Transportation Vehicle Light-Weighting with Polymeric Glazing and Mouldings

Reinhold H. Dauskardt *(dauskardt@stanford.edu)*

Organosilicate Films and Coatings
Scott Isaacson, Joe Burg, Siming Dong, Michael Hovish, Florien Hilt

Polymers and Hybrid Nanomaterials
Jeff Yang, Marta Giachino, Qiran Xiao, Linying Cui, Zhenlin Zhao, Yichuan Ding

Membranes for Fuel Cells and Batteries
Daisy Yuen

Complex Multi-Junction Device Structures
Ryan Brock

Photovoltaic and Flexible Electronic Materials
Fernando Novoa, Chris Bruner, Stephanie Dupont, Nick Rolston, Warren Cui, Brian Watson

Biological Hybrids

Krysta Biniek, Jacob Bow, Chris Berkey, David Kanno

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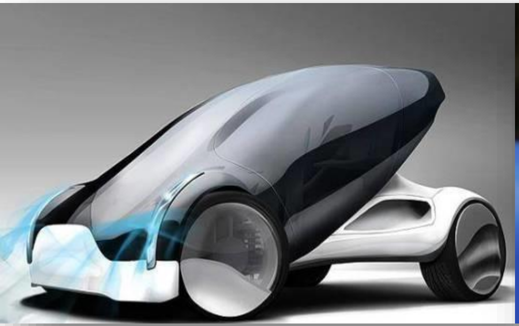
DOE-BES and AFOSR programs on hybrid materials, BA PV Consortium, Stanford-GCEP program on lightweighting.

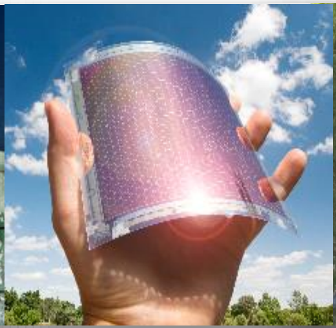
WORLD MATERIALS FORUM

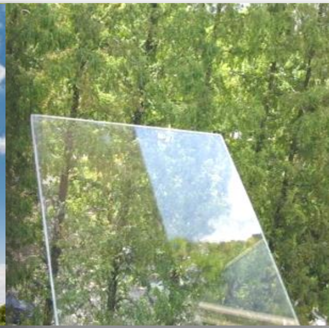
Processing and Thermomechanical Reliability of Hybrid Films


light-weight vehicle


touch display


wearable

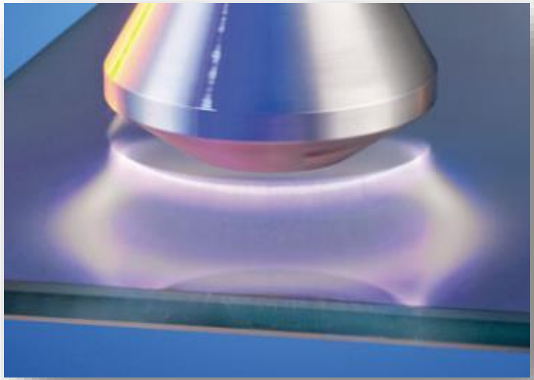

sensors and PV


AR coatings

…current polymeric glazings do not meet durability/performance requirements for near-term implementation

Coatings and deposition methods need improvement

- Vacuum-based techniques: high cost and inconvenient
- Solution-based techniques: multiple steps, coating low crosslinking density, solvents pollution


atmospheric plasma

Outline

- Coating Reliability and Lifetimes
  - coating characterization techniques for reliability
  - accelerated testing and lifetime prediction
- Protective and Transparent Coating Systems
  - controlling organosilicate molecular structure
  - bi-layers with optimized adhesion and hardness
  - strategies for incorporating UV protection
- Anti-Reflection Coating Systems
  - single and graded layer strategies
- Transparent and Conducting Films
  - applications for sensor and display technologies

Coating Reliability and Evolution of Defects

damage propagates if mechanical stresses are large enough so that

mechanical "driving force"

$$G \geq G_c \left[J/m^2 \right]$$

cohesion or adhesion

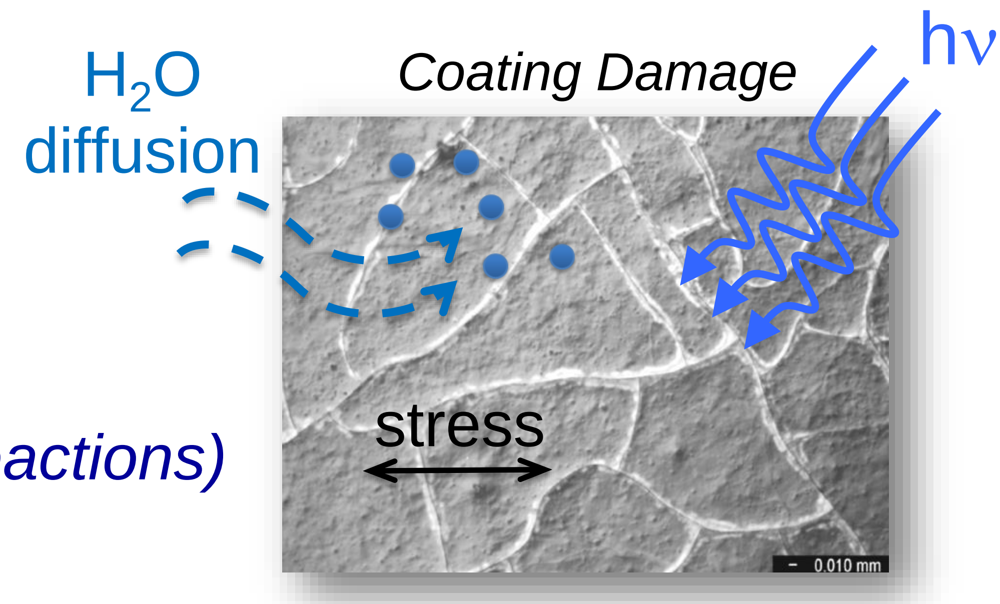
presence of chemical species and photons, damage propagates even if

$$G < G_c \left[J/m^2 \right]$$

environment and stress accelerates defect evolution

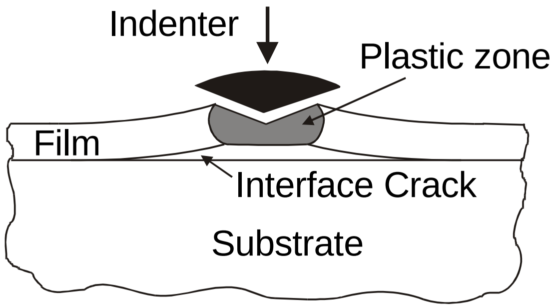
Role of coupled "stress" parameters in coating reliability and lifetimes:

- *mechanical stress*
- *temperature*
- *environmental species*
- *photons (photochemical reactions)*

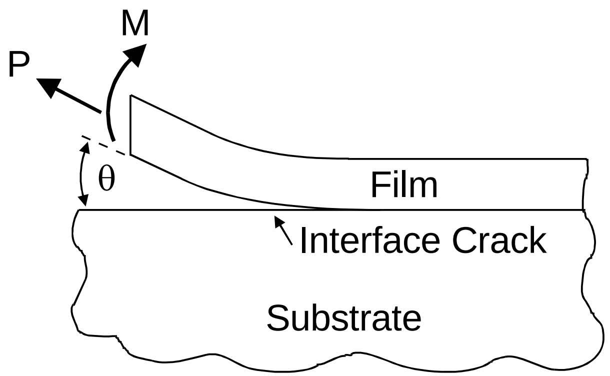


Limitations of Thin-Film Adhesion Tests

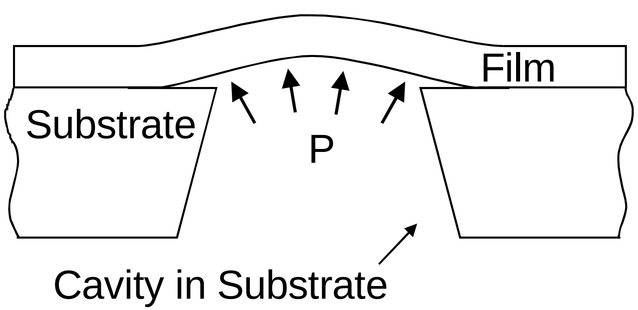
- Indentation/Scratch Test
  - complex stress and deformation fields
  - principally qualitative results
  - (nano) scratch test even less quantitative



- Peel/m-ELT Test
  - difficult to apply loads
  - plastic deformation of film
  - temperature complications in m-ELT



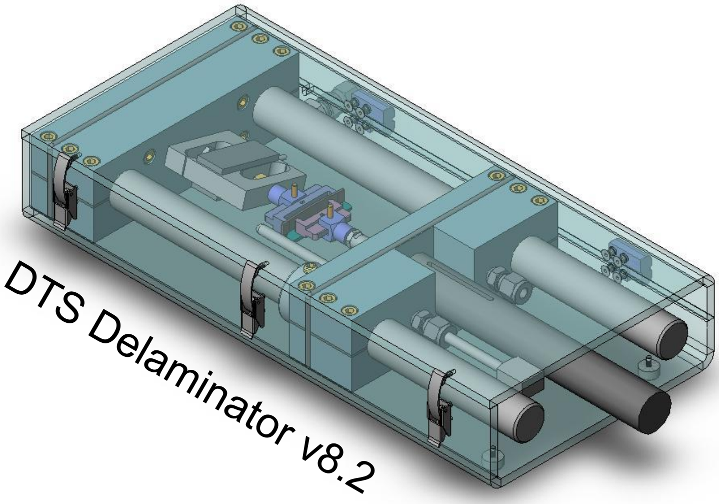
- Blister Test
  - compliant loading system
  - environmental effects
  - etching/machining of cavity difficult

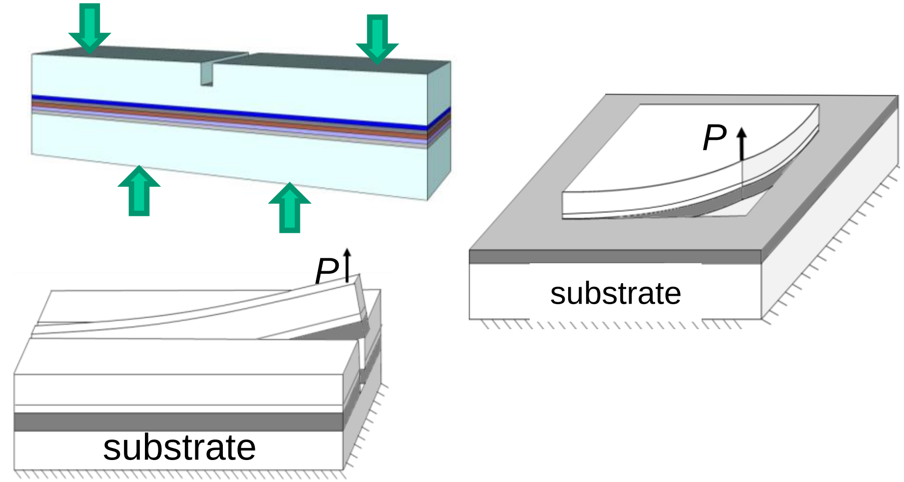


Major limitations: need detailed film properties, film stress relaxation and film plasticity

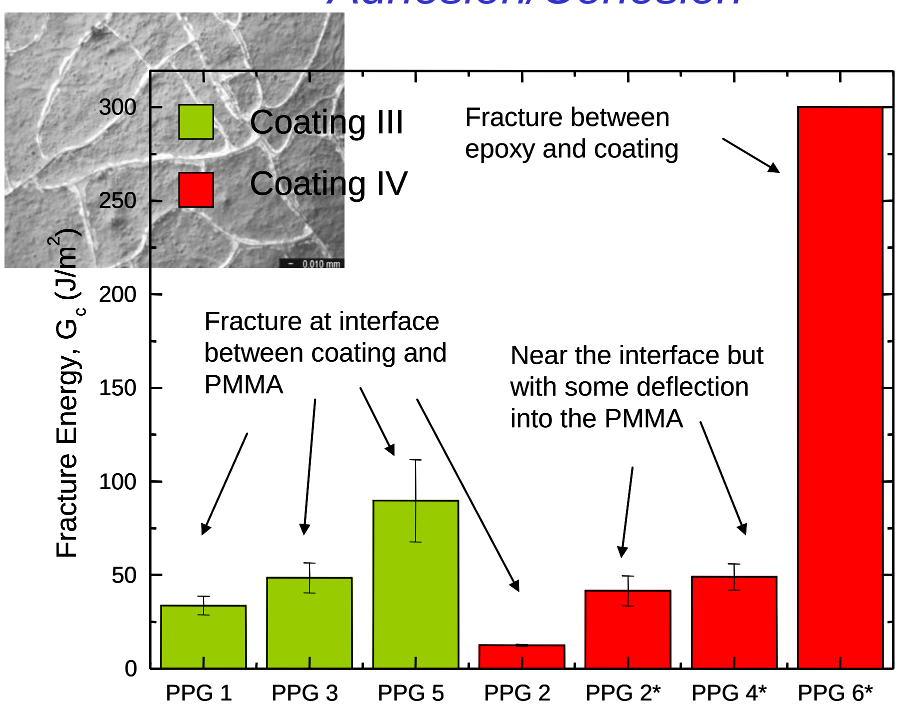
$\Rightarrow$ principally qualitative results for all above methods!

Quantitative Adhesion/Cohesion and Debond Kinetics

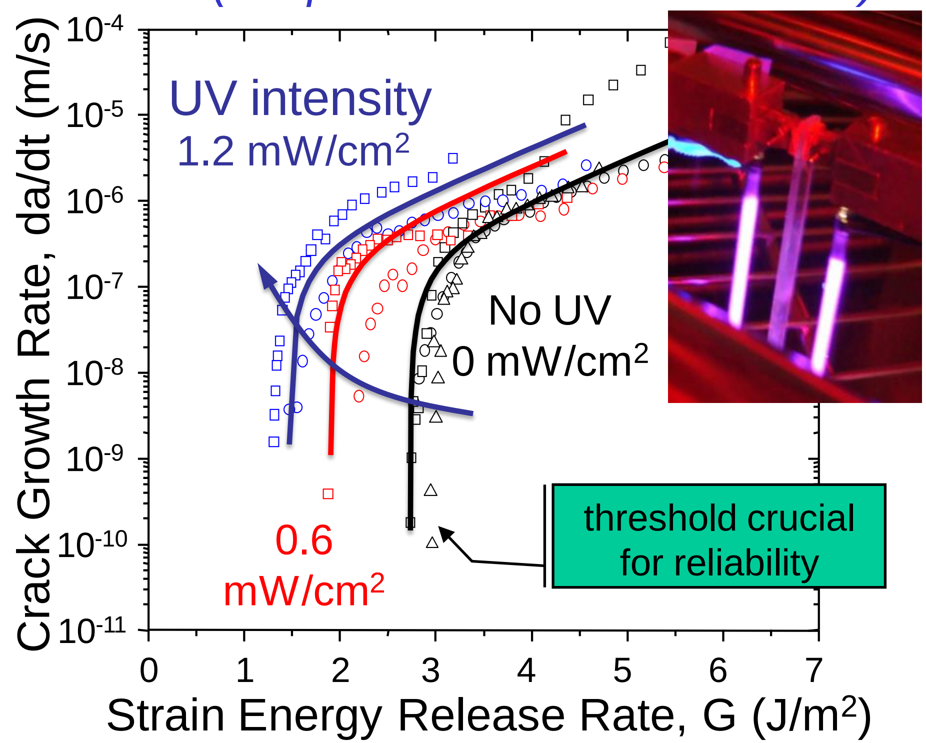




Adhesion/Cohesion



Degradation Kinetics (temp/environment /UV effects)



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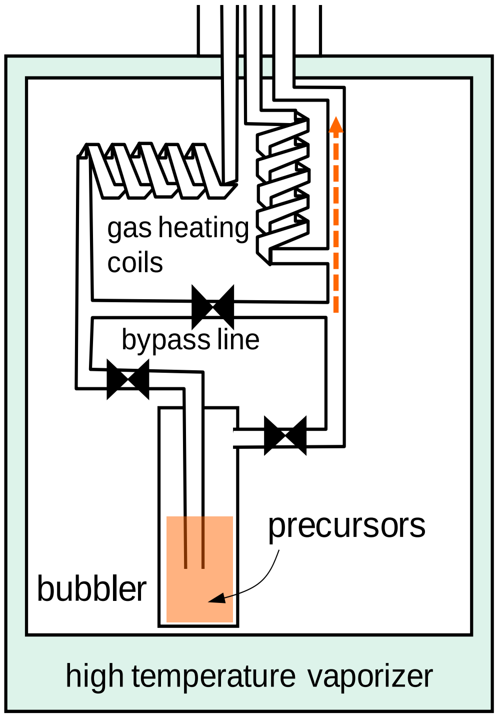
Atmospheric Plasma Deposition of Hybrid Films

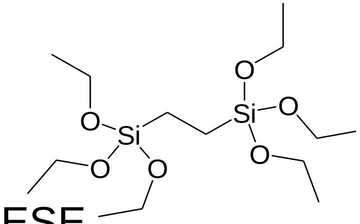
Innovation in Precursor Delivery



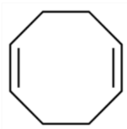
- higher molecular weight precursors
- higher boiling point
- larger range of material choices

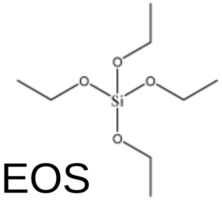
Capacitively Coupled Plasma

- *low temperature*
- *He and N_2 plasma gas*



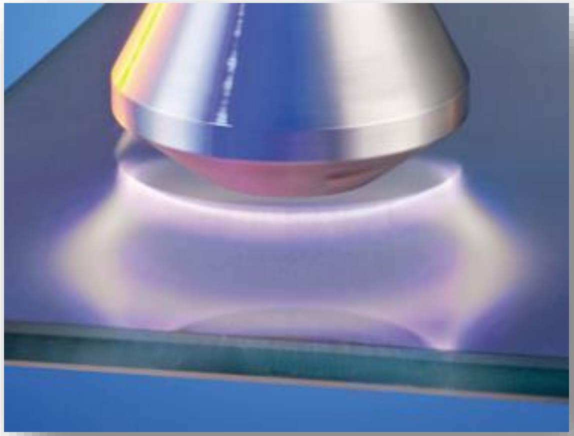
BTESE



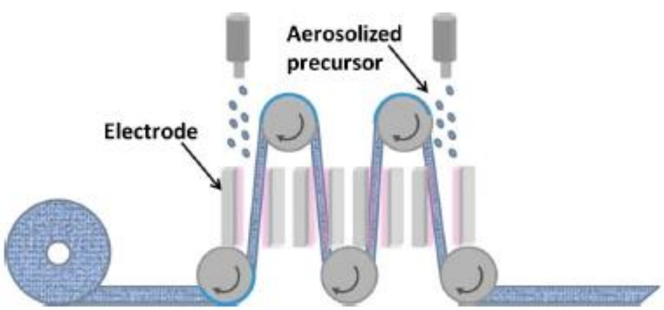


TEOS

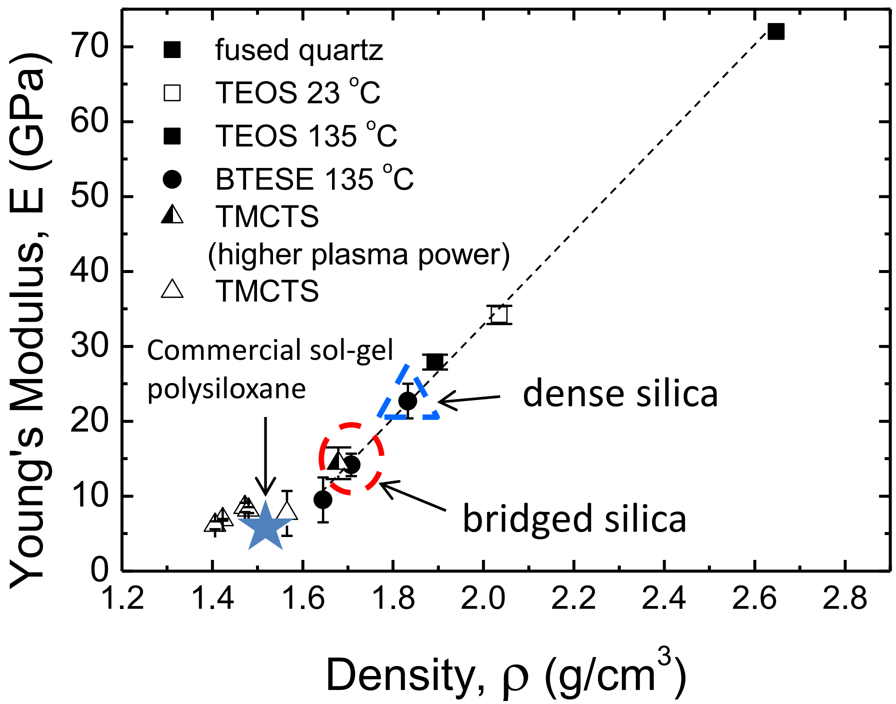
Dielectric Barrier Discharge Plasma

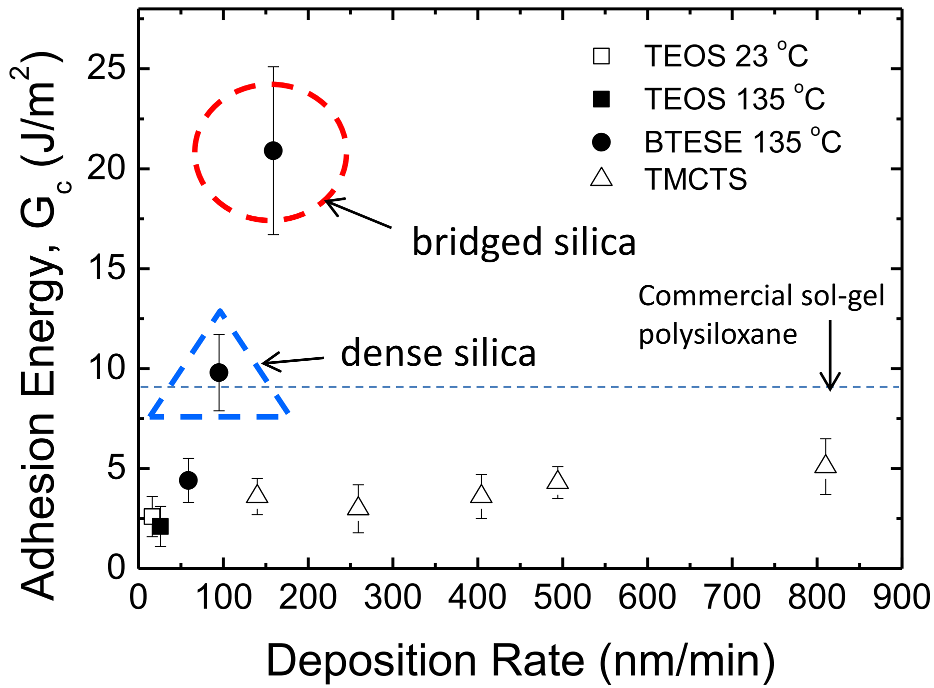


- *medium temperature*
- *N_2, O_2, air plasma gas*



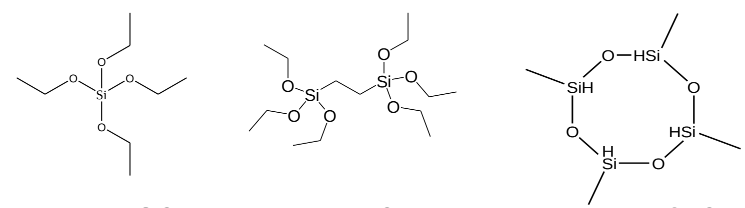
Silica Coatings Deposited by Atmospheric Plasma



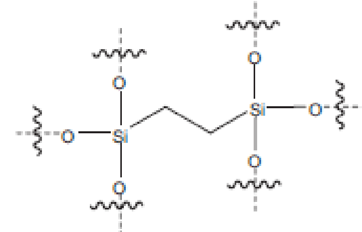


~100% visible transparency

Precursors studied:



TEOS BTESE TMCTS



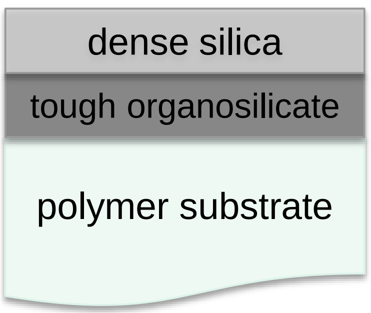
Molecular bridging

Cui, Dauskardt, et al., ACS Applied Mat Interfaces, 2012.

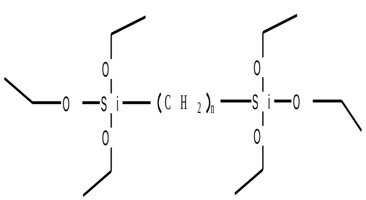
Single Precursor Method - Hard and Adhesive Bilayer

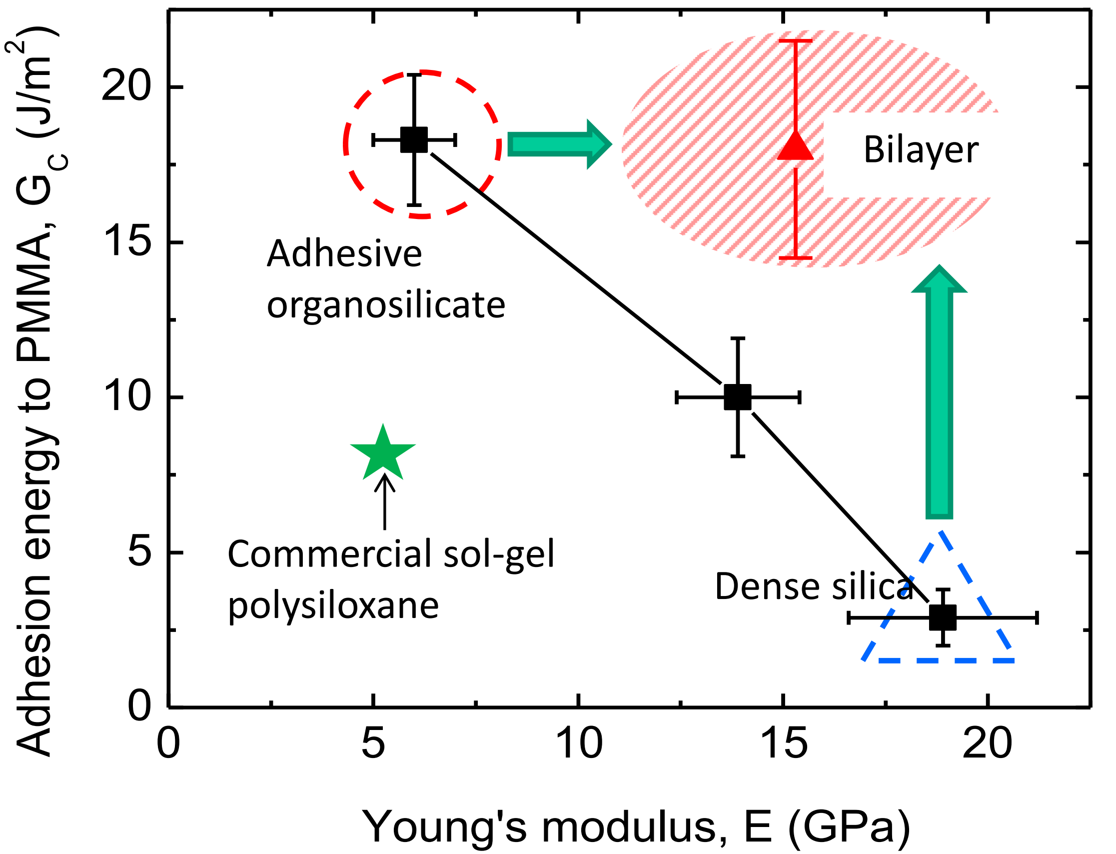
Integrate layers deposited under different conditions

- carbon-bridged organosilicate bottom layer exhibits excellent adhesion to PMMA
- dense silica top layer exhibits high hardness and scratch resistance



<u>Carbon bridged precursors</u>





Cui, Dauskardt, et. al., ACS Nano, 2014.

Strategies for Highly Adhesive Multilayer Deposition

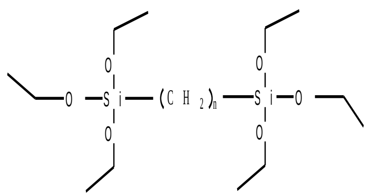
Integrate multi-layers layers deposited under different conditions

- high toughness carbon-bridged organosilicate bottom layer
- dense silica top layer with high hardness and scratch resistance
- ~100% visible transparency

Single precursor method

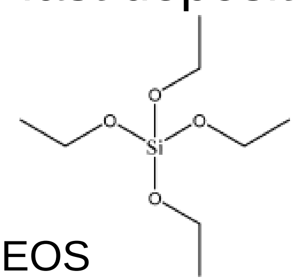
- graded or multi-layers

BTSE

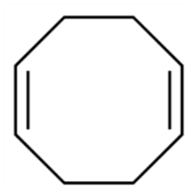


Multi-precursor method

- graded or multi-layers
- fast deposition

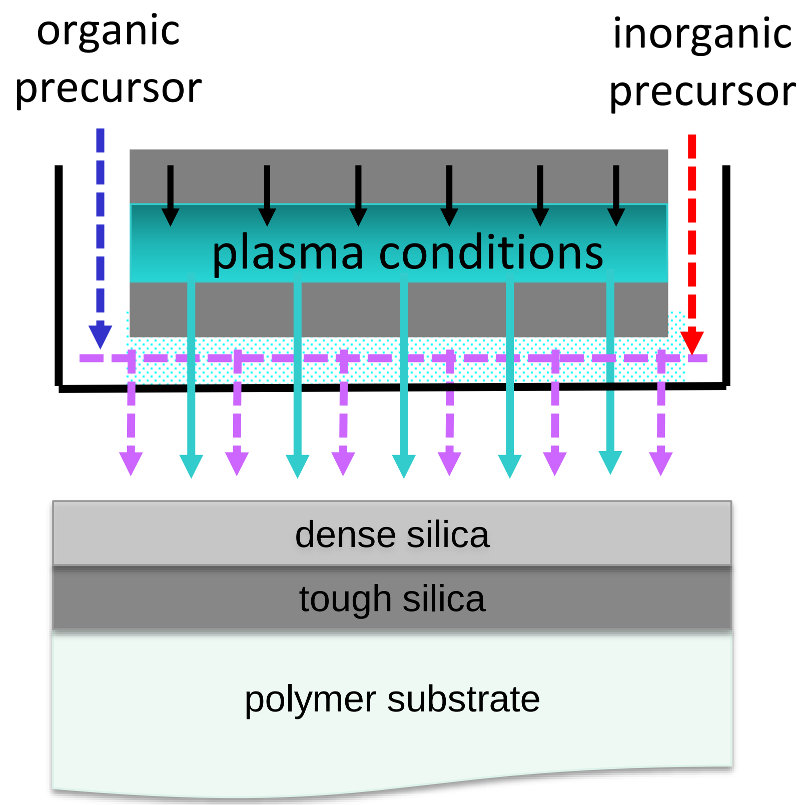


TEOS
widely used, cheap



1,5-cyclooctadiene
easy ring opening and
network former

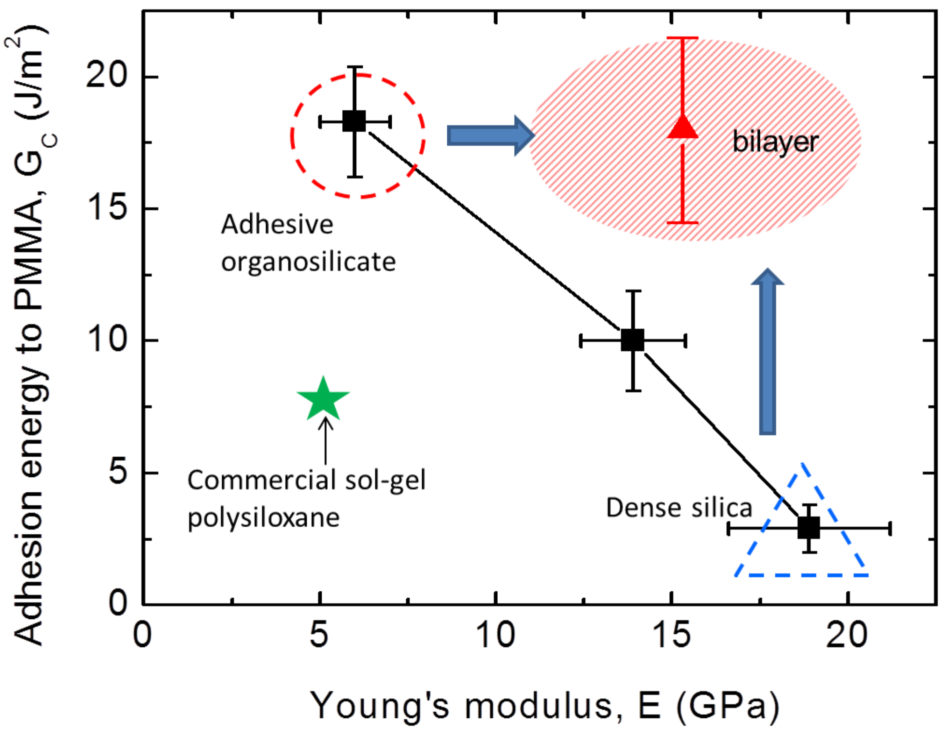
Processing Parameters



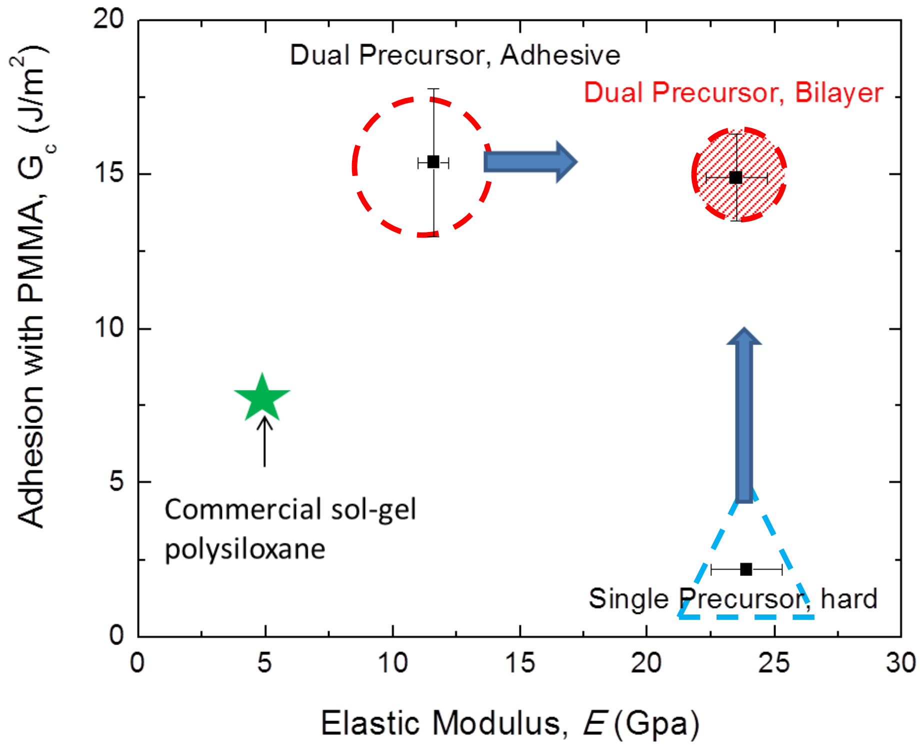
Strategies for Highly Adhesive Multilayer Deposition

Integrate bilayer deposition under single/dual precursors choice

- high adhesion organosilicate bottom layer and dense silica top layer
- ~100% visible transparency



Single Precursor Method



Dual Precursor Method

Cui, Dauskardt, et. al., ACS Nano, 2014.
Dong, Zhao, Dauskardt, ACS Appl. Mater. Interfaces, 2015.

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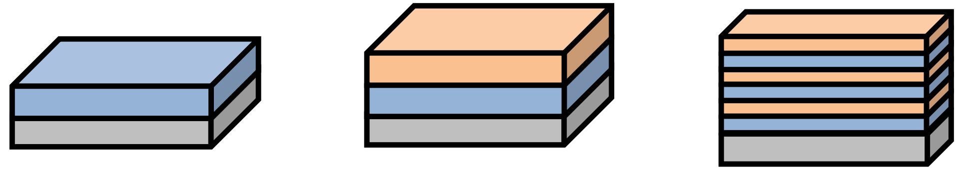
Atmospheric Plasma and Anti-Reflection Coatings (ARC)

Applications

- transportation windows
- sensor technologies
- ophthalmic lenses

Architecture

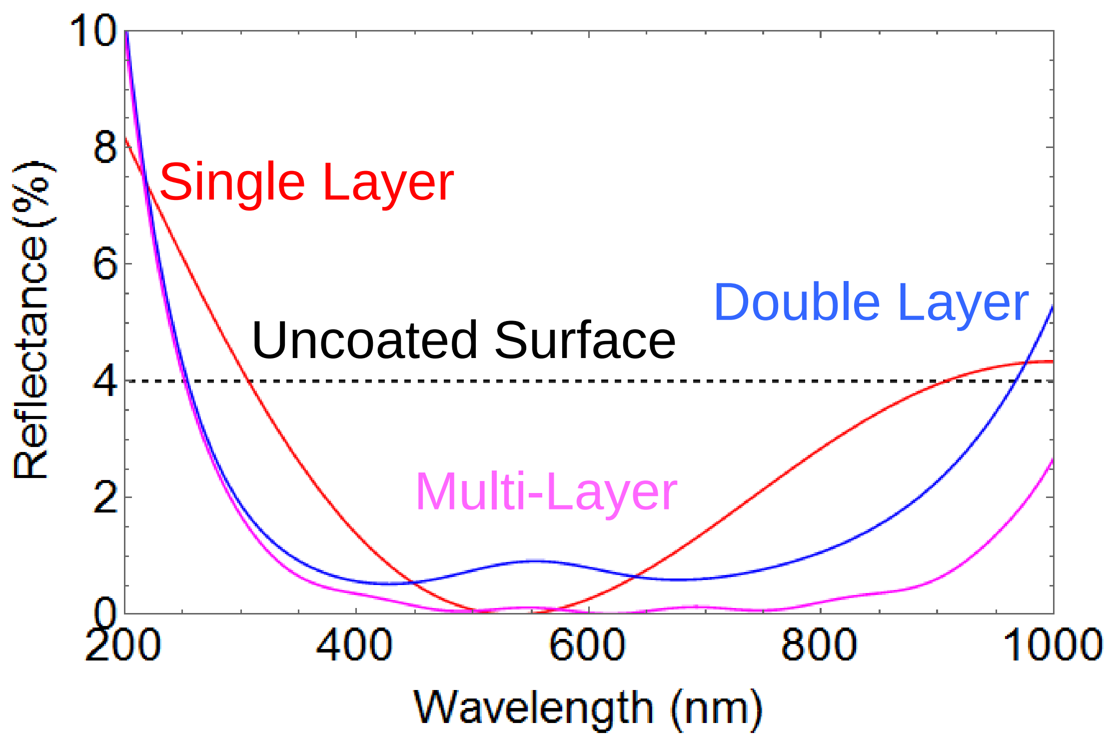
Single Layer | Double Layer | Multi-Layer



$$n_{slarc} = \sqrt{n_{sub} * n_{air}}$$

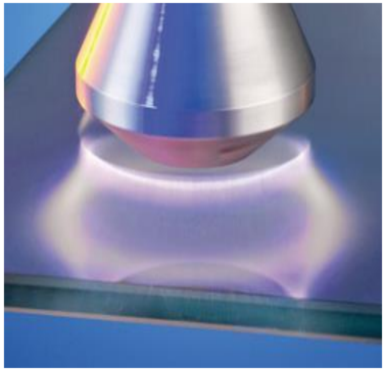
$$\frac{n_{air}}{n_{substrate}} = \frac{n^2{}_1}{n^2{}_2}$$

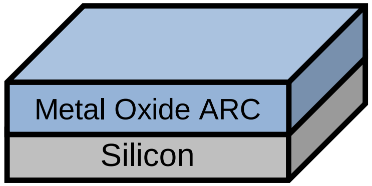
Alternate n_1,n_2 from DLARC

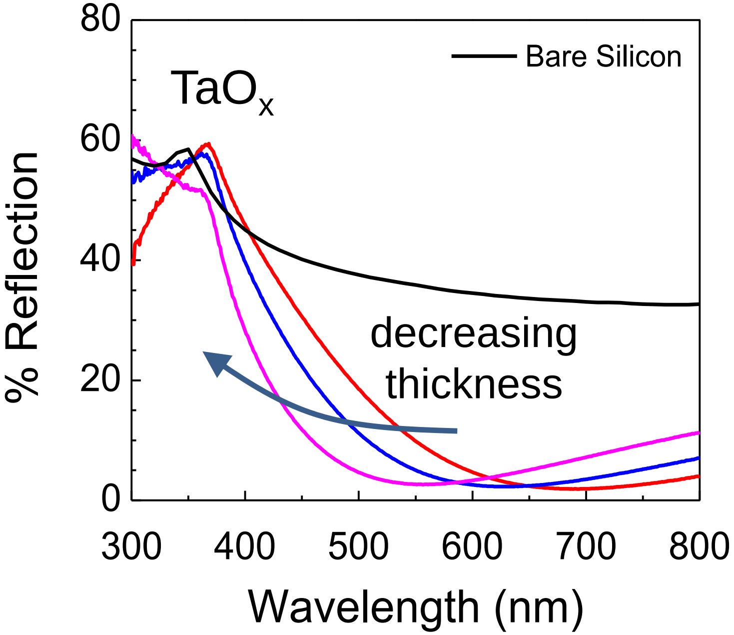


Atmospheric Plasma and Anti-Reflection Coatings (ARC)

Single Layer ARC

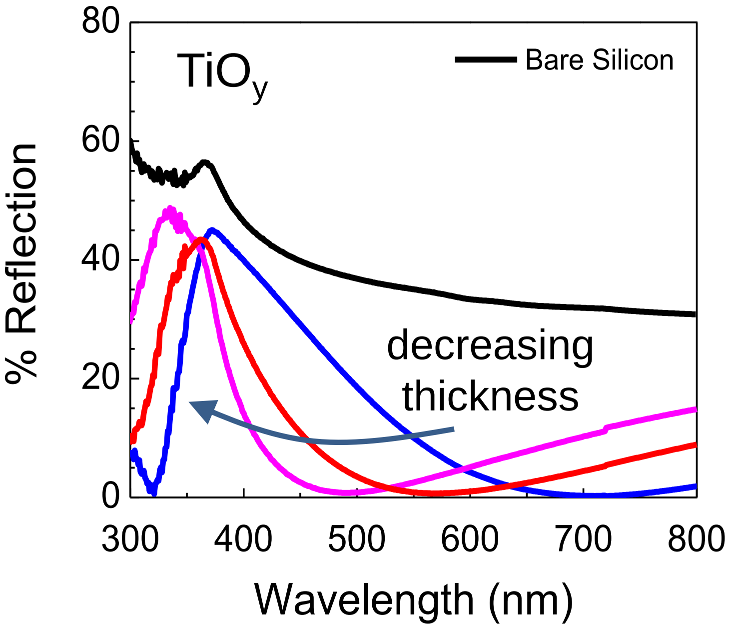






Significant AR reduction in both systems

SLARC	Average Reflectance	Absolute Reflection Minimum
Silicon	42%	38%
TaO_x	<7%	1.90%
TiO_y	<5%	0.3%



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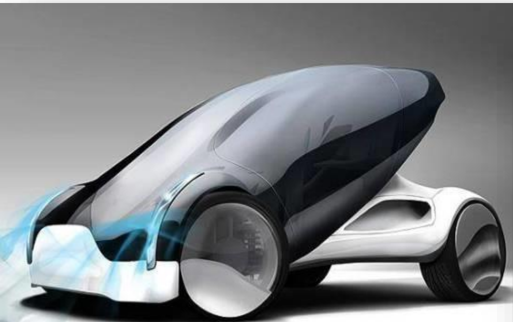
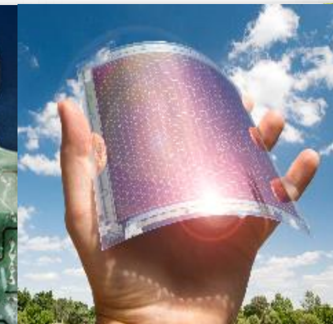
Deposition of Transparent Conducting ZnO Thin Films



light-weight vehicle

touch display

wearable



sensors and PV

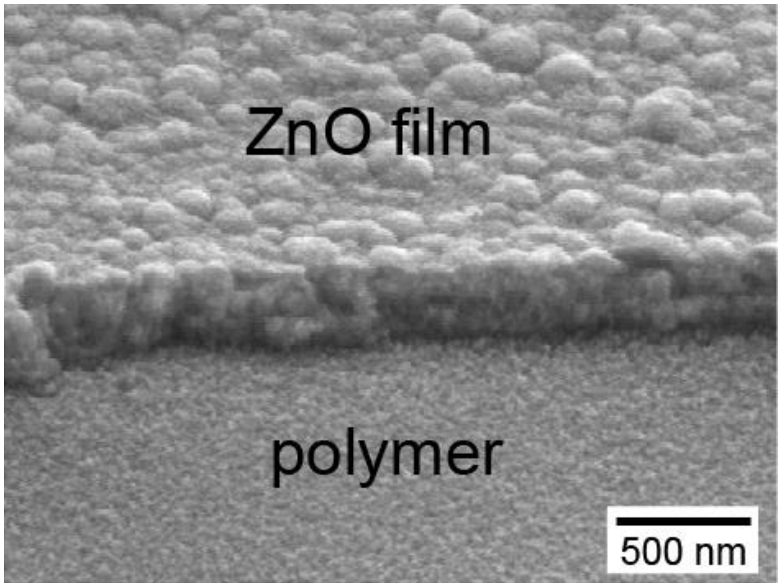
AR coatings

Characteristic features of ZnO:

- wide bandgap semiconducting material
- high electric conductivity
- high visible transmittance
- abundant resource
- replacement for Indium Tin Oxide (ITO)

…atmospheric plasma deposition of ZnO films in ambient air at low temperature on plastics.

Atmospheric Plasma Deposition of Transparent Conducting ZnO Thin Films



T_v = 98%

T_v = 84%

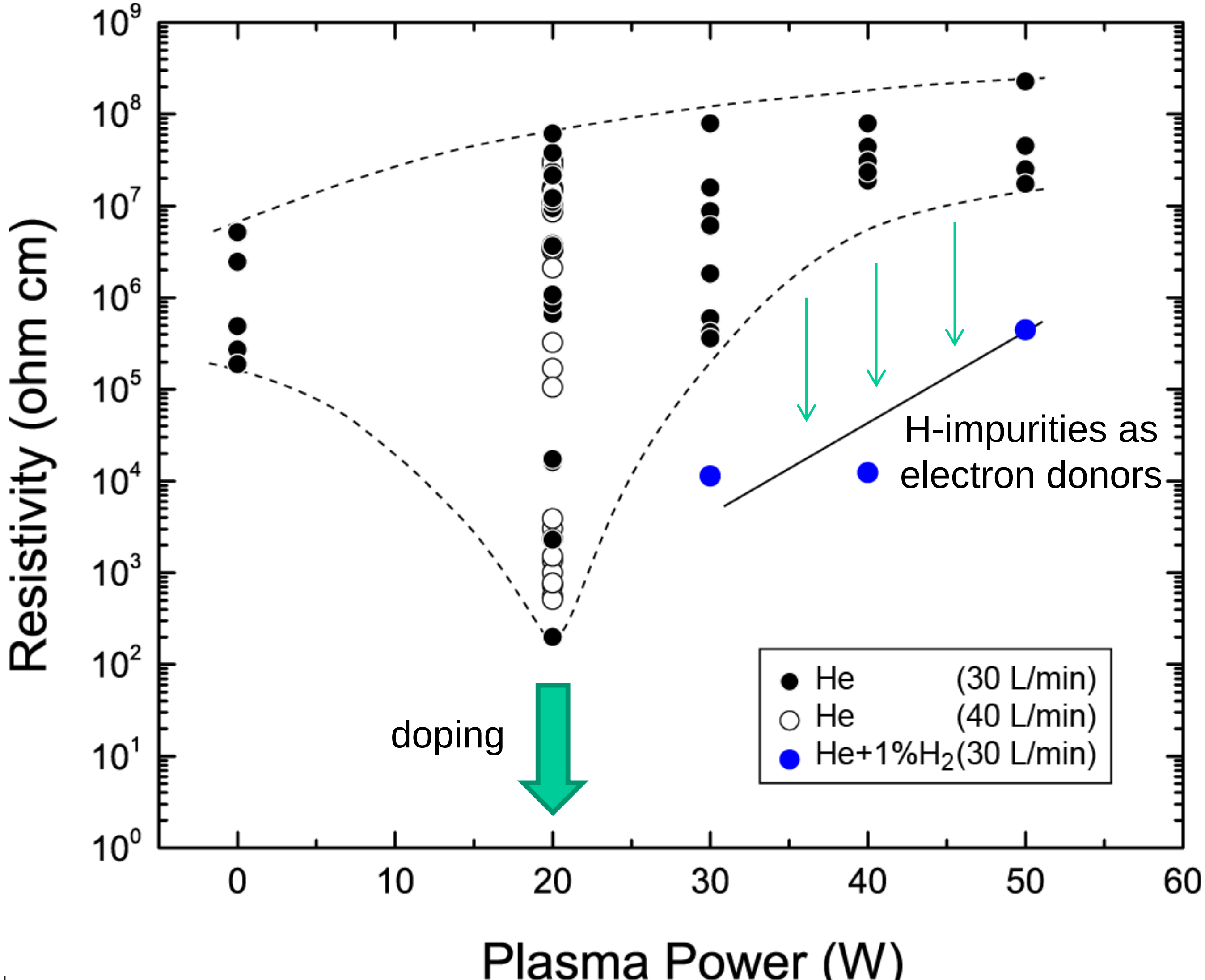
ZnO films with a transmittance above 98% successfully obtained in ambient air at 25 ºC by atmospheric plasma deposition.

- Precursor: Diethylzinc ($Zn(C_2H_5)_2$)

- Substrate: PMMA, PET, PC

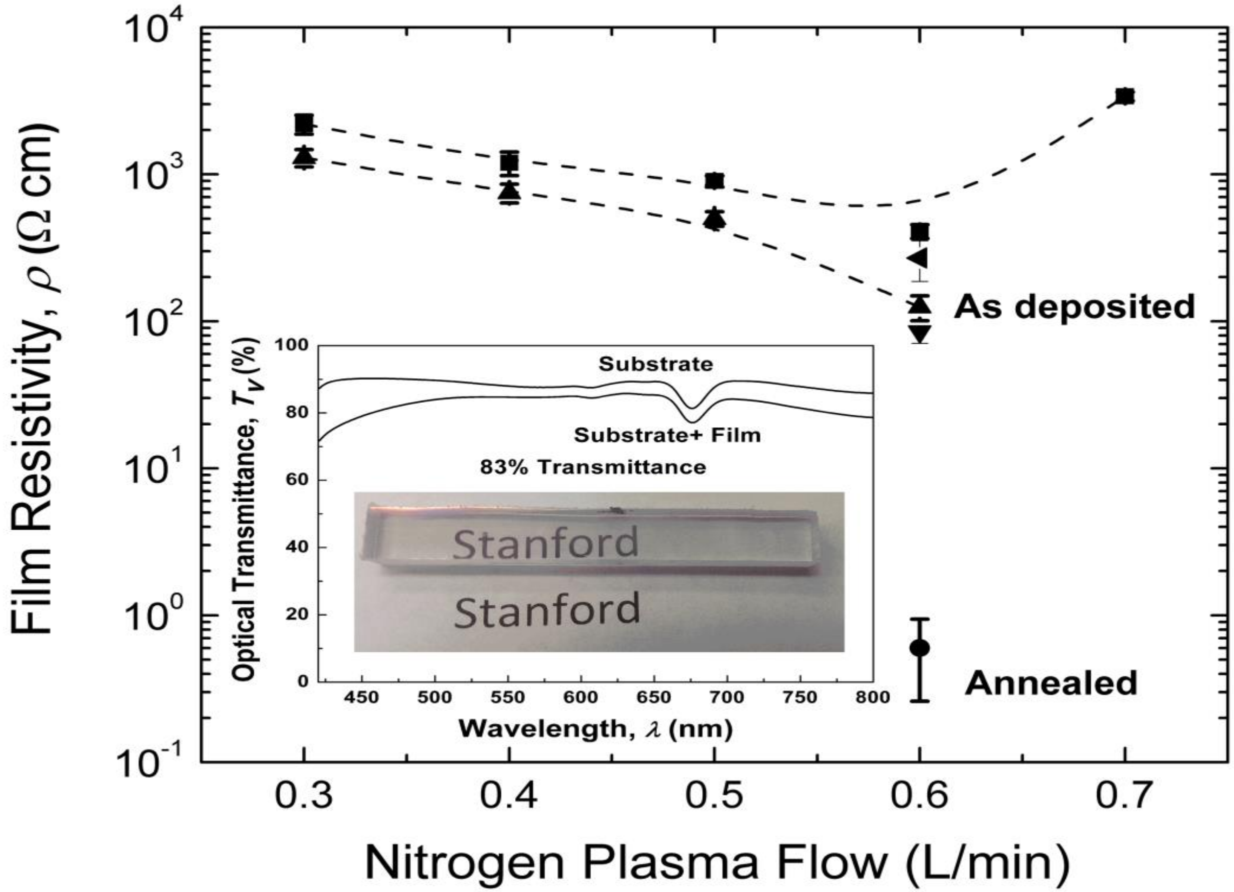
Watanabe and Dauskardt, Organic Electronics, 2014

Atmospheric Plasma Deposition of Transparent Conducting ZnO Thin Films



Watanabe and Dauskardt, Organic Electronics, 2014

Atmospheric Plasma Deposition of Transparent Conducting TiN_x/TiO_2 Hybrid Films



Visible transmittance ~80% and resistivity as low as 10^{-1} ohm cm successfully obtained in ambient air

Precursor: titanium ethoxide on PC substrate

Siming Dong and Dauskardt, **Advanced Functional Materials**, 2014

Summary

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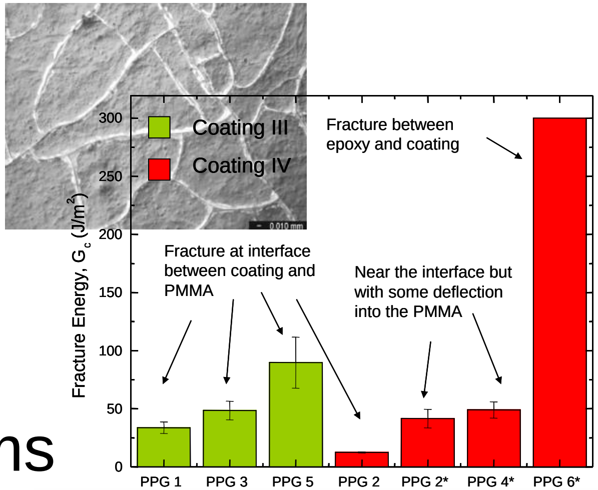
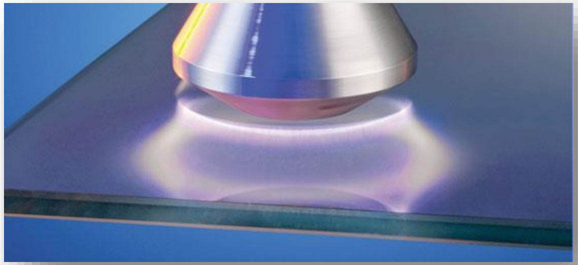
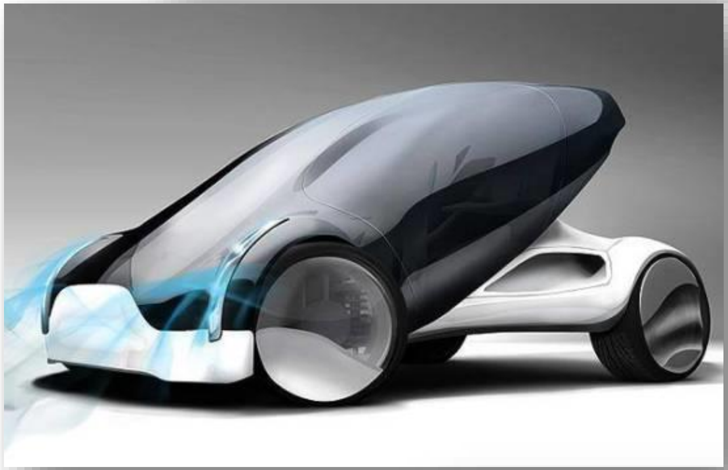
  - coating characterization techniques
  - accelerated testing and lifetime prediction



- Protective and Transparent Coating Systems
  - current polymeric glazings/windoes do not meet durability/performance requirements
  - hybrid coatings with optimized adhesion and hardness



- Anti-Reflection Coating Systems
  - single and graded layer strategies



- Transparent and Conducting Films
  - sensor and display technologies