



Organic Devices

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Optics Seminars Final Presentation



Goals

- Introducing organic light emitting diodes and organic solar cells
- Describing the process of developing these devices in Lab

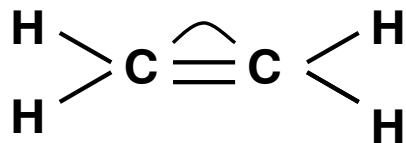


Summary

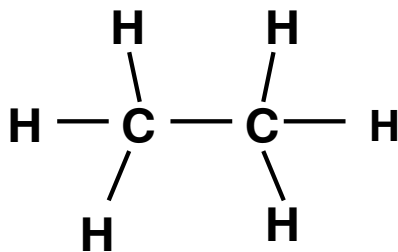
- Organic semiconductors
- OLEDs
- Organic solar cells
- Device preparation

Organic semiconductors

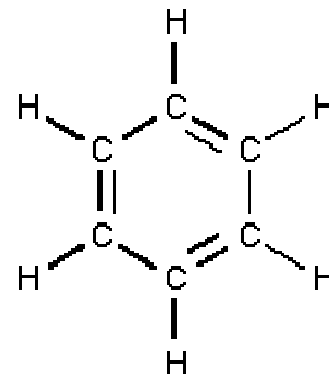
- Carbon based instead of Si based
 - Organic does not mean bio
- π band
- π conjugation: could of electrons



Methanol



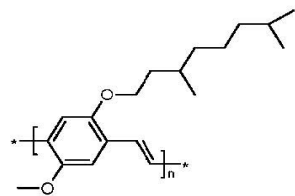
Ethanol



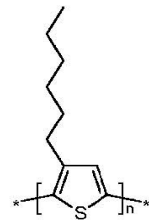
Benzene

Materials

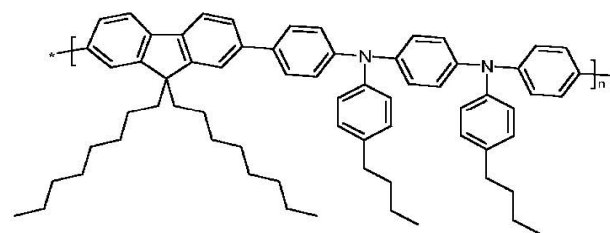
- Small Molecules
- Conjugated polymers
 - alternating single and double carbon–carbon (sometimes carbon–nitrogen) bonds



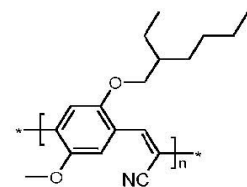
MDMO-PPV



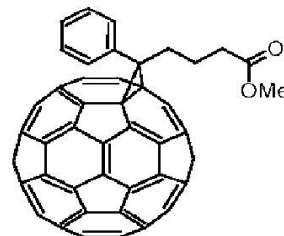
P3HT



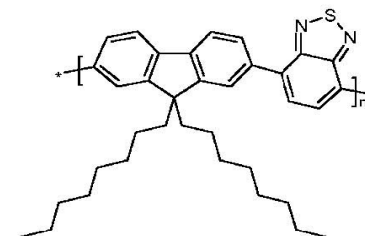
PFB



CN-MEH-PPV



PCBM



F8BT

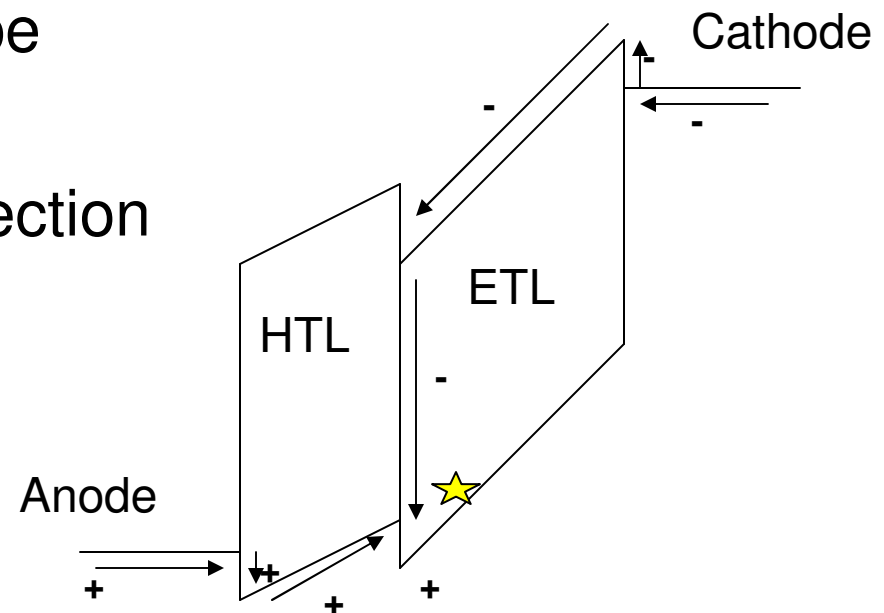
Organic Light Emitting Diodes (OLEDs) and displays

- thin, lightweight, printable displays;
- low voltage, low power, emissive source;
- good contrast;
- high resolution ($<5\mu\text{m}$ pixel size) and fast switching ($1-10\mu\text{s}$);
- broad color gamut;
- wide viewing angle;
- **low bill of materials;**
- **Flexible;**



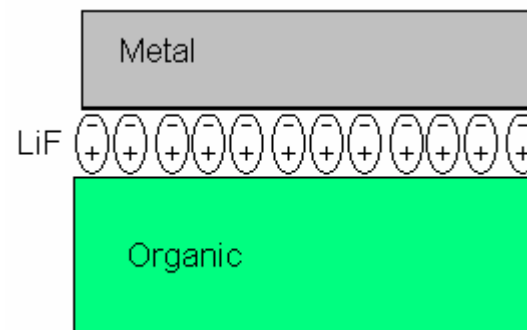
Basic Operation of OLED

- Operation very similar to non-organic LEDs
- ETL: Electron transport layer
- HTL: Hole transport layer
- An emissive layer might be between ETL and HTL
- There might be a hole injection Layer (CuPc, PEDOT:PSS)



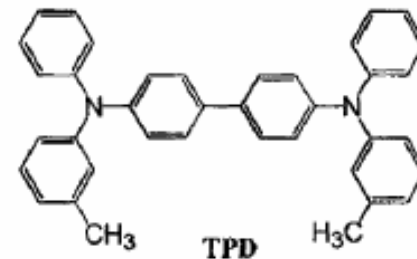
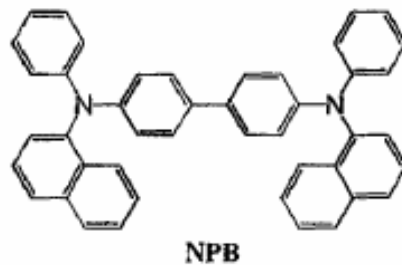
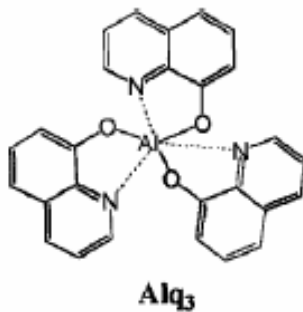
Anode and Cathode

- Anode is usually Indium Tin Oxide or ITO ($15-100\Omega/\text{cm}^2$)
 - The work function of anode should match the HTL
 - Anode should be transparent
- Cathode is usually a metal: Mg:Ag, Ca, Al
 - The work function of the metal should match the ETL
 - We can modify cathode's work function by a very thin layer of dipole layer (about 1nm thick)



Organic Layers

- ETL and HTL are organic material
 - ETL should have high electron mobility: Alq₃ (mobility $\sim 10^{-5}$ cm²/Vs)
 - HTL should have high hole mobility: NPB, TPD (mobility $\sim 10^{-4}$ - 10^{-3})



- Emissive layer between ETL and HTL
 - Emission would happen in this layer
 - Color tuning by varying the Band gap of this layer
 - ETL and HTL can be characterized specifically for transmission



Organic Solar Cells

Advantages:

- **Cheaper to produce**
- Flexible
- Lighter

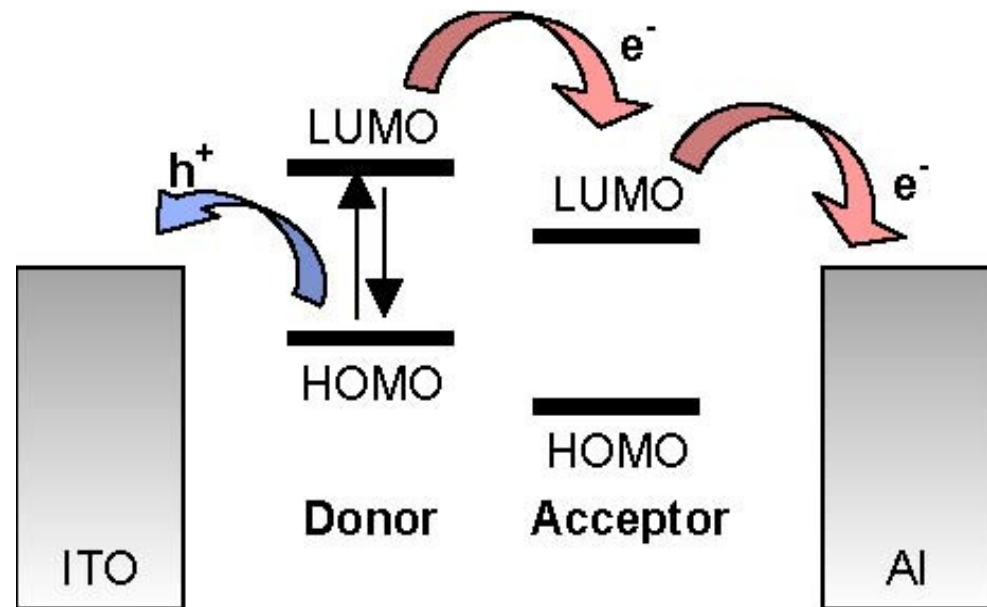
Problems

- Instability
 - Sensitive to heat, oxygen and humidity
- Low efficiency

Bilayer Heterojunction

There is a donor (p-type) and an acceptor (n-type) material stacked together. Charge separation occurs at their interface.

This figure shows the basic operation of a bilayer heterojunction device (from reference 4). acceptor has higher electron affinity and ionization potential





Bulk Heterojunction Solar Cells

- It uses the same donor-acceptor concept of the bilayer devices
- Ideally, donor and acceptor are mixed so that the distance between any absorbing site and the charge separation interface is less than the exciton diffusion length.
- There should be percolated pathways for electron and holes to cathode and anode respectively. Therefore this type of devices are much more sensitive to the nano-scale structure.
- These devices could be fabricated by co-deposition of donor and acceptor pigments or solution casting donor-acceptor blends.



General Characteristics of organic solar cells

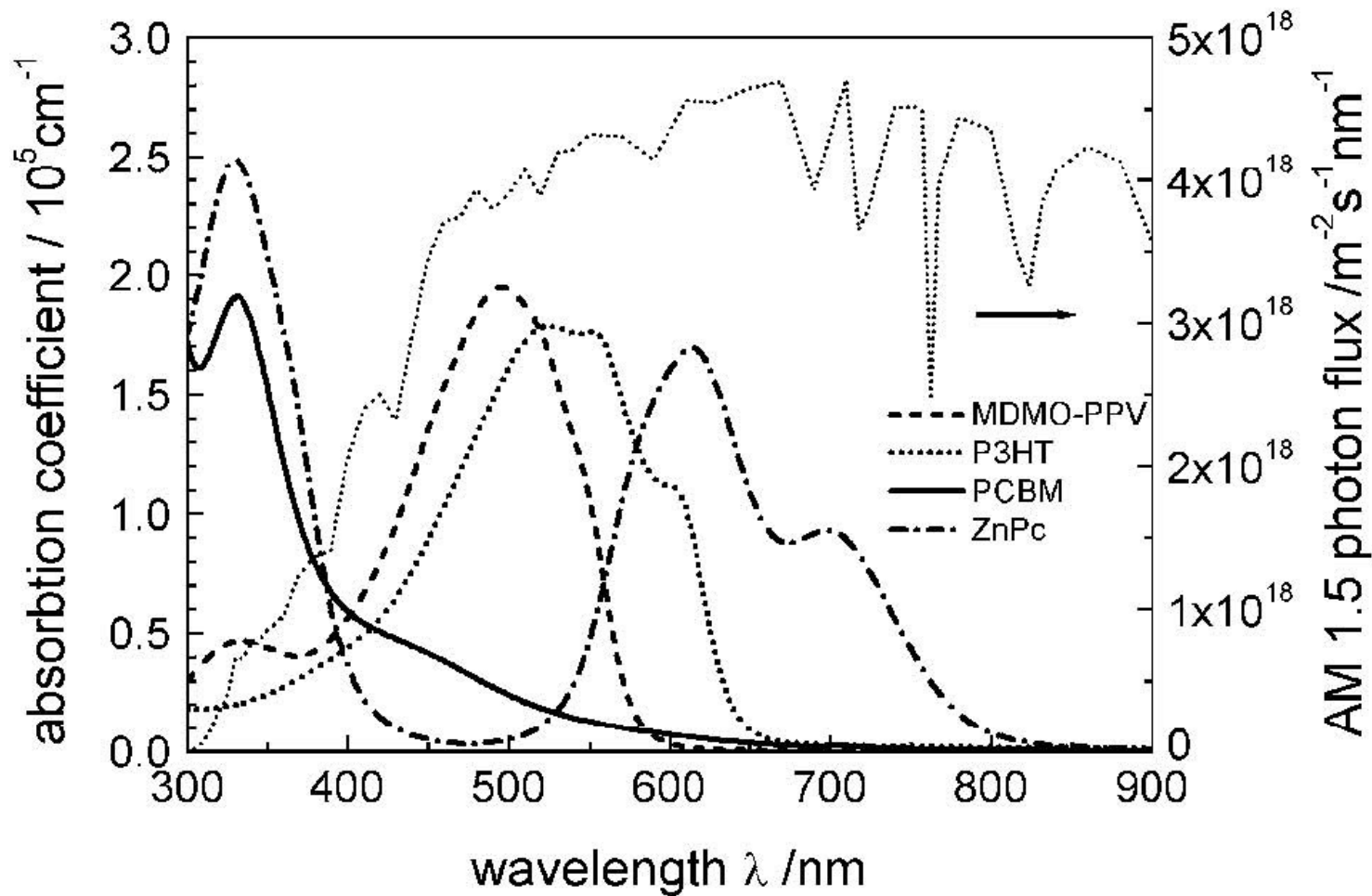
- Large optical band-gap (about 2 eV)

- *Usually absorb ultraviolet and blue (as the emission is in visible region)*
- *Research on material which absorb in red and near infrared*

- Generally poor charge-carrier mobility

As a result of the above two: almost insulator if not excited

- Relatively strong absorption coefficients (usu. > 10^5cm^{-1})



Absorption Coefficient of some commonly used organic materials compared with solar radiation (taken from reference 1)

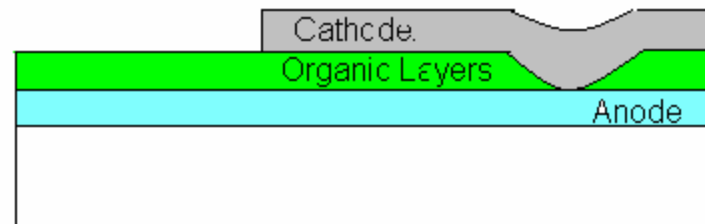


Thin Films

- Overall thickness of organic layers is usually less than 200nm
- Individual layers are usually between 10-60nm
- Therefore they are very delicate
 - Need to be very clean: dust
 - Sensitive to scratch

Sensitivity of Thin Films

- Figure shows a short situation



- Impurity can block electron, hole transport
- Defects site make electron/hole to recombine
- Extreme care about cleanness



Development

- Preparing the substrate
- Depositing thin film layer
- Testing and Characterization



Substrate Preparation

- Substrate can be glass or plastic
- ITO coated glass sheets could be purchased
- Another option is to deposit ITO on glass or plastic
- Substrates are ultrasonically cleaned in detergent solution, followed by thorough rinsing in deionized water
- Then, they get ultrasonically cleaned in organic solvents and dried in pure nitrogen gas
- Immediately prior to deposition, the substrate would get subject to an oxygen treatment either using UV ozone or oxygen plasma to improve hole-injection
- Cleaning is very critical and it effects the performance significantly



Deposition Techniques

■ Evaporation

- Sputtering
- E-beam evaporation
- Vapor deposition

Suitable for small molecules

■ Wet processing

- Spin coating
- Screen printing
- Inkjet printing
- Doctor blading

Suitable for polymers



Vacuum Deposition

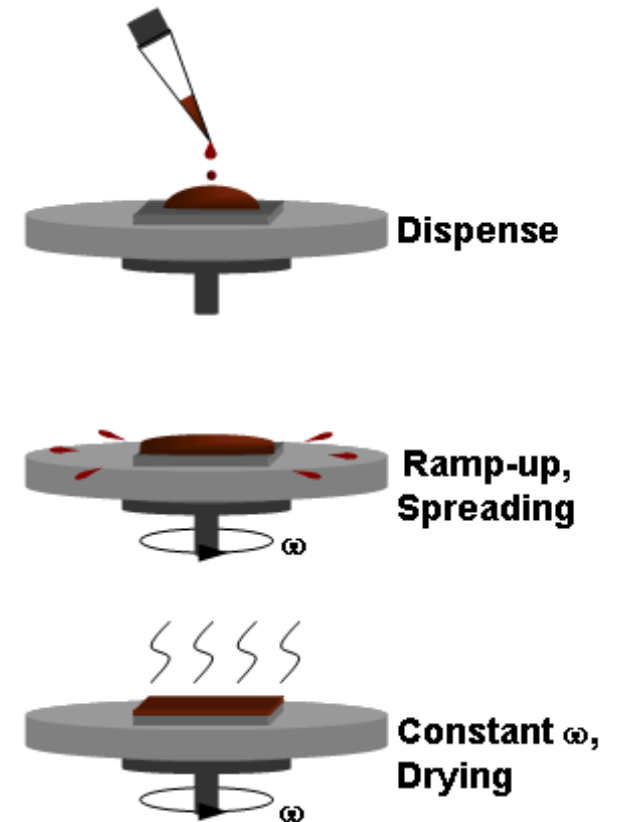
- e-beam evaporation and sputtering are for high temperature material, (both available in cleanroom)
- Sputtering is esp. useful for large substrates (Used for ITO)
- These methods can damage the organic layers
 - Organic material have low glass transition
- Vacuum evaporation by direct heating is the most appropriate for organic materials
- the pressure needed to deposit organic devices is about 10^{-5} - 10^{-6} torr (760 torr = 1 atm)
- Deposition rate for organics is about 1-10Å/s - usu. 6-10 Å/sec
- Deposition Temperature depends on vacuum quality and material
- Substrates should be kept at low temperature during deposition
- Deposition rate is usu. Controlled by crystal monitor

Our Devices



Spin Coating

- Solution is dropped on the rotating substrate
- By centrifugal force, solution spreads on the substrate
- Thin film properties depend on rotation speed curve, solution, temperature, vapor pressure of material...



Solution Preparation

- First we need to prepare the solution
 - Solution is stirred with magnetic stirrers for a long period (days)
 - Temperature is used to speed up the process, but it can also destroy the organic





Spin Coating Process

- Spin rate for organic solvents that I have worked with vary between 600rpm to 4000rpm
- After spin coating each layer, the new layer should be dried in oven- preferably vacuum or nitrogen oven
- Spin coating should be done in clean room with excessive care about cleanliness
- For better performance, spin coating can be done in a glove box (nitrogen/Argon environment)

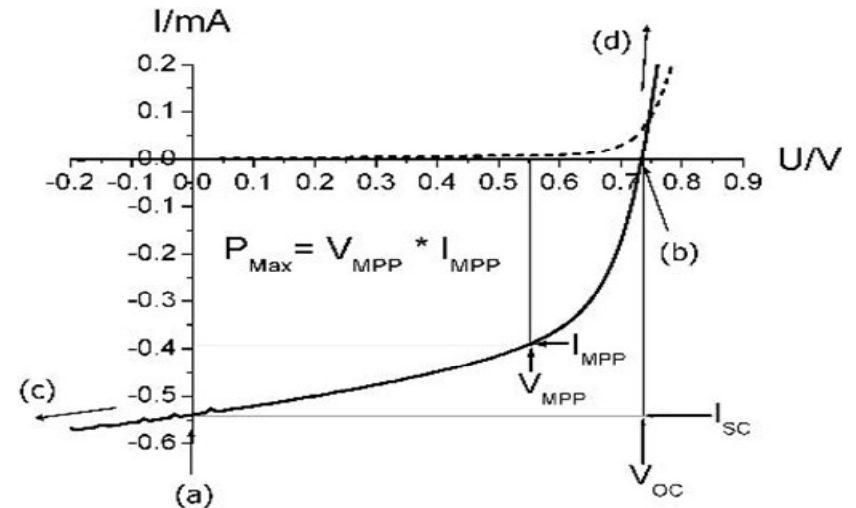
Characterization

- Devices should be kept in inert environment
- Usually testing is done in a glove-box



Characterization

- I-V curves
- Emission profile
- Absorption profile
- Thickness measurement
- Transmission profile (profilometer)
- Other thin film characterization processes (AFM, SEM, TEM...)





Our Projects

- Using doped and pure amorphous carbon to improve the characteristics of cathode and anode of OLED
- Incorporated organic dyes into organic solar cell to broaden the cells absorption into the near infrared
- Detecting explosives by using the quenching of organic material fluorescence in the presence of the key materials in explosives



Group Members

- My Supervisor
 - Prof. Nasser Peyghambarian
- My direct supervisors
 - Prof. Robert Norwood and Prof. Jayan Thomas
- Students
 - Michael Lotters, Konstantin Yamnitskiy, Mir Salek



References

- [1] L.S. Hunga, C.H. Chenb, Recent progress of molecular organic electroluminescent materials and devices, *Materials Science and Engineering R* 39 (2002) 143–222
- [2] J. N. Bardsley, International OLED Technology Roadmap, *IEEE JOURNAL OF SELECTED TOPICS IN QUANTUM ELECTRONICS*, VOL. 10, NO. 1, JAN/FEB 2004
- [3] P. Peumans, A. Yakimov, S. R. Forrest, Small molecular weight organic thin-film photodetectors and solar cells, *JOURNAL OF APPLIED PHYSICS* 95 (5): 2938-2938 MAR 1 2004
- [4] H. Spanggaard, F. C. Krebs, A brief history of the development of organic and polymeric photovoltaics, *Solar Energy Materials & Solar Cells* 83 (2004) 125–146