Solution-Derived Coating Deposition and Microstructure Control

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3 June 2009

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Outline

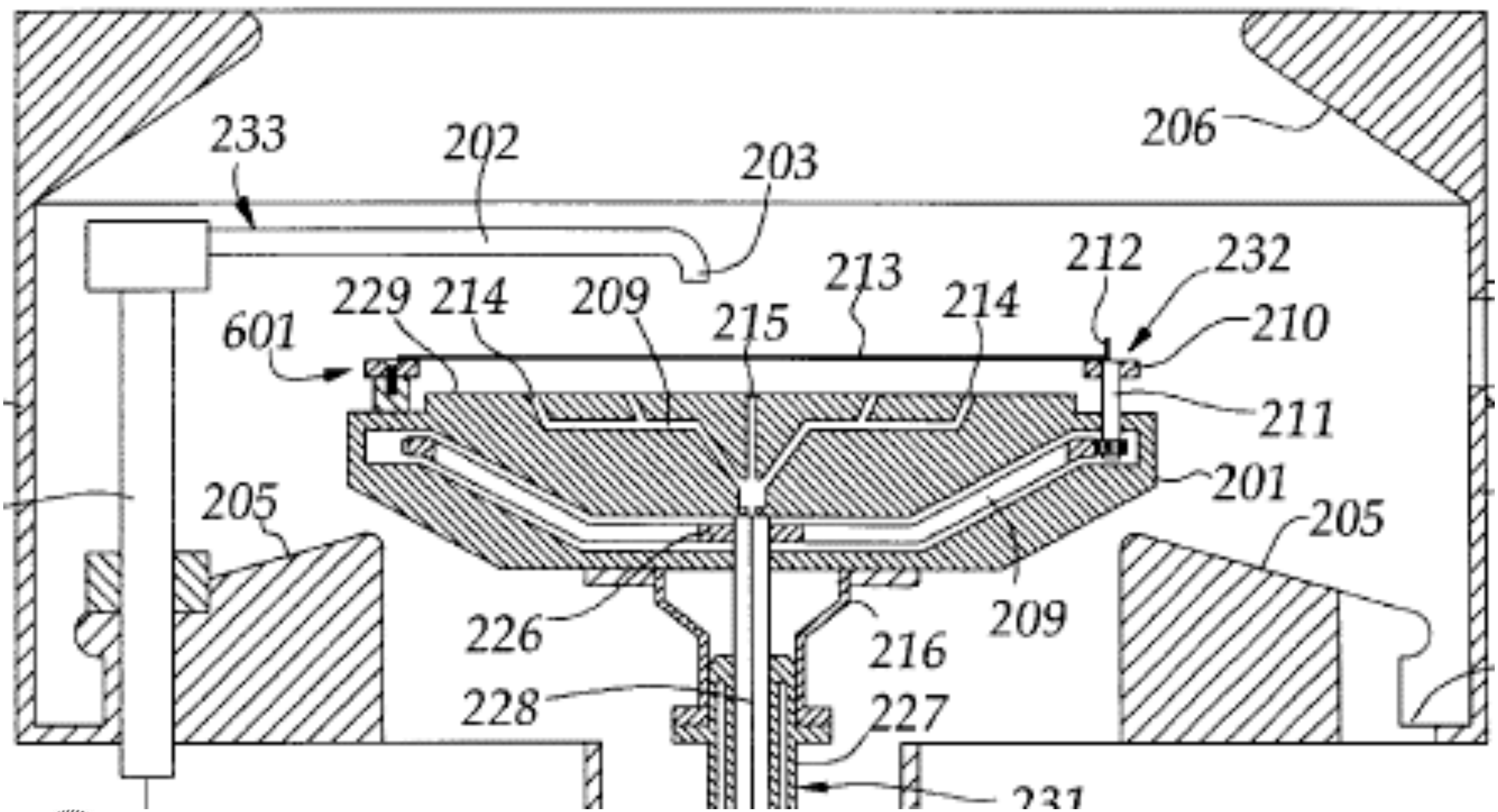
- My Background/History
  - Coating Flows and Instabilities
- Current Research:
  - Solar Coatings and Device Fabrication
  - Energy Systems and Electric Vehicles

My Background/History

- MIT BS and PhD – SiC ceramics, point defects and diffusion studies, phase equilibrium calcs
- University of Arizona – Lithium Niobate defects, diffusion, ferroelectric thin films, sol-gel coating solution chemistry, spin coating, solar racing car team
- 2004: Rutgers – emphasis on solar coatings

Schematic Coater Cross-Section

from US Patent 6,708,701



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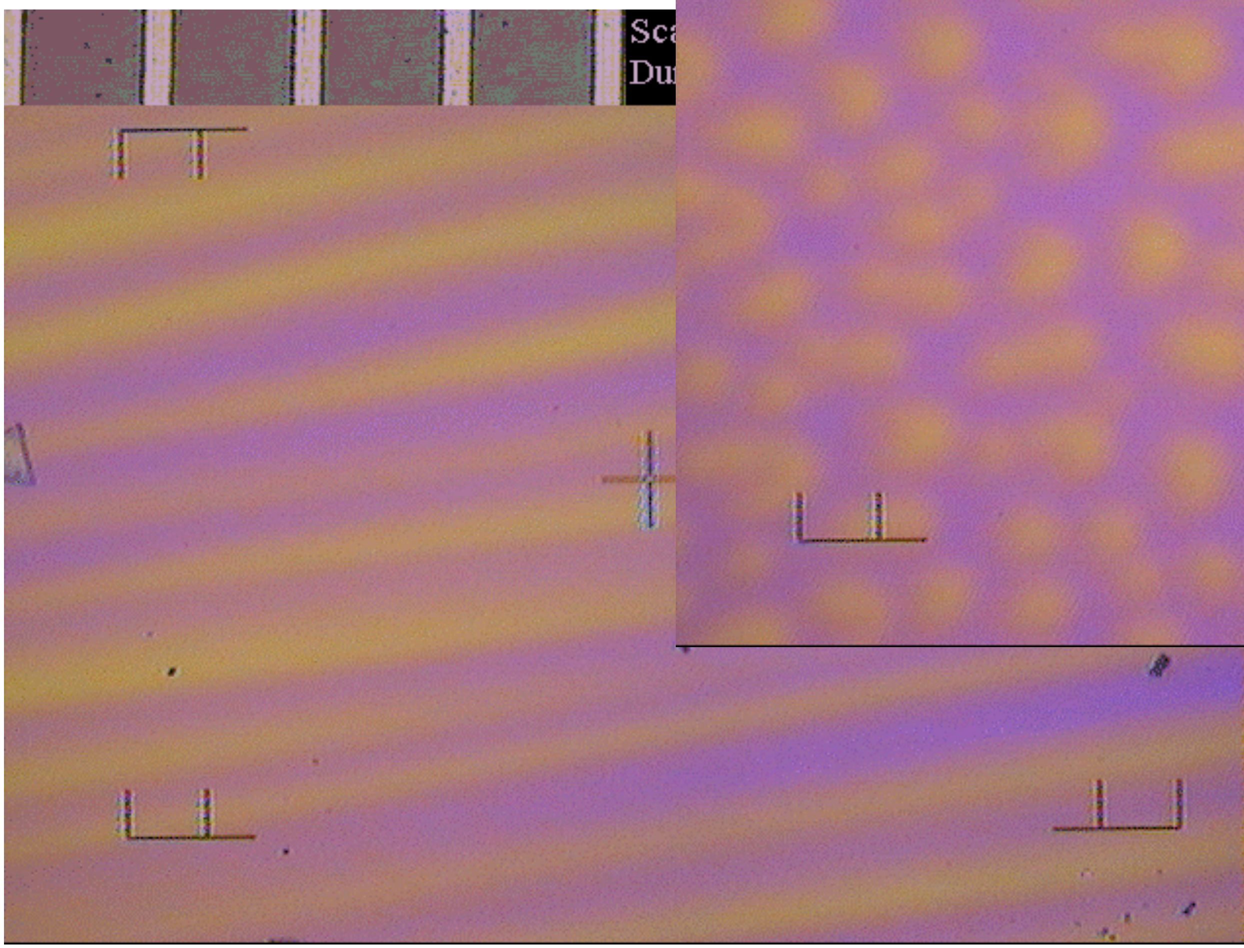
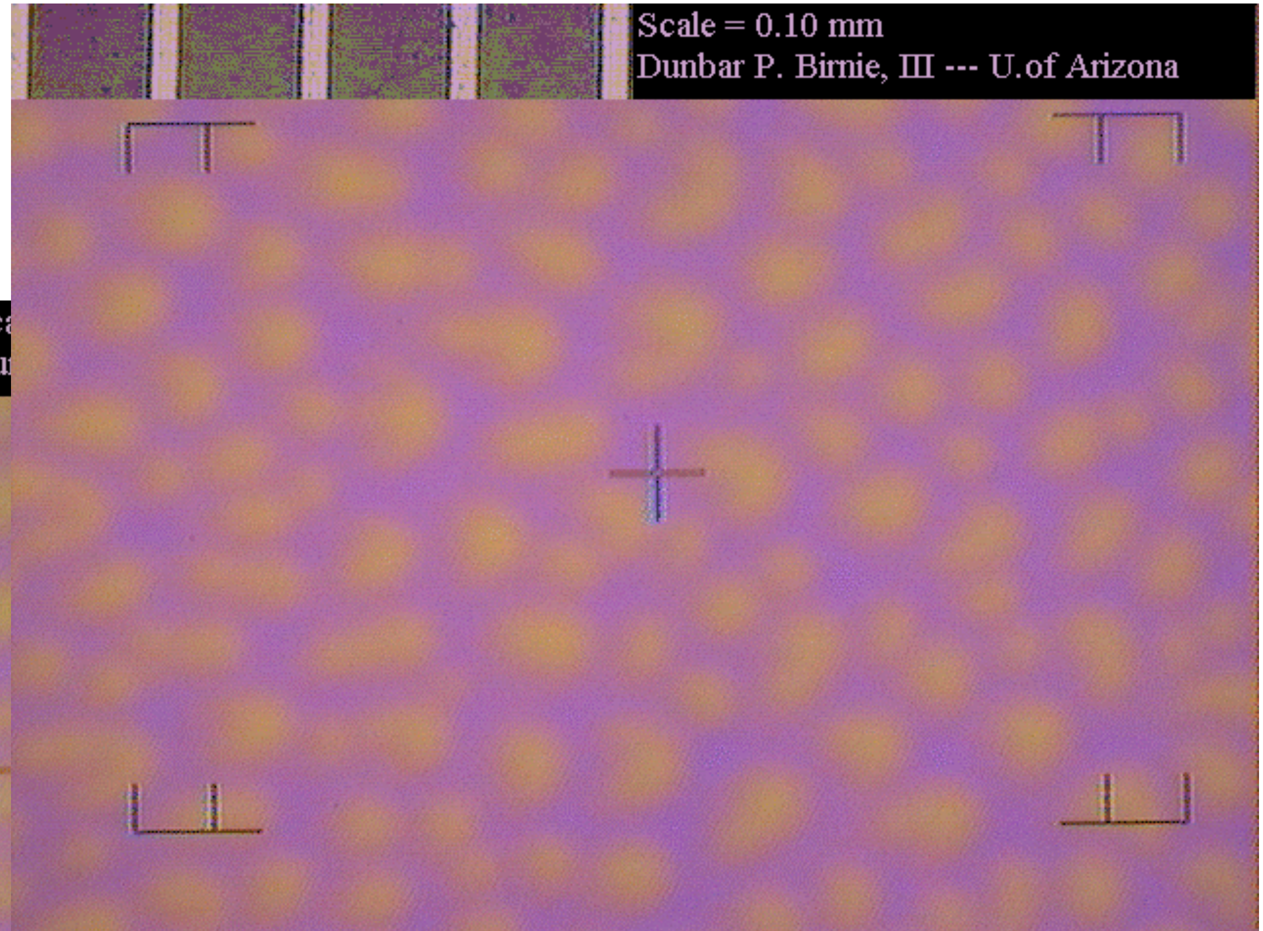
Striations in Sol-Gel PZT





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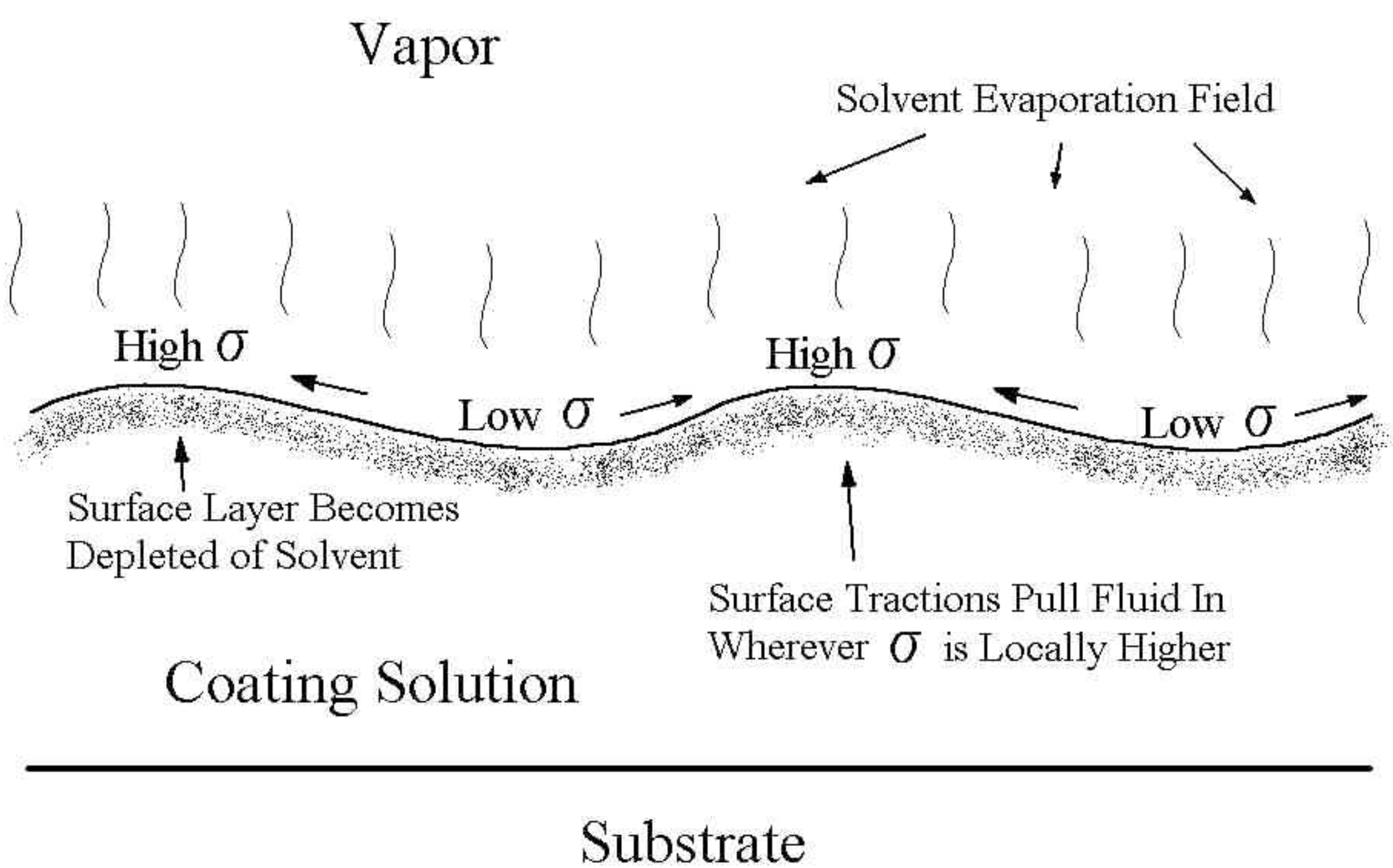
Schematic View



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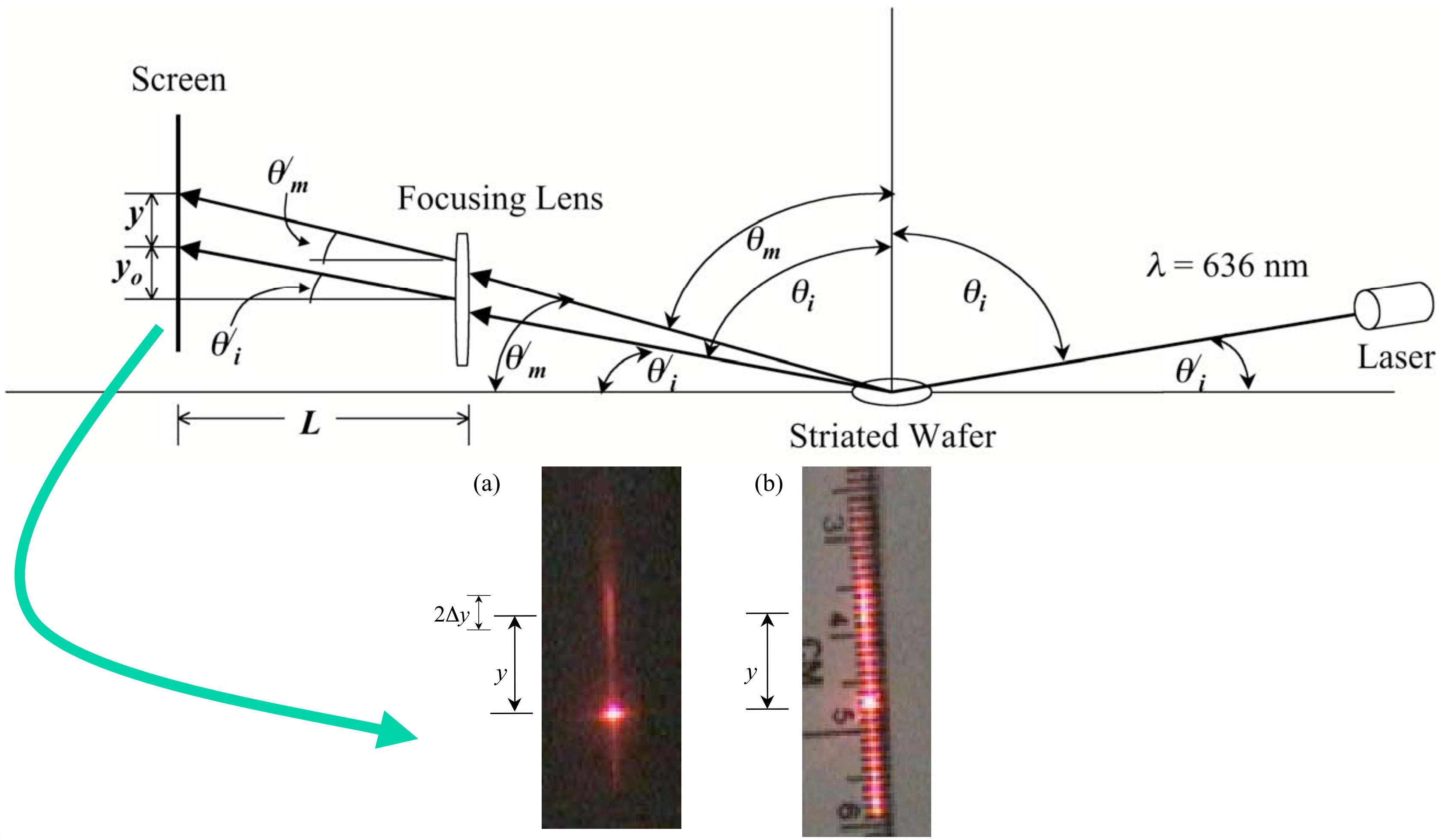
D. P. Birnie, III, "Rational Solvent Selection Strategies to Combat Striation Formation during Spin Coating of Thin Films", J. Materials Research, **16** (4), 1145-54 (2001)

Laser Diffraction



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D. E. Haas and D. P. Birnie, III, in Sol-Gel Commercialization and Applications (Ceramic Transactions, Vol 123), (2001). Pp 133-138.

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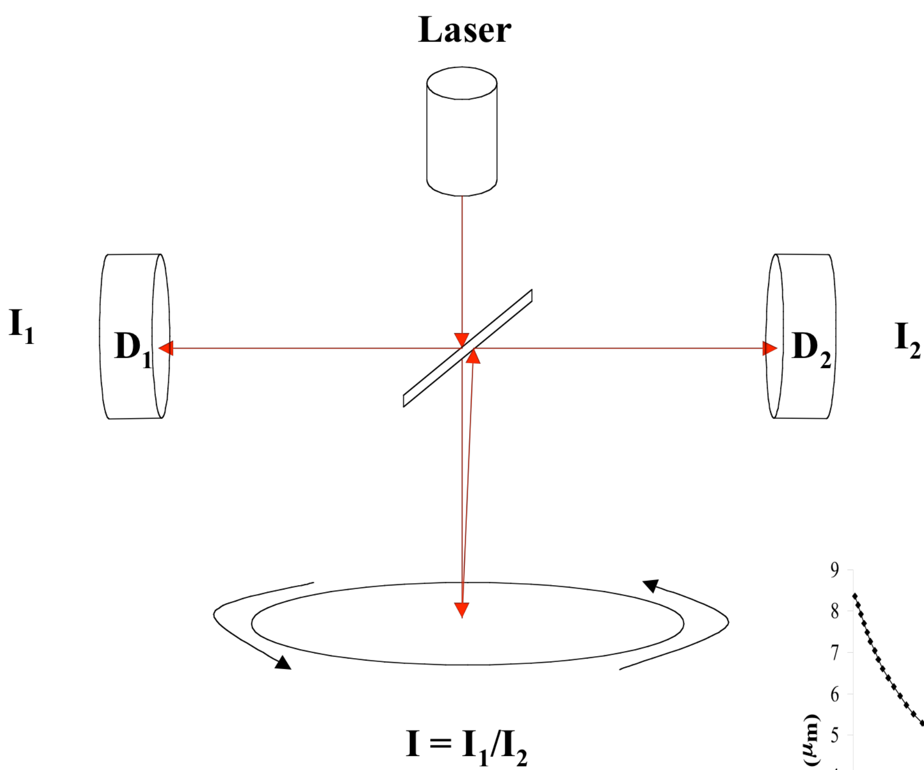
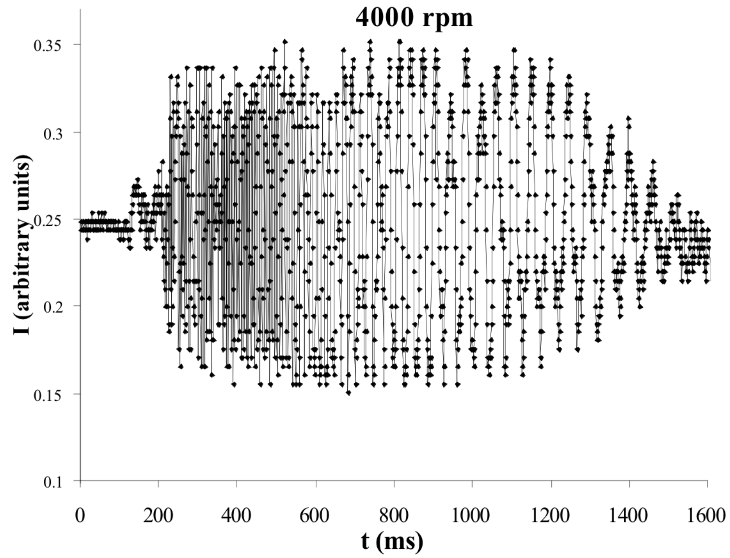
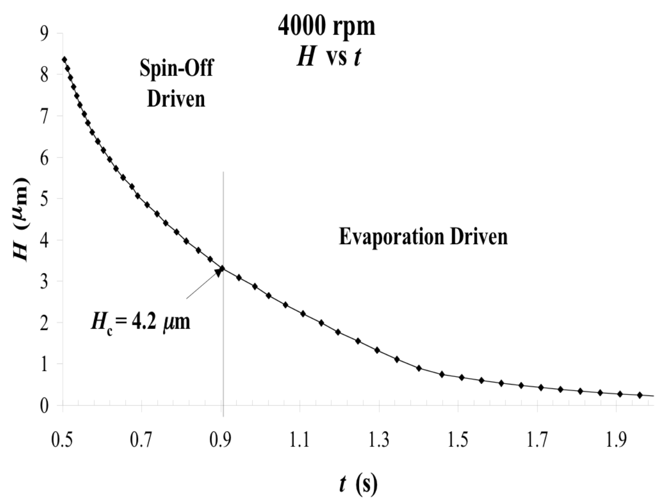
Measurement of Thickness Evolution







D. P. Birnie, III and Manuel Manley, "Combined Flow and Evaporation of Fluid on a Spinning Disk", Physics of Fluids, **9**, 870-875 (1997)

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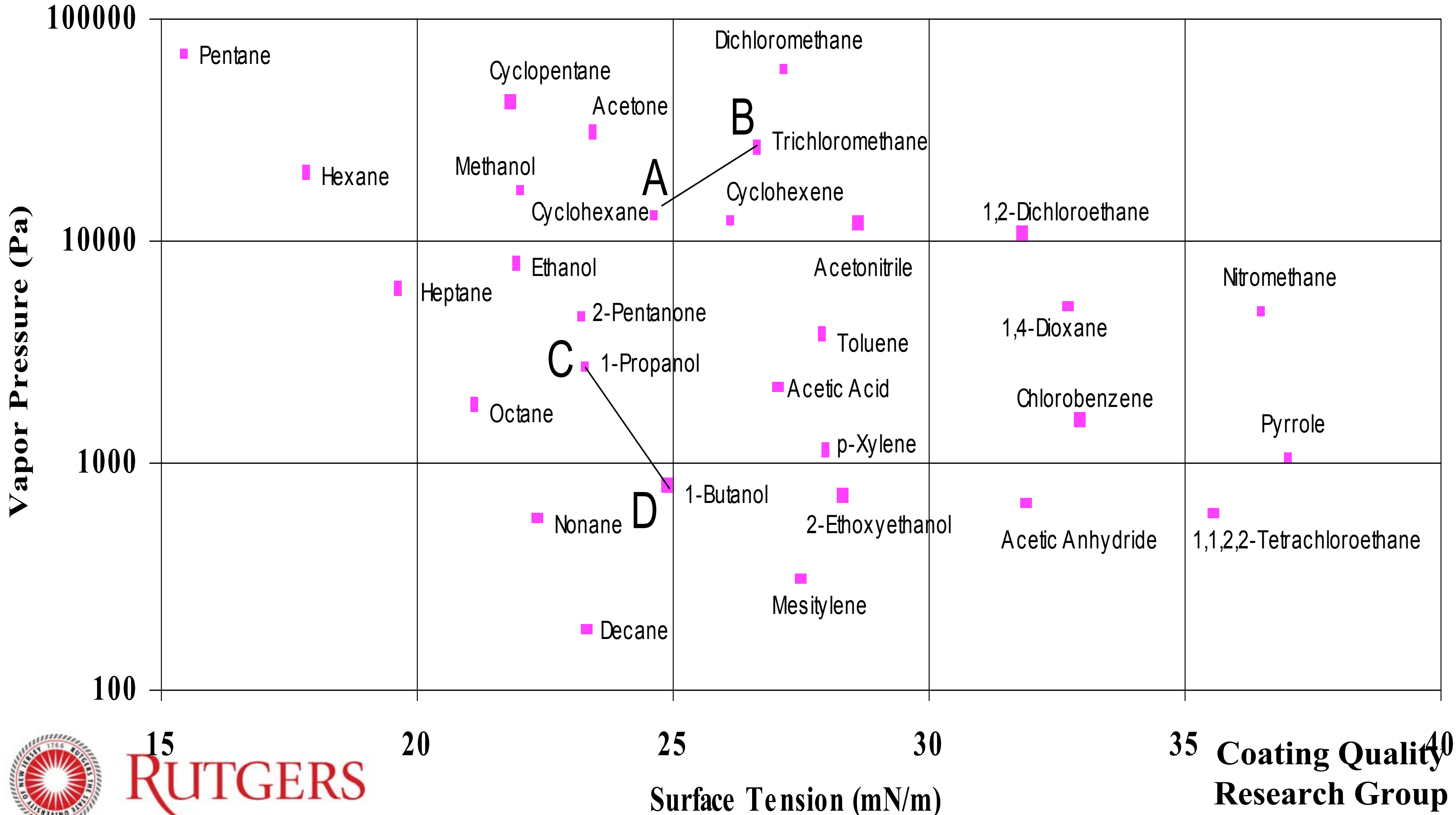
Solvent Slopes



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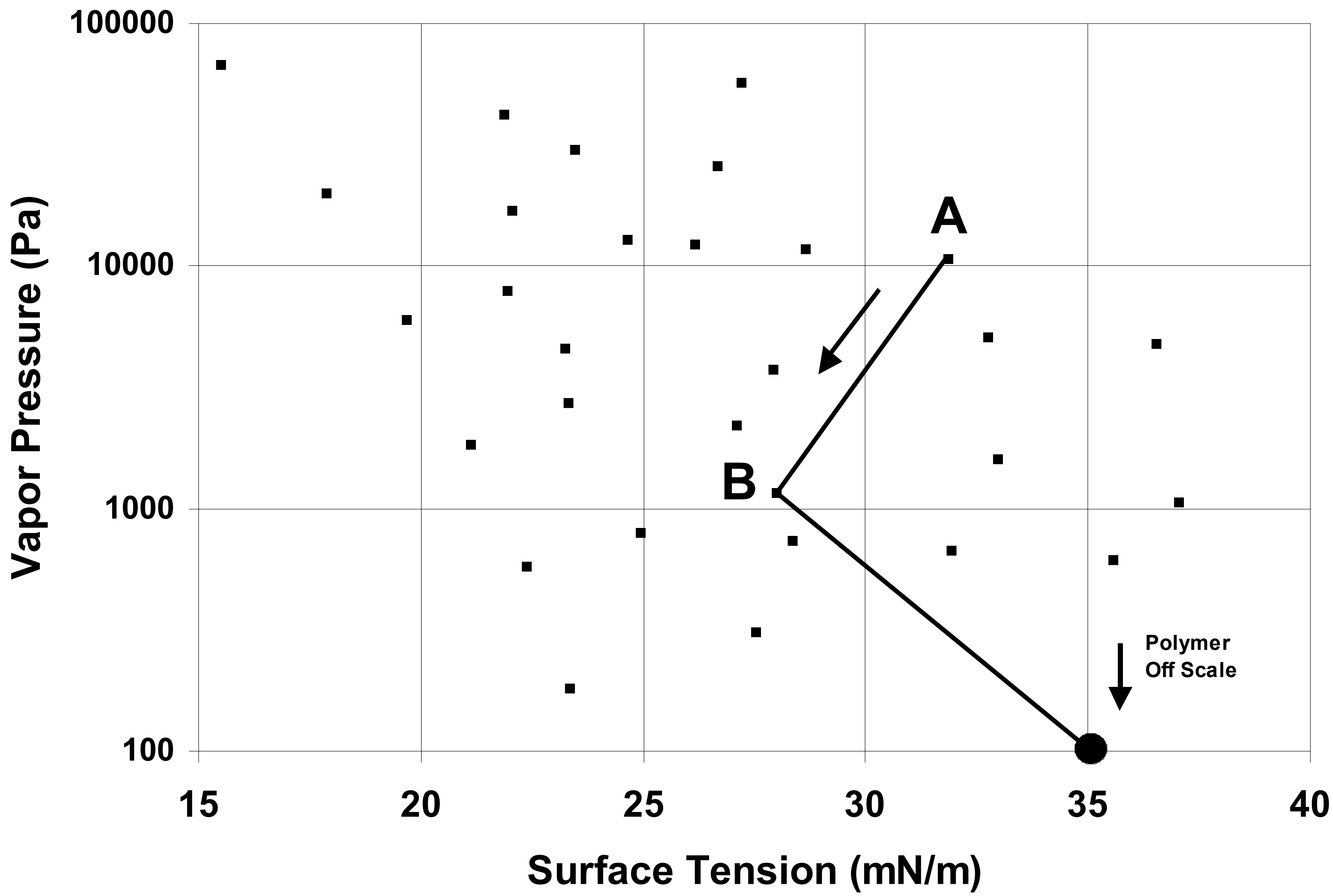
Selecting a Solvent



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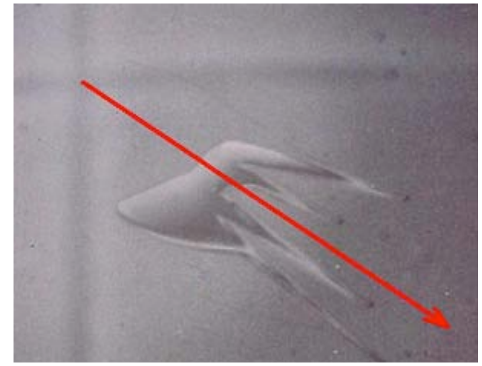
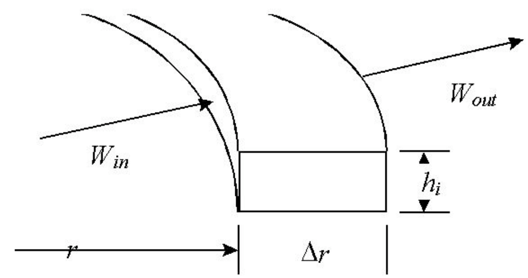
Other Coating Quality Studies

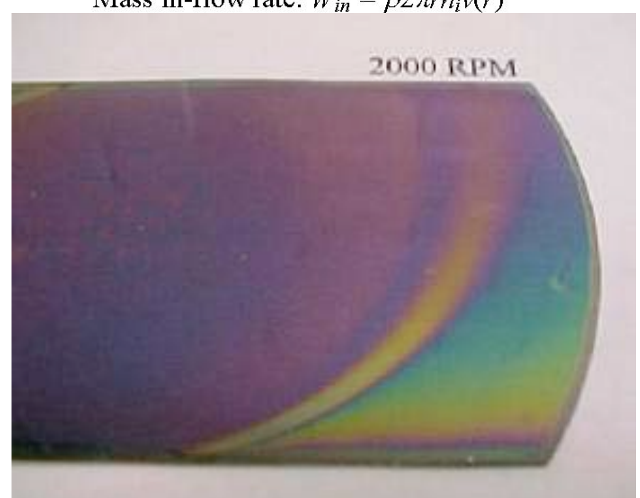
- Understanding How Coatings Form
- Analysis of Coating Defects
  - Unintended Thickness Variations
  - Roughness Assessment
- Coating Solution Chemistry Studies – Surface Tension Effects
- Nanoparticle Containing Coatings
- Coatings Applications Areas
  - Solar, Microelectronics, Optical





Volume of annulus = $2\pi r \Delta r h_i$

Mass in-flow rate: $W_{in} = \rho 2\pi r h_i v(r)$



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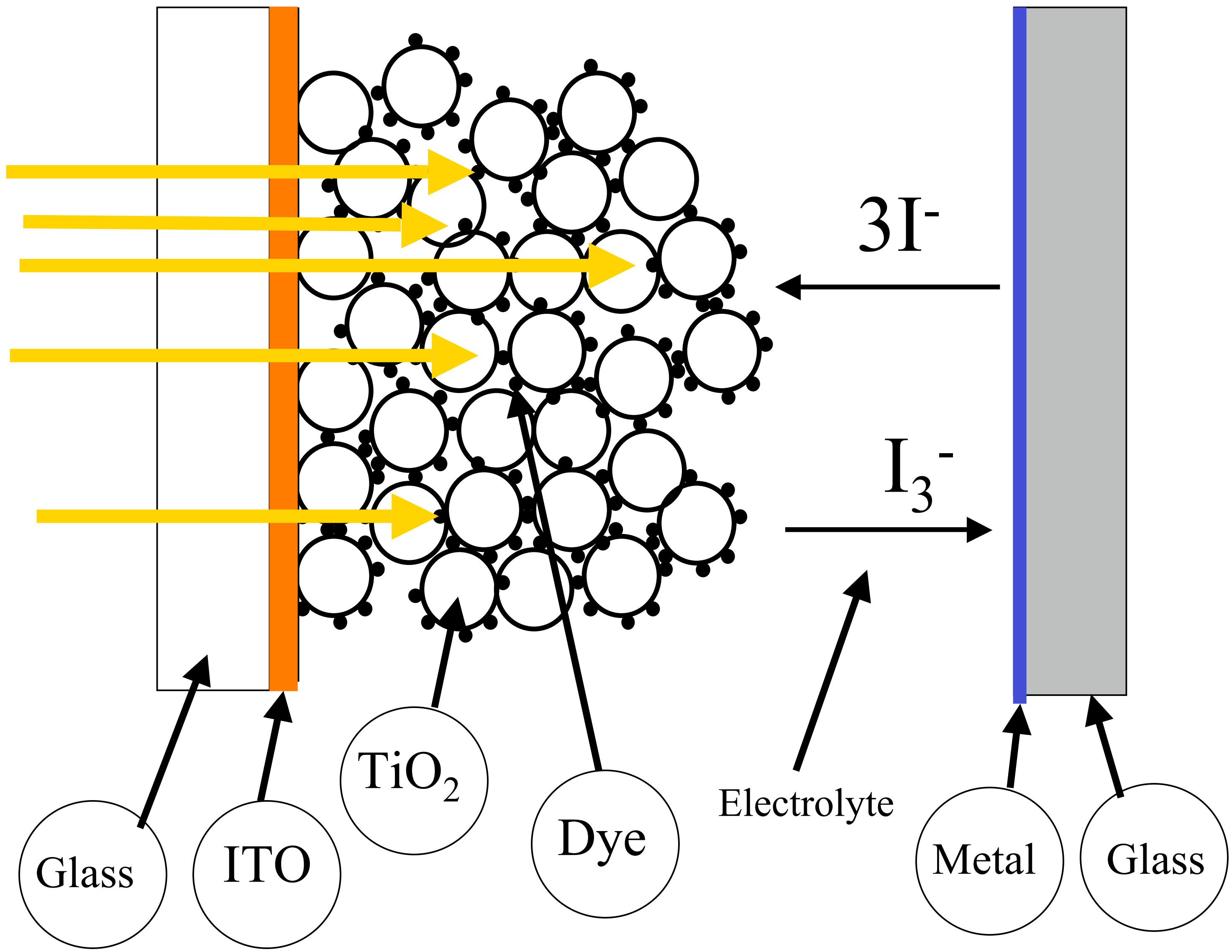

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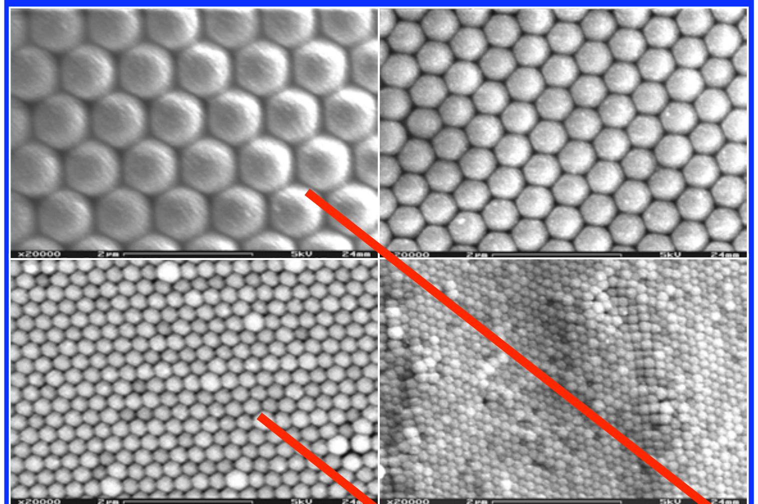
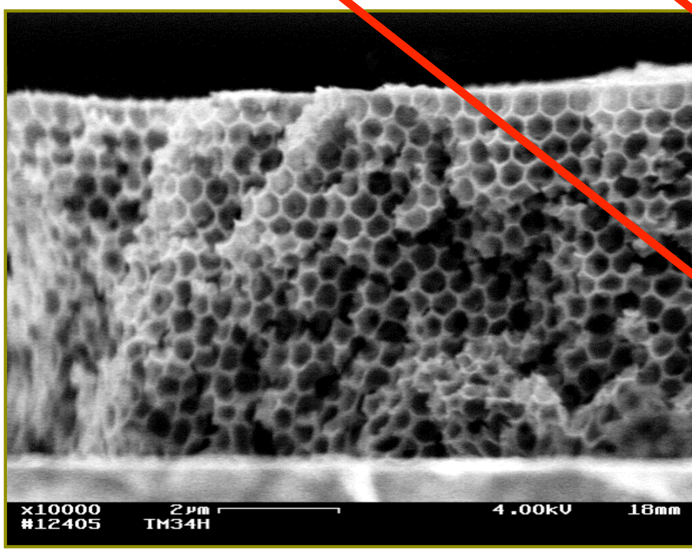
Self-assembled polystyrene

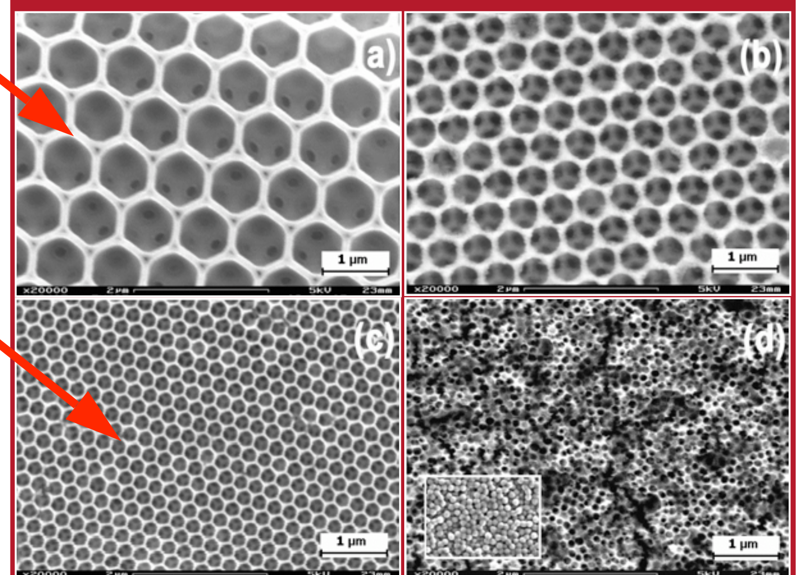




Nanostructured TiO_2 films with controllable porosity and pore size.

Sample	Ave. pore size (nm)	Brunauer-Emmett-Teller (BET)		
		Spec. surf. area (m^2/g)	Roughness factor (/µm)	Porosity (%)
A	1000	33.2	53.7	61.5
B	600	60.1	69.7	71
C	300	119.1	148.1	70.4
D	160	137.2	197.1	65.8

Ultra-porous TiO_2 films



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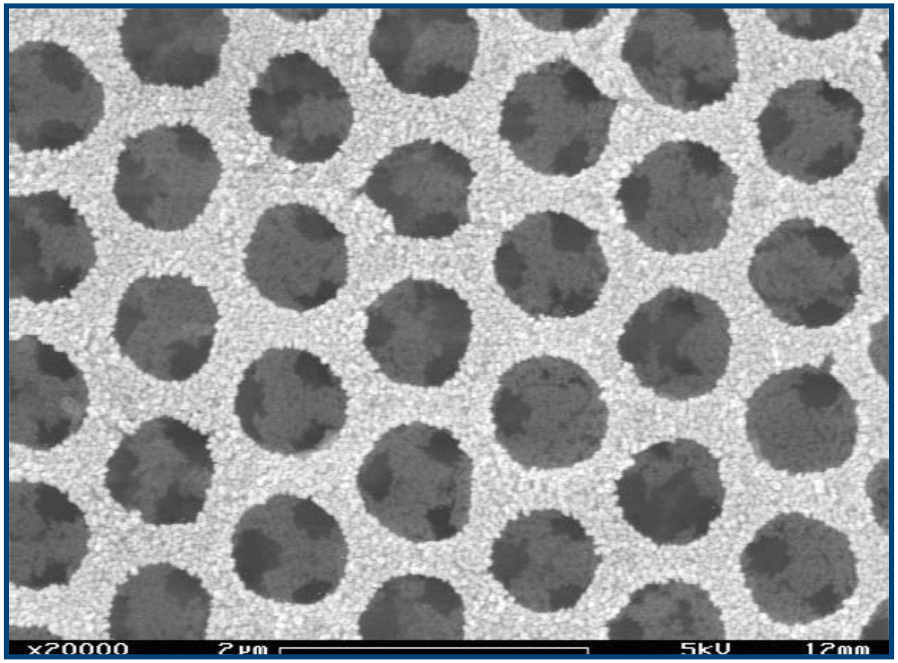
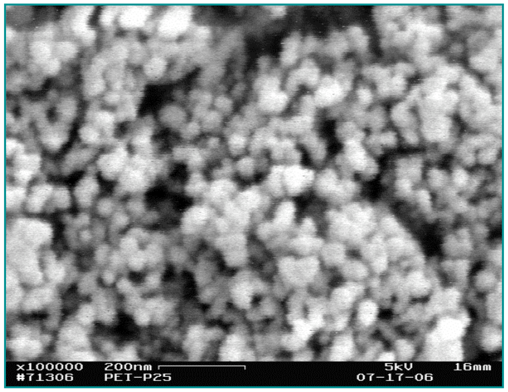
Prototype nanostructure

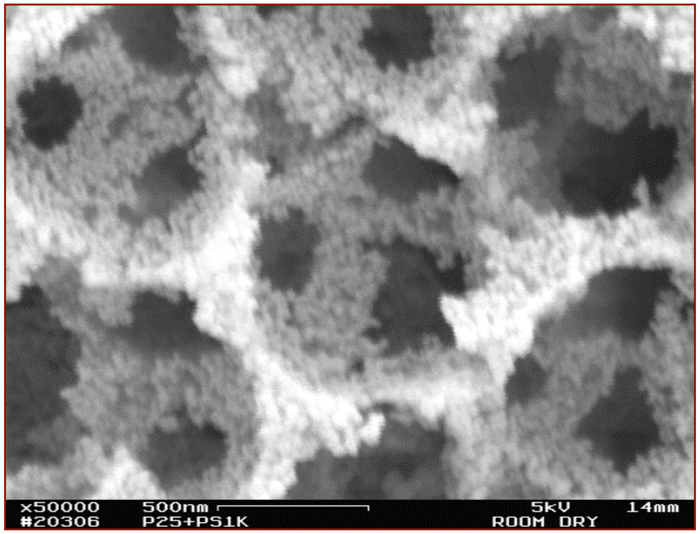
Templated TiO_2 nanoparticles (Degussa, P25)



← Typical templated P25 films with very few cracking and good adhesion.

↓ Pure P25 film





↖ Dual-porosity P25 film

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journal

J. Am. Ceram. Soc., ■■ [■■] 1–5 (2009)
DOI: 10.1111/j.1551-2916.2009.02970.x

Dye-Sensitized Solar Cells Based on TiO_2 Coatings with Dual Size-Scale Porosity

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Dye-sensitized solar cells with efficiencies greater than 4% were produced with templated "inverse opal" titania coatings. A novel one-step method produces uniform and crack-free coatings made using commercially available titania nanoparticles with high reproducibility and uniformity. In this research, a volatile solvent electrolyte was tested; however, it shows proof-of-concept that larger pore volumes can be created for increased penetration of more viscous electrolytes that can be utilized in high-efficiency cells. This dual size-scale porosity film is a promising structure for DSC applications, especially for those solid-state or quasi-solid-state cells that require polymer electrolytes.

I. Introduction

DSCs' are photoelectrochemical cells based on sensitized semiconductor–electrolyte interfaces,[1,2] which were first introduced

surface area also allows for a greater possibility of recombination between the electrolyte and the titania layer. If a titania particle is not covered in dye and an injected electron passes back to the electrolyte instead of through to the back electrode, current loss is encountered. A similar balance is observed for the pore volume as more pores allow the electrolyte to reach every dye molecule, which is necessary for sustained high current, but this can lead, again, to greater recombination between the electrolyte and the titania layer.

It has been shown that the optimized TiO_2 film geometric structure is that of mesoporous channels aligned in parallel to each other and perpendicular to the electrode substrate.[10,11] A good model for this concept is organized TiO_2 nanorod or nanowire arrays aligned perpendicular to the transparent conducting oxide (TCO) substrate, which can be produced by a sol–gel method with a template or in an oxidizing environment.[12,13] However, aligning the nanorods/wires into an organized structure on top of a TCO substrate rather than on opaque metal

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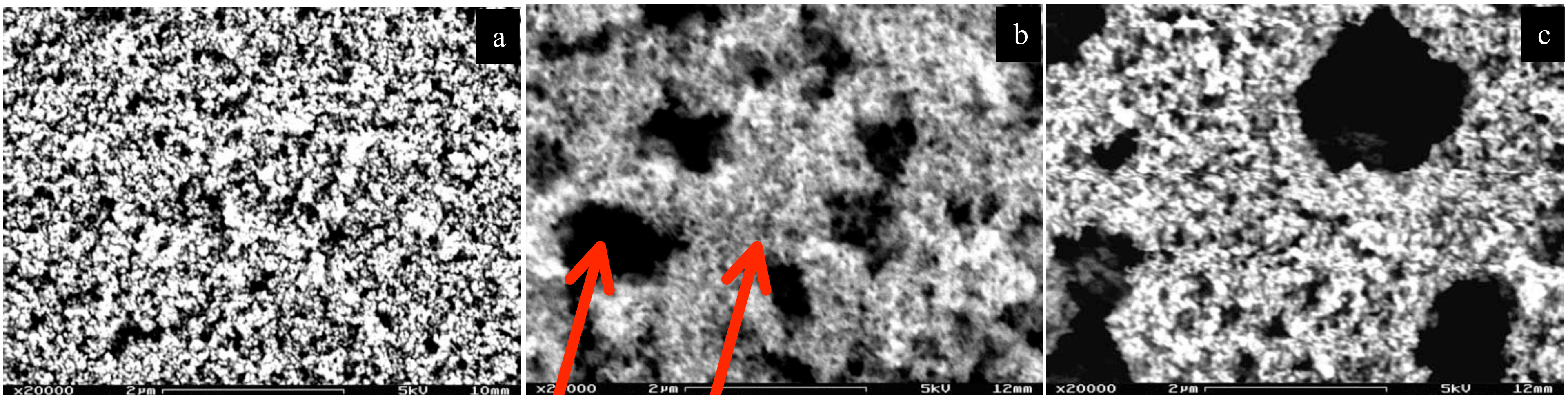
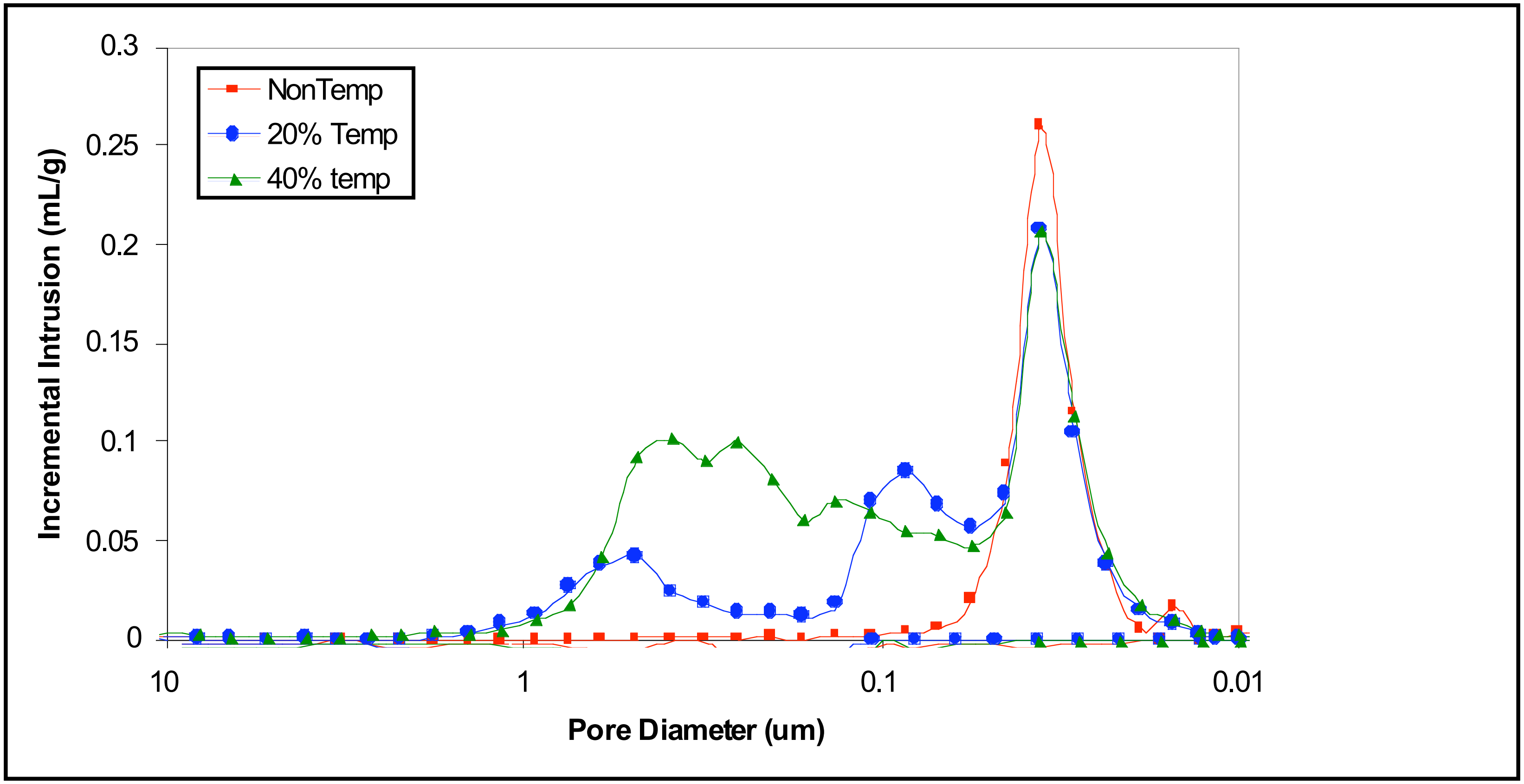
Microstructure Comparison



Non templated titania | **20% emulsion templated** | **40% emulsion templated**

Dual Porosity – Macro and Meso Pores

Porosimetry



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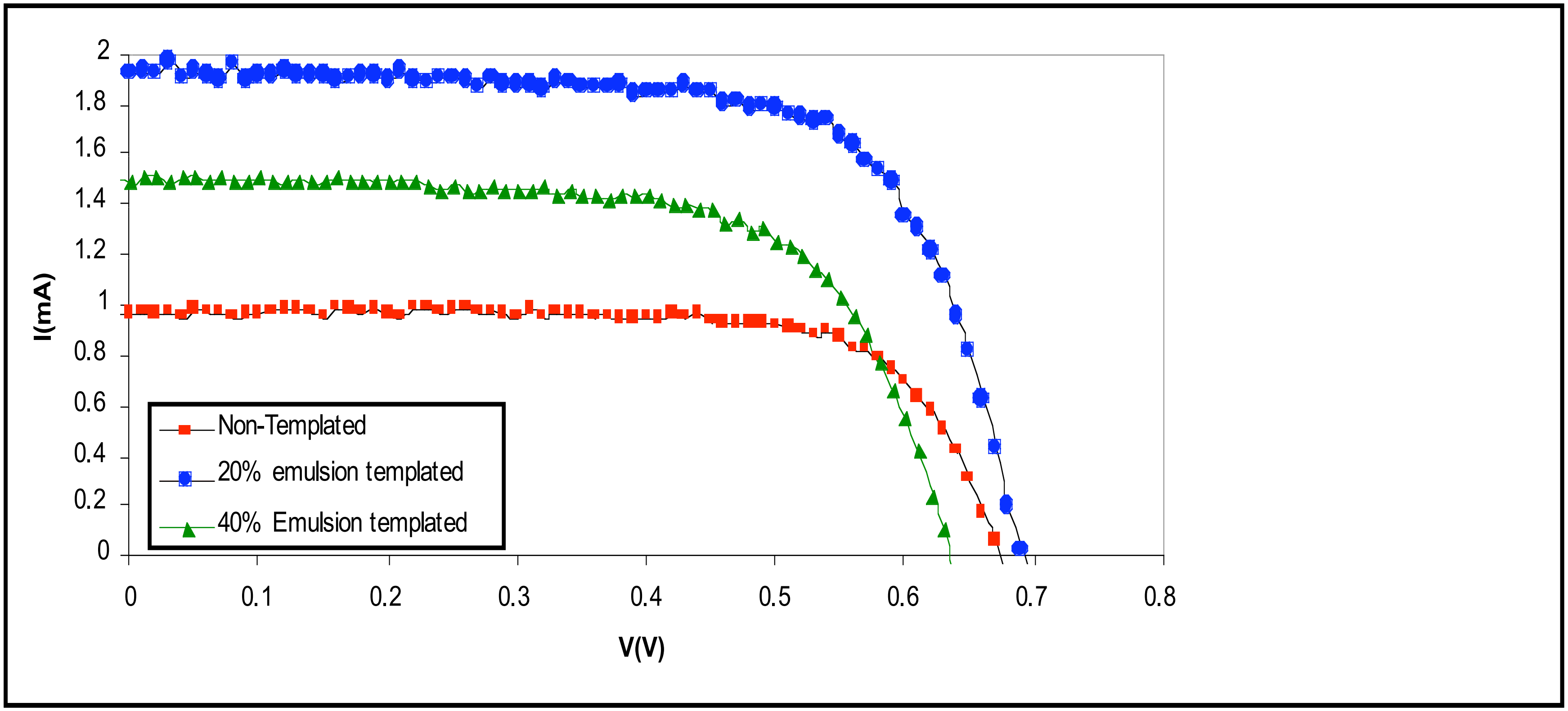
I-V Characteristics



Cell	Photo Current (mA)	Photo voltage (mV)	Fill Factor	Efficiency (%)	Thickness (micron)
Non templated	0.96	0.68	0.74	2.17	17
20% emulsion templated	1.93	0.7	0.69	4.17	20
40% emulsion templated	1.49	0.64	0.67	2.86	29

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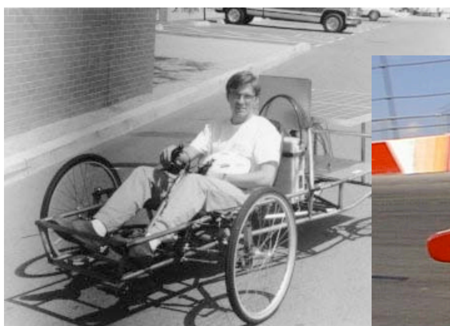
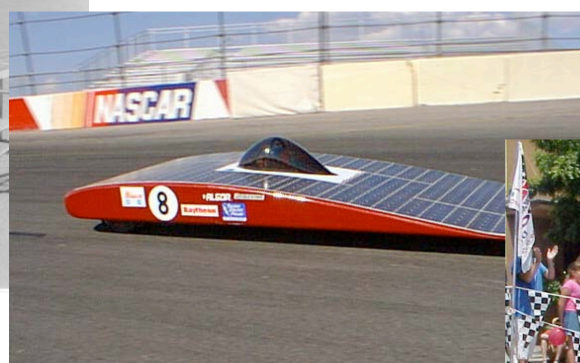
Solar Car Racing Experience

1997 — *1998* — *1999* — *2000* — *2001* — *2002* — *2003*



The Mule



Daedalus

Monsoon

Turbulence

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Journal of Power Sources 186 (2009) 539–542

Contents lists available at ScienceDirect

Journal of Power Sources

journal homepage: www.elsevier.com/locate/jpowsour

Short communication

Solar-to-vehicle (S2V) systems for powering commuters of the future

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ARTICLE INFO

Article history:
Received 14 August 2008
Accepted 27 September 2008
Available online 17 October 2008

Keywords:
Solar power
Hybrid electric vehicles
Plug-in hybrids
Commuter vehicles

ABSTRACT

Hybrid electric vehicles are growing in popularity and significance in our marketplace as gasoline prices continue to rise. Consumers are also increasingly aware of their carbon "footprint" and seek ways of lowering their carbon dioxide output. Plug-in hybrid and electric vehicles appear to be the next wave in helping transition from a gasoline-based transportation infrastructure to an electric-grid-sourced mode, though most plug-in scenarios ultimately rely on having the electric utilities converted from fossil sources to renewable generation in the long run. At present, one of the key advantages of plug-in hybrid/electric vehicles is that they can be charged at home, at night, when lower off-peak rates could apply. The present analysis considers a further advancement: the impact of daytime recharging using solar arrays located at commuters' work sites. This would convert large parking areas into solar recharge stations for commuters. The solar power would be large enough to supply many commuters' needs. The implications for electric car design in relation to commuter range are discussed in detail.

1. Introduction

Recent discussions of climate change have focused on anthropogenic sources of carbon dioxide and the cumulative effect of these emissions that, over time, are expected to have grave impacts on

"regenerative braking" that then recoups some of the car's motional energy and recharges the battery a bit every time you hit the brakes instead of the normal frictional losses.

As soon as hybrid vehicles became available, hobbyists and electric vehicle enthusiasts were quick to design custom conver-

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Connections??

- Fluid flow, rivulet formation, instability, etc…. Connection to liquid lithium curtain flow?

- Dense ceramic fabrication to prevent erosion in plasmas?
- Coatings to prevent interactions??