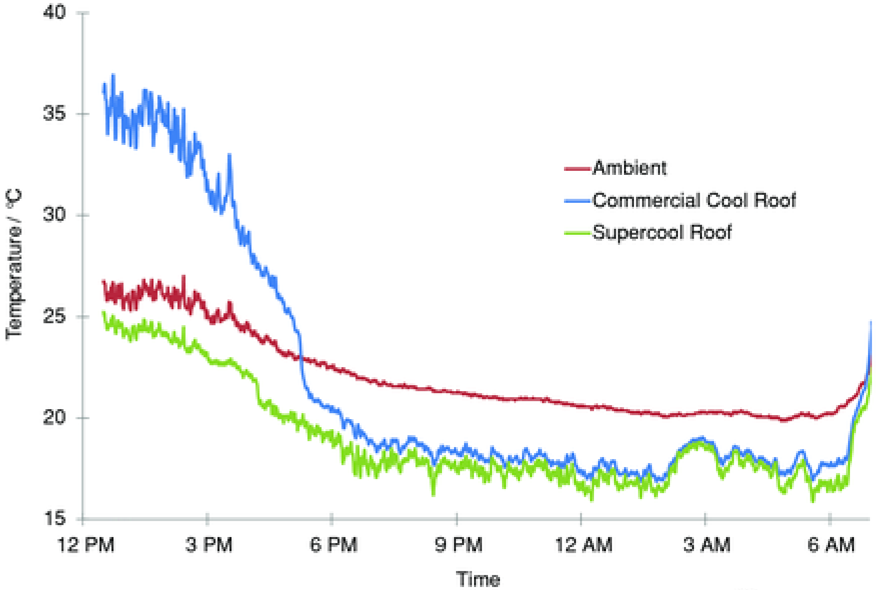
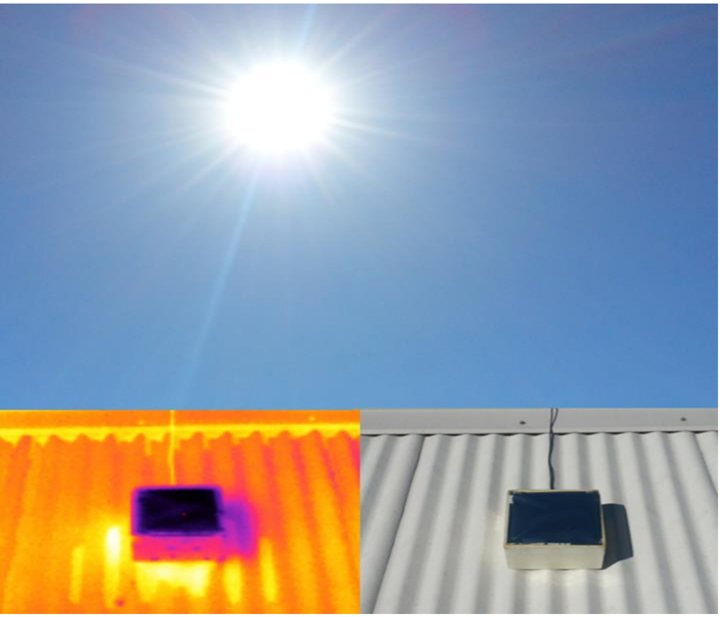
A Subambient Open Roof Surface under the Mid-Summer Sun , Angus R. Gentle and Geoff B. Smith

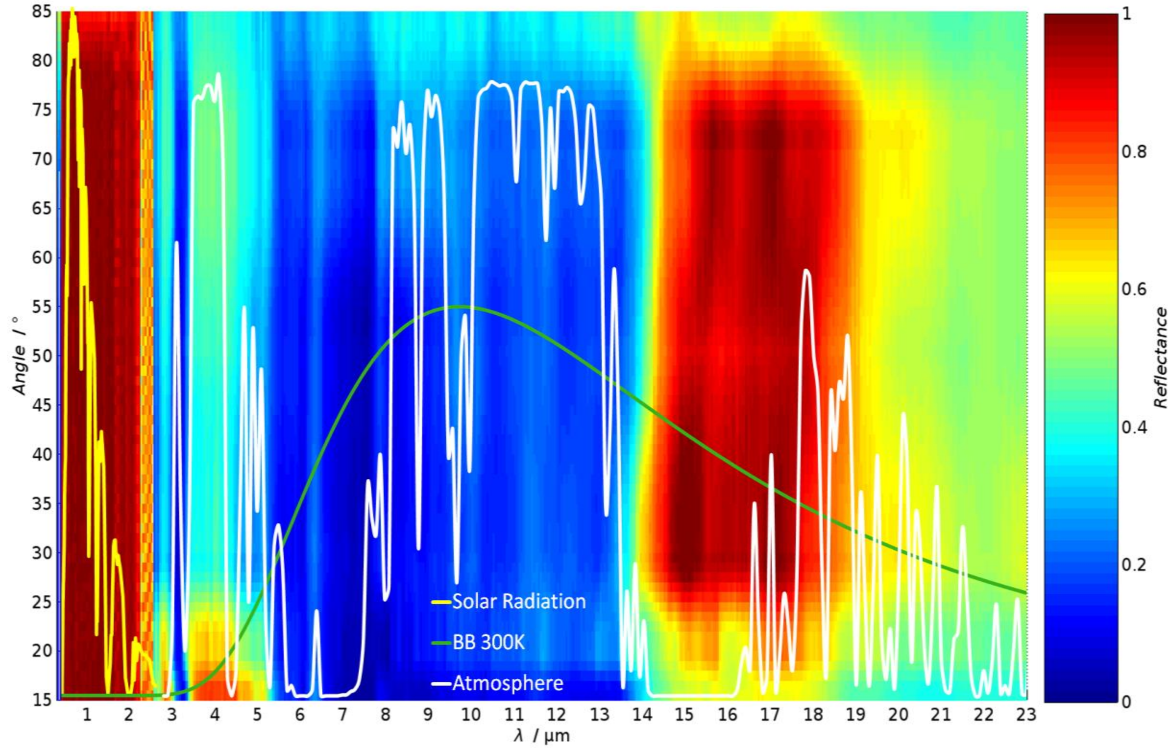
Advanced Science, Vol 2, Issue 9, 1500119

(doi: 10.1002/advs.201500119)

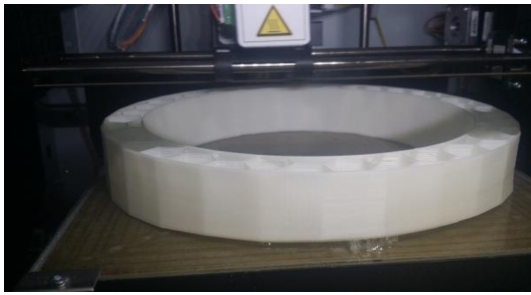


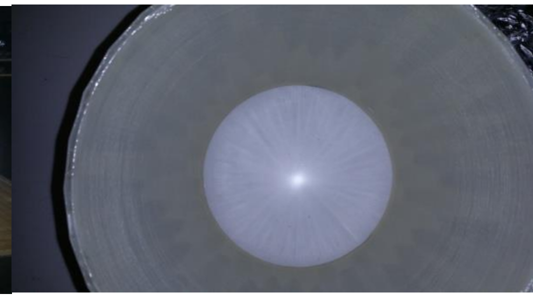


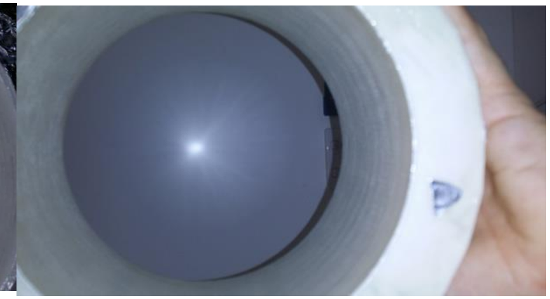
Super-cool material on a regular cool roof



3d printed Reflectors?

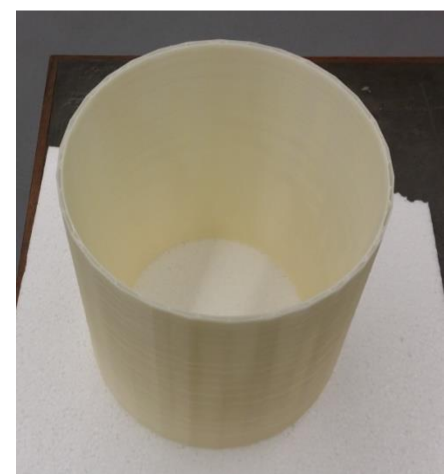




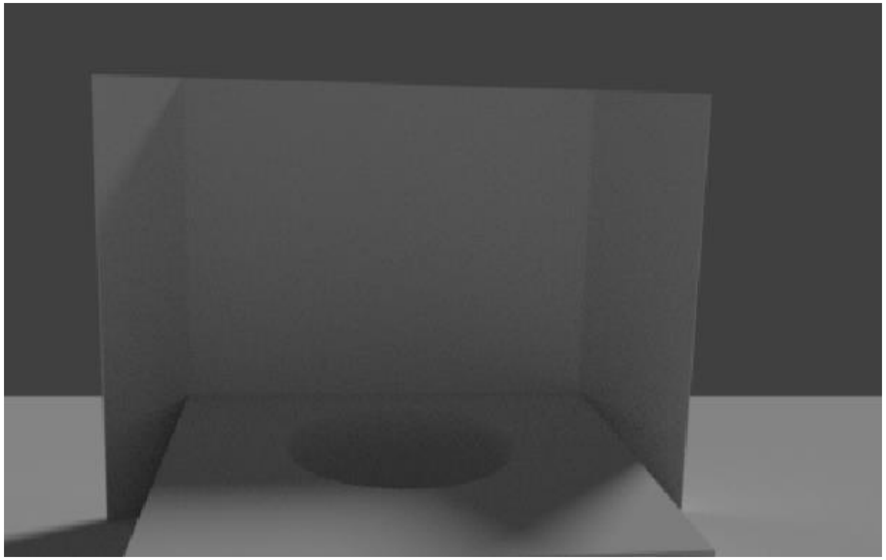


3D print in ABS: 10% infill -> low thermal mass / thermal conductivity structure
Surface finishing: Acetone to reflow/polish the surface
Sputtercoat with Silver

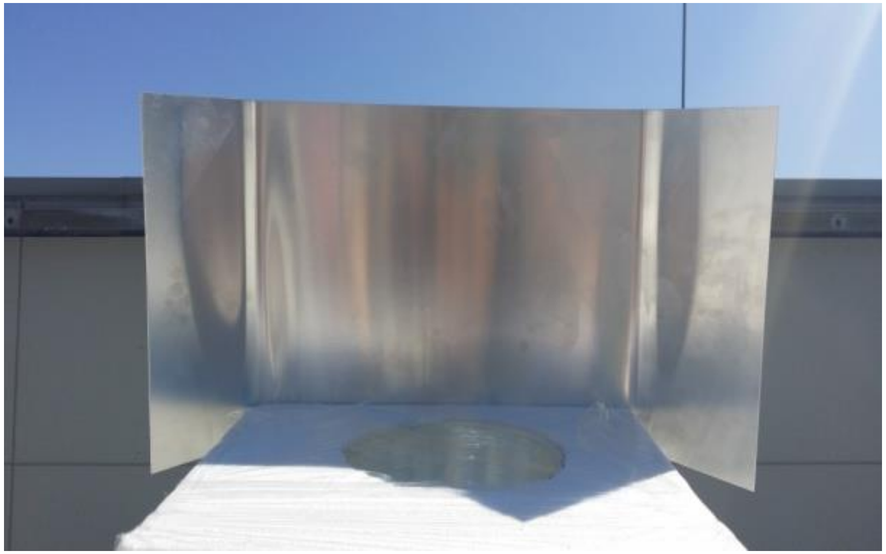
200mm diameter x 200mm height, 140mm base
Compound Parabola focusing to an area



Outdoor test rig



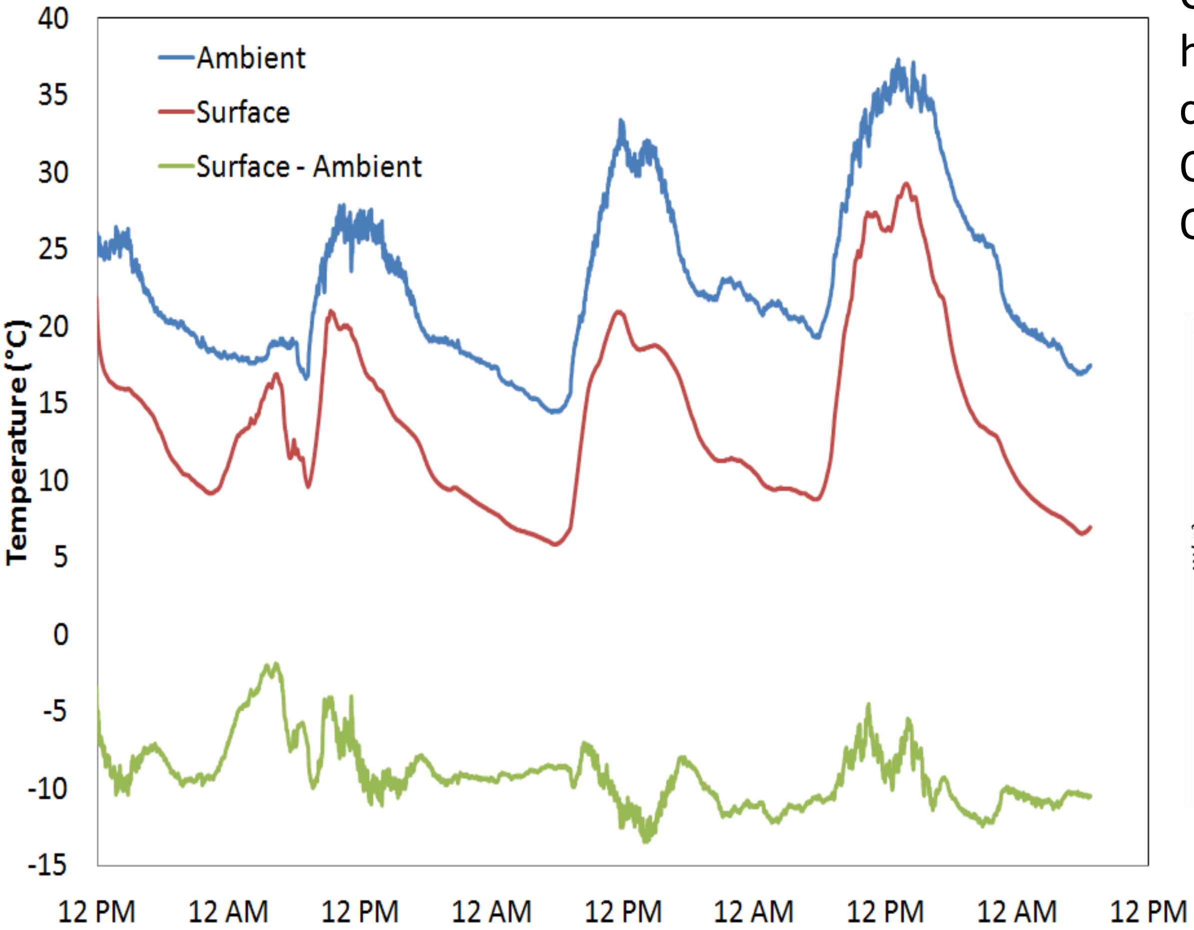
Blender Rendered Image



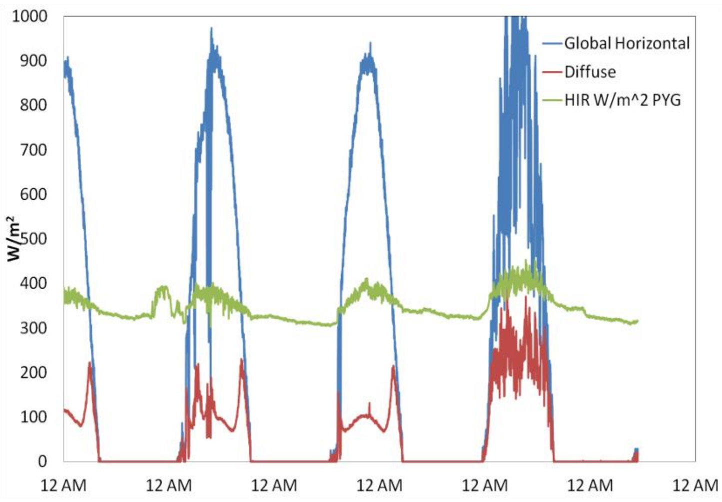
Photo

Recessed in 400x400x240mm polystyrene
Additional northern side aluminium sun shade
10um polyethylene cover

Outdoor results

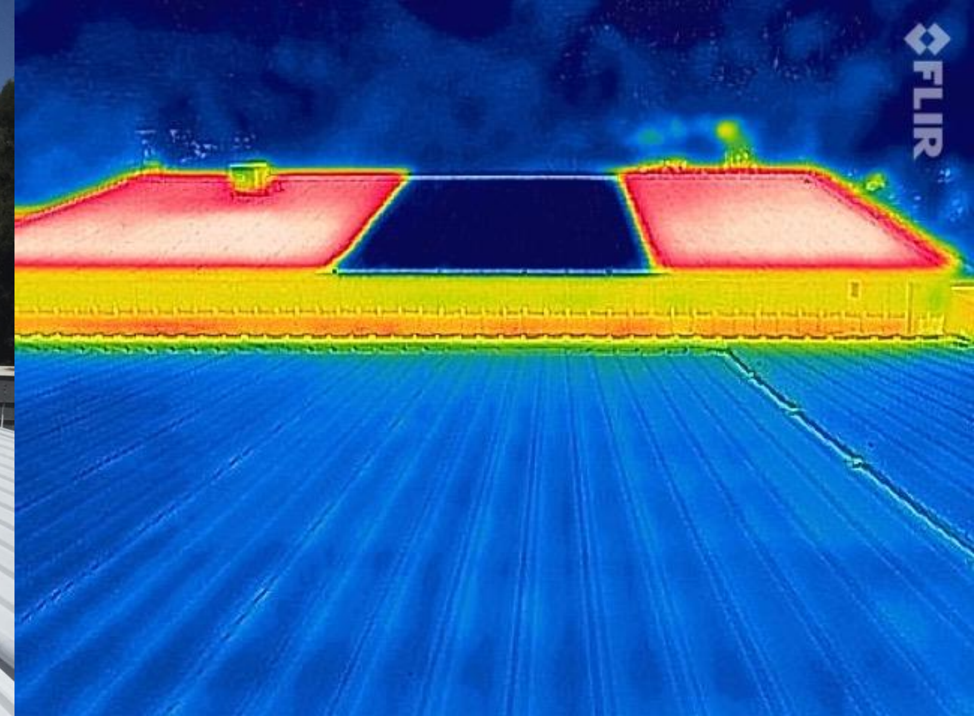


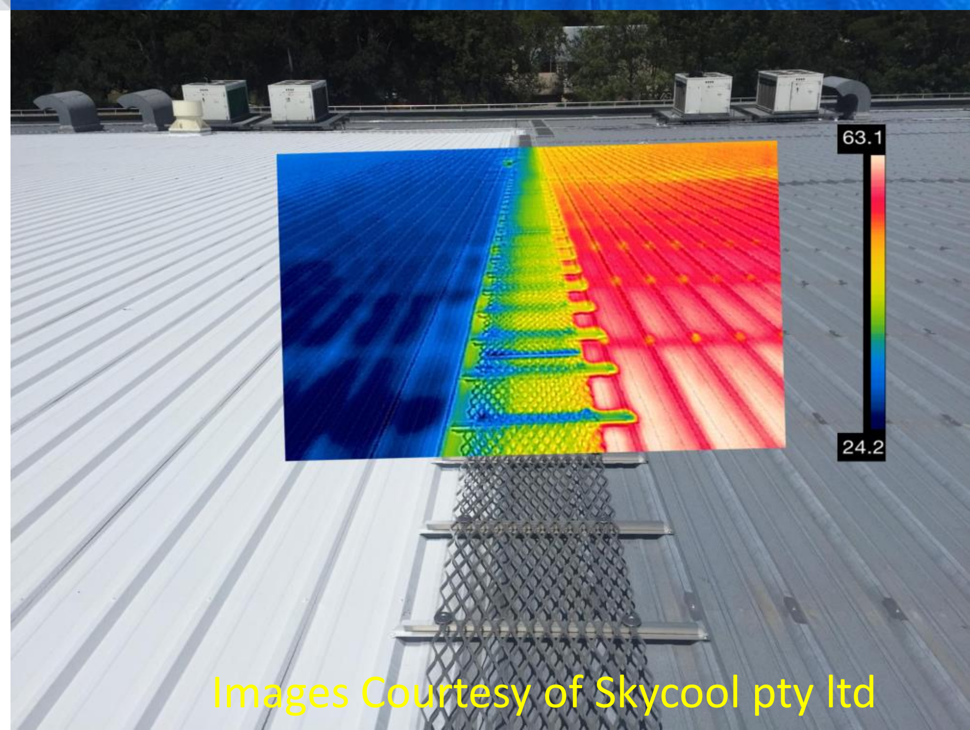
Outdoor test results for near horizontally mounted parabolic cooler, commencing midday 1st of October 2015, through to 6am 5th October 2015.



3D printable optical structures for sub-ambient sky cooling, AR Gentle, A Nuhoglu, MD Arnold, GB Smith, SPIE Thermal Radiation Management for Energy Applications 10369, 103690B, 2017


Commercial transformation of a large roof
hot to cool is fast

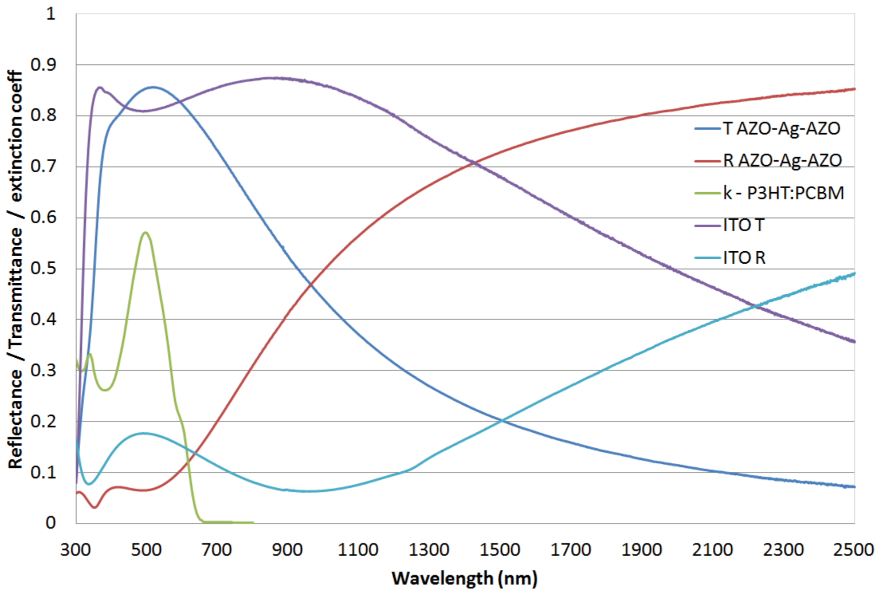

FLIR


63.1
24.2
Images Courtesy of Skycool pty ltd

How does this relate to PV?

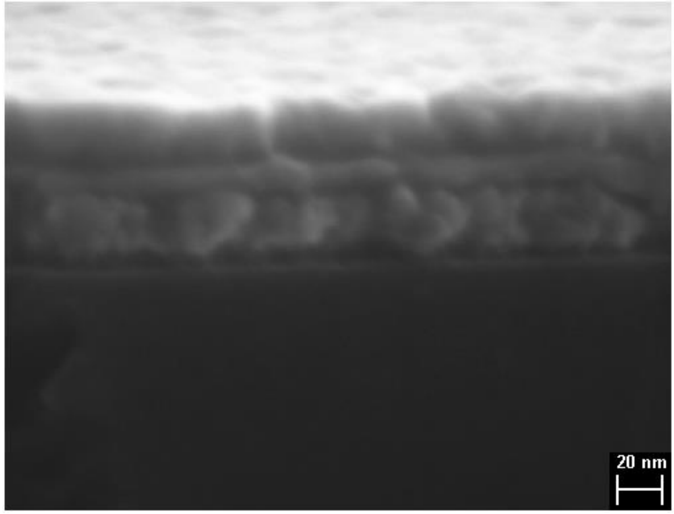
- Cell temperature effects performance
- Similar techniques apply to spectrally improving the thermal efficiency of modules
- Microclimate from roof – encourage PV installation on cool roofs

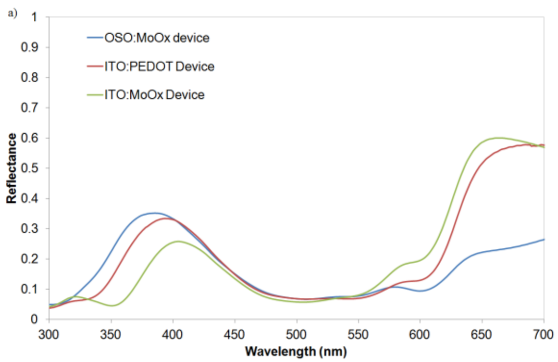
Transparent Electrodes

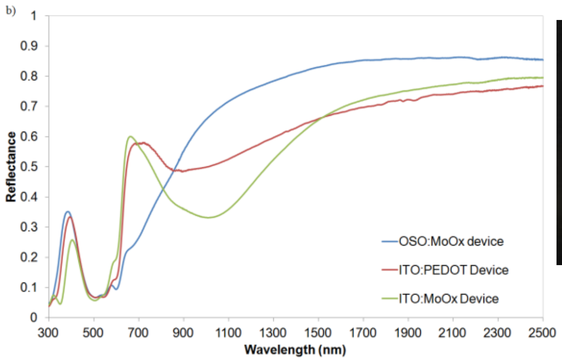


AZO
Ag
AZO

8.4 Ohm/Sq

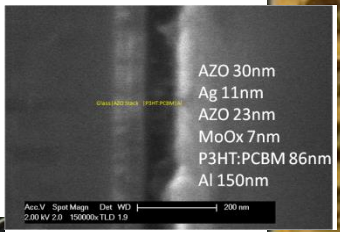


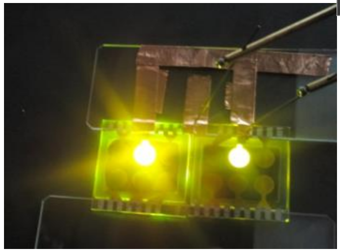


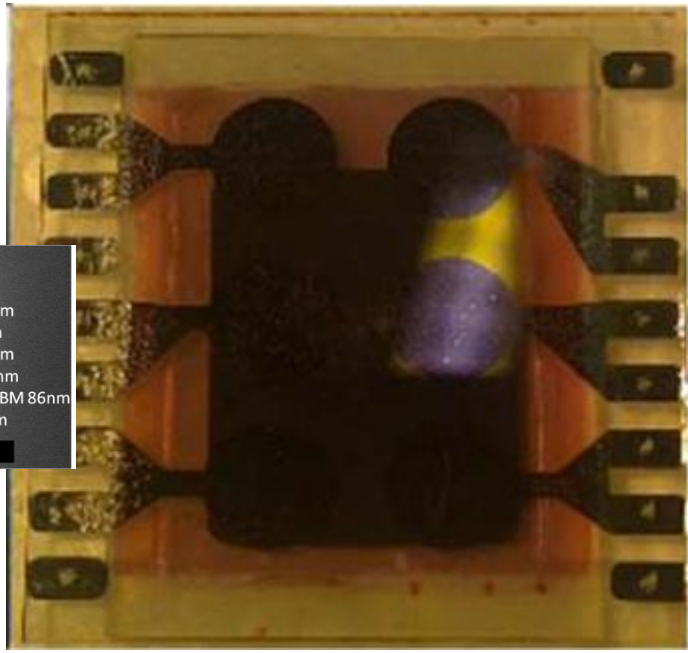


Optimise stack for carrier generation not in air Transparency!

Device Ellipsometry:
Backside through glass.
Small spot size
Multiple Regions

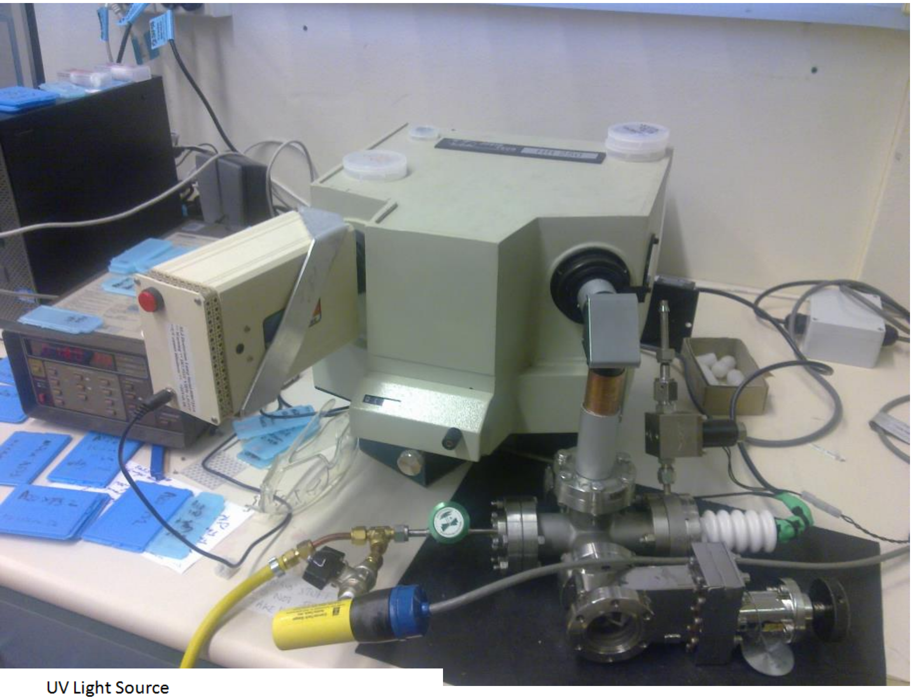


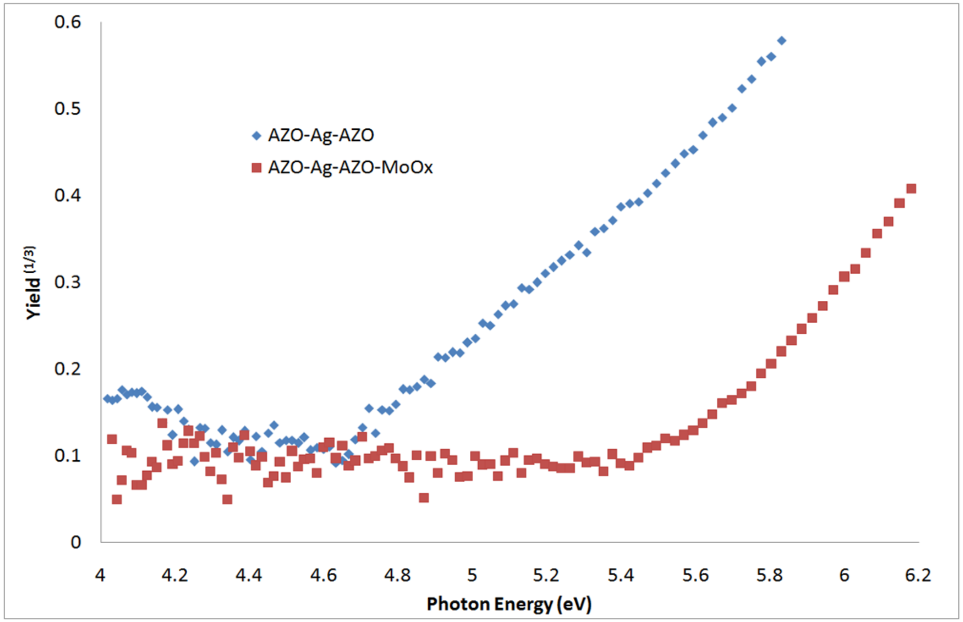


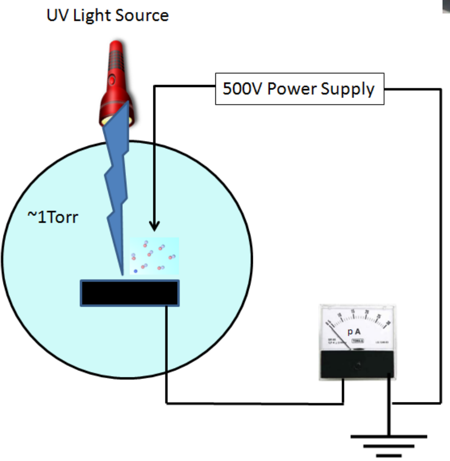


Optimized multilayer indium-free electrodes for organic photovoltaics
AR Gentle, SD Yambem, GB Smith, PL Burn, P Meredith
physica status solidi (a) 212 (2), 348-355 (2015)

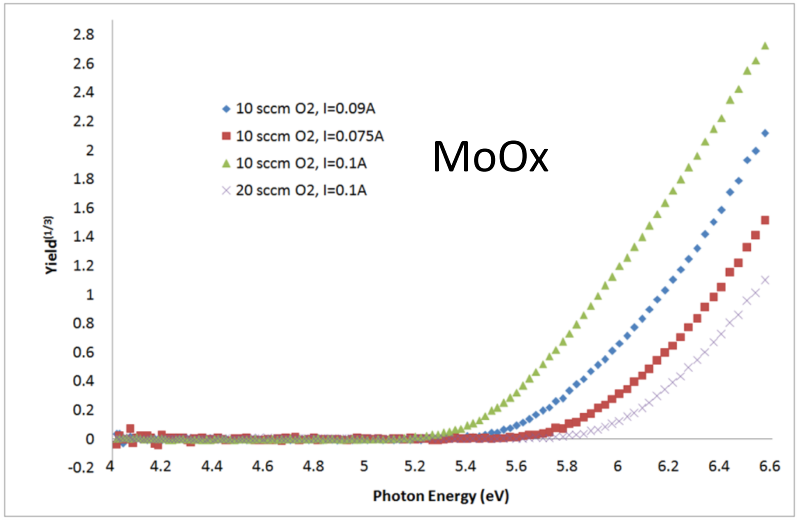
Work Function / Ionisation Potential
Photoelectron Yield Spectroscopy





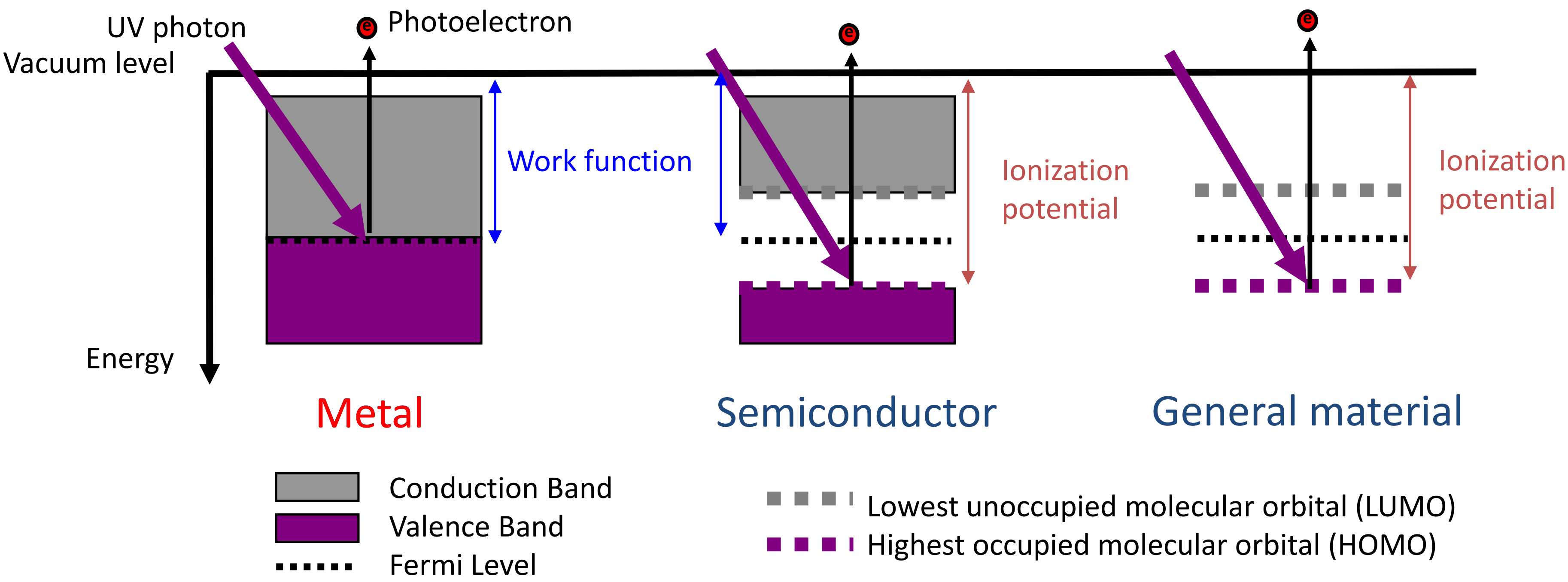


Gas cascade amplified PYS



Discharge amplified photo-emission from ultra-thin films applied to tuning work function of transparent electrodes in organic opto-electronic devices, AR Gentle, GB Smith, SE Watkins Applied Surface Science 285, 110-114

The relationship between the threshold energy and the energy diagrams

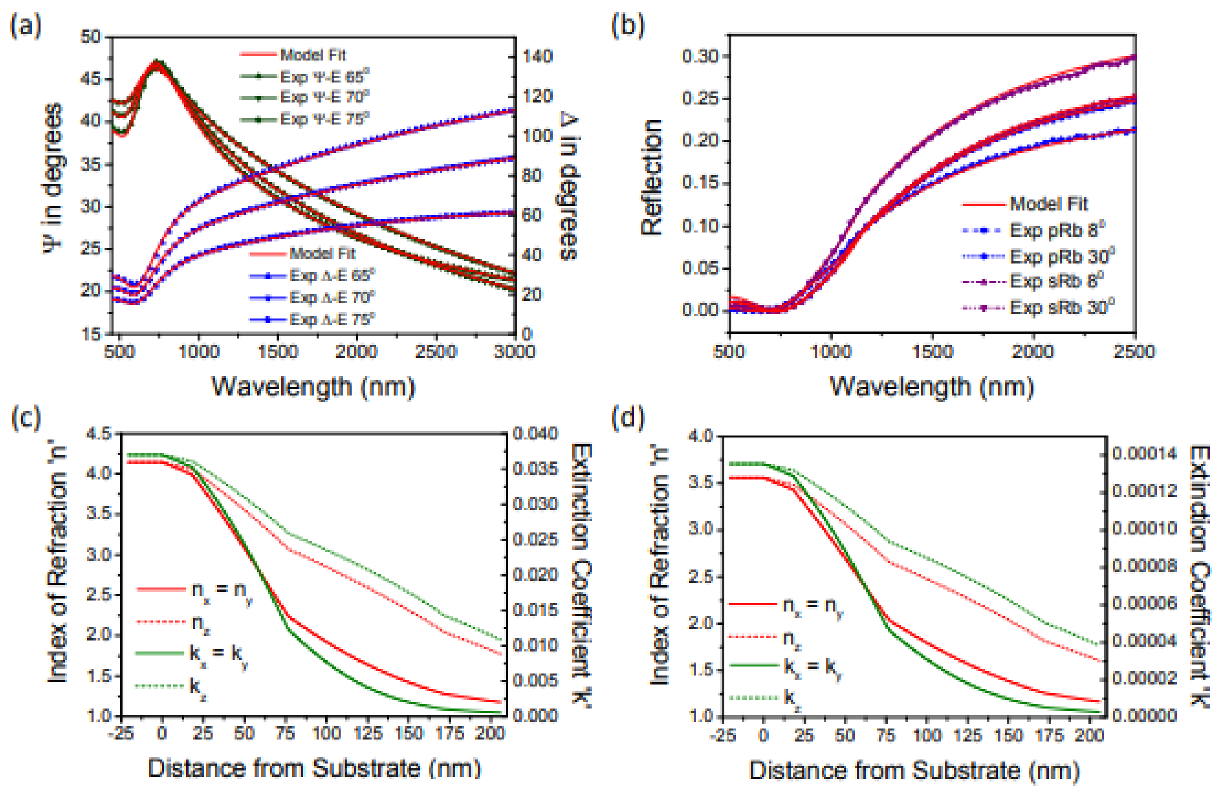


We can estimate the work functions or ionization potentials of the materials from the photoemission threshold energy.

http://www.rkiinstruments.com/pdf/ac2.pps

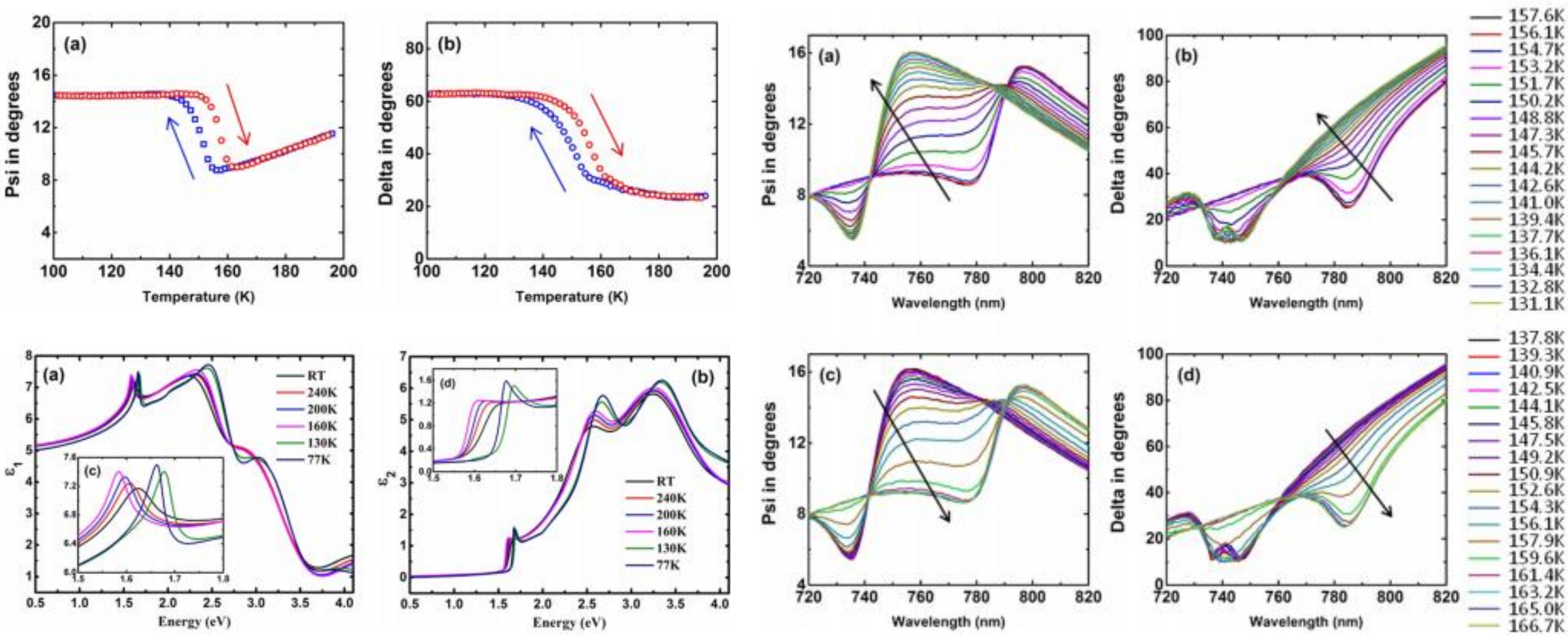
Black Silicon

Graded Effective Medium: Fitting Multi Angle Reflection and Ellipsometry Data



Light-induced reflectivity transients in black-Si nanoneedles, P. Ščajev, T. Malinauskas, G.Seniutinas, M.D.Arnold, A.Gentle, I.Aharonovich, G.Gervinskas, P.Michaux, J.S.Hartley, E.L.H.Mayese, P.R.Stoddart, S.Juodkazis, Solar Energy Materials and Solar Cells, Volume 144, January 2016, Pages 221-227

Temperature dependent optical properties of CH3NH3PbI3 perovskite by spectroscopic ellipsometry



Temperature dependent optical properties of CH3NH3PbI3 perovskite by spectroscopic ellipsometry,
Yajie Jiang, Arman Mahboubi Soufiani, Angus Gentle, Fuzhi Huang, Anita Ho-Baillie, and Martin A. Green
Applied Physics Letters 108, 061905 (2016)

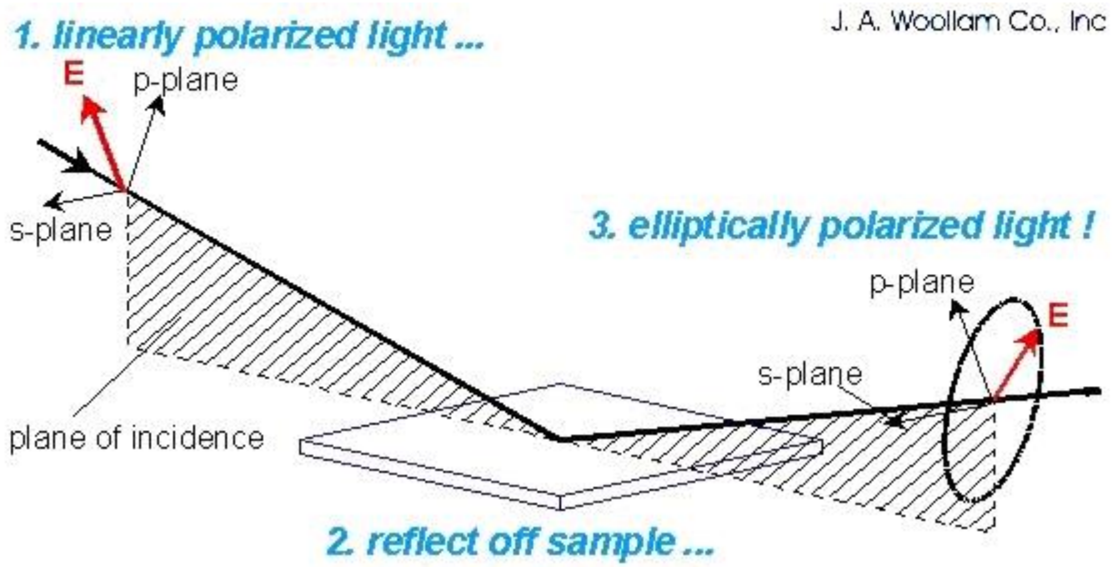
UTS Optical Equipment/Techniques

- Ellipsometery
  - Wide Wavelength Range [190nm-3300nm] (Simon, Ivan, Mattias, Ning)
  - Temperature (Ziv, Armin, Jessica, Mattias, Simon)
  - Sample Mapping (Ivan)
  - Small spot size
- Spectrometers
  - Specular/diffuse (Ning)
  - Scattering (David)
- FTIR
  - Variable Angle Reflectance/transmittance / *ellipsometry / temperature stage*
- Rotating Cavity Emisometer
- Photoelectron Yield Spectroscopy: workfunction
- Insitu Monitoring (HT Annealing in Air or Vac with Reflectance)

Always happy to collaborate.
(SPREE folk who have made measurements with us)

Wide range of accessories and happy to make custom stages if its worth while.

Ellipsometry

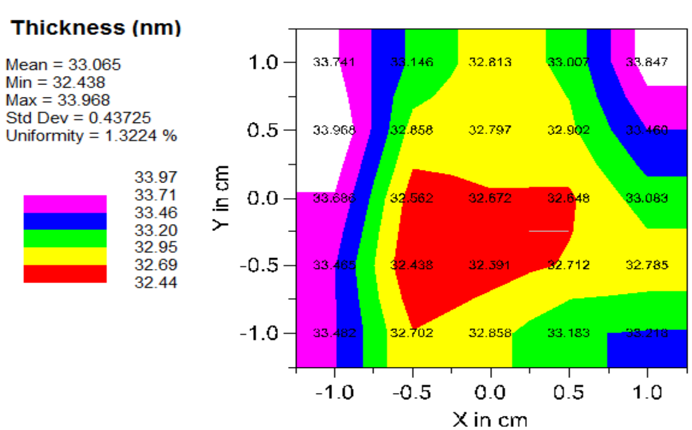


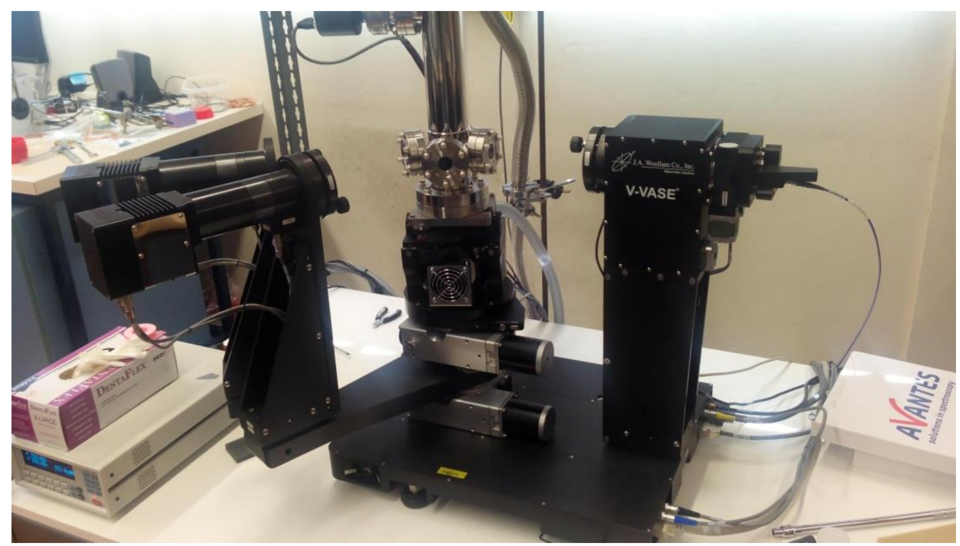
$$\rho = \frac{R_p}{R_s} = \tan(\Psi) e^{i \cdot \Delta}$$

Measurements are fairly straight forward, the trick is fitting the data.

Woollam V-VASE Ellipsometer

- 190-3500nm → wide spectral range
- Full angular capability → complex multilayers
- Mueller matrix → anisotropy & scattering
- T & R
- 150mm wafer mapping → uniformity
- 4-800K (In Vaccum ~ 10^{-8}Torr)
- 0-90°C In Air (Homemade temp stage)



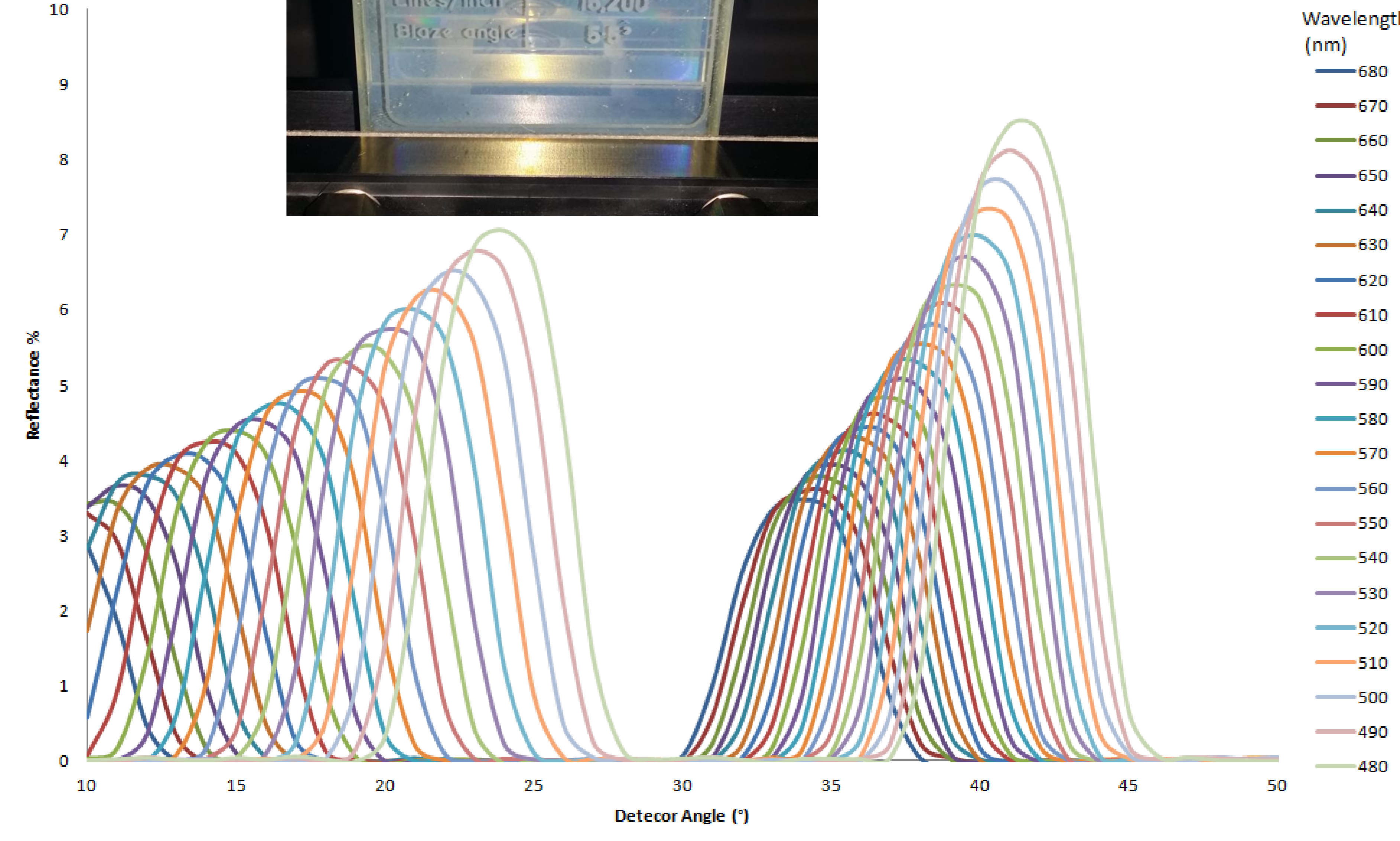


Cary 7000 UMS

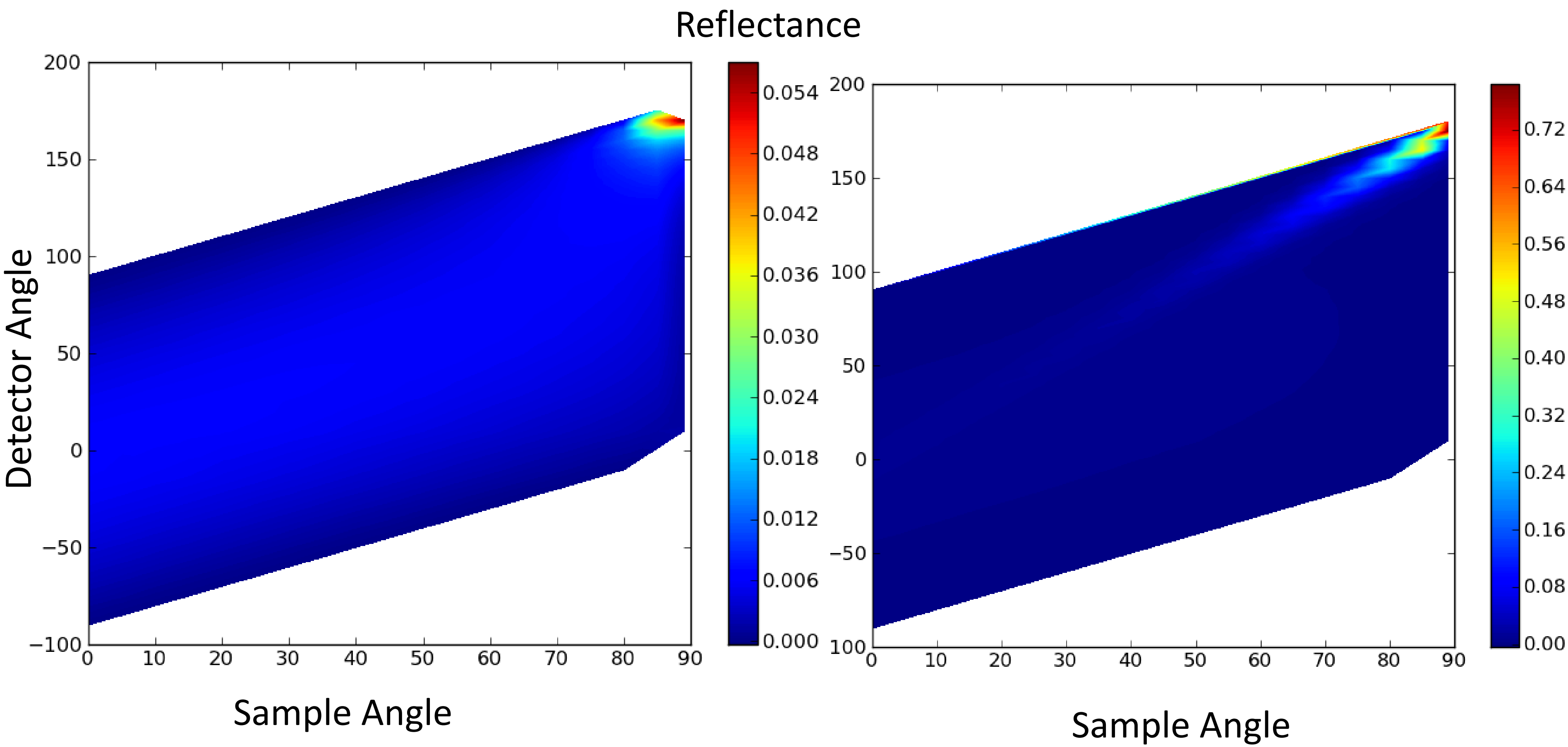
Various Measurements

- With UMA attached:
  - Reflectance / Transmittance
    - Polarisation
    - Angle
  - Diffuse Samples
    - Scattering (BDRF)
      - Vary Detector and Sample Angle independently
- With Integrating Sphere attached:
  - Hemispherical R/T
    - And Variable angle R/T

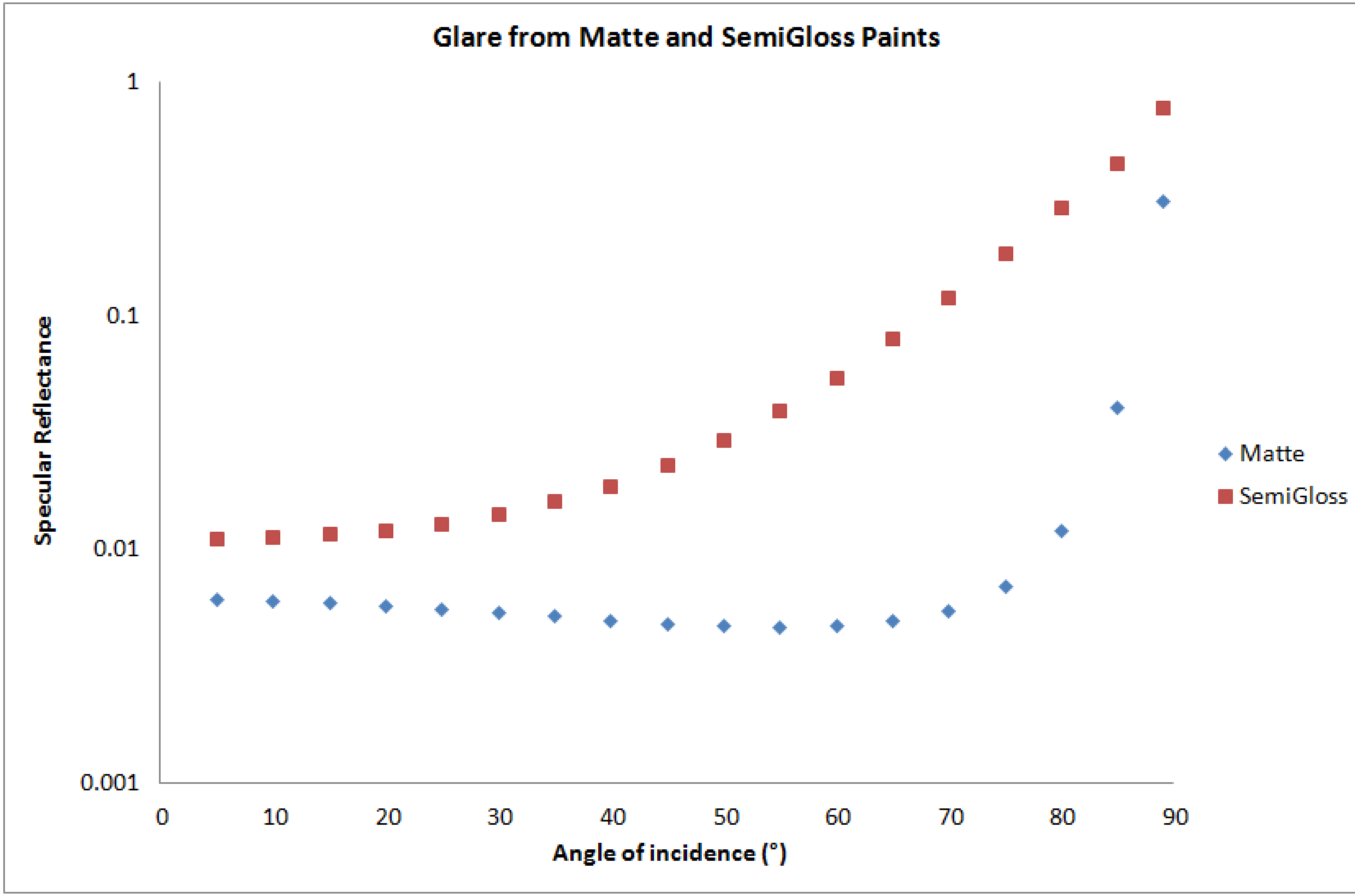
~4 hour measurement



Matte Surface / Semi gloss Surface



Scan ±90° around sample angle


Glare from Matte and SemiGloss Paints
Specular Reflectance
1
0.1
0.01
0.001
0
10
20
30
40
50
60
70
80
90
Angle of incidence (°)
Matte
SemiGloss

Thanks for listening!