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?
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

Organic solar cells: Harvesting sunlight and generating power with plastic...
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

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

Generation time approx. 50fs. Recombination time is a few microseconds.
Double Layer & Bulk Heterojunctions

**Bilayer**
- Aluminum
- PEDOT-PSS
- ITO
- Plastic foil
- Light
- MDMO-PPV
- PCBM

**Bulk Heterojunction**
- Aluminum
- PEDOT-PSS
- ITO
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- Light
- MDMO-PPV
- PCBM
Typical I-V Curves for 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

Typical Dust Particles In Semiconductor Clean Room

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

Elastic Modulus (GPa)
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

Contact Area vs. Pressure

--- 1um dust, PDMS stamp

Glass support 100μm

Stamp 100μm

Adhsion Reduction layer 100nm
Au layer 100nm
Au layer 15nm
Organic layers 130nm

Glass substrate 200 μm

Half pattern size 100μm

Pressure (Pa)

Contact Area vs. Pressure

0.0E+00 2.0E+03 4.0E+03 6.0E+03 8.0E+03 1.0E+04 1.2E+04

Lcontact / L

0% 10% 20% 30% 40% 50% 60% 70% 80%
Mechanical Properties Obtained for Au/Si system

Mechanical Property | Current Study | Others’ Study
---|---|---
$E_{(Au \text{ film})}$ | 110 GPa | $E_{100}=43 \text{ GPa}$ *,
$E_{110}=82 \text{ GPa}$ *,
$E_{111}=117 \text{ GPa}$ *
Stamp Modulus Design

**Contact Area vs. Stamp Modulus**

- **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

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C. Hui, et al. (2002)
### Au Film Thickness Design

#### Contact Area vs. Au Film Thickness

- **Ar sputter etch**
- **PDMS stamp, 1µm dust, 400KPa**

#### Sink-in vs. Au Film Thickness

- 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

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

- **Students** – Wali Akande, Onobu Akogwu, Tiffany Tong, Jing Du, Androniki Tsakiradou, Timi Opeke, Kehinde Öyewole, Joseph Asare, Vitalis Anye Chioh, Emmanuel Vodah, David Kwabi, Yifang Cao, Changsoon Kim, Thomas Woodson

- **Colleagues** – Dr. Zebaze Kana, Dr. Shola Odusanya, Prof. Banti Workalemahu, Prof. Stephen Forrest, Dr. Willie Siyanbola, Prof. Oumar Sakho, Prof. Babaniyi Babatope, Prof. W. Mammo, Prof. Shimelis Adamsie, Prof. Olusegun Adewoye, Prof. M.D. Mochena, Prof. Aboubaker Beye, Dr. G. Osinkolu

- **Staff** – Conrad Watola
Thank You

- Any Questions?