Optical Properties of Materials

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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

- 2000 Started working at UTS as internship (continued part time during undergraduate/honours)
- 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)
- (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

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

Spontaneous growth of polarizing refractory metal 'nano-fins',
M C Tai et al 2018 Nanotechnology 29 105702
UV
1000W/m²
Near IR
6000 K
Far IR
380W/m²
300K
Wavelength (μm)
Manages radiation 3 ways: solar in / thermal out / atmospheric in

Out to outer space

Very Cold

Total Heat flows: (solar and atmospheric) in and out
24 hour averages
Infrared:
324 W/m² in
390 W/m² out

Solar:
~240 W/m²

The CO₂ problem
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


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/m²²)
- **PIRout**(T) = $e_h \sigma T_{surface}^4$ (200-400W/m²²)
- **PIRin** = $e_h \sigma T_{sky}^4$ = $e_h$ HIR (200-400W/m²²)

$$P(T) = Ppc(T_{surface}, Ta) + Psol - PIRout(T_{surface}) + PIRin(T_{sky}) + Pconv(T_{surface}, Ta)$$
Thermal Properties of the Sky?

Down-welling sky radiation:
~240-400W/m²
24h
(depending on weather conditions)

\[ T(\theta) = T(\text{Zenith}) \frac{1}{\cos(\theta)} \]
Selective Emitter vs High Emittance Surface

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
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
• 850 W/m², with glad wrap “convection suppressant”

• 1060 W/m², wind exposed
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

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.
Commercial transformation of a large roof from hot to cool is fast.

Images Courtesy of Skycool Pty Ltd
How does this relate to PV?

- Cell temperature affects performance
- Similar techniques apply to spectrally improving the thermal efficiency of modules
- Microclimate from roof – encourage PV installation on cool roofs
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)
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
We can estimate the work functions or ionization potentials of the materials from the photoemission threshold energy.
Black Silicon

Graded Effective Medium: Fitting Multi Angle Reflection and Ellipsometry Data

Temperature dependent optical properties of CH$_3$NH$_3$PbI$_3$ perovskite by spectroscopic ellipsometry,
Yajie Jiang, Arman Mahboubi Soufiani, Angus Gentle, Fuzhi Huang, Anita Ho-Baillie, and Martin A. Green
UTS Optical Equipment/Techniques
• Ellipsometry
  – 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
• In-situ 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

Measurements are fairly straightforward, 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 Vacuum ~ $10^{-8}$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
Incident Angle 30°

~4 hour measurement
Matte Surface / Semi gloss Surface

Scan ±90° around sample angle
Thanks for listening!