Frontiers in Organic Electronics

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Outline of Presentation

- Background and introduction
- Research on solar cells
- Research on OLEDs
- Integrated electronics
- The need for a manufacturing strategy
- Summary and concluding remarks

Background and Introduction

- In 1905 Albert Einstein won the first of 2 Nobel Prizes for his work on the photoelectric effect
- Later in 1956 William Shockley, John Bardeen and Walter Brattain won the Nobel Prize for work for the development of the transistor that lead to the development of silicon microelectronics
- By the early 1960’s Korea, Taiwan and Silicon valley started to invest seriously in silicon microelectronics
- At that time Korea and Ghana had similar income and growth patterns
- Since then the divergence between the growth pattern can be attributed at least partly to the emergence of Korea in microelectronics
- So what is the silicon opportunity of today?

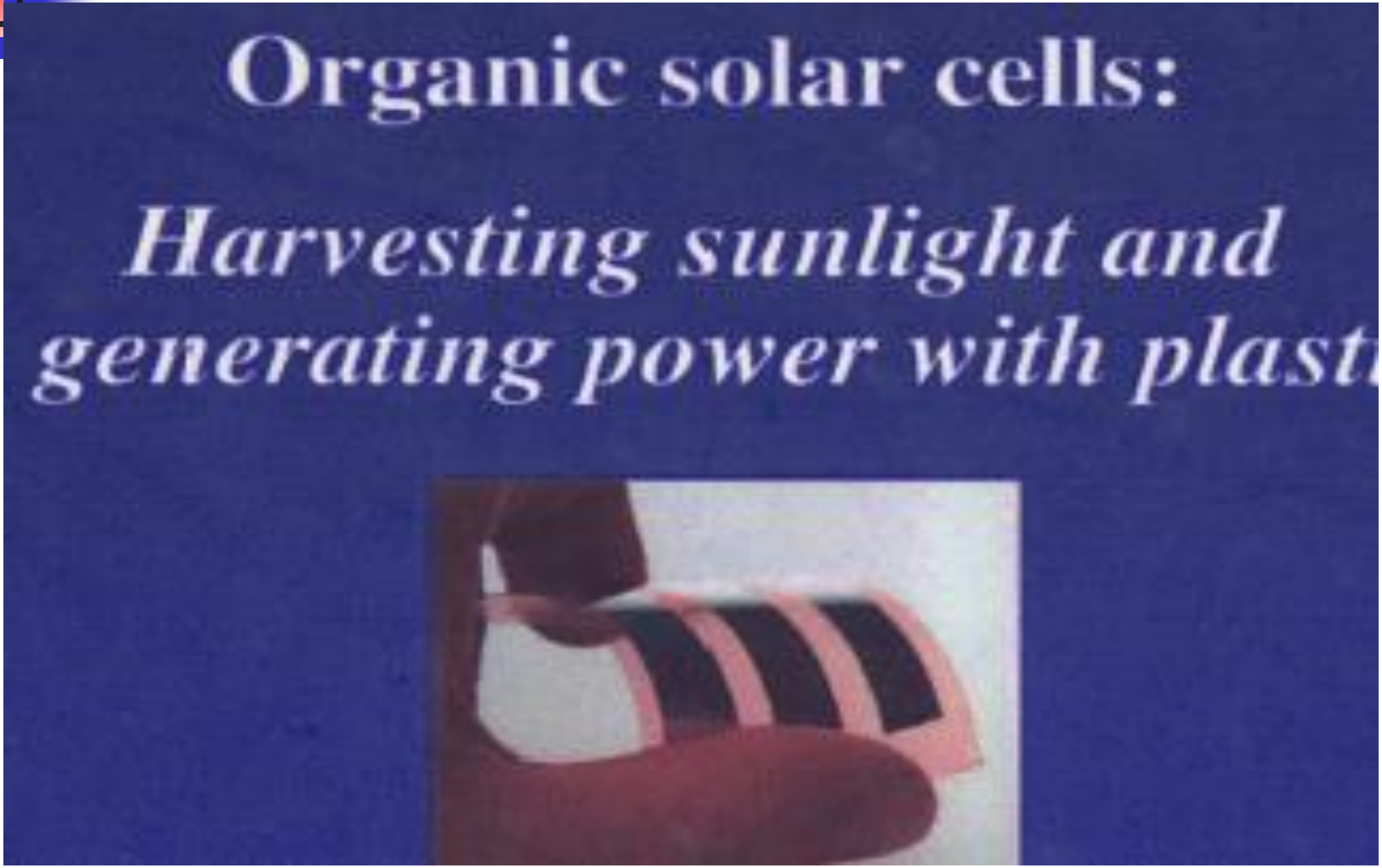
Background and Introduction to Organic Electronics Research

- Just a few years ago in 2000 the Nobel prize was given to Alan Heeger, Alan MacDairmid and Hideki Shirakawa for organic electronics
- Organic electronics could represent the next frontier beyond silicon microfabrication – why?
- Potential applications in OLEDS and organic solar cells
- Ongoing interdisciplinary research
  - Synthetic chemistry
  - Device physics and fabrication
  - Modeling of cold welding and reliability

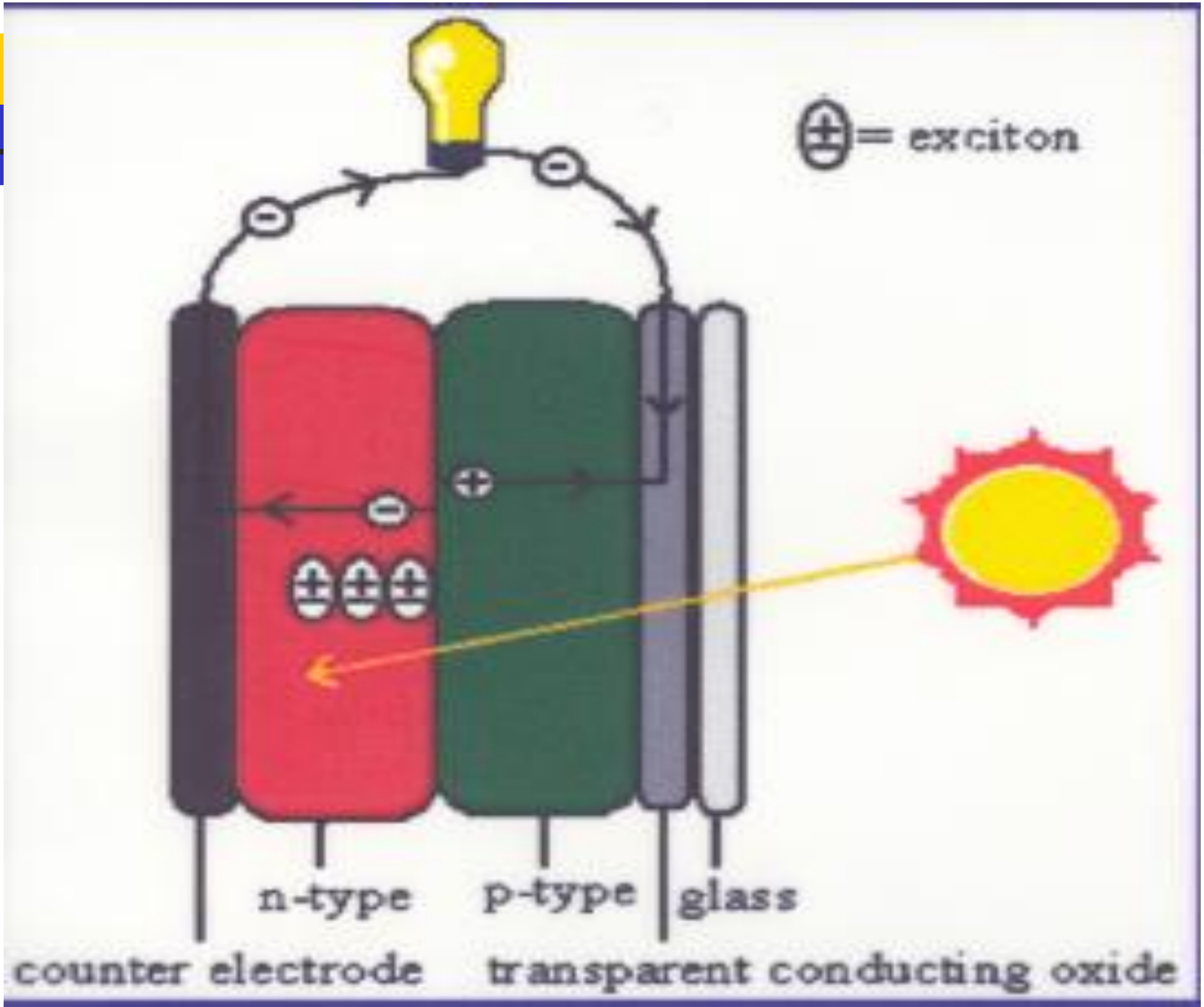
Objectives of This Class

- This class presents an overview of ongoing US/Africa collaboration in organic electronics
- The objective is to develop a US/African effort similar to the US/Korea and US/Taiwan effort in silicon electronics
- Current partners are from
  - Ethiopia
  - Nigeria
  - Senegal

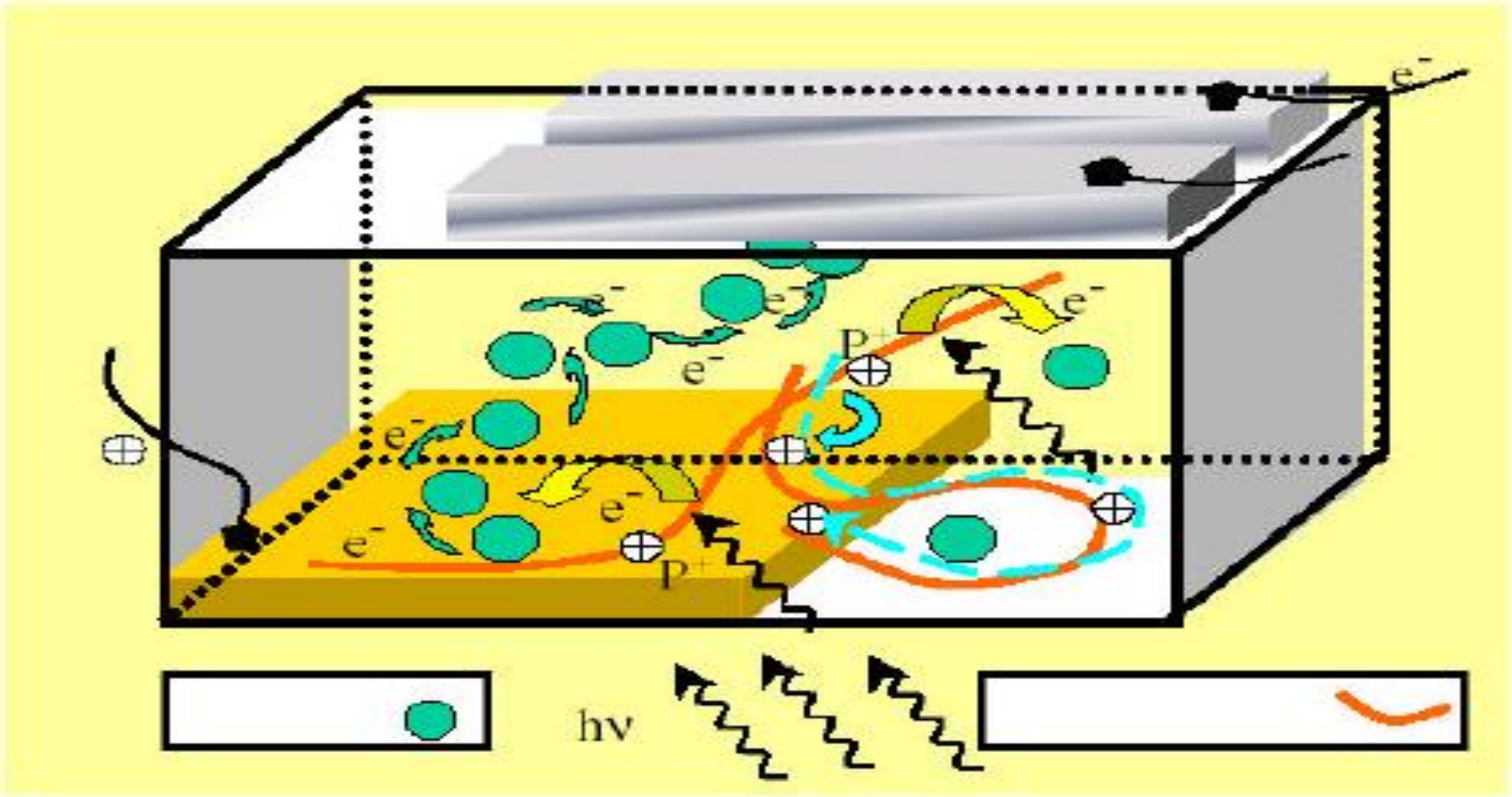
Flexible Devices



Future … Solar cells and OLEDs



Charge Transport in Organic Semi-Conductors

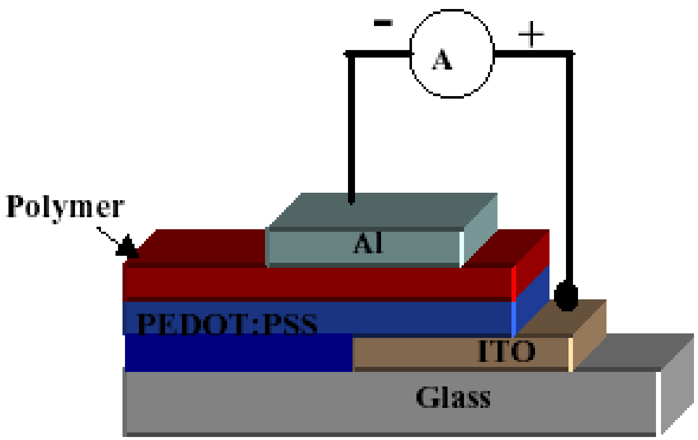


Three Operation Mechanisms in Organic PV Devices*

- Absorption of light
- Generation & separation of +/- charge pairs known as excitons
- Selective transport of charges through active polymer to the appropriate electrodes

*Sariciftci, et al. Syn. Met. 121 (2001)

Constituents of Solar Cell



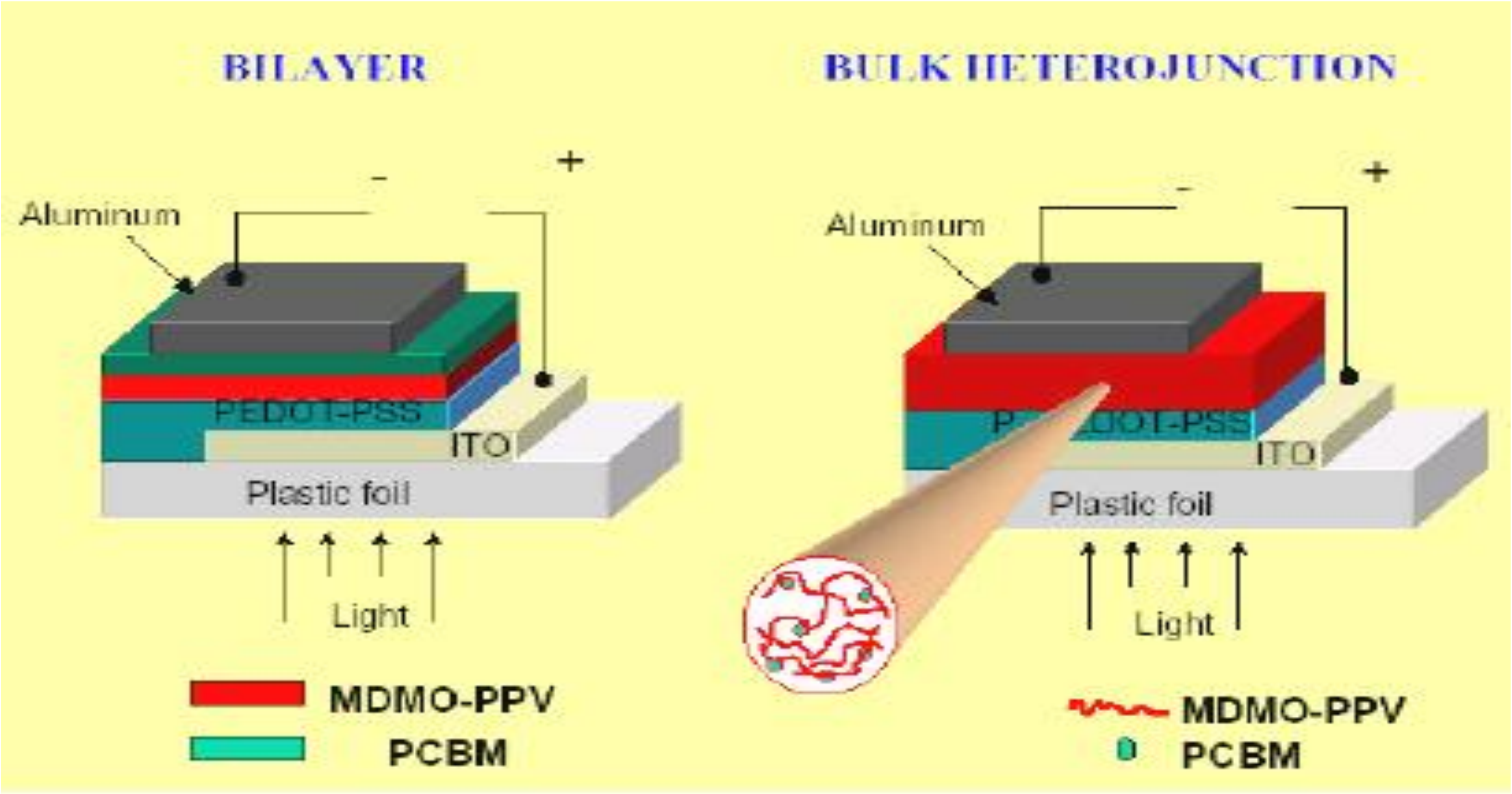
Donor: poly[3-(4'-1"-oxooctylphenyl)thiophene] (POOPT)

Acceptor : [6,6]-phenyl-C61-butyric acid methyl ester (PCBM)

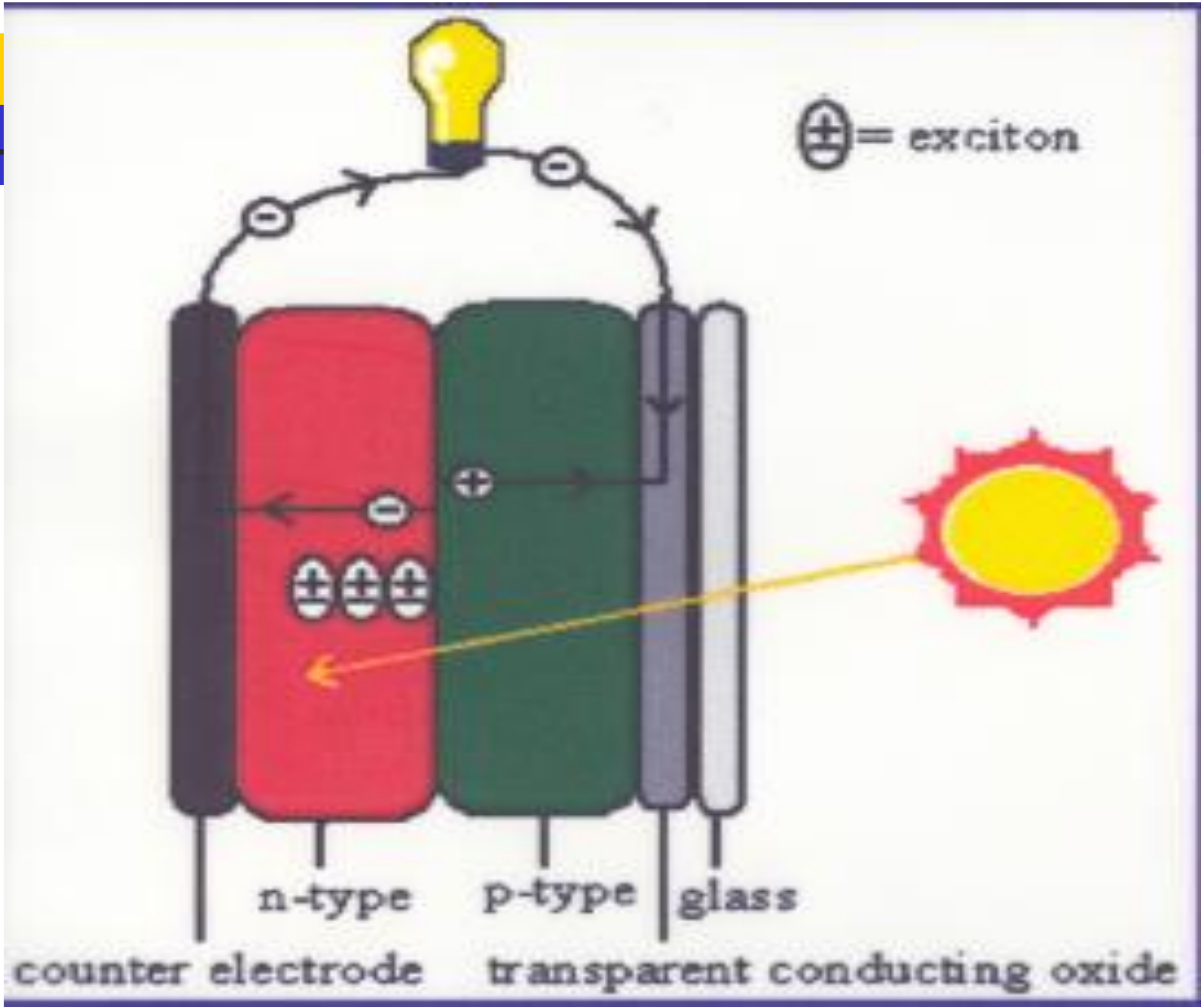
Organic Electrode: poly(3,4-ethylenedioxythiophene)-poly(styrenesulfonate) (PEDOT:PSS)

Bulk Heterojunction Vs. Bilayer

Double Layer & Bulk Heterojunctions



Future … Solar cells and OLEDs



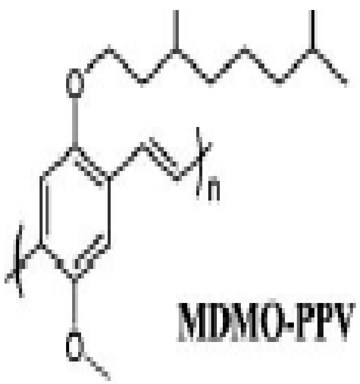
Blending Conjugated Polymers

- **For the generation of electrical power by absorption of photons, it is necessary to spatially separate the excitons generated by photo-excitation before recombination can take place.**

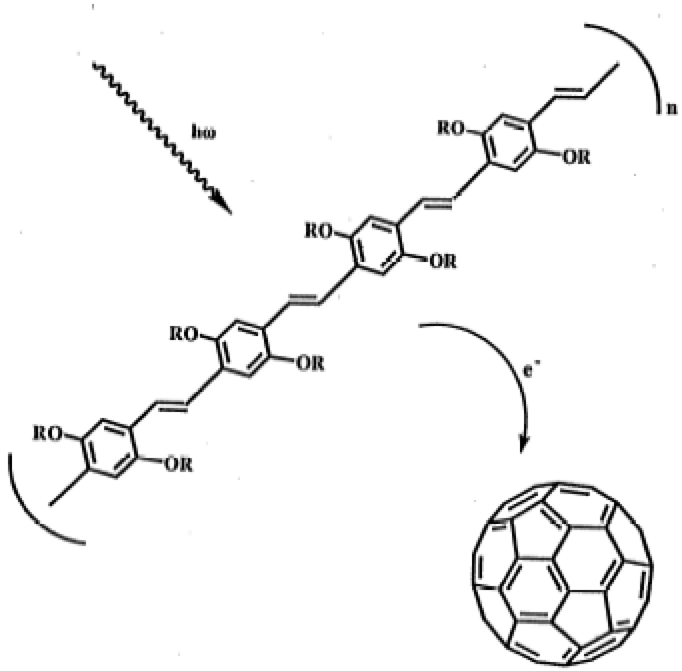
- **This could be achieved by blending conjugated polymers with an electron acceptor molecule or charge carriers**

- **The highest occupied molecular orbital (HOMO) of the acceptor molecule should be lower than the HOMO of the conjugated polymer**

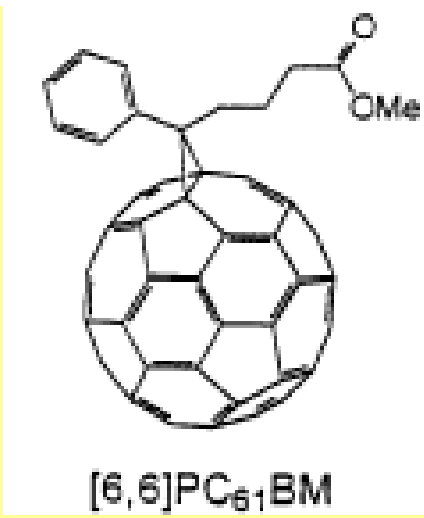
Generation and Recombination of Excitons



DONOR



EXCITON GENERATION

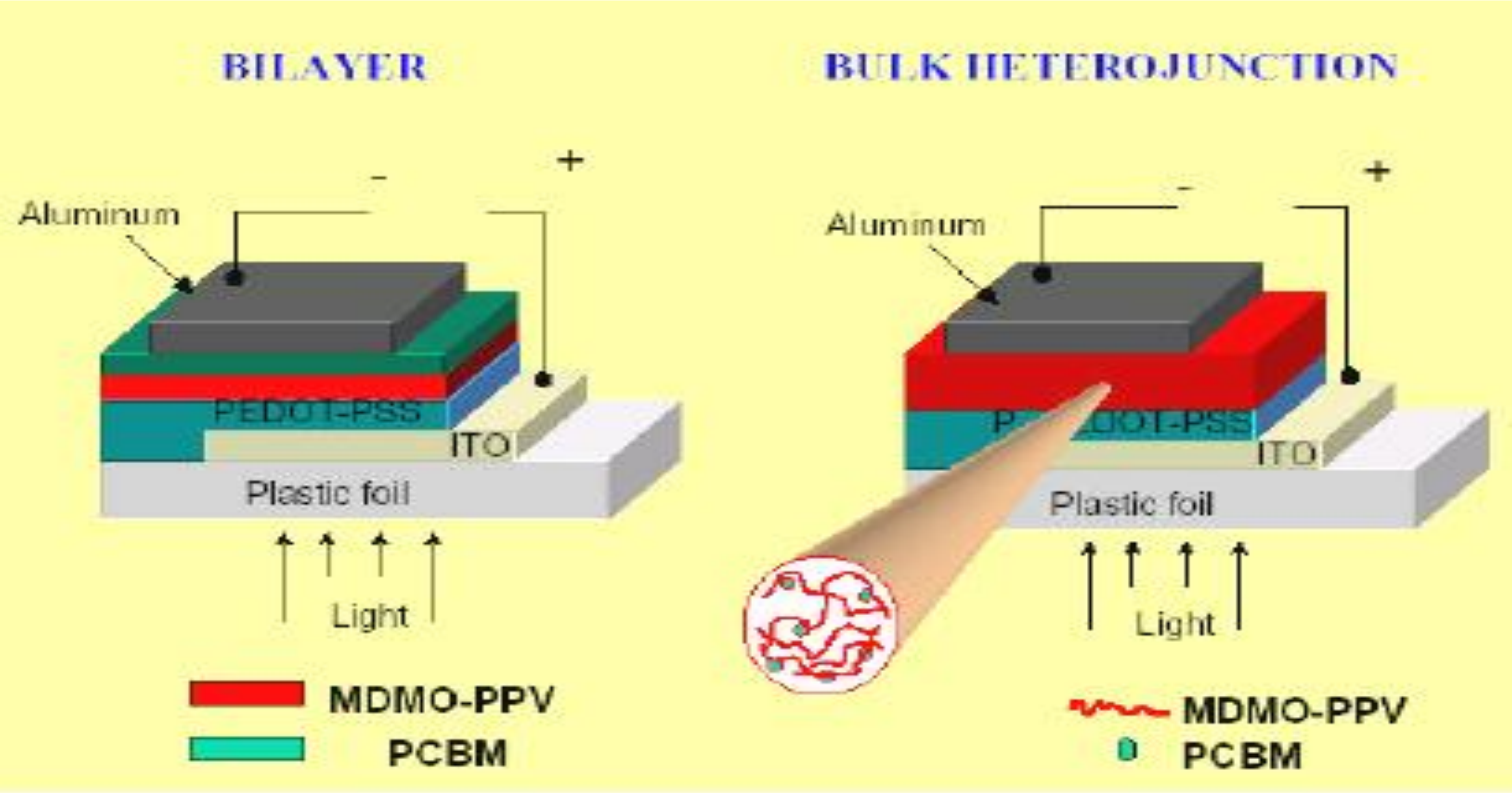


ACCEPTOR

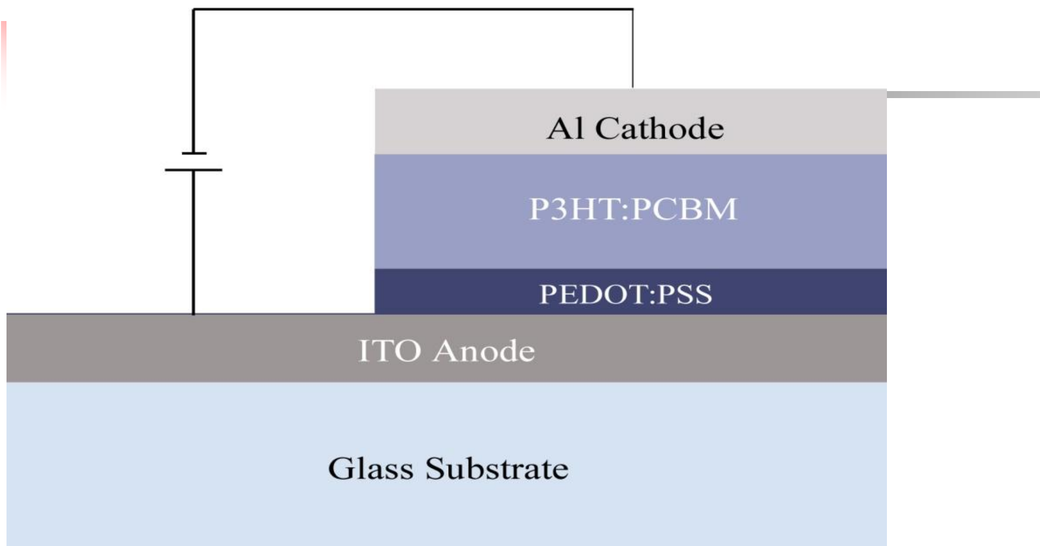
(PCBM)

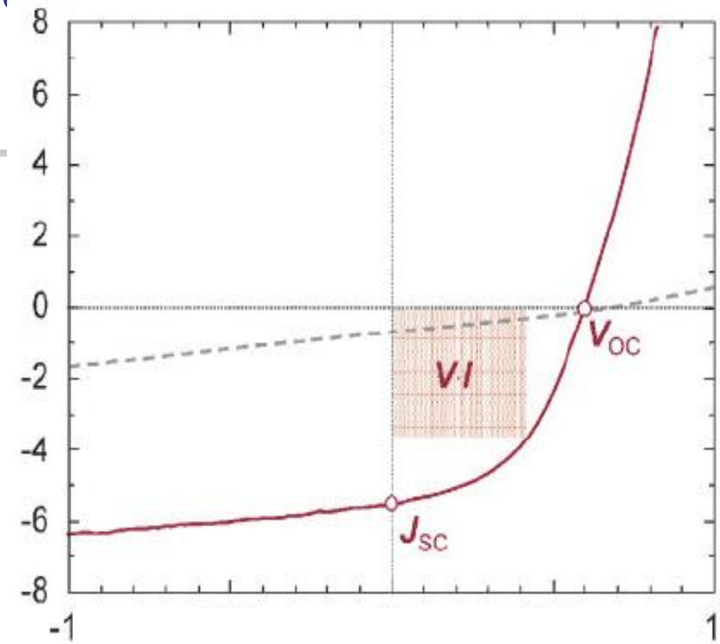
Generation time approx. 50fs. Recombination time is a few microseconds

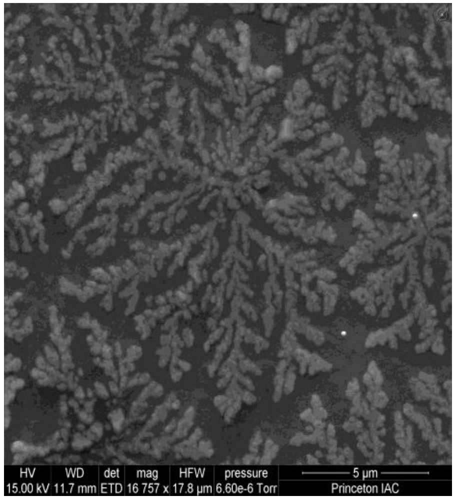
Double Layer & Bulk Heterojunctions

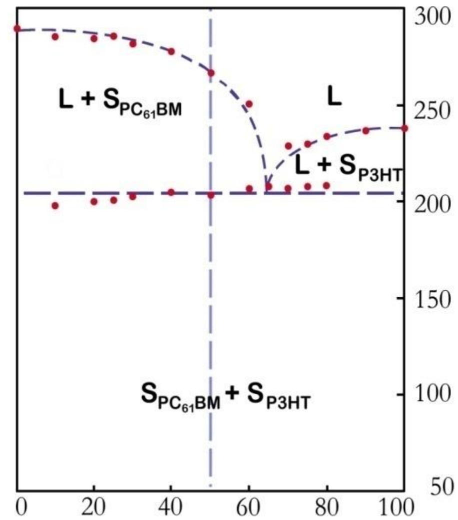


Typical I-V Curves for Solar Cells







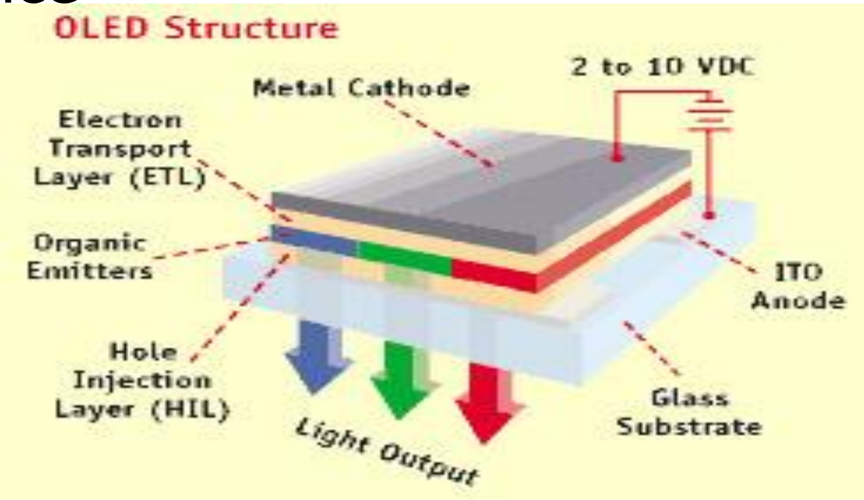


Summary - Organic Solar Cells

- Our record is about 2% efficiency in lab air
- World record is about 6.5% - in inert environments
- This can be increased by the control of the “eutectic” microstructure and processing to higher levels
- Remember that the world record was just 1% a few years ago…..
- However device stability requires the control of the environment
- We have also developed new ways of depositing and adhering organic solar cells to flexible substrates

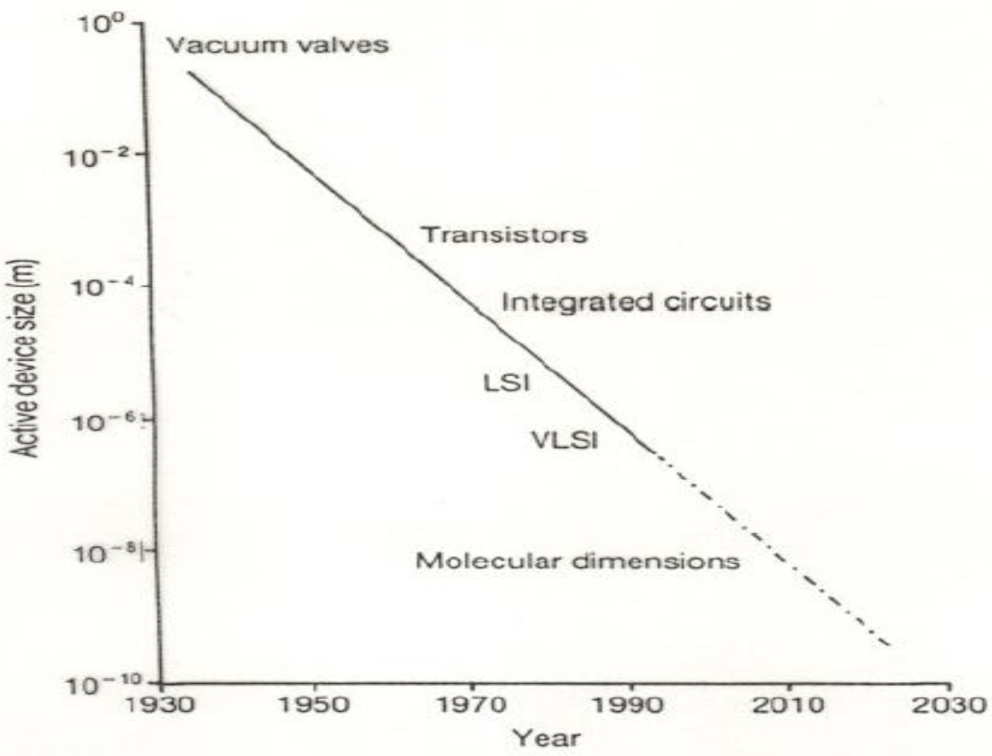
Introduction to OLEDs

- OLED = Organic Light Emitting Device



http://www.kodak.com/

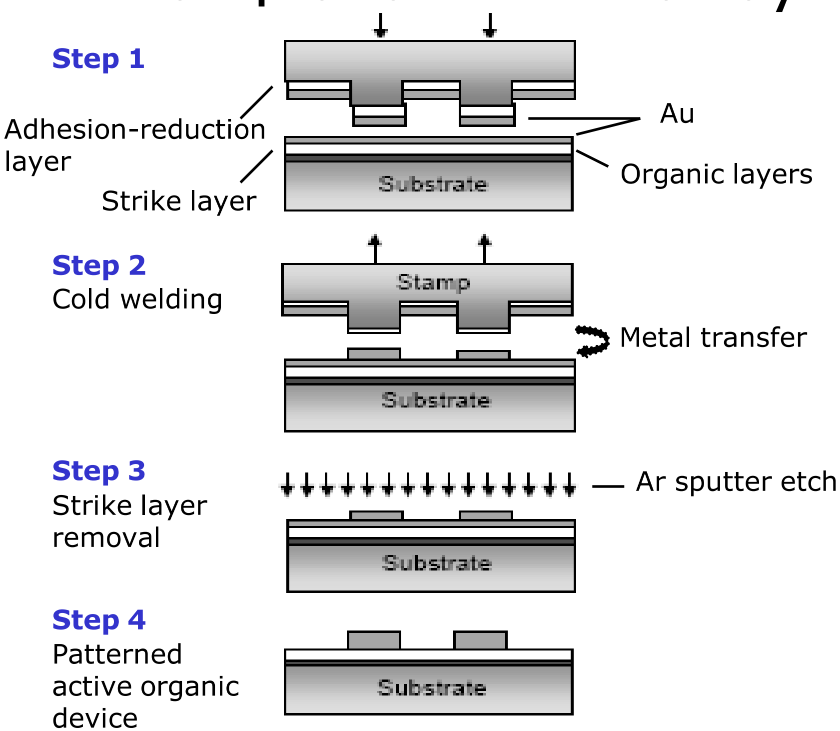
Global trend:
Device dimensions

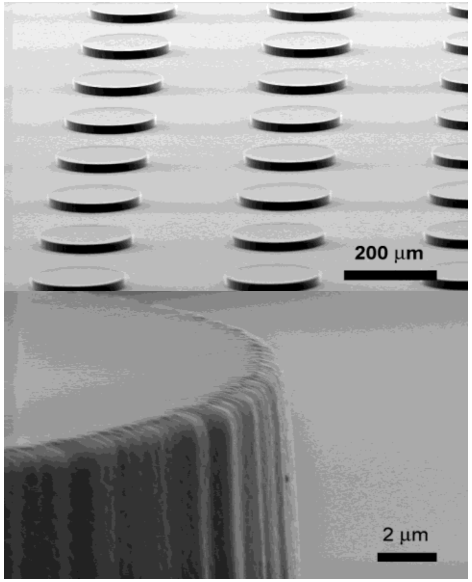


Historical and projected reduction in the dimensions of active semiconductor devices.

Cold Welding for OLED Fabrication

- Patterning of the OLED electrodes is difficult by photolithography due to organic material degradation in conventional solvents or high temperature
- Nano- and micro-patterning can be realized by inducing cold-welding between a metal coating on the stamp and the metal layer on the organic film

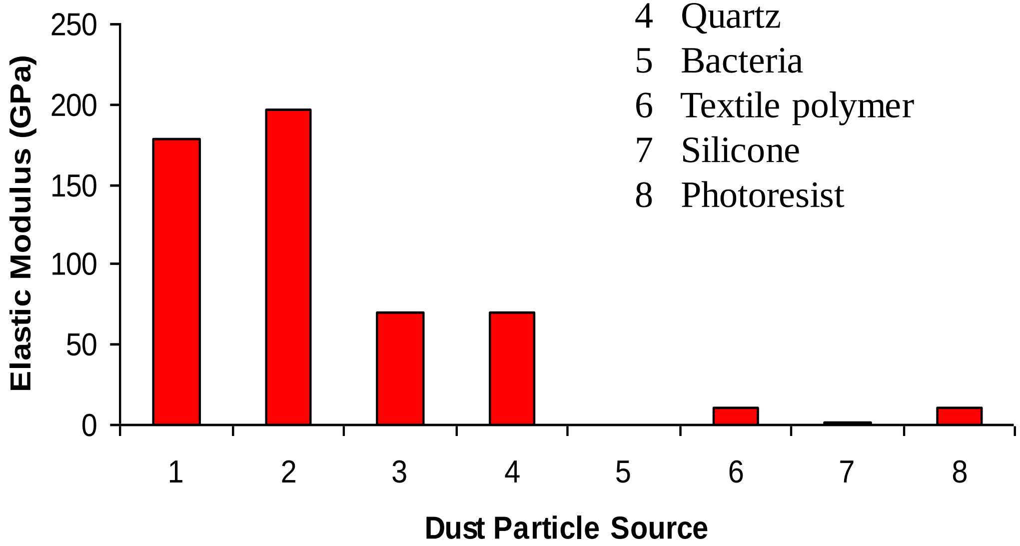


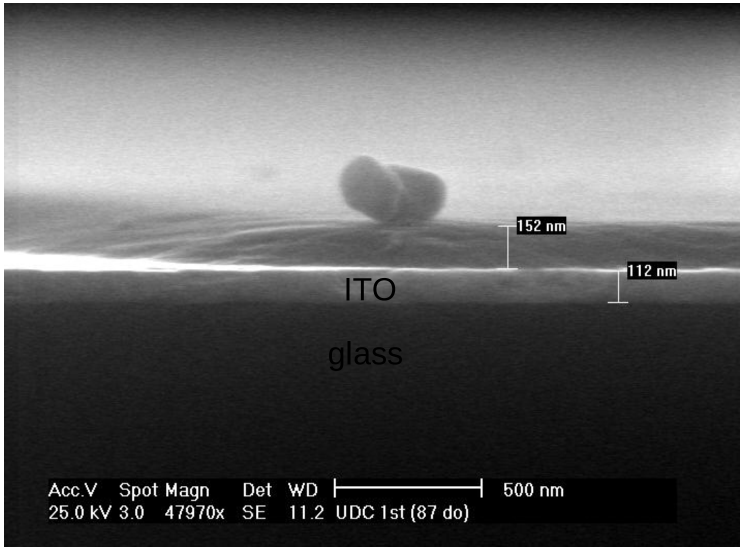


--- Kim, Forrest, *Adv. Mater.* (2003)

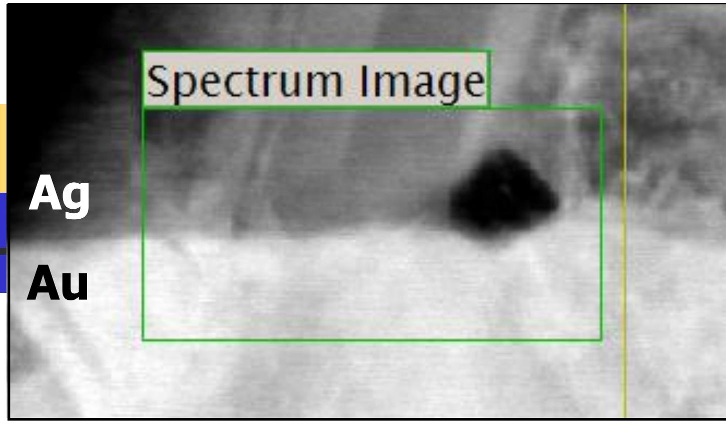
Typical Dust Particles In Semiconductor Clean Room

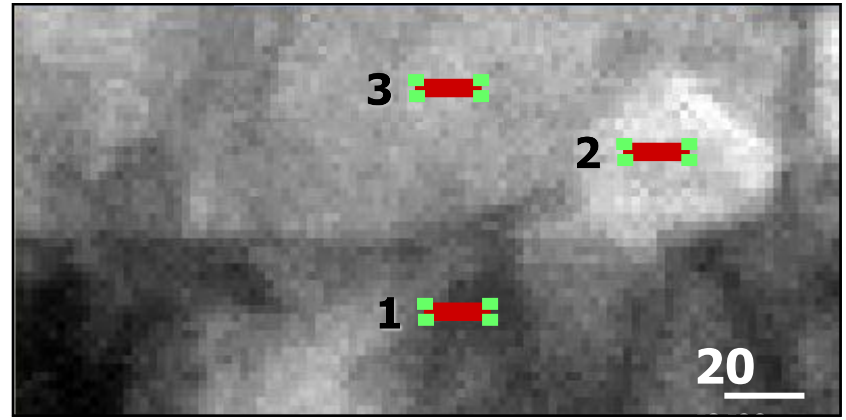
1 Silicon
2 Iron
3 Aluminum
4 Quartz
5 Bacteria
6 Textile polymer
7 Silicone
8 Photoresist

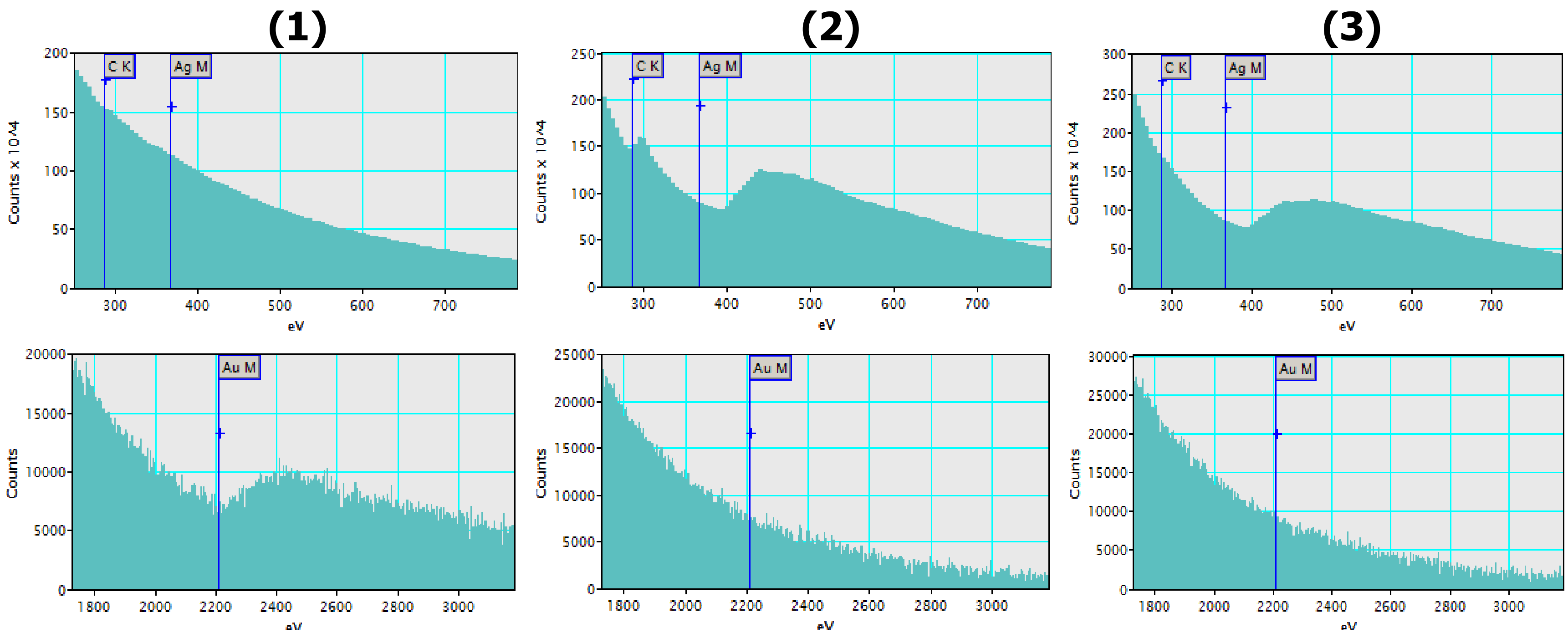




Electron Energy Loss Spectra of Au-Ag Interface

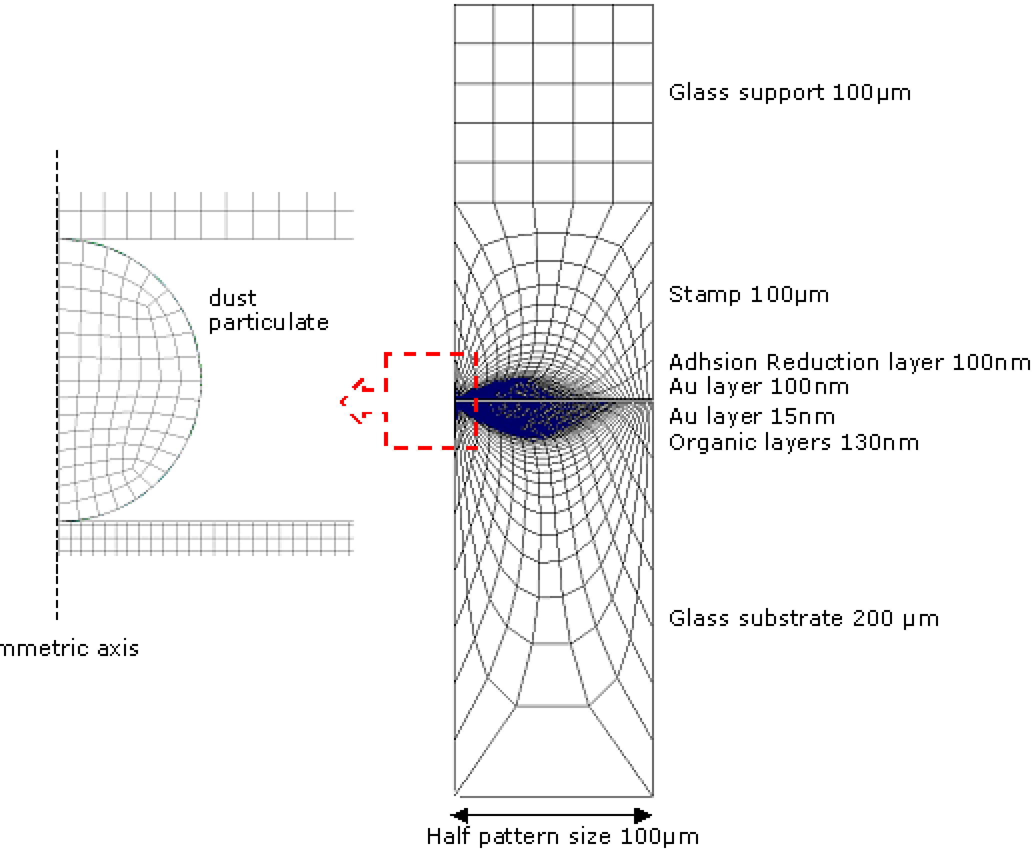


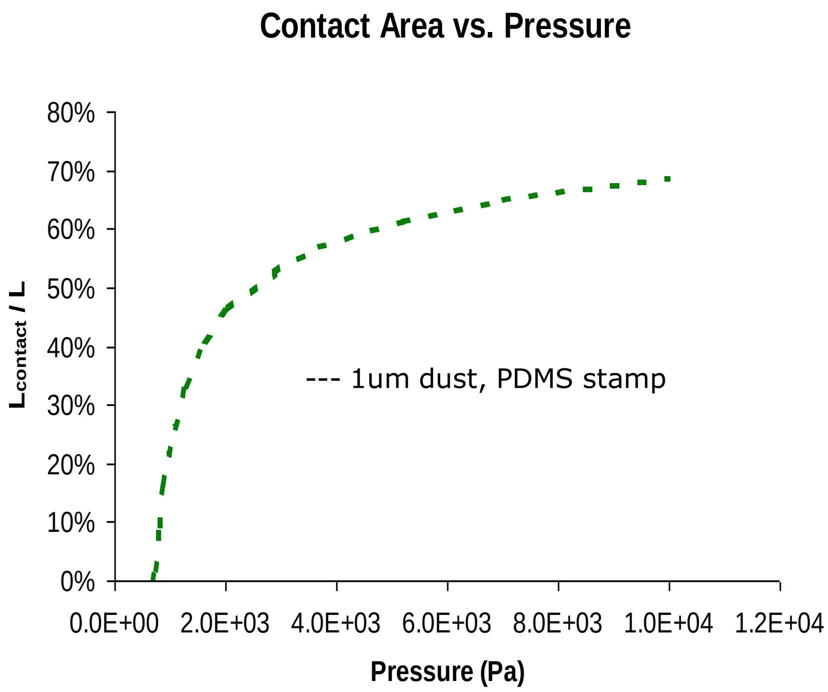




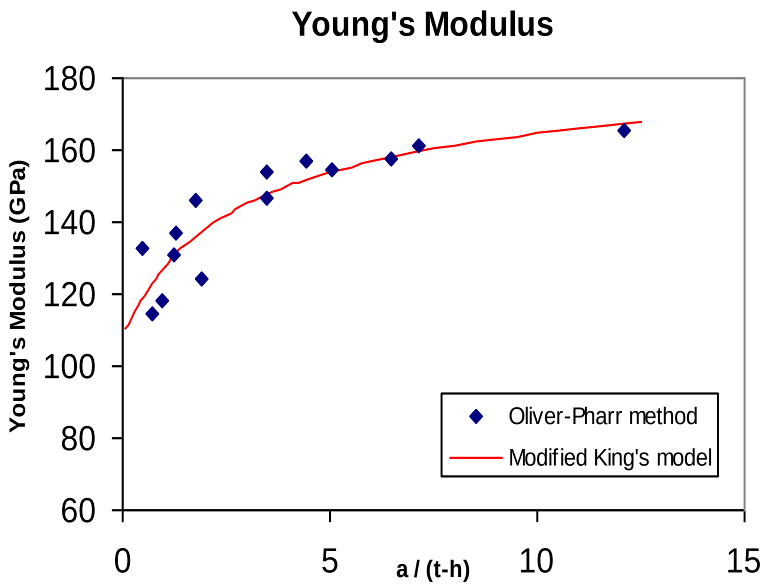
Comparison of EELS collected from various locations across the Au-Ag cold-welded interface. It shows there is a clear increase in both carbon and Ag peaks in position 2.

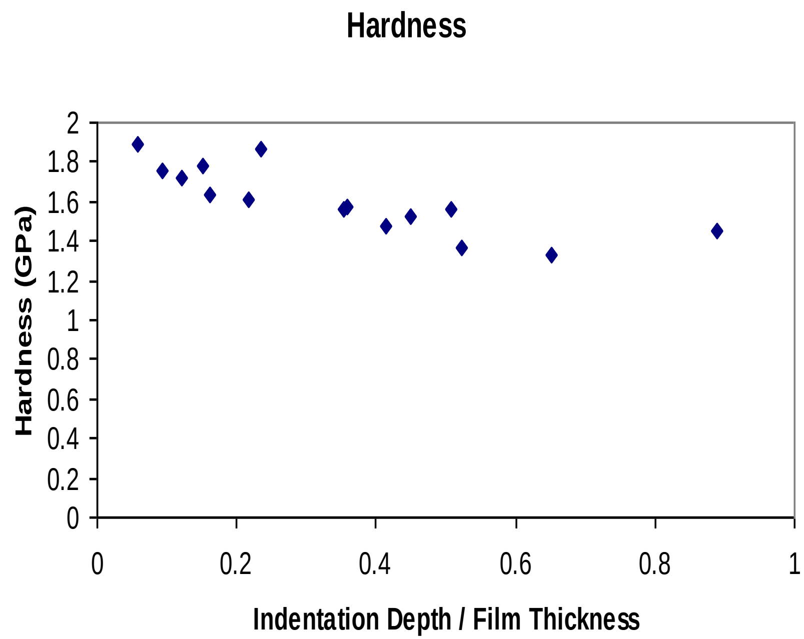
Finite Element Simulation of Stamping Process

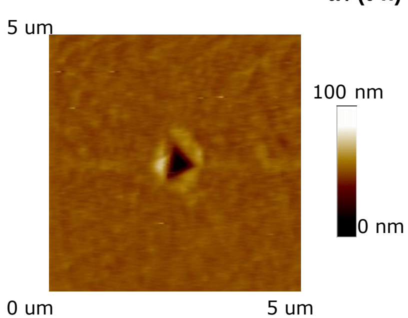




Mechanical Properties Obtained for Au/Si system



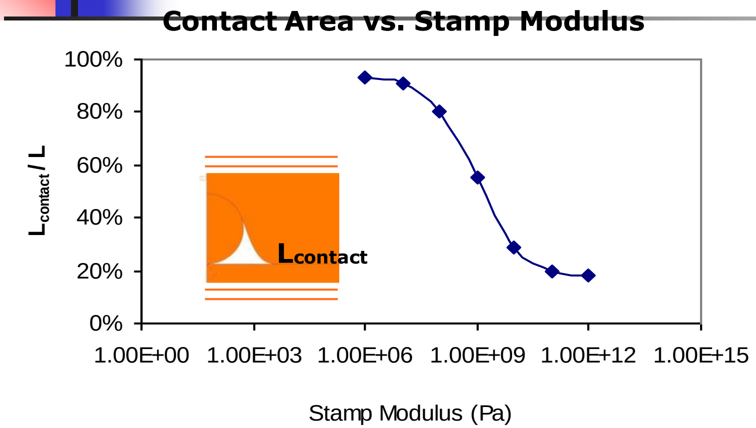


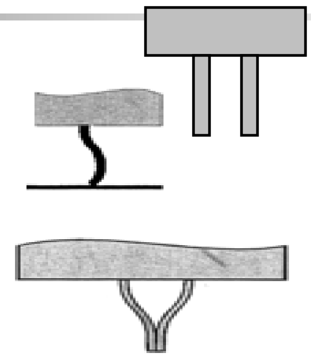


AFM scan after the indendation for 500nm Au / Si

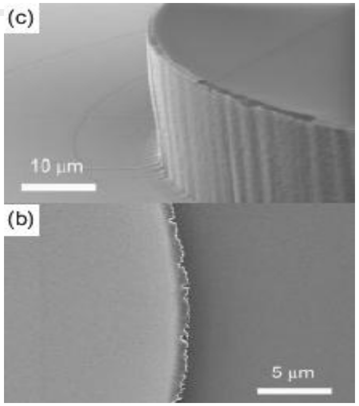
Mechanical Property	Current Study	Others' Study
E(Au film)	110 GPa	E_{100}=43 GPa *, E_{110}=82 GPa *, E_{111}=117 GPa *

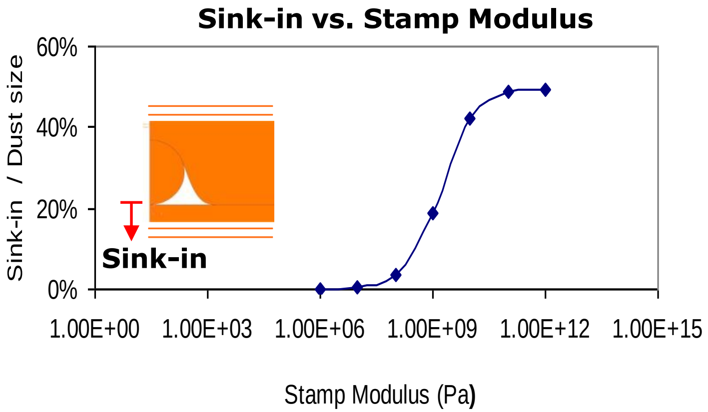
Stamp Modulus Design





---C. Hui, et al. (2002)

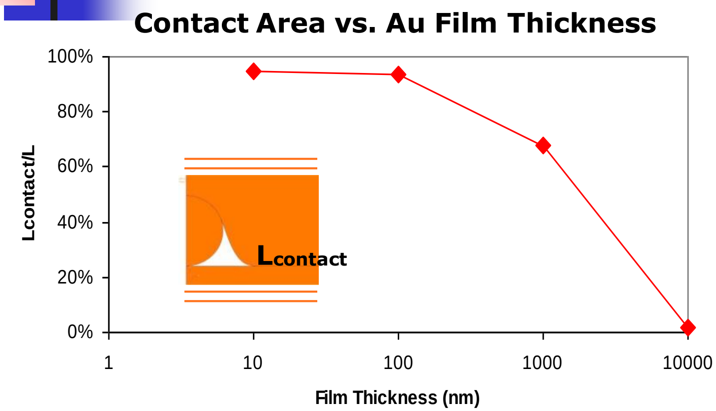


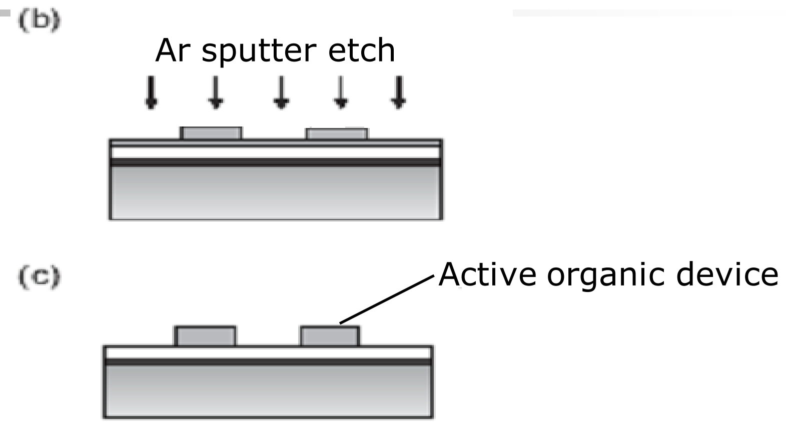


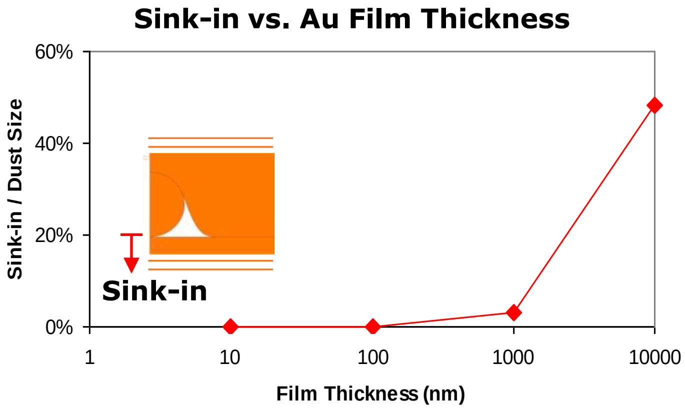
---400KPa, 1μm dust

- Advantages of soft stamps: flexibility & low damage
- Disadvantages of soft stamps:
  - Dimensional instability problems
  - Stamp edge rounding
- Trade-off in design:
  - Low modulus vs. high modulus stamp

Au Film Thickness Design







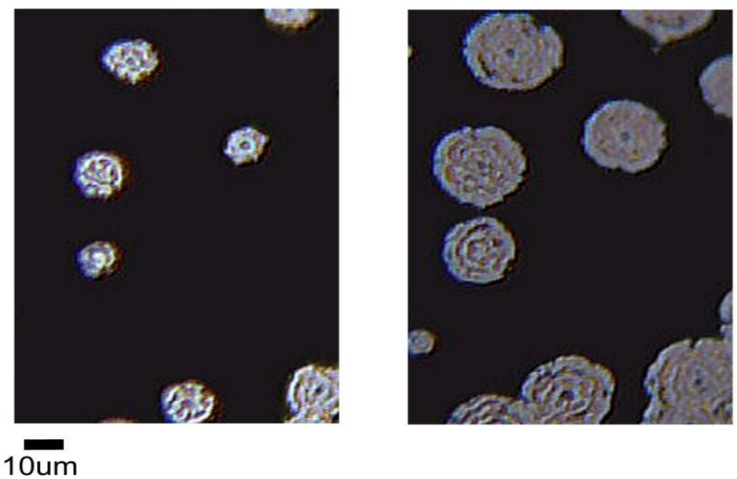
- Thin metal film : flexibility & low damage
- Thick metal film is required for good thickness contrast in cold welding
  - Further etching
- Trade-off in design
  - Thin Au layer vs. thick Au layer

---PDMS stamp, 1μm dust, 400KPa

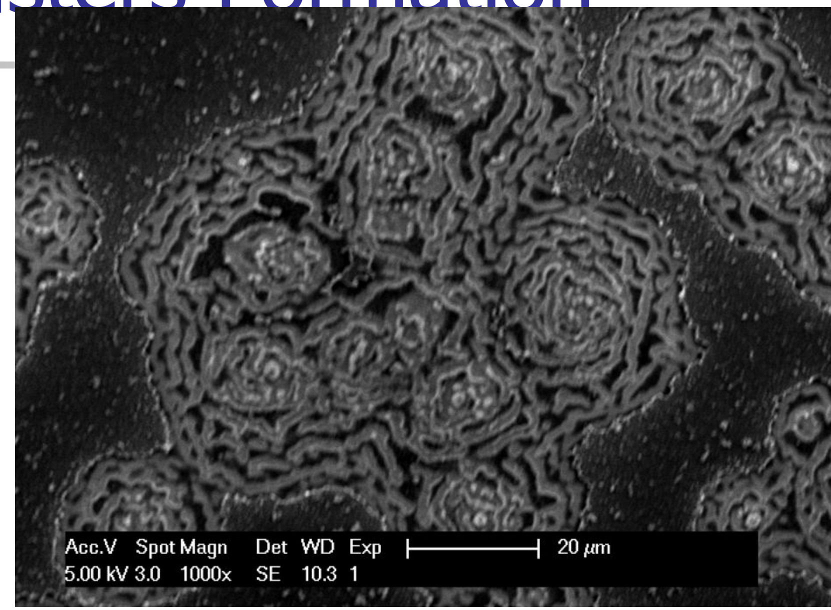
In-Situ and Ex-Situ Observations of Telephone Cords/Blisters Formation

In-Situ observation of Telephone Cord Formation

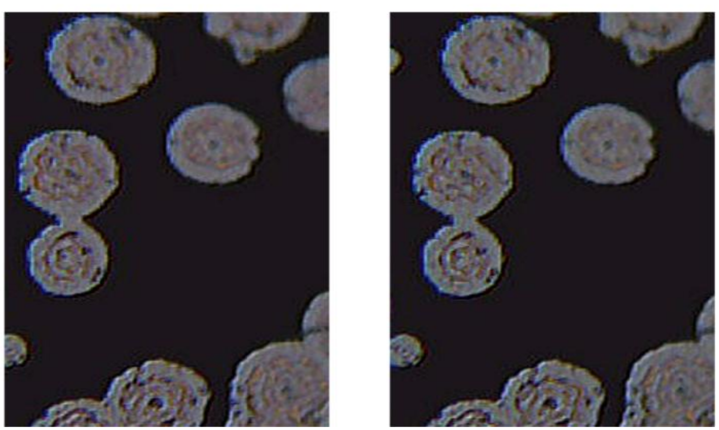
a)



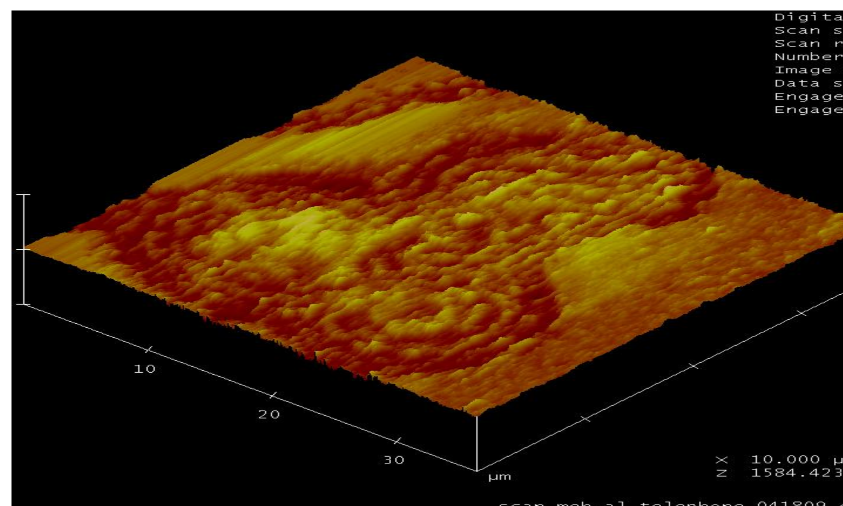
b)



d)

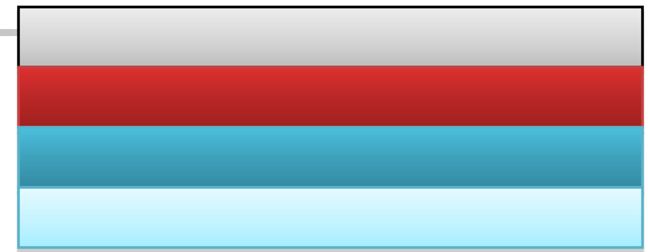


c)



Critical Condition for Blister Formation and Growth

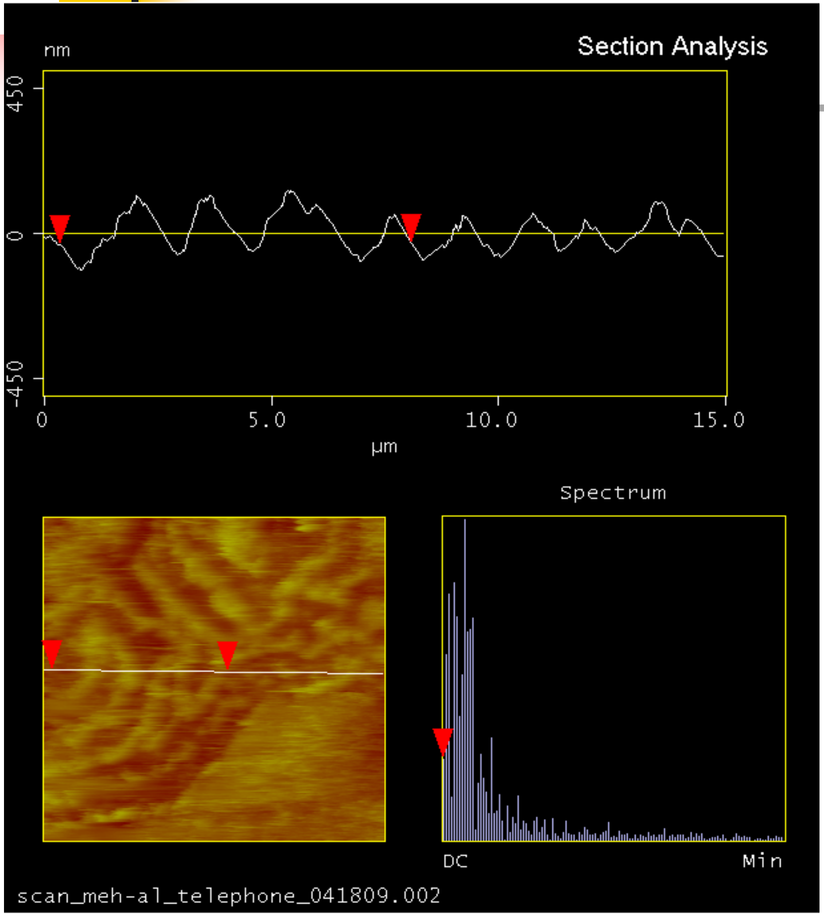
- Blisters form due to buckling under biaxial compression
- Critical buckling stresses due to processing are estimated to be ~1Gpa
- Temperature increase due to charge transport and presence of contaminants induces stress due to thermal mismatch
- Combination of residual and thermal stresses causes spiral blisters

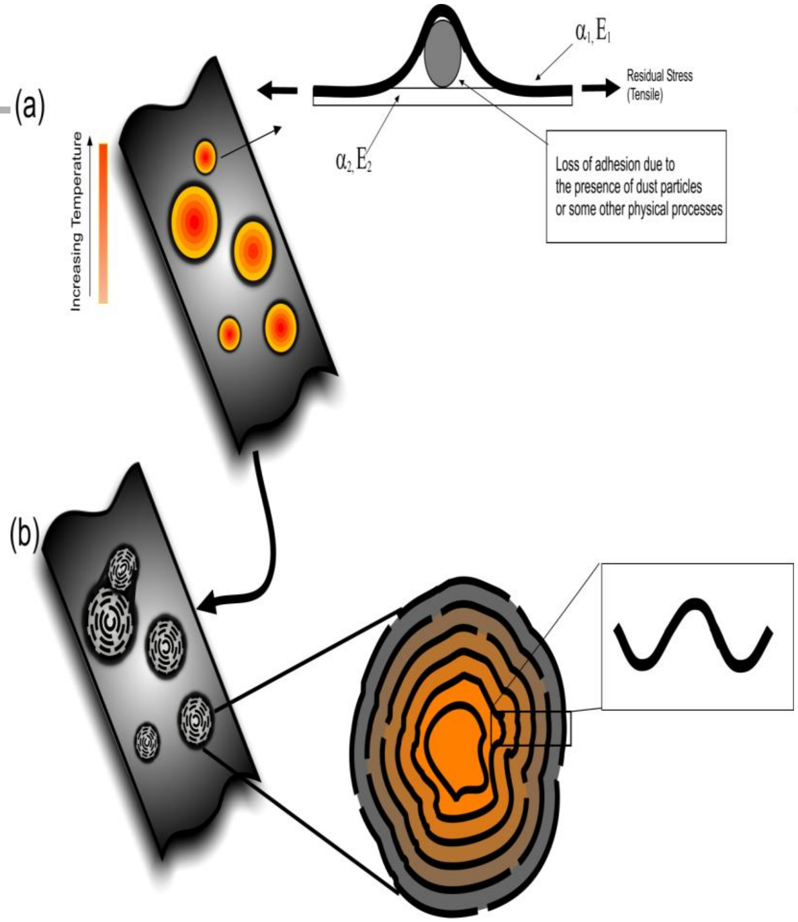


$$\sigma_i = E_i \Delta\alpha_{i,i+1} \Delta T$$

Thermal Imaging of PLED (0.1cm²)

Periodicity observed in Blister Morphology





- Periodic ordering of blisters due to variations in thermal stresses within a radial temperature distribution

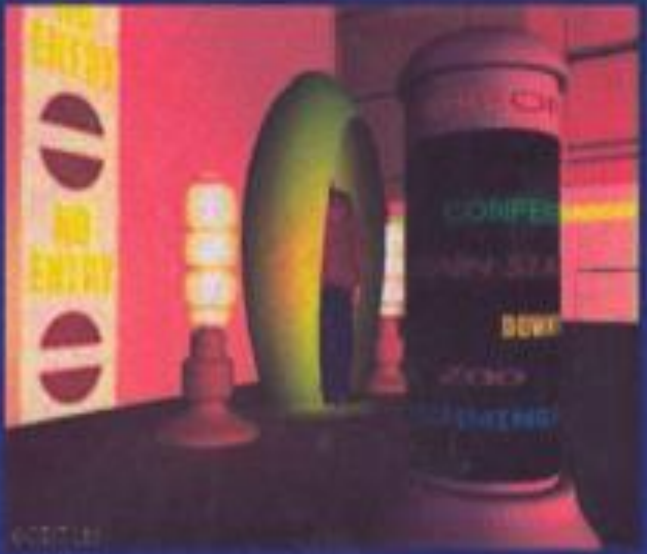
- Radial temperature distribution develops at hot spots due to defects which result in buckling and coalescence of blisters

Summary - OLEDs

- Developed guidelines for the control of cold welding for OLED fabrication
- Provided understanding of cold welding physics
- Developed guidelines for pattern transfer of ploymers
- Goal is to establish micro- and nano-fabrication methods that do not require clean room
- Other goal is to develop OLED packaging capability to improve OLED lifetimes

Integrated Systems and E-Textiles …

- Consumer applications (smartcards) will pave the way for large area PV systems (industrial coating technologies)
- Full plastic integrated systems containing solar cells, transistors and LEDs



The Need For a Manufacturing Initiative

- Quite clearly manufacturing issues are not too far ahead….
- Africa’s goal should be to develop low cost manufacturing capability
- However strategy should not wait for organic electronics to mature
- The sandwich structure for solar cells and OLEDs is the same
- The only real difference is what is in the sandwich

Possible Strategy for African Solar Cell/LED Manufacturing

- Start with amorphous silicon manufacturing – low cost and possible & creative marketing
- Scale up pilot plants to manufacturing of solar cells and LEDs (short term)
- Develop nanocrystalline silicon and dye sensitized solar cells from research scale to modules (medium term)
- Long term introduction of organic solar cells and OLEDs in the third stage (long term)
- Expand access to large fraction of population

Summary and Concluding Remarks

- This class presents an introduction to organic electronics and possible US/African strategy for PVs
- Organic solar cells might represent the possible frontier beyond silicon microelectronics
- These are being developed with increased efficiency - further research needed
- OLEDs provide some opportunities for rural lighting and high definition screens – some research needed
- Future products could include integrated electronics for e-textiles, high definition TVs and BioMEMs
- There is a need for an US/African manufacturing initiative with short/medium/long term strategy…..

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- Staff – Conrad Watola

Thank You

- Any Questions?