Adhesion and Debonding Kinetics in PV Devices and Modules

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Fernando Novoa, Warren Cui (encapsulation and optics)
Scott Isaacson, Tissa Mirfakhrai (ultra barrier films)

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Adhesion and Debonding Kinetics in PV Devices and Modules

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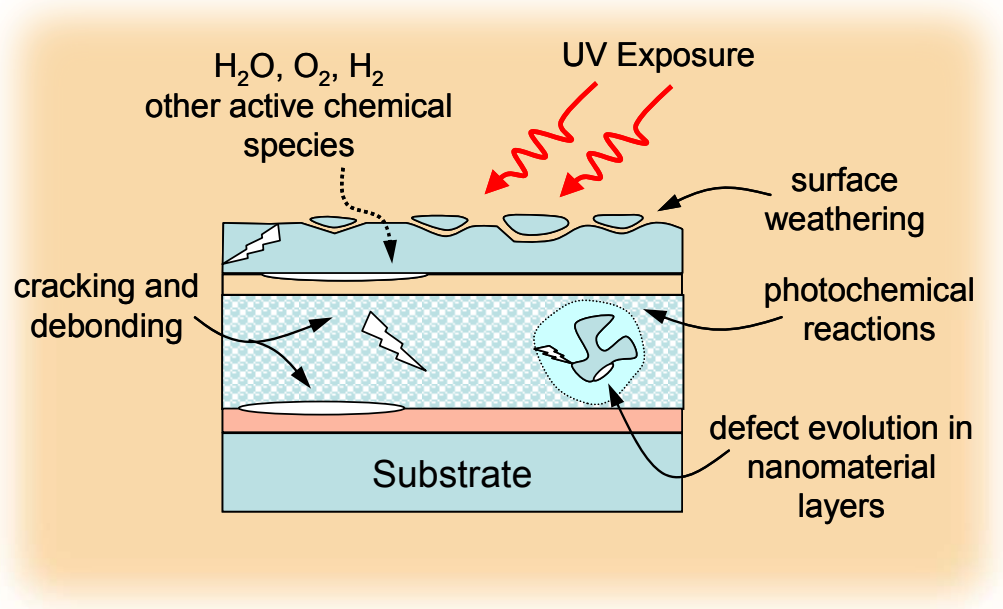
Support:

DoE support through the Bay Area PV Consortium, Predicts CPV program through SunShot, and the CAMP-KAUST center.

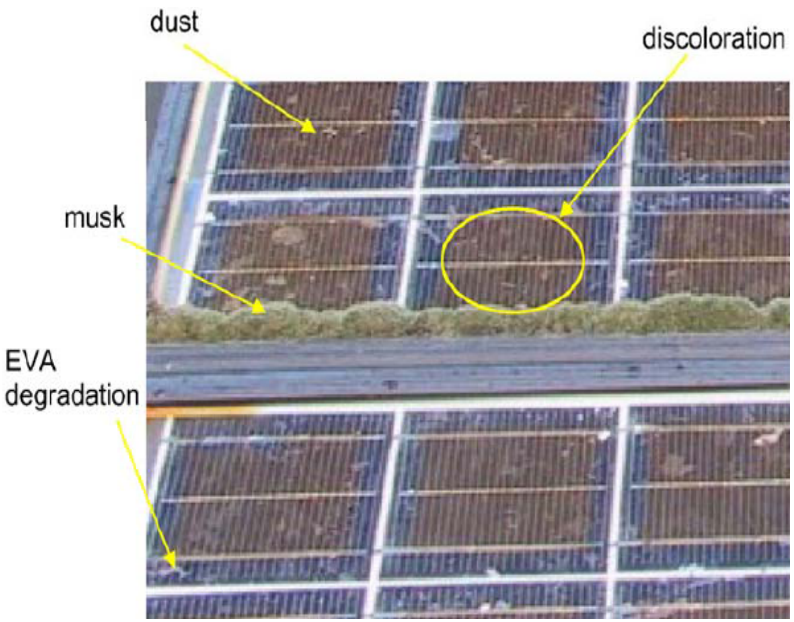
Degradation and Reliability of PV Devices and Modules



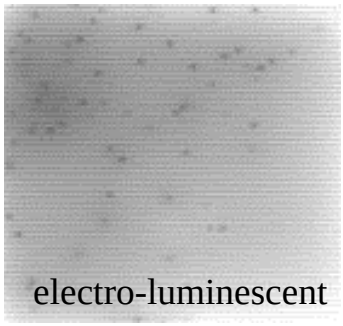
Severe operating environments:

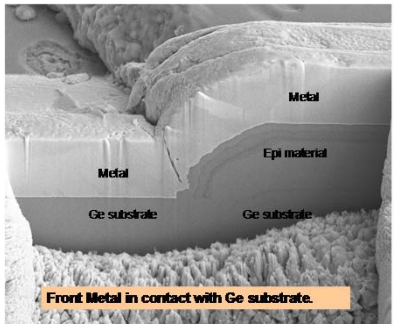
Thermal cycling, stress, moisture, chemically active environmental species, and solar UV.

Uncertain degradation kinetics and reliability models.



defects in semi-conductor layers





peeling metallized grids after thermal cycling

Device Reliability and Evolution of Defects

damage propagates if mechanical stresses are large enough so that

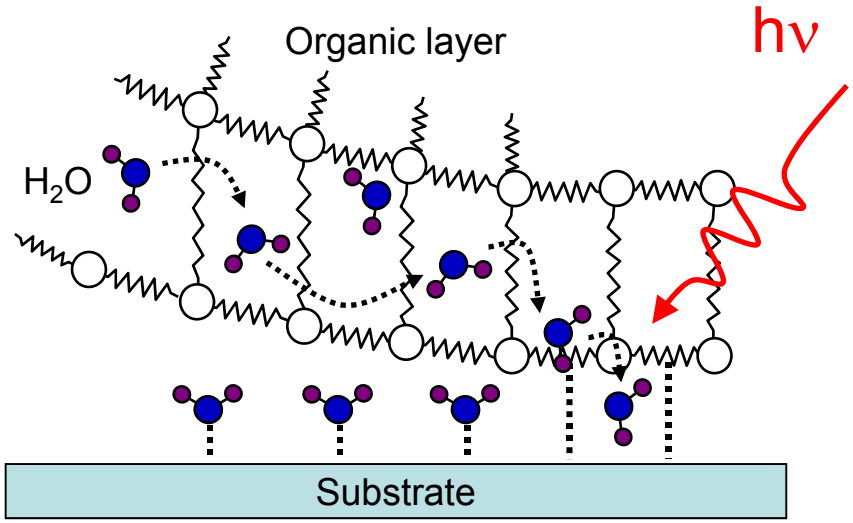
mechanical "driving force" $$G \geq G_c \left[J / m^2 \right]$$ *cohesion or adhesion*

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:

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



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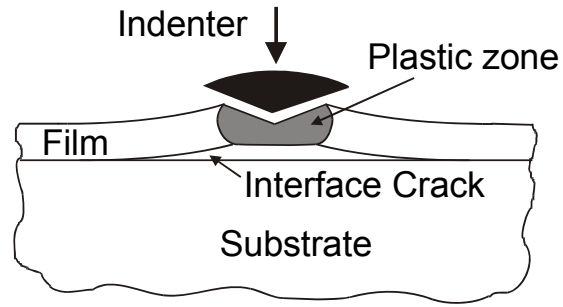
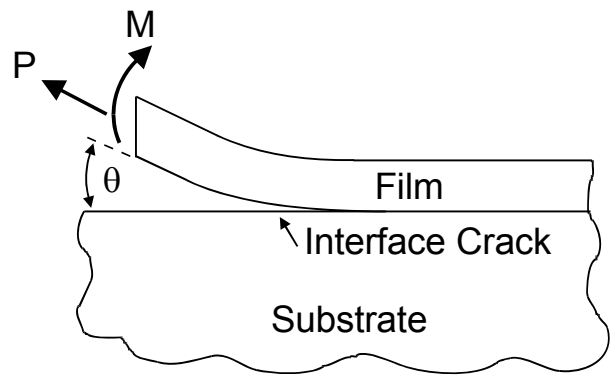
Limitations of Thin-Film Adhesion Tests

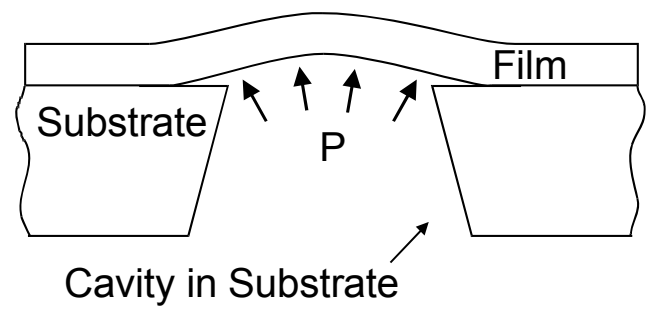
- Indentation/Scratch Test
  - complex stress and deformation fields
  - principally <u>qualitative</u> results
  - (nano) scratch test even less quantitative



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



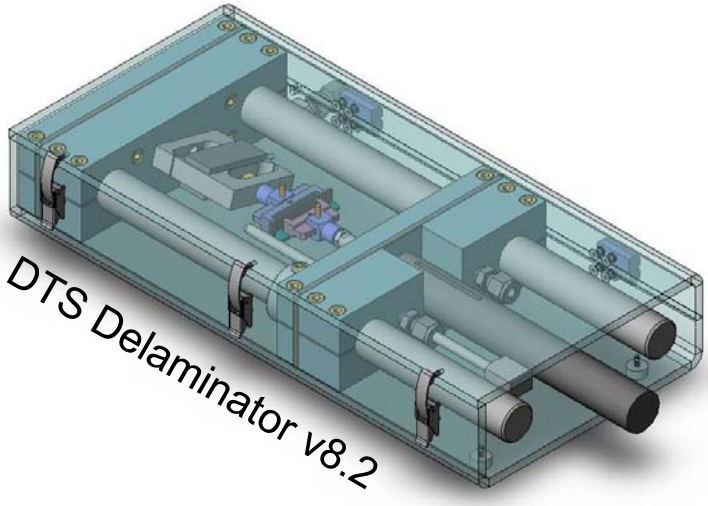
- Blister Test
  - compliant loading system
  - environmental effects
  - etching/machining of cavity difficult

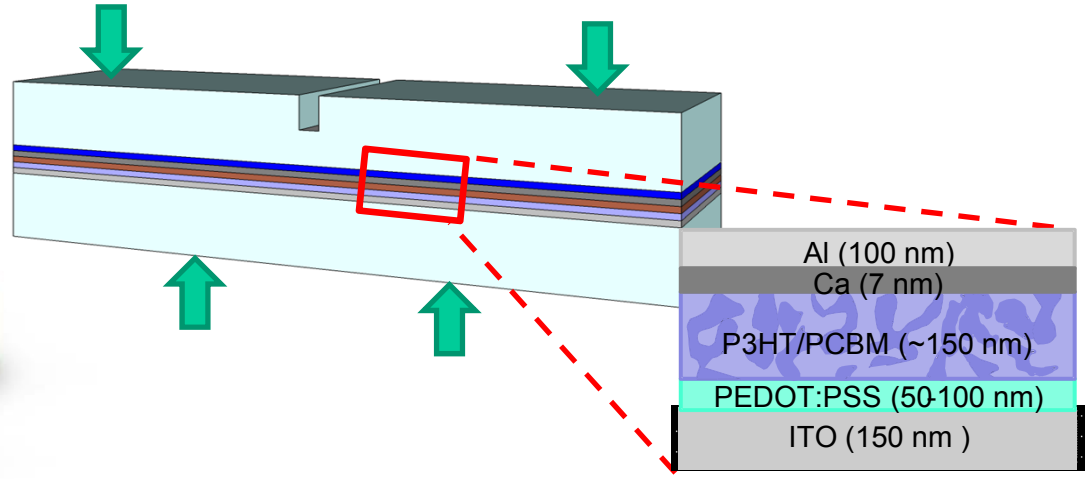


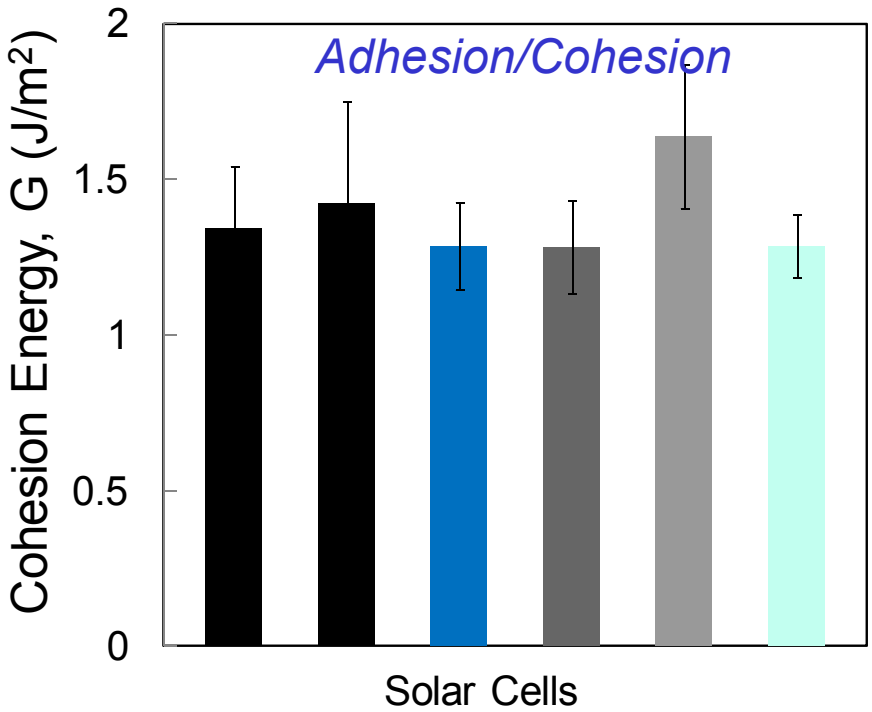
Major limitations: need detailed film properties, film stress relaxation and film plasticity

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

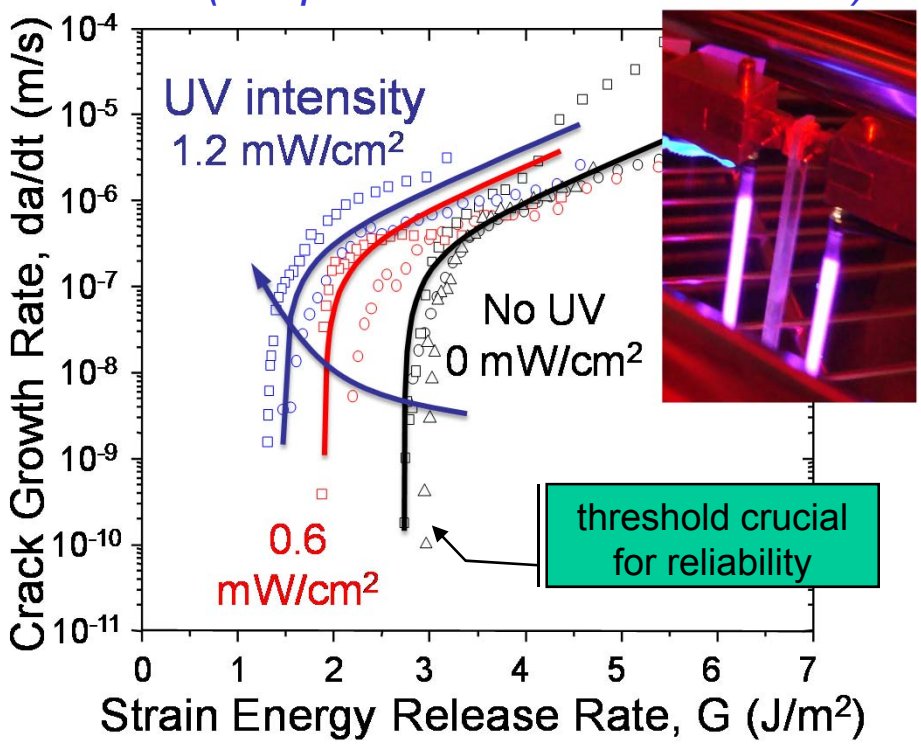
Quantitative Adhesion/Cohesion and Debond Kinetics







Degradation Kinetics
(temp/environment /UV effects)

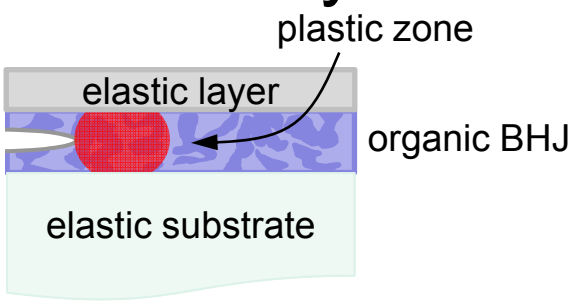


Outline

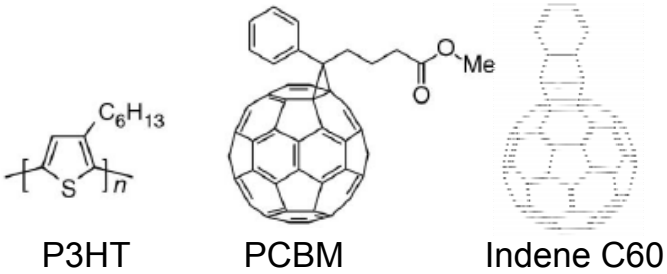
- Inherent Solar Cell Thermo-Mechanical Reliability
  - polymer / PCBM BHJ type devices
  - adhesion and cohesion properties in flexible systems
- Encapsulant and Ultra-barriers in Solar Modules
  - synergistic effects of multiple “stressing parameters”
  - kinetics and lifetimes

Factors Effecting Cohesion of BHJ Layers

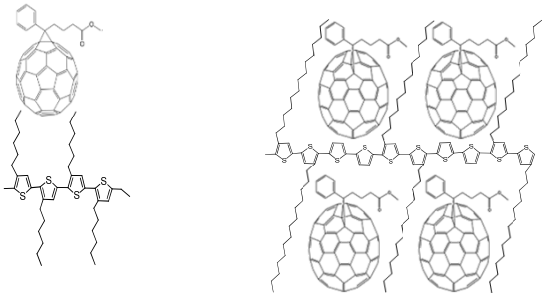
- Heterojunction layer thickness
  - is cohesion in organic layers sensitive to layer thickness?



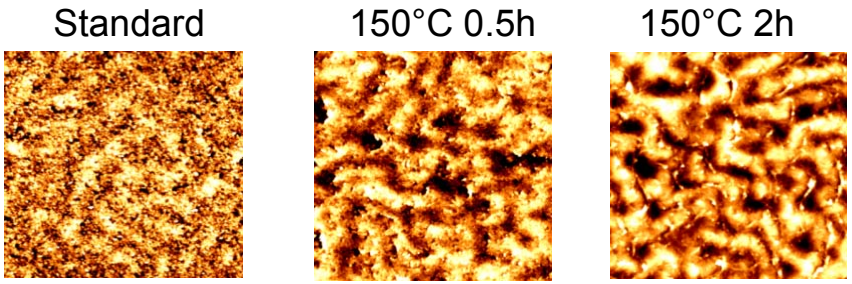
- Composition of the heterojunction layer
  - limited bonding to fullerene
  - polymer/PCBM ratio makes stronger layer



- Molecular intercalation
  - manipulating the types of intermolecular interactions



- Annealing
  - morphology of the BHJ layer changes with annealing



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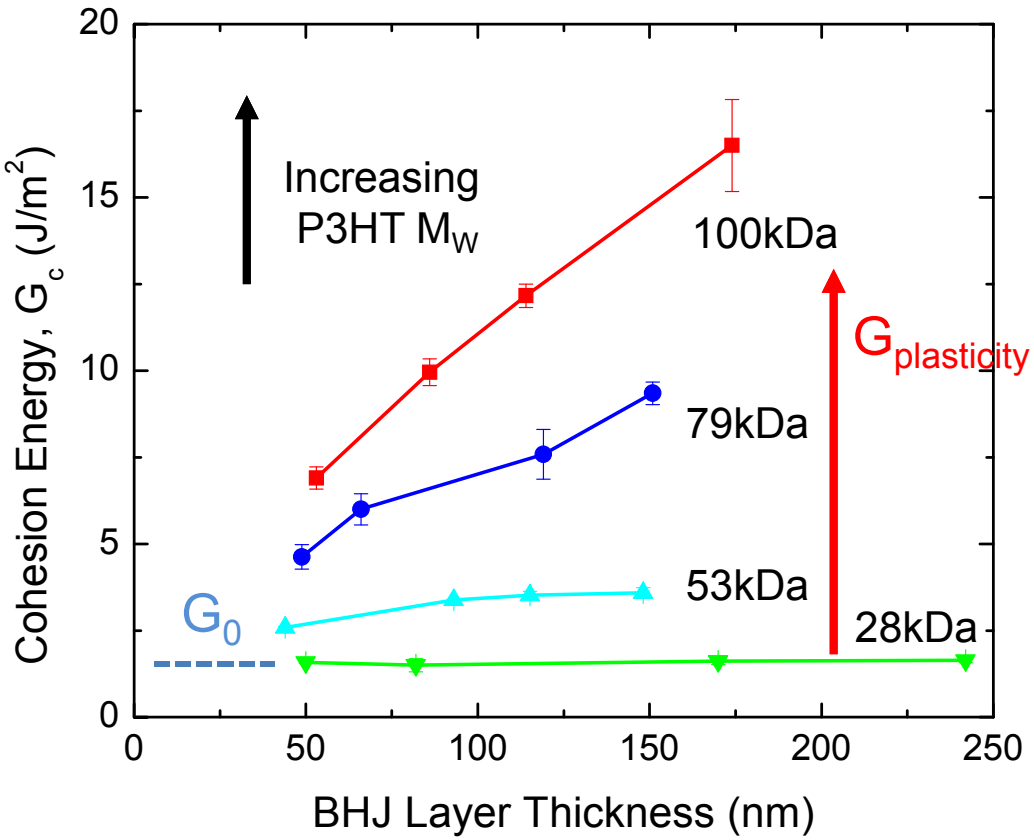
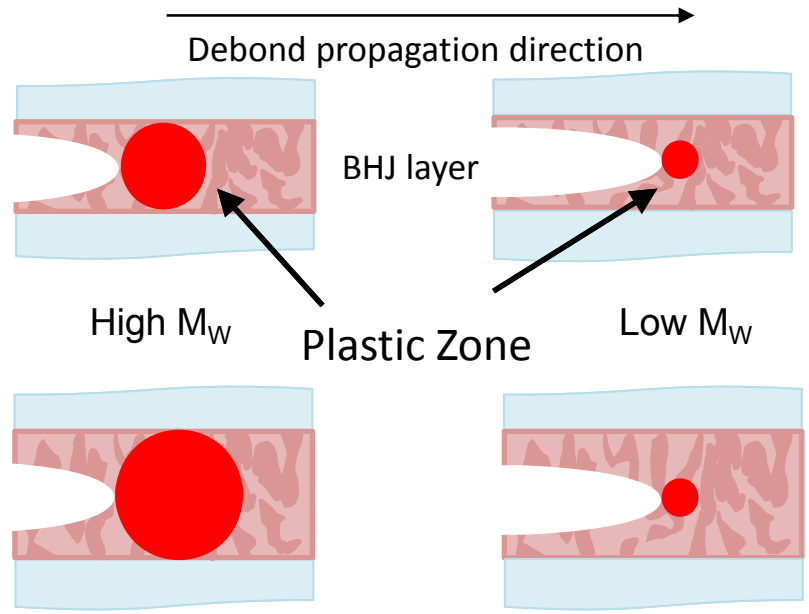
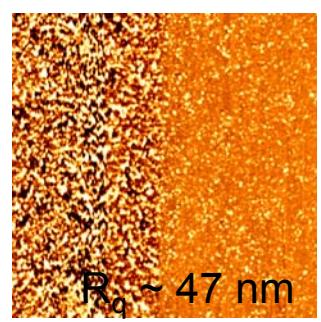
BHJ Layer cohesion w/ P3HT M_W



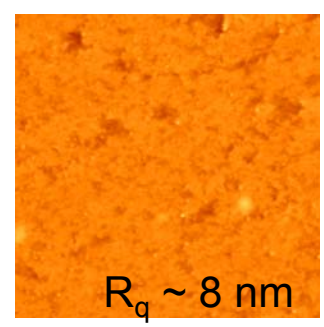
$$G_C = G_0 + G_{plasticity}$$



100 kDa P3HT



28 kDa P3HT

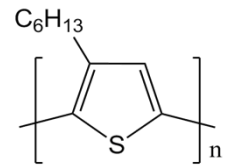


M_W increases cohesion energy significantly

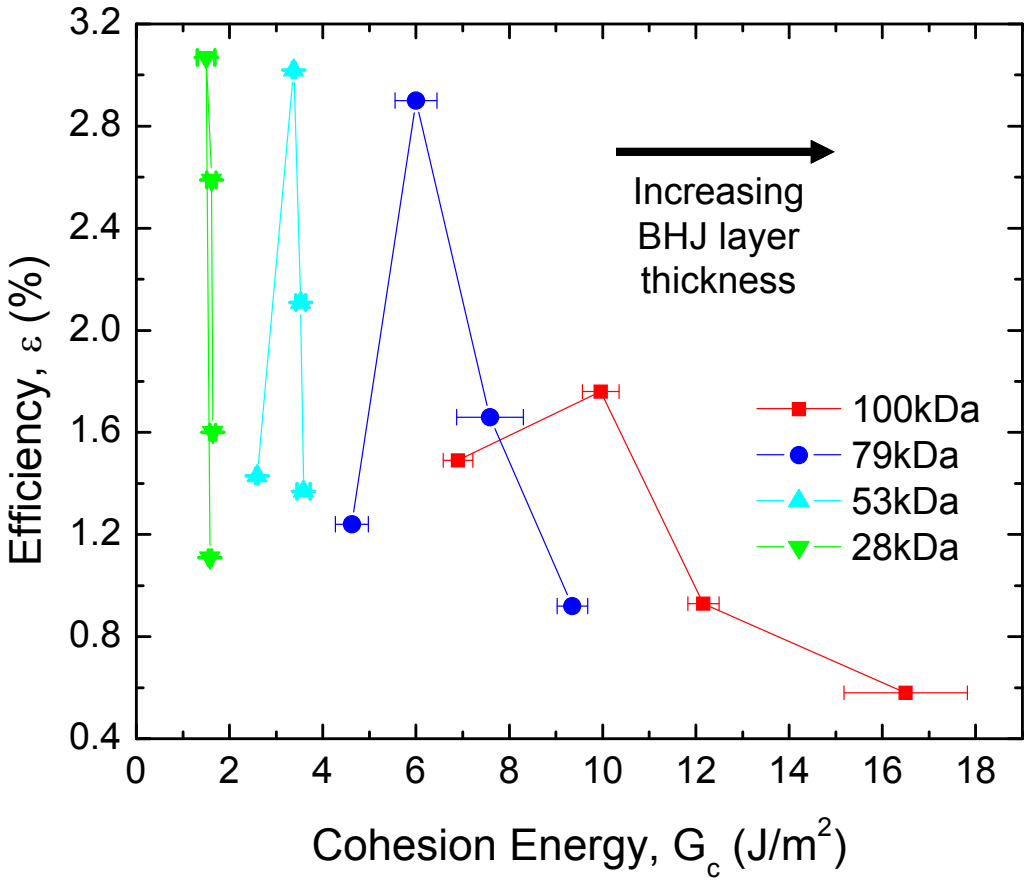
- increased inter-chain entanglement/bridging
- larger polymer domains as polymers fold

Rising slope with thickness due to plasticity

Efficiency vs. Cohesion



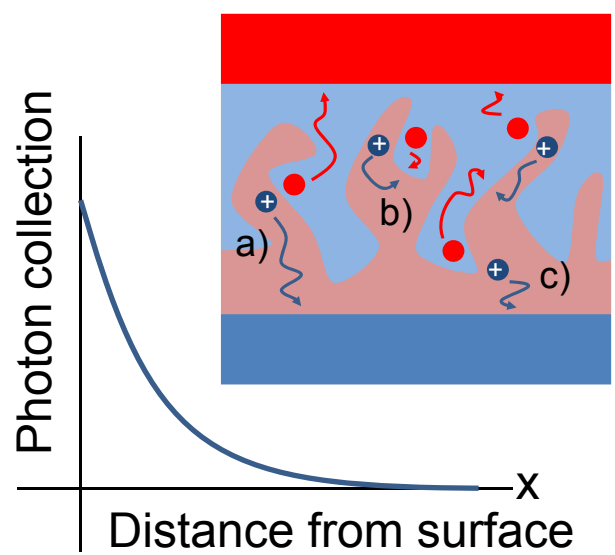
P3HT



$$\varepsilon = \frac{V_{OC} J_{SC} FF}{P_{in}}$$

Thin BHJ layer - low efficiency due to lower photon harvesting

Thicker BHJ layer - greater degree of charge carrier recombination

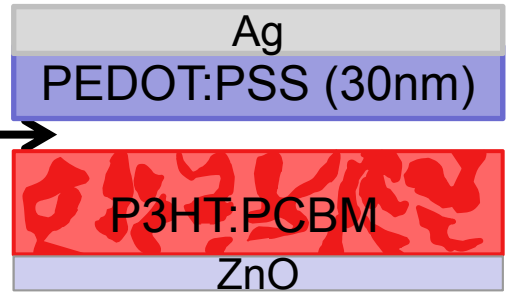


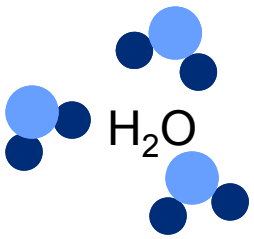
Synergistic Effects on Decohesion Kinetics

Inert Environment

$G \geq G_c$

adhesive failure

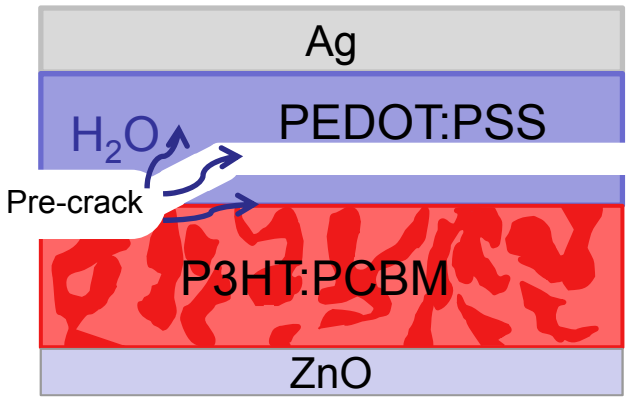


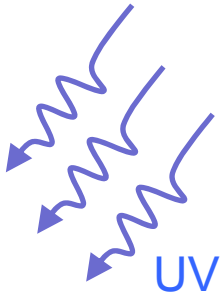


Effect of Moisture

$G < G_{cc}$

cohesive in PEDOT:PSS

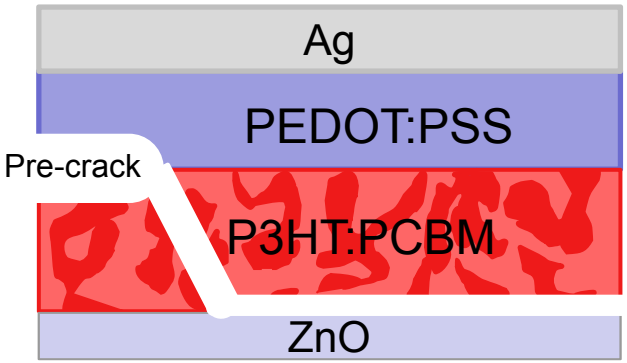




Effect of In-Situ UVB

$G < G_{cc}$

cohesive in P3HT:PCBM
adhesive at the ZnO interface



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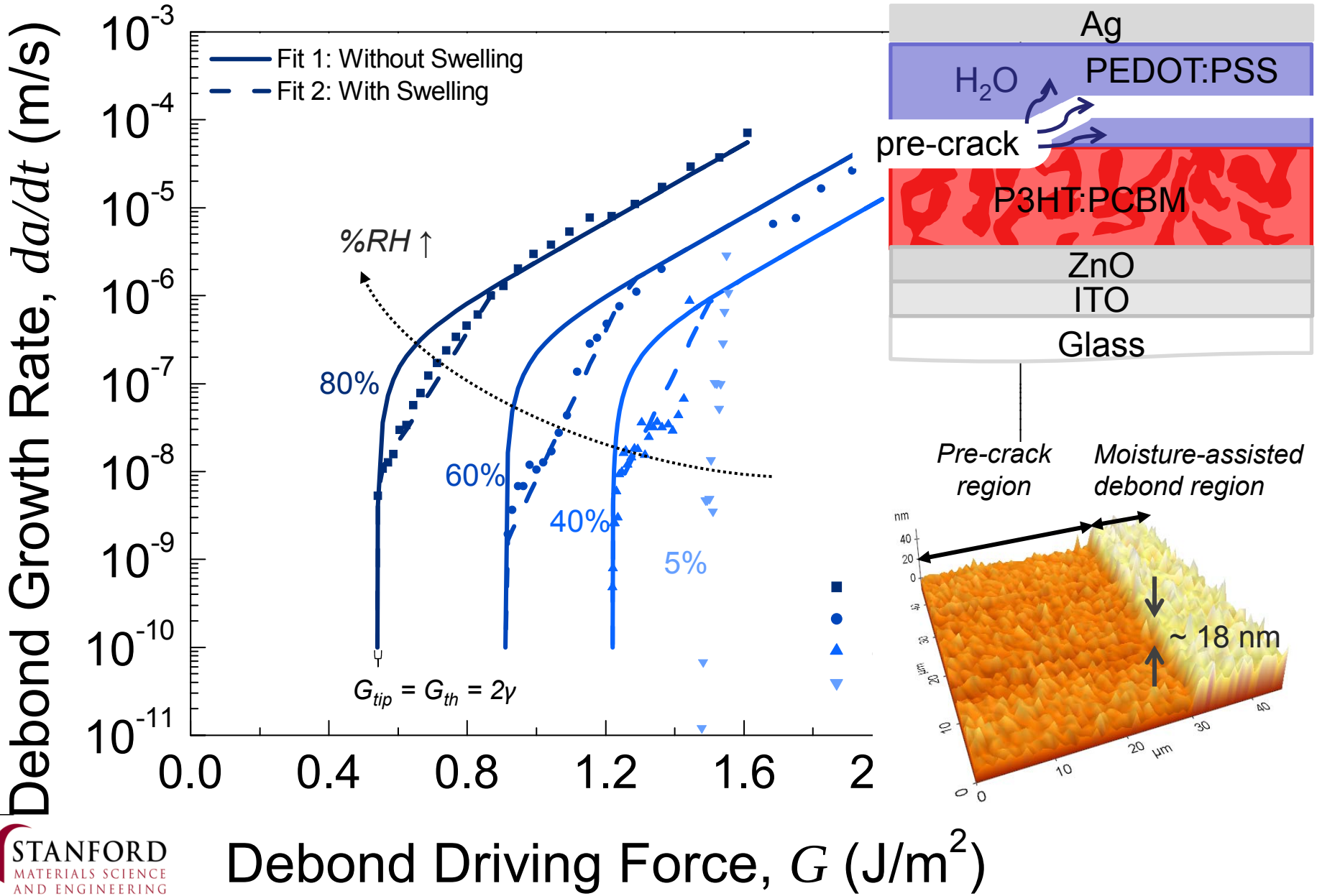
Decohesion of PEDO:PSS Transparent Electrodes



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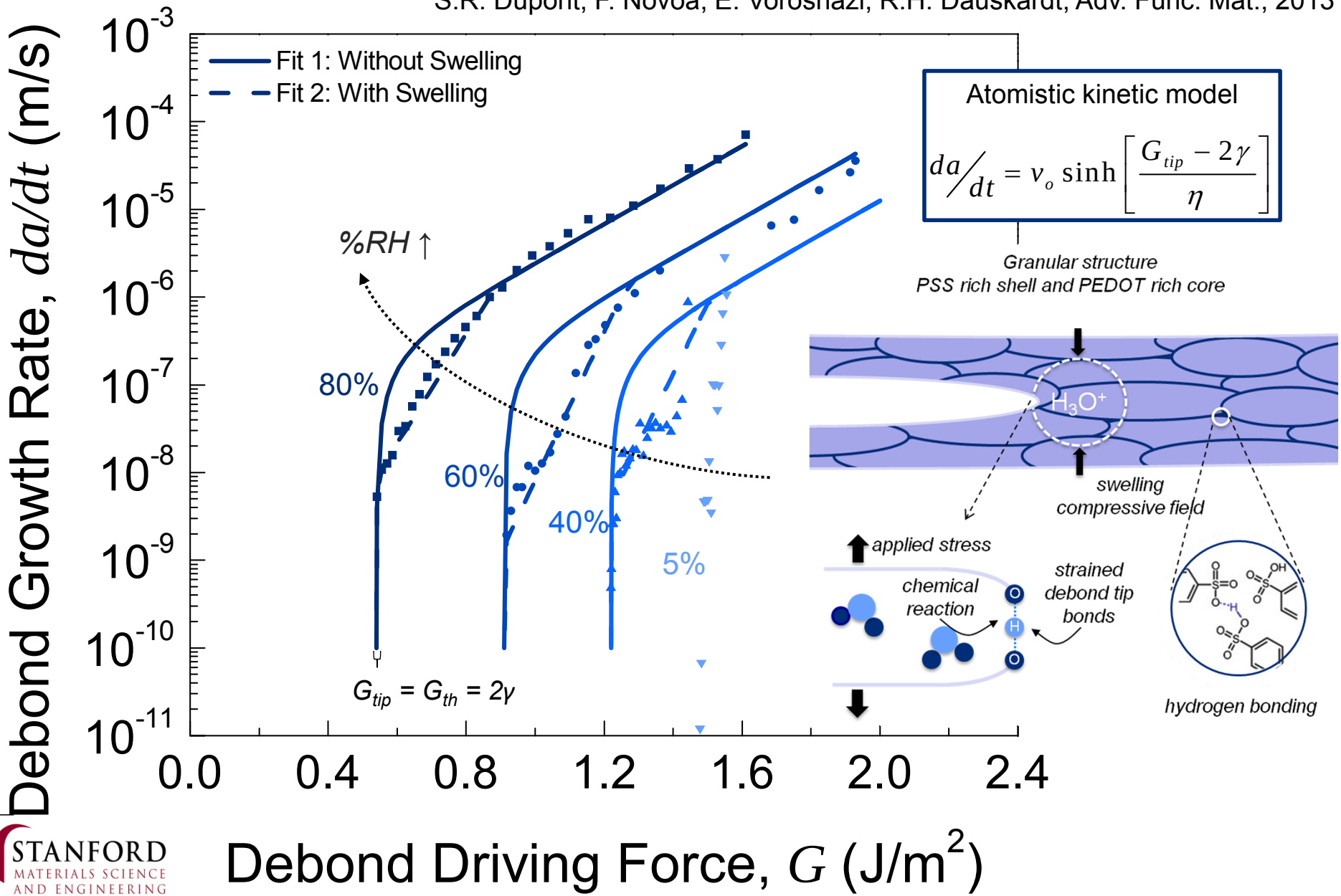
Decohesion of PEDO:PSS Transparent Electrodes

S.R. Dupont, F. Novoa, E. Voroshazi, R.H. Dauskardt, Adv. Func. Mat., 2013



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Outline

- Inherent Solar Cell Thermo-Mechanical Reliability
  - polymer / PCBM BHJ type devices
  - adhesion and cohesion properties in flexible systems
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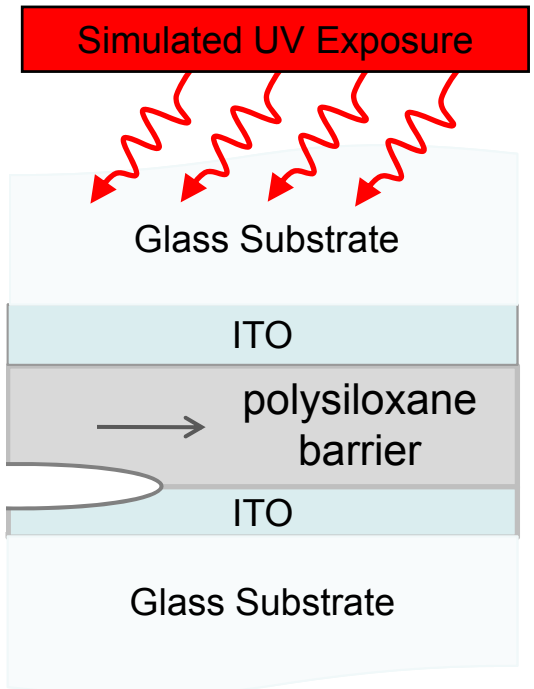
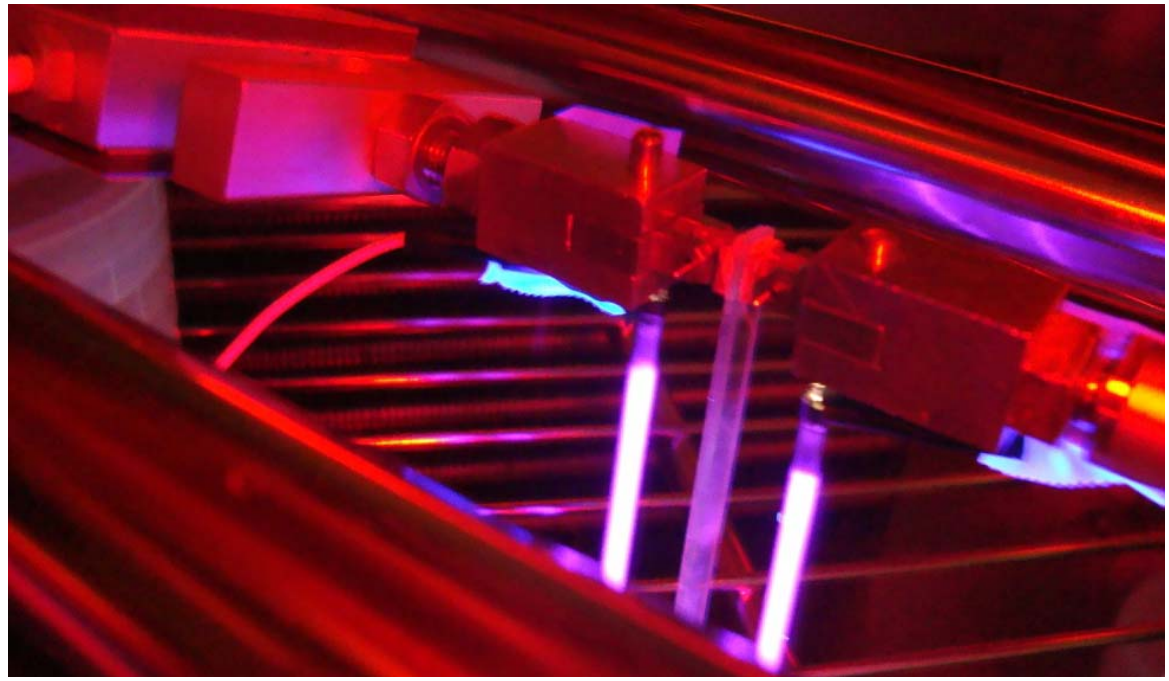
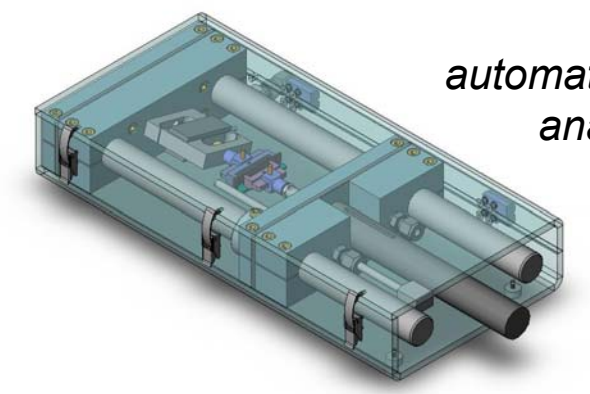
  - synergistic effects of multiple “stressing parameters”
  - kinetics and lifetimes

Assessing UV and Environment on Debonding Kinetics



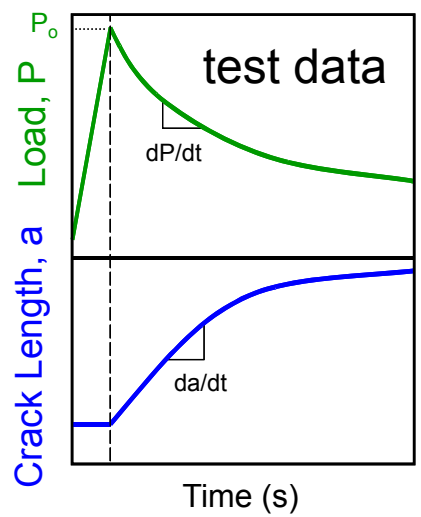


DTS Delaminator v8.2



automated growth analysis

sensitivity to < 10^{-11} m/s



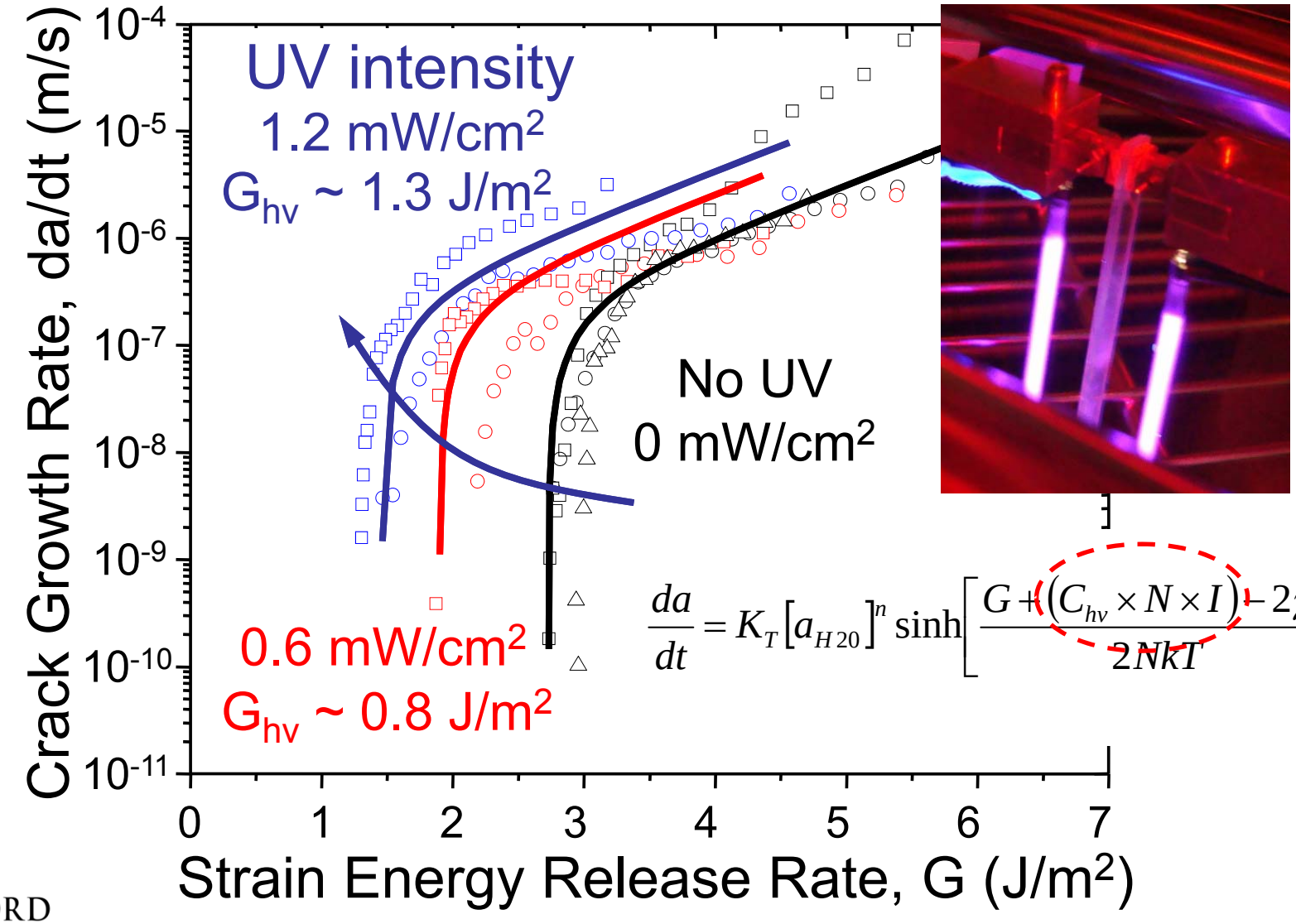
Debonding Kinetics

explore role of:

- UV flux
- humidity, O_2, OH, …
- temperature
- mechanical loading

UV Effects on Molecular Bond Rupture

UV Exposure (3.4 eV)



$$\frac{da}{dt} = K_T \left[a_{H20}\right]^n \sinh\left[\frac{G + \left(C_{hv} \times N \times I\right) - 2\gamma_E}{2NkT}\right]$$

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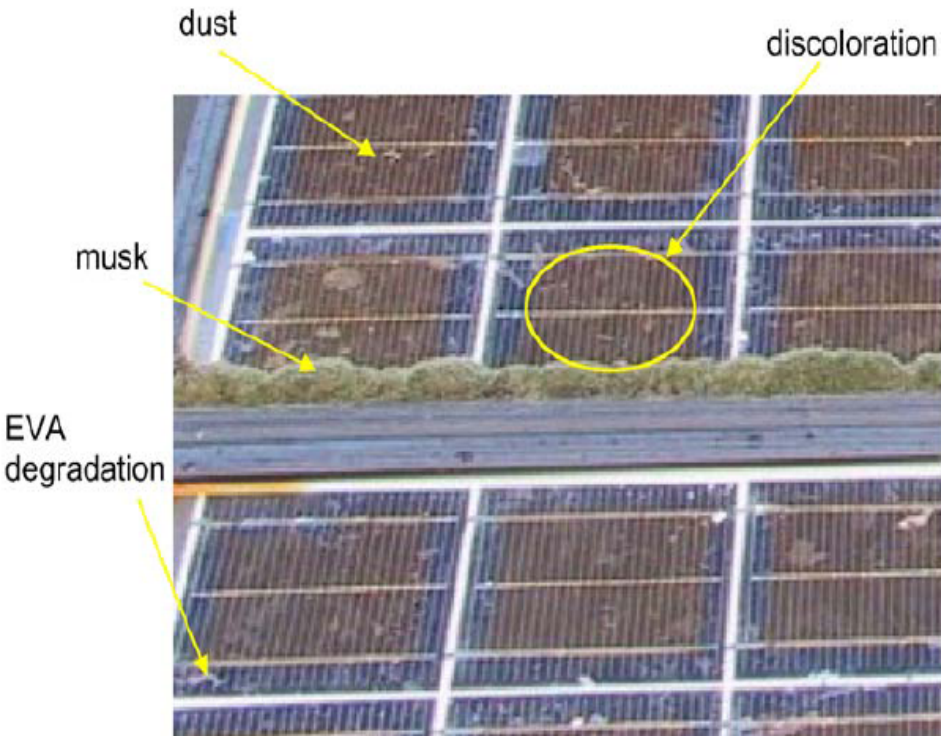
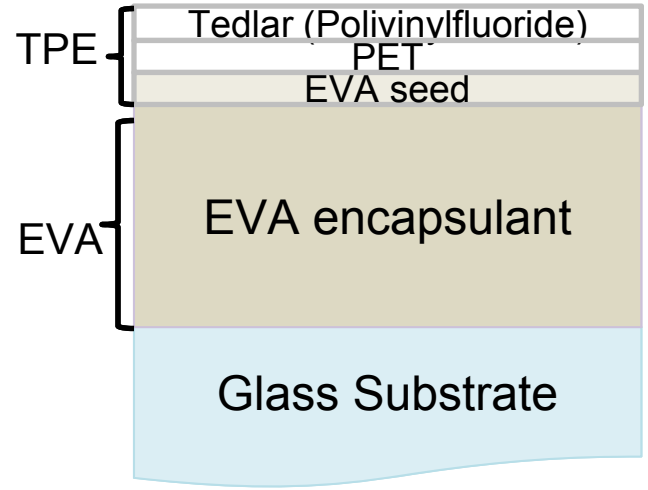
Delamination of EVA-TPE Lamination



Parreta Antonio, et al., Solar Energy Materials & Solar Cells, 2005



- EVA T_g ~ -15°C
- "ductile-to-brittle" transition at lower T
- poor adhesive/cohesive properties at lower T

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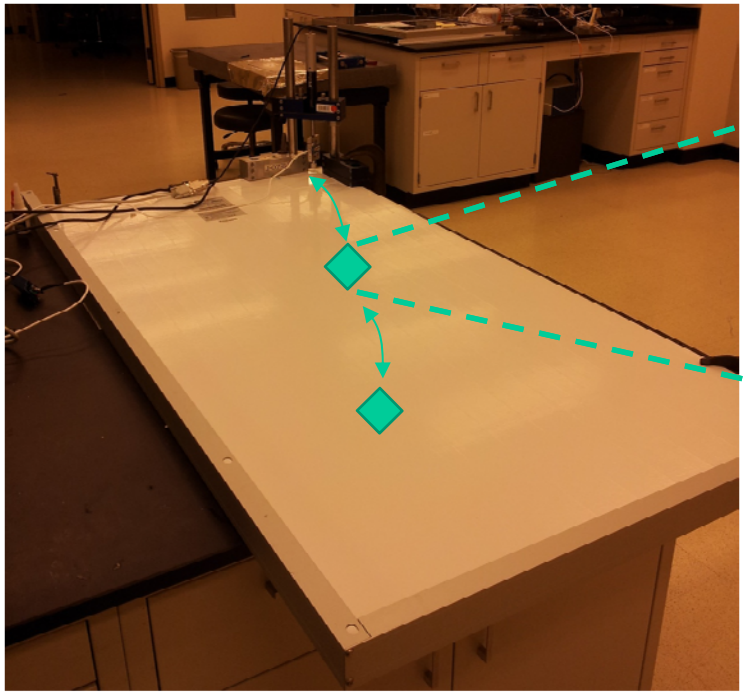
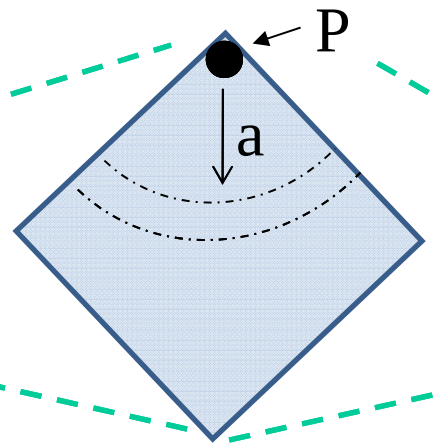
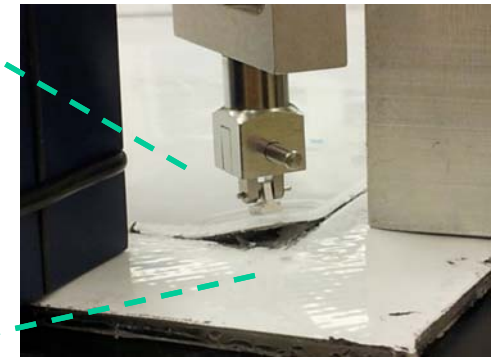
New Portable Full Panel Adhesion

Back Side of Full Panel





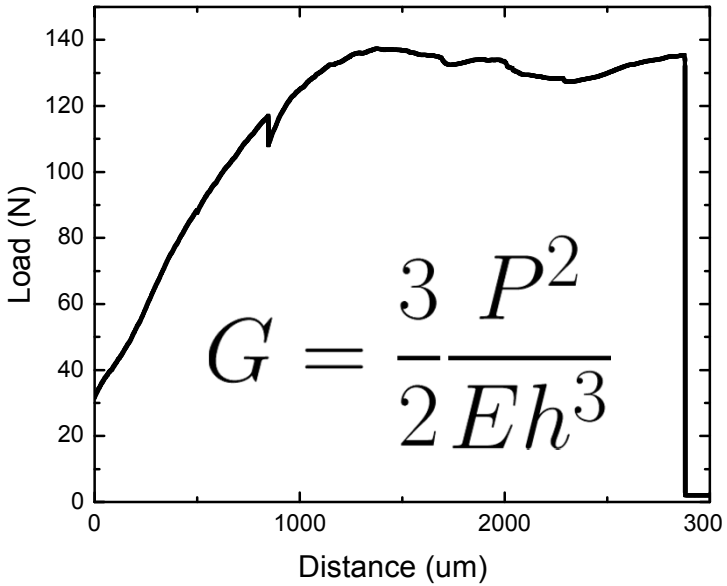


Delaminator (v8.2)
Adhesion Test System

Square Cantilever Beam Adhesion

Adhesion energy, G_c, depends on:

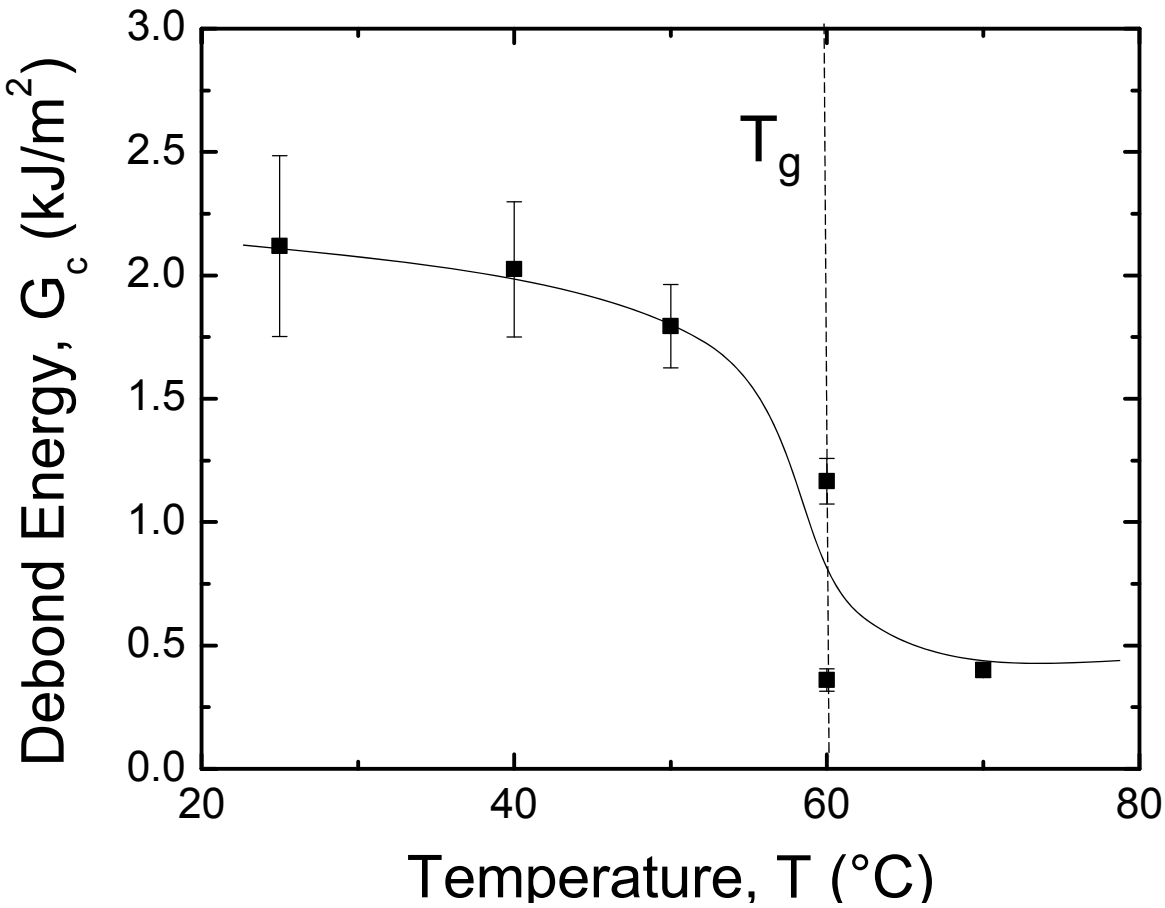
P (delamination force)
E (young modulus of the square)
h (thickness of the square)

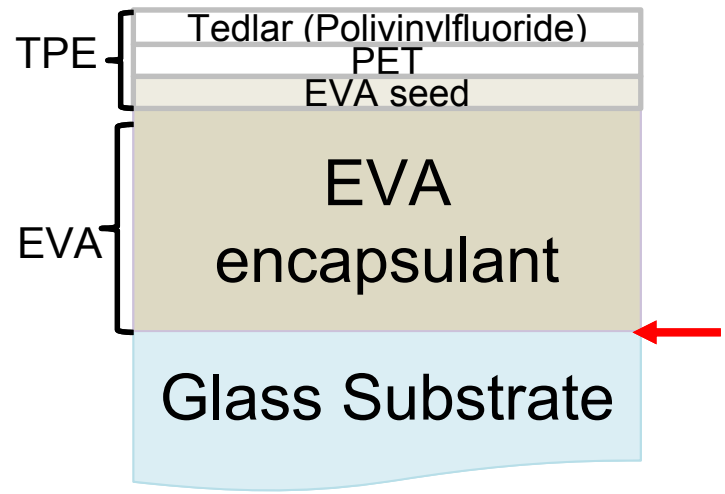


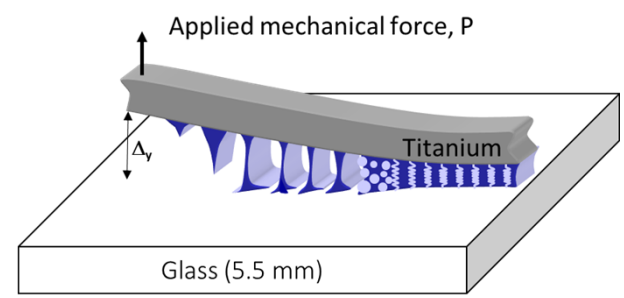
$$G = \frac{3}{2}\frac{P^2}{Eh^3}$$

DTS system and support: dauskardt@stanford.edu

Temperature Dependent EVA Debond Energy







Bridging and cavitation process

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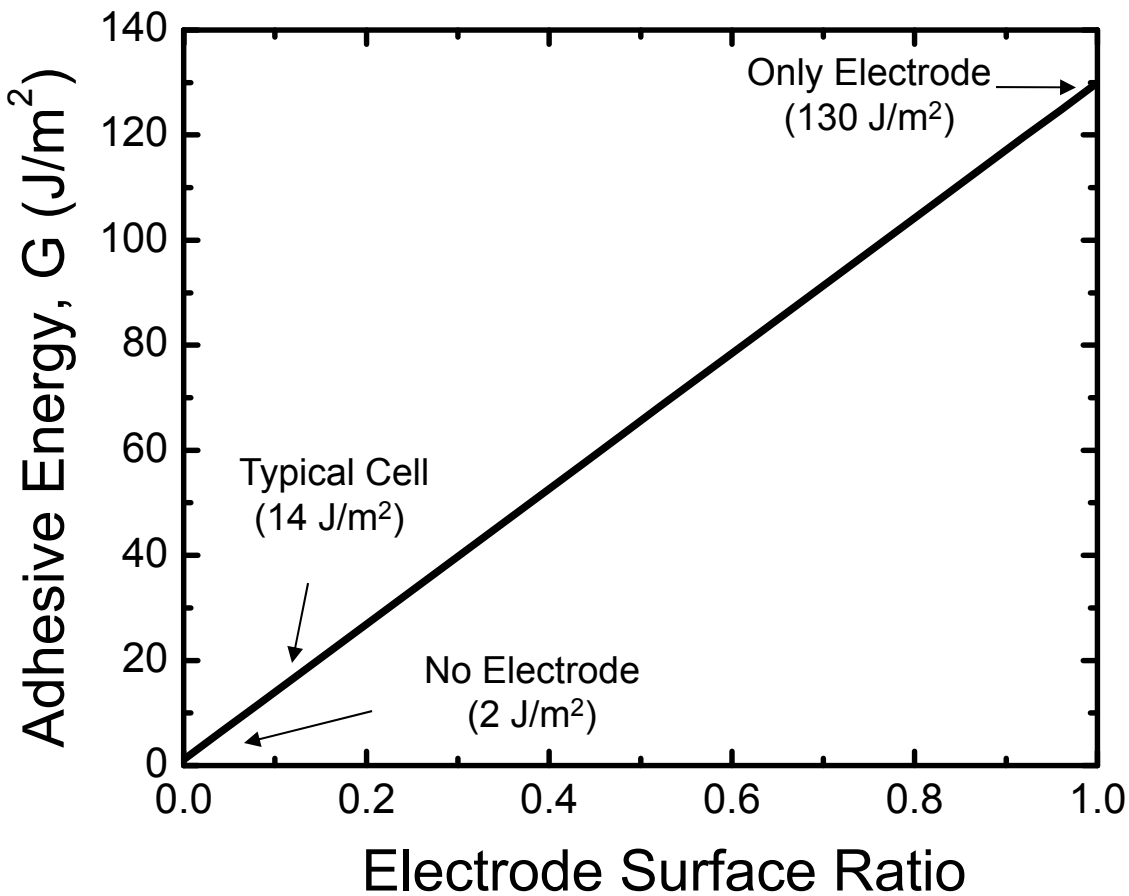
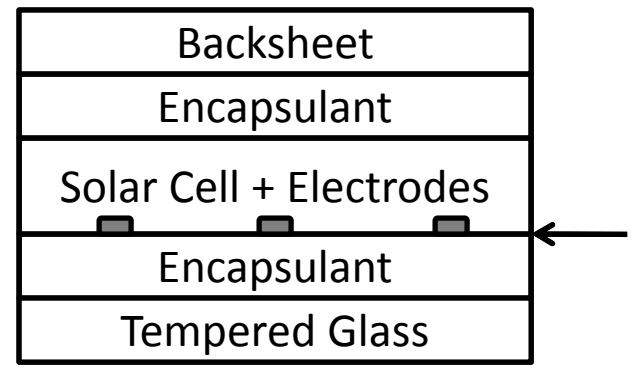
Encapsulant Adhesion is Highest at the Electrodes





Reducing electrode surface decreases adhesive energy and affects module reliability!

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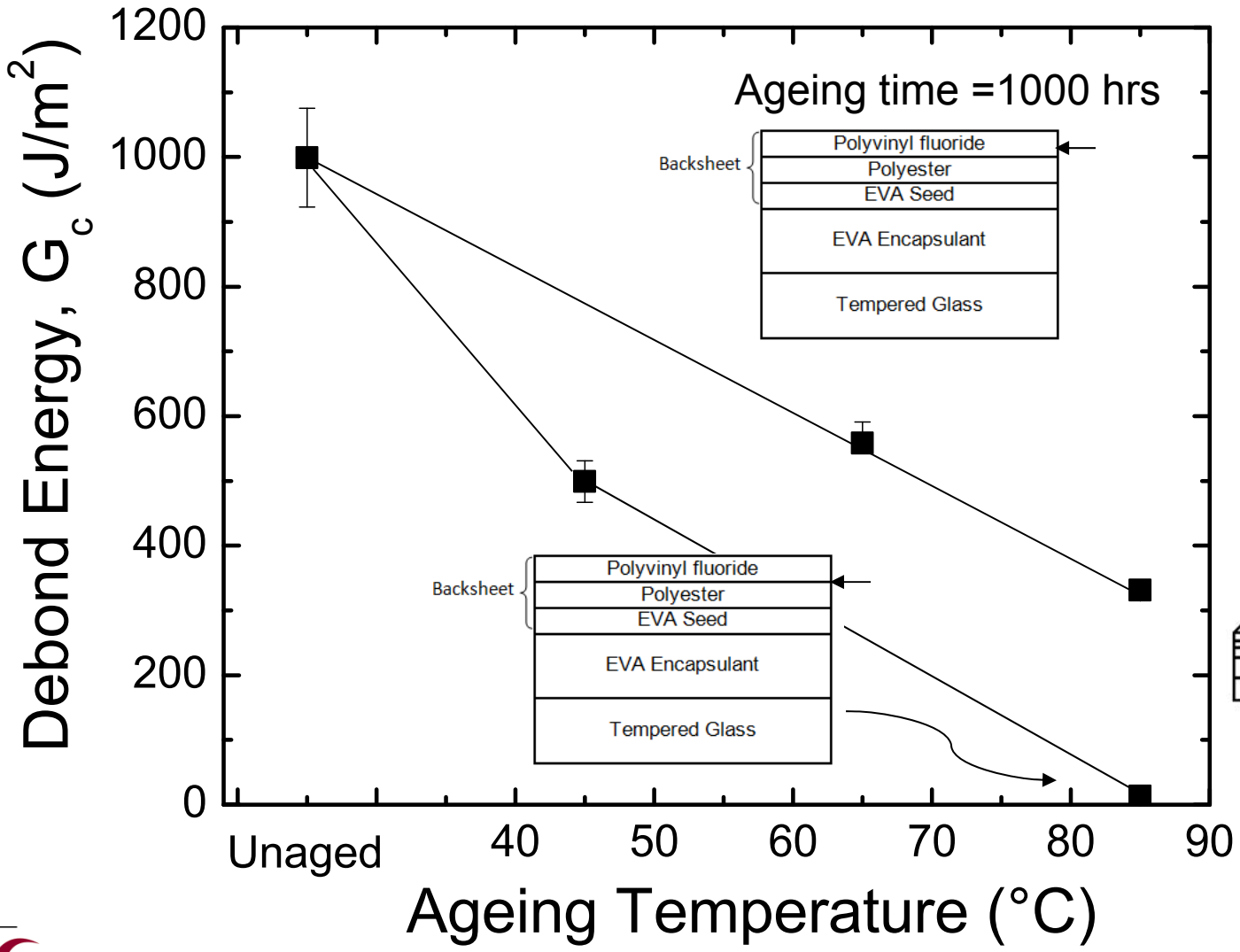
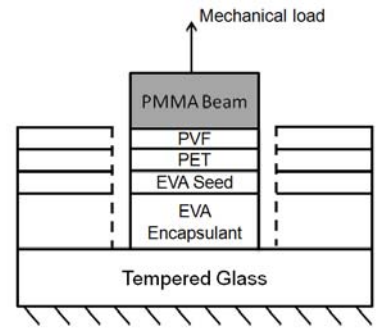
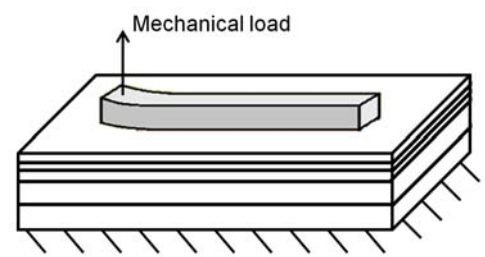
Ageing Temperature Effect on Debond Energy







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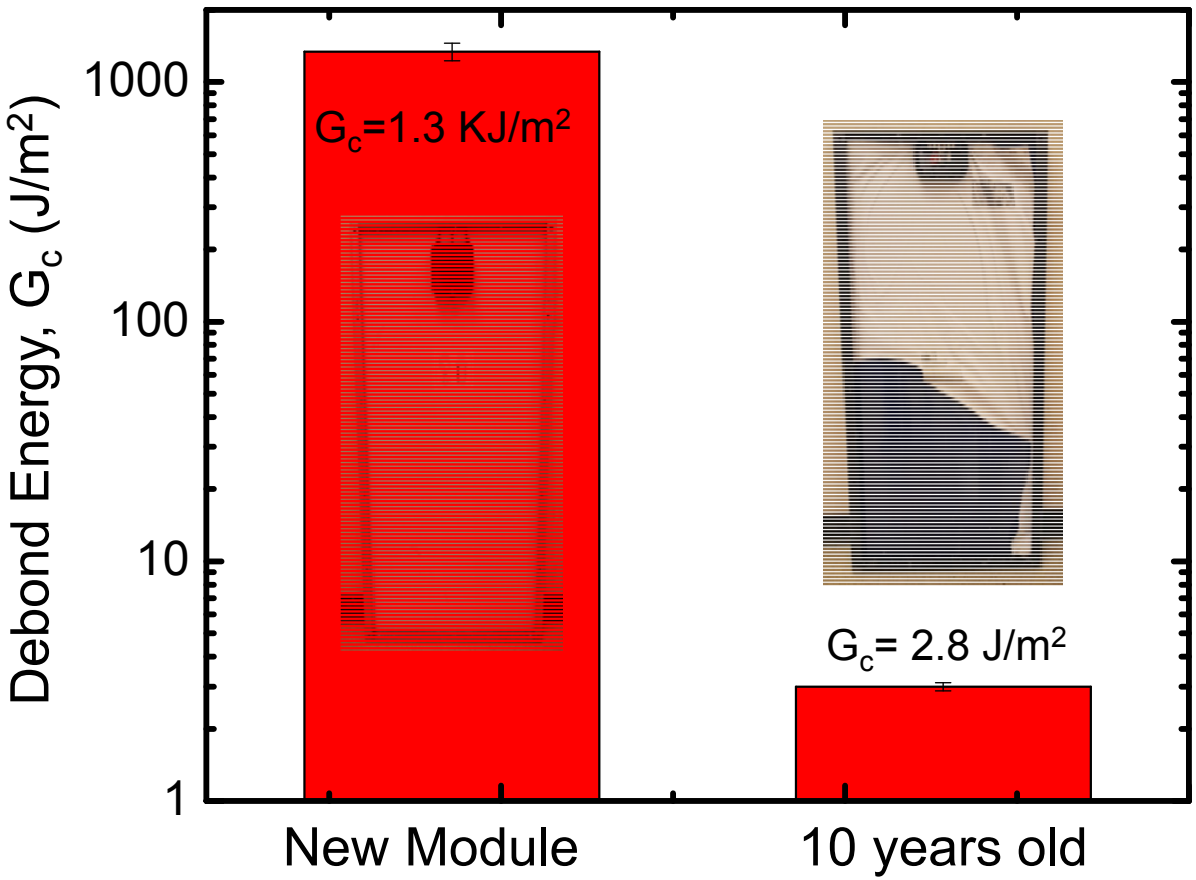
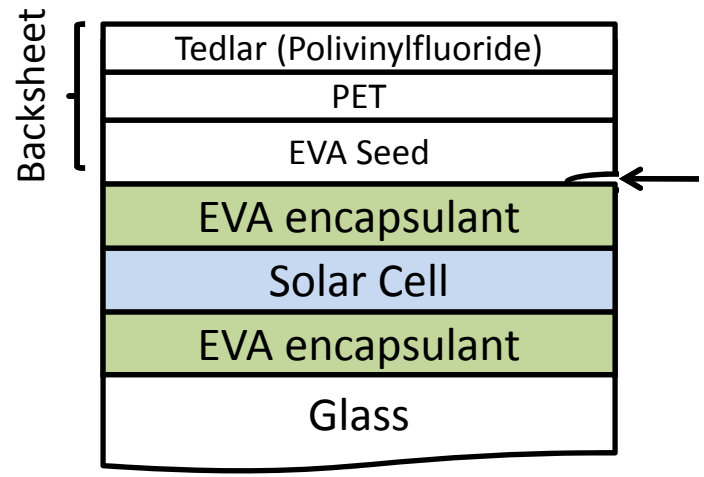
Backsheet Adhesion of Deployed Modules





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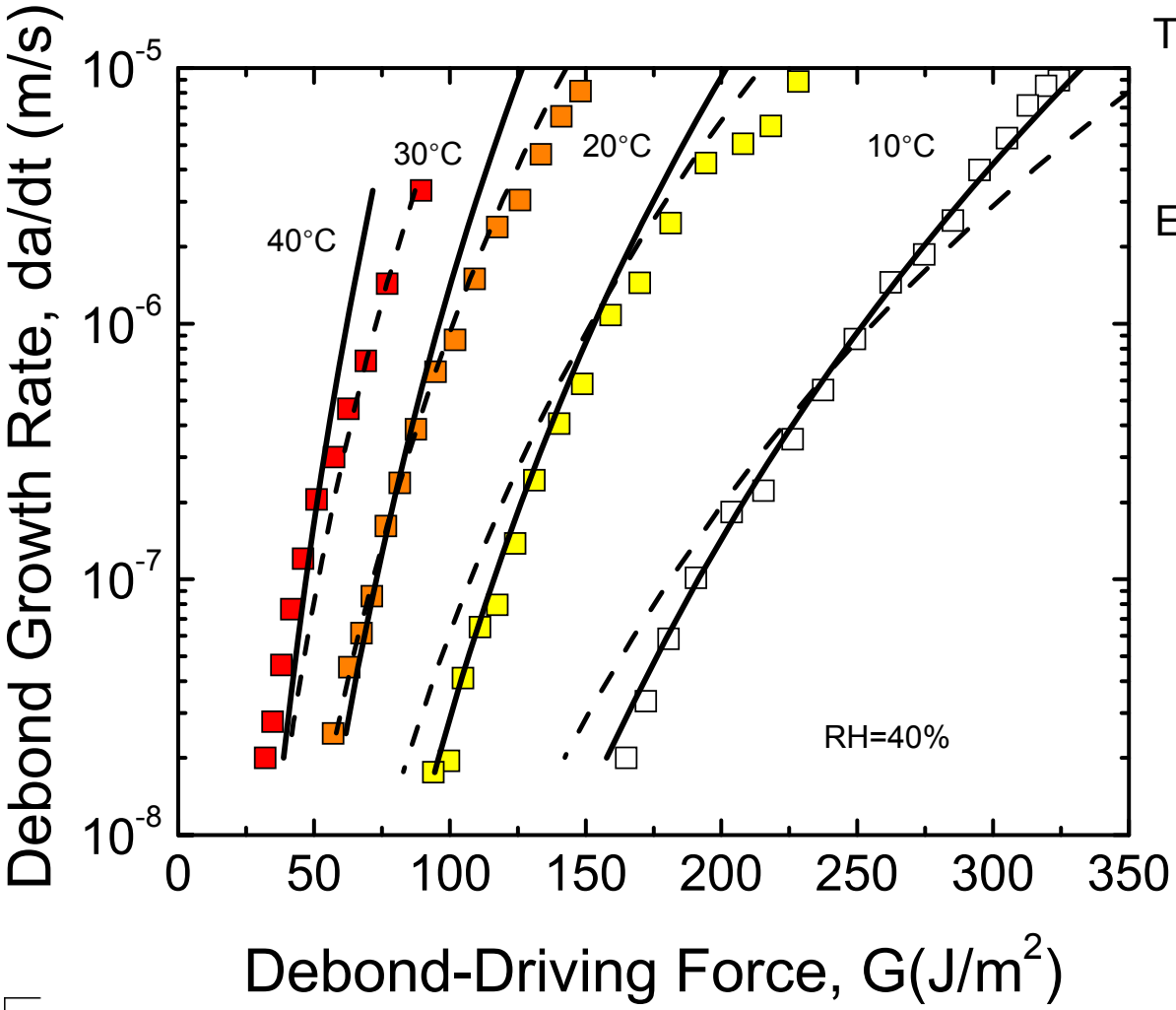
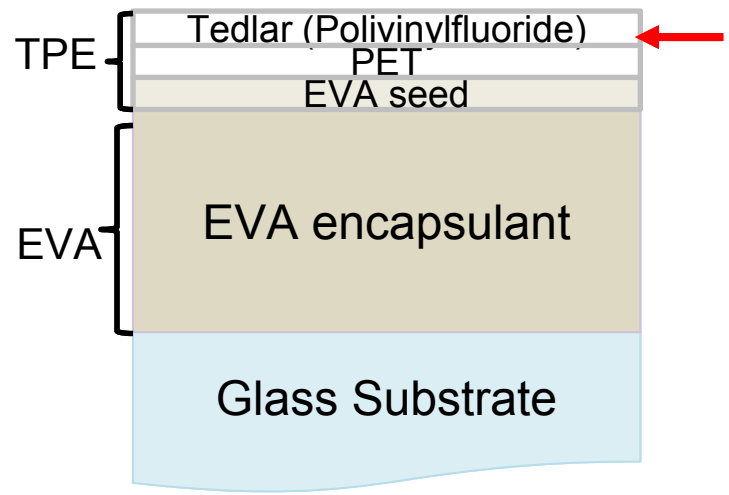
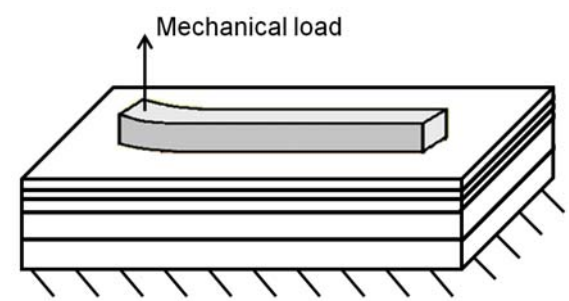
Temperature Effect on Debond Kinetics







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Summary

- Inherent Solar Cell Thermo-Mechanical Reliability
  - polymer / PCBM BHJ type devices
  - adhesion and cohesion properties in flexible systems
- Encapsulants and Ultra-Barriers in Solar Modules
  - synergistic effects of multiple “stressing parameters”
  - kinetics and lifetimes