# CMDITR 101: Project 4.2
# Packaging and Processing For Printed Electronics

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http://www.stc-mditr.org

# Example: Flexible Electronics



**The Functionality, Reliability and Processing of Organic Electronic Devices Are Linked To Packaging and Processing Methods**

**What is Important In Designing and Evaluating Packaging???**

# Reliability Issues: Device Encapsulation

## Need for Barrier Layers

• Highly reactive cathode and organic layer are very sensitive to water vapor and oxygen.

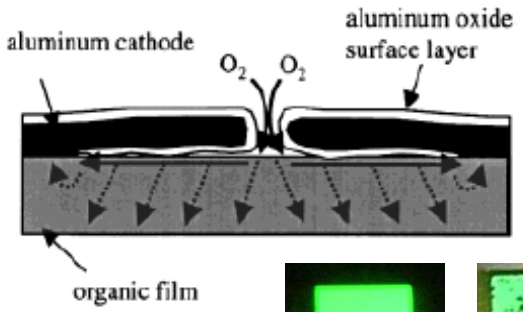
• Organic materials are sensitive to high temperatures and oxidizing agents.

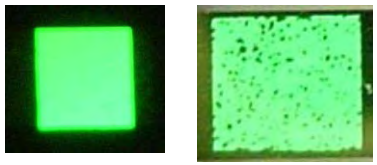
Must address:

⇒**Development of high barrier performance films.**

⇒**Process compatibility with device.**

⇒**Extending technology to large areas and devices with topography.**



## Mechanical Concerns

• Inorganic layers found in encapsulation are generally very brittle and may crack during bending.

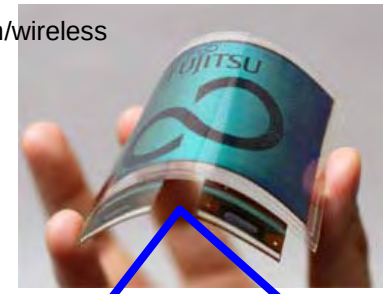
• Internal stresses from processing can impact the reliability of the encapsulation.

Must address:

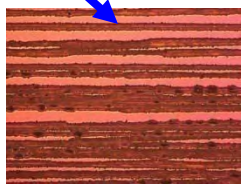
⇒ **Mechanically robust barrier layers.**

⇒**Adhesion and stress management.**

http://wirelessmedia.ign.com/wireless/image/article



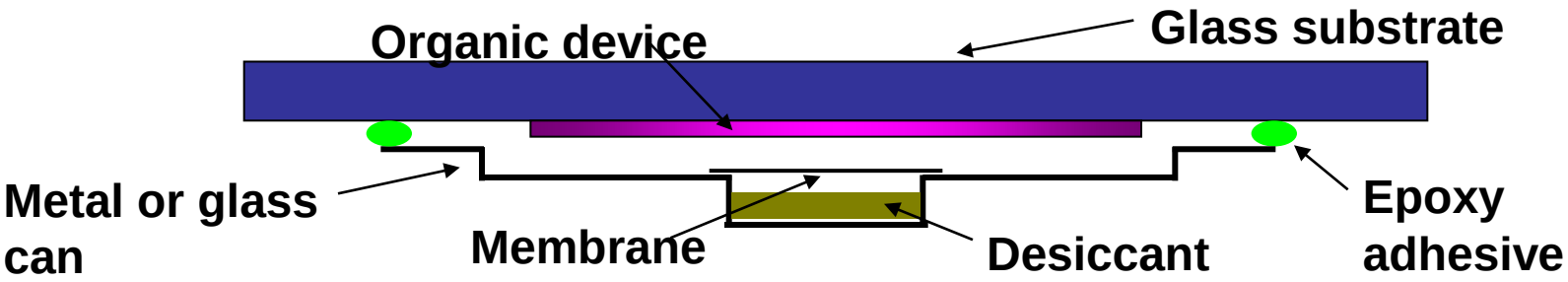

1 min

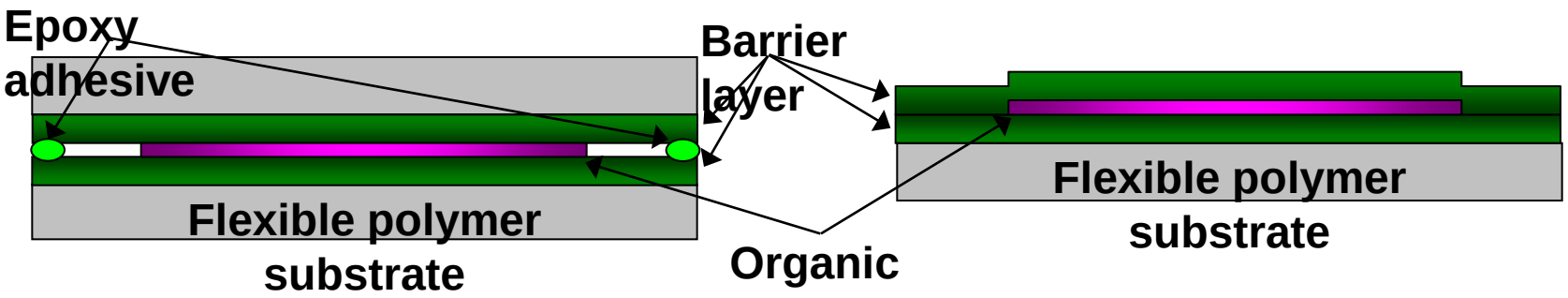


1 hr

# Encapsulation Structures

heavy, thick, rigid,
side permeation through epoxy




+ : flexible, light

- : need to fabricate barrier layer on both substrates, side permeation

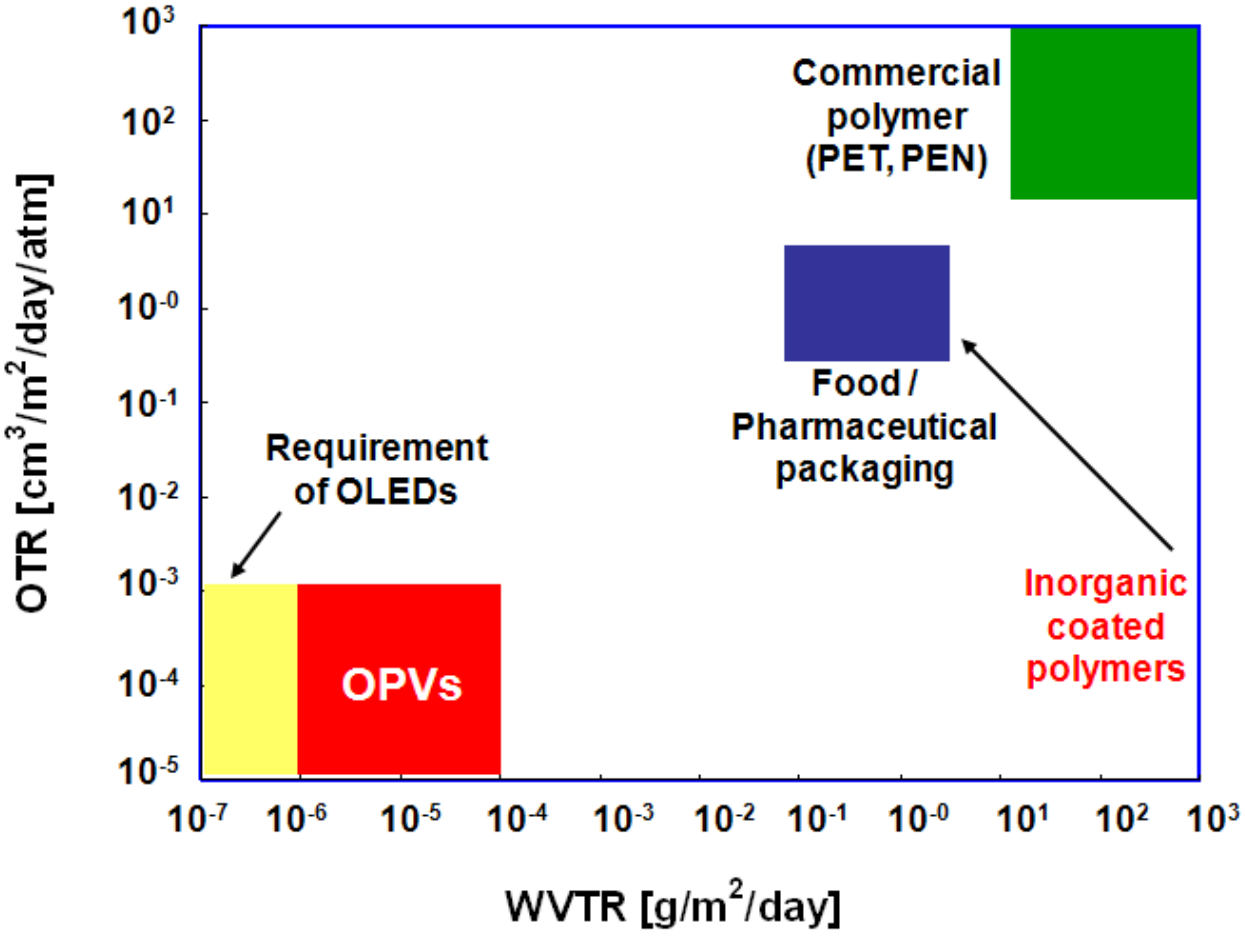
+ : thin, very flexible, light, no side permeation

- : need to fabricate barrier layer on device



J. S. Lewis, et. al., *IEEE Journal of Selected Topics in Quantum Electronics* 2004, *10*, 45-57

# Encapsulation Performance Needs





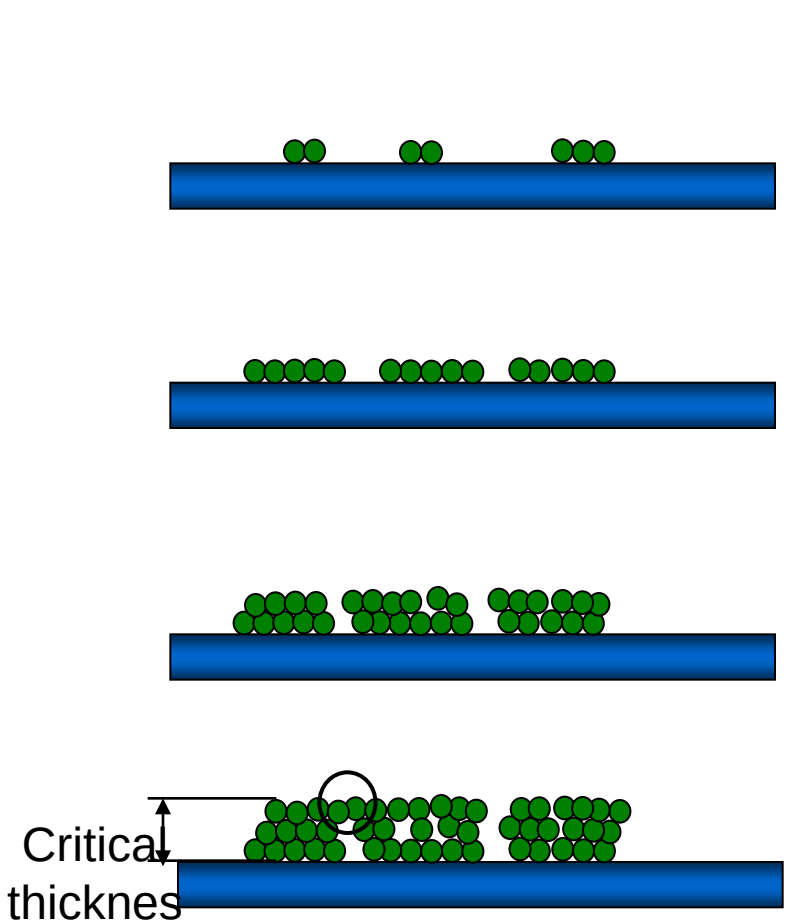


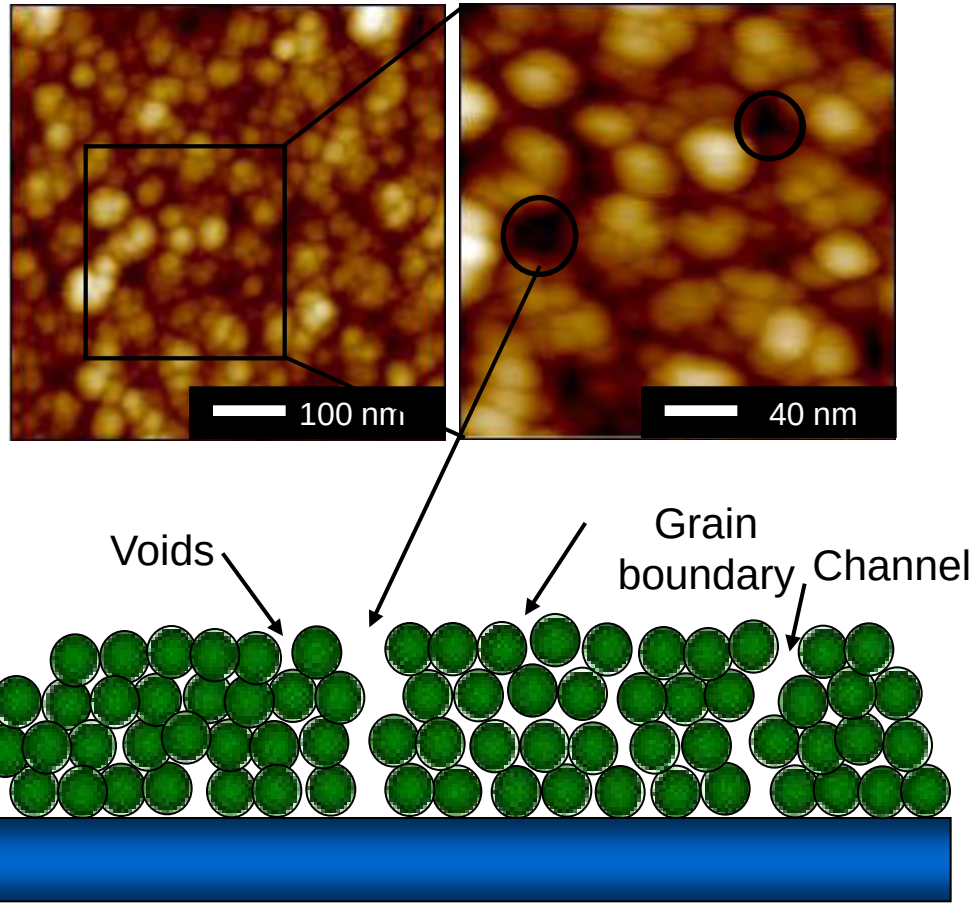


**G. Dennler, et. al., J. Mater. Res., Vol. 20, No. 12, Dec 2005. Vol.20, 3224**

# Defects in Barrier Films

## Single Layer Thin Films



# Key Terminology

- **Water Vapor Transmission Rate**
  - The mass of water vapor which diffuses through a solid per unit area and unit time ($g/m^2/day$)
- **Permeability**
  - transmission rate x film thickness/pressure
- **Bending Strength**
  - The load at which a material undergoes nonlinear deformation (yield) or undergoes failure (failure strength)
- **Fatigue Strength**
  - The strength amplitude at which failure does not occur in materials under cyclic loading. Usually defined for a given number of cycles (e.g. $10^6$)
- **Toughness**
  - The amount of energy a material can absorb before failure.

# Mass Transport in Barrier Films

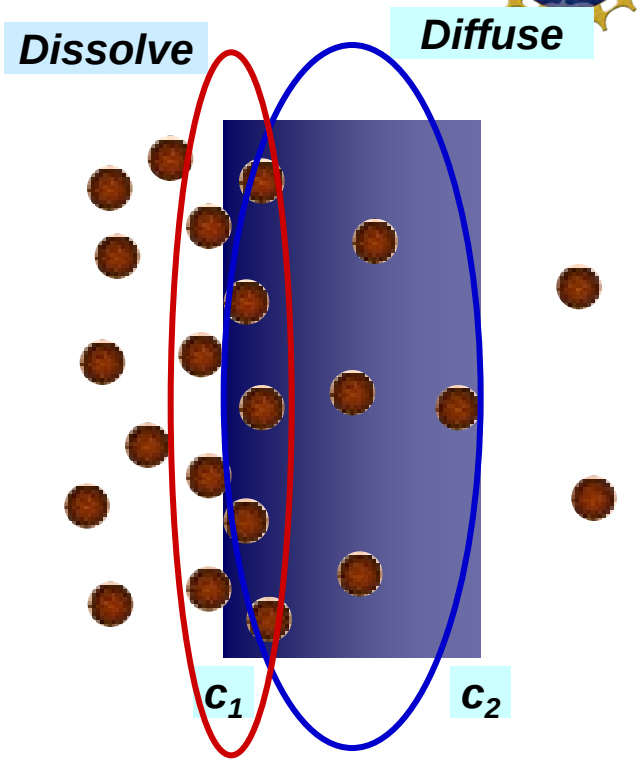
## Principles of permeation

$$P = DS$$

*P* : Permeation coefficient (permeability)

*D* : Diffusion coefficient, determines how **fast** the permeant can **move** in the media

*S* : Solubility coefficient, determines how **much** of the permeant can **be dissolved in in the film**




## Driving force

$$J = -D\left(\frac{\partial c}{\partial x}\right) \qquad \textit{Fick's first Law}$$

$$\rightarrow c = Sp \qquad \textit{Henry's Law}$$

$$J = DS\frac{\Delta p}{l}$$

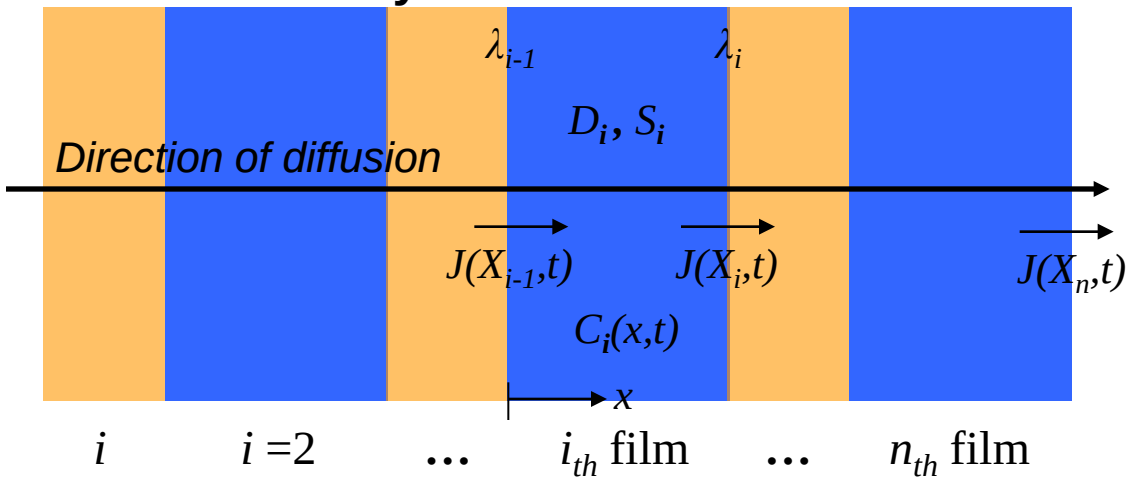
*J* : Flux of permeant

$\partial c / \partial x$ : concentration gradient

*p* : Partial pressure of permeant

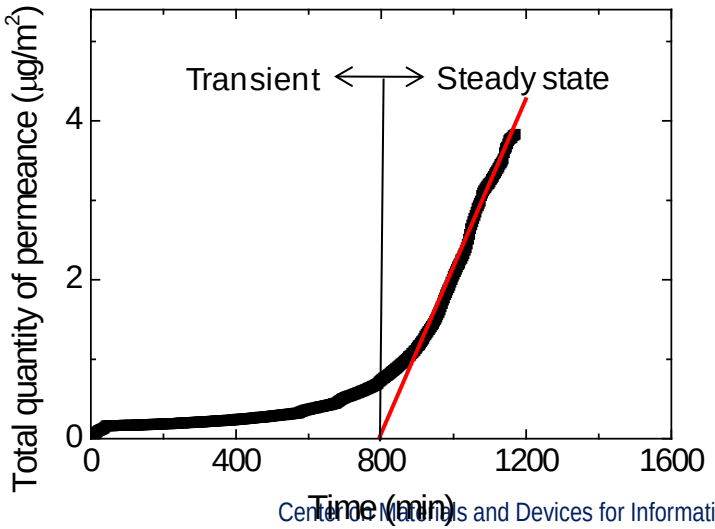
# Mass Transport in Barrier Films

**Diffusion in multilayer structure**




$D_i$ (diffusivity),
$S_i$ (Solubility),
$L_i$ (thickness)-fixed
Defect spacing

***WVTR, Lag time***



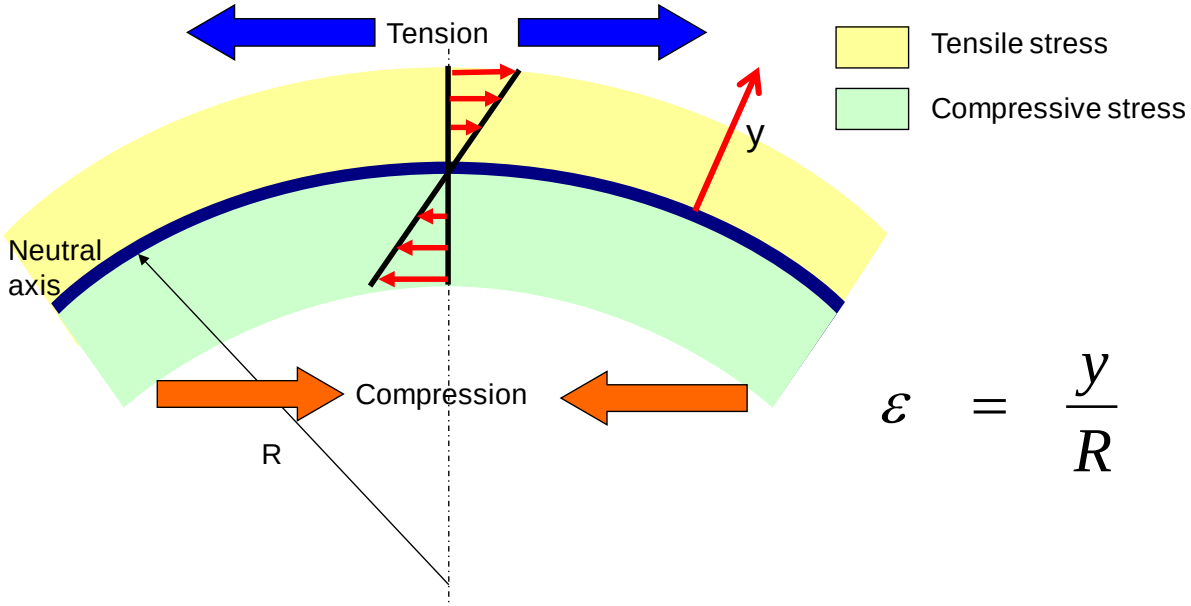

Lag Time: 1300 hours

Transient WVTR: $8 \times 10^{-6}$ g/m$^2$/day

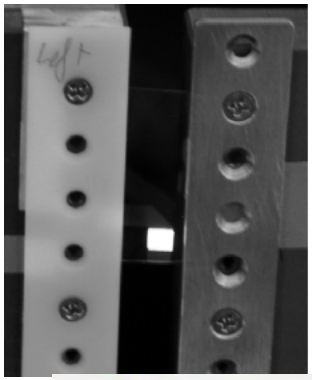
Steady State: $2 \times 10^{-3}$ g/m$^2$/day

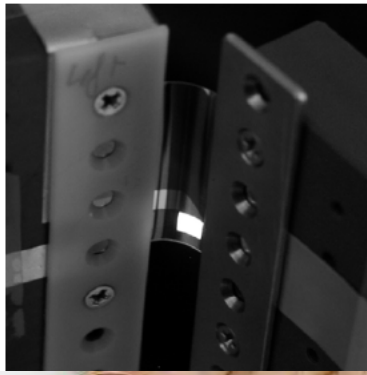
# Bending of Flexible Electronics

**Flexural deformation puts one surface in tension, one in compression.**
**Brittle Materials used in encapsulation fail easily under tension, not compression.**
**The strain or stress induced in the films are a function of bending radius AND substrate thickness.**
**Under 2 point bending, the strain is highest in the center, lower at the edges.**
**Repeated bending results in the initiation of damage and failure.**



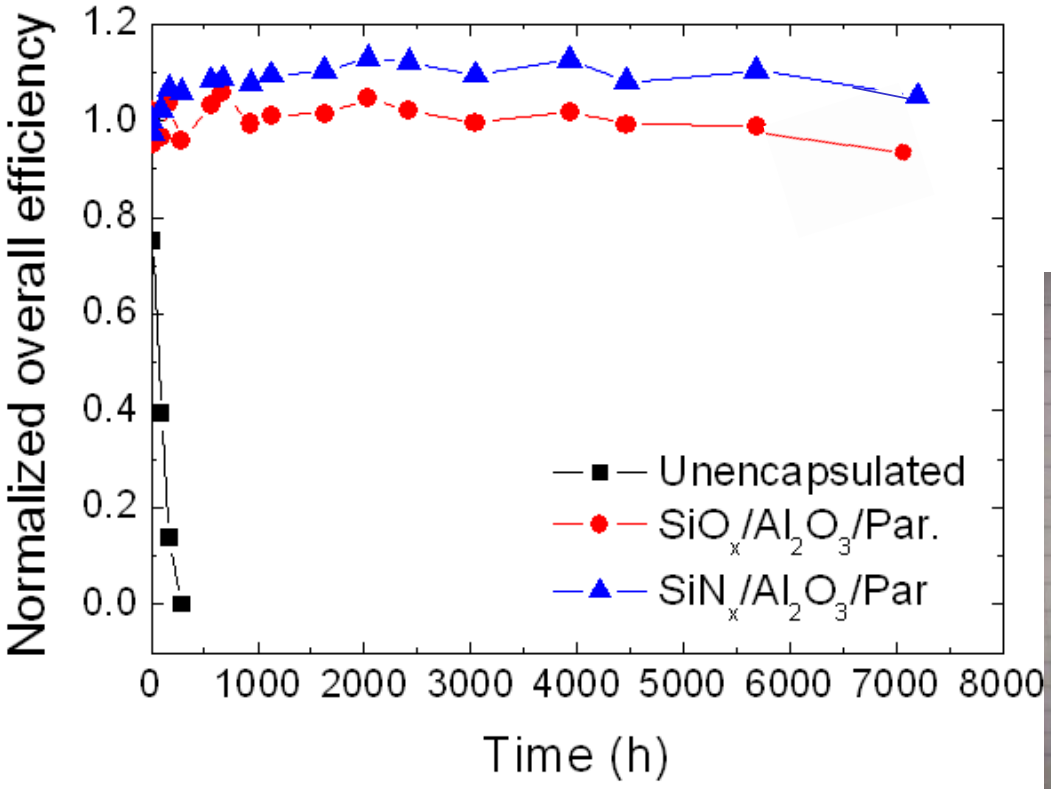

$$\varepsilon = \frac{y}{R}$$

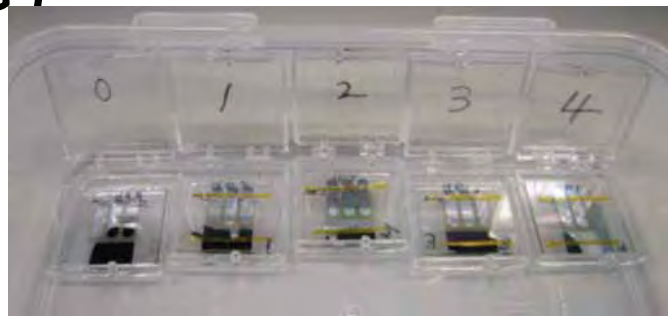


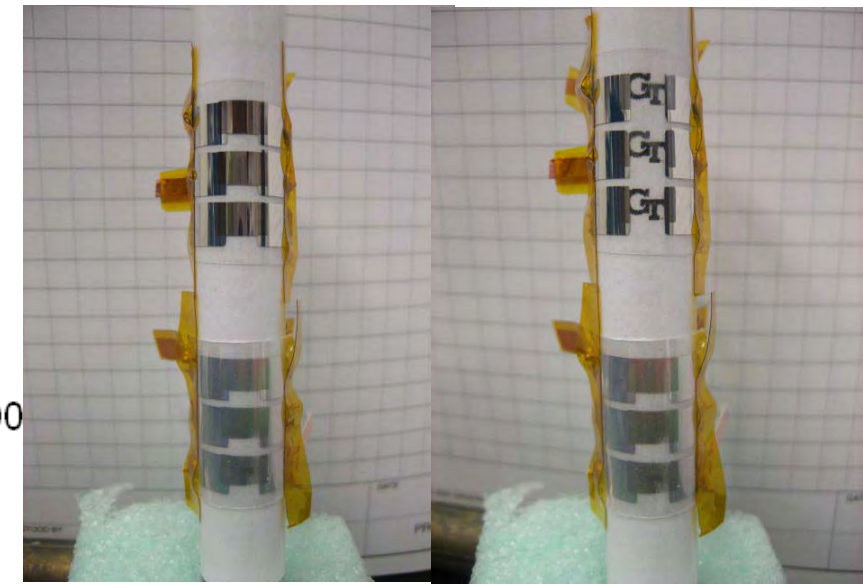


# Lifetime and Reliability

**Overall device efficiency ( Oriel 91160, AM 1.5G )**



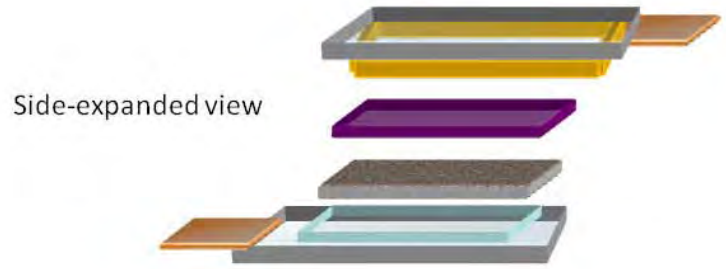



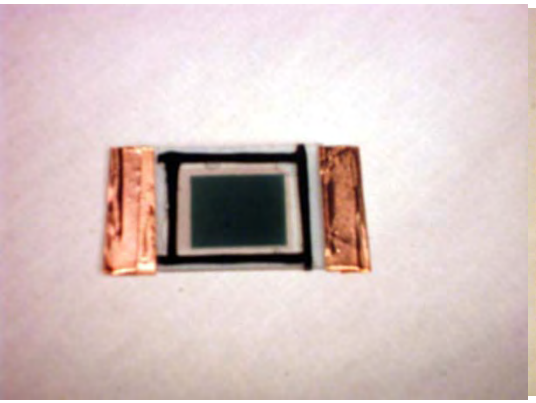



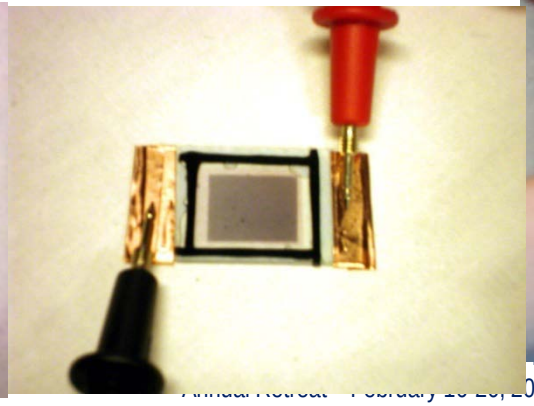
(N. Kim, et al., Applied Physics Letters, 2009)

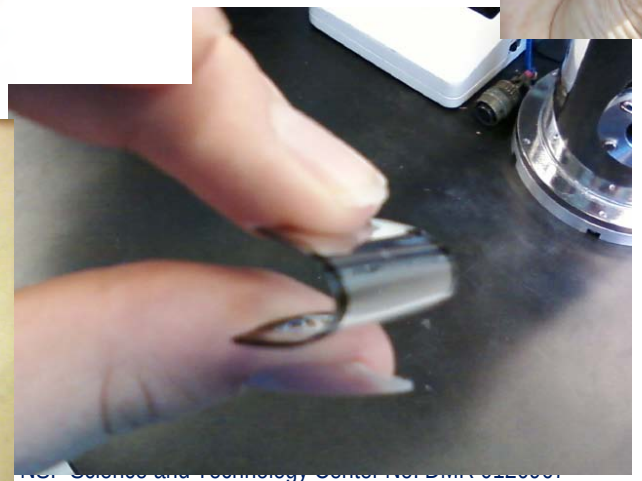
# Sealing Materials

**New Sealant Material used to encapsulate electrochromics.**
**Shows WVTR values as low as $5x10^{-5}$ g/m$^2$/day at 50C/80% RH.**
**Ca samples tested for 3 months.**



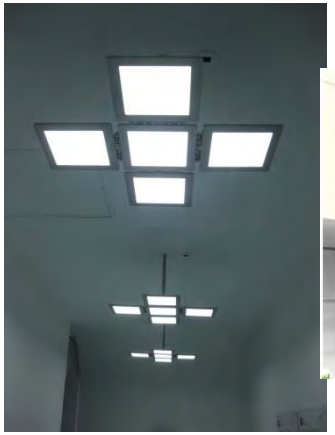




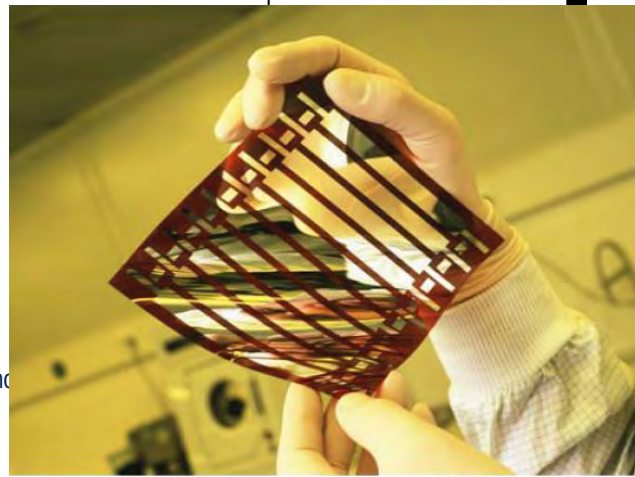
# Societal Impact/ Applications

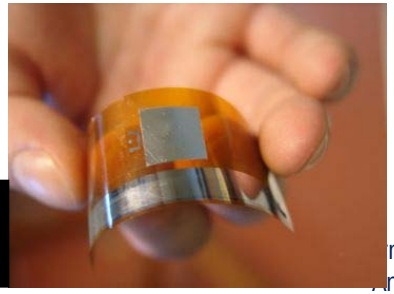
Displays

Solid State Lighting



Solar Cells





Flexible Transistors