Center for Optical Technologies

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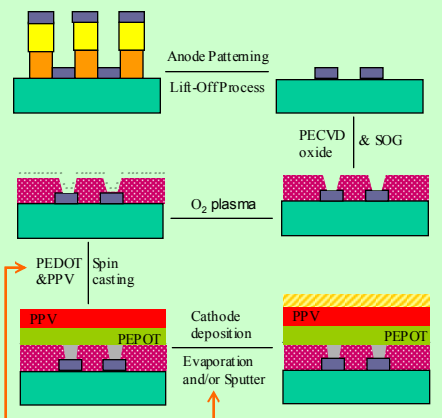
Top-Emitting Polymer LED Devices for Flexible Displays: Materials, Processes, and Properties

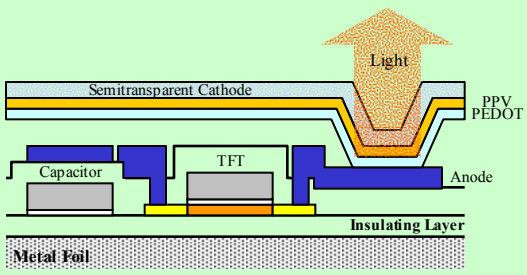
LEHIGH ARL

Lehigh University Department of Electrical and Computer Engineering[1] and Department of Chemistry[2]

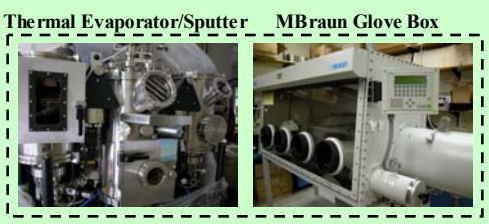
Ta-Ko Chuang[1], Yu-Lin Chang[1], Jeffery A. Spirko[2], Kamil Klier[2], Po-Chin Kuo[1], and Miltiadis Hatalis[1]

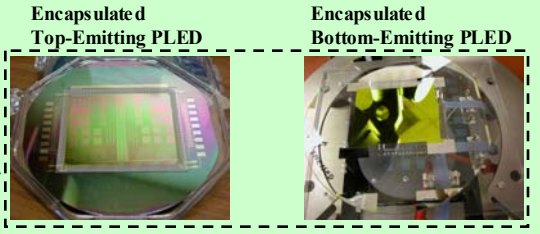
Current PLEDs Process Flow :





- Hole Transporting Layer (PEDOT) and Light-Emitting Layer (PPV) are both spin-casting, and then baked on a hot-plate and dried in a vacuum oven respectively.
- The laminated cathode, which has the thermally grown calcium and the sputtered ITO, was deposited in the same system without breaking the vacuum.
- A cover glass with sealant was prepared, and the sealant was dispensed by Asymtek automatic dispenser. Then, the PLED samples were encapsulated in the glove box.
- Polymeric top-emitting diodes will be integrated with poly-silicon TFT backplanes on metal foils.
- In the near future, another set of thermal evaporator/sputter will be connected to the glove box. Then, the entire PLED process can be done without exposing the polymers (PEDOT and PPV) to the air.

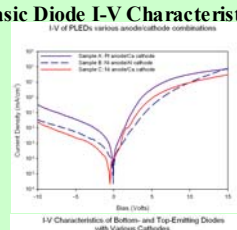




AMOLED Displays on flexible metal foils must be:
- **Fabricated on top of the TFT backplane**
- **Top-emitting, with a transparent cathode**

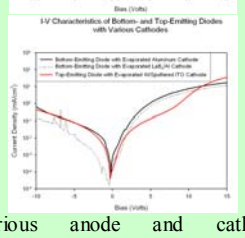
Versatile Mesurements

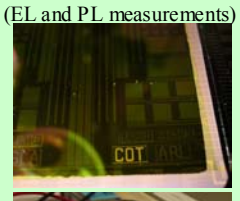
Basic Diode I-V Characteristics

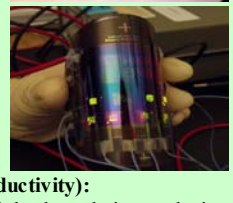


Cary Eclipse

(EL and PL measurements)



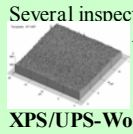


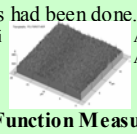


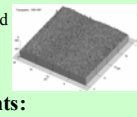
Various anode and cathode materials are investigated, for instance, ITO, Al/Ni, and Pt as the anodes; LaB_6, Al, and Ca as the cathodes.

IPP (Integrated Inpuled Photoconductivity):
Determine and characterize traps and the degradation analysis.

AFM-Surface Roughness Analysis:
Several inspections had been done.


Al/Ni


Annealed Al/Ni


Thermal Oxide

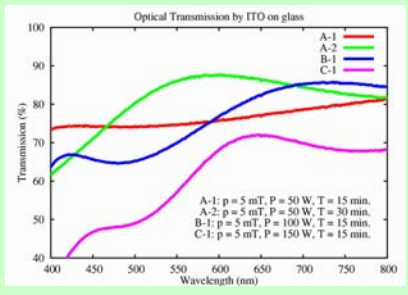
XPS/UPS-Work Function Measurements:
Work functions will be measured on new cathode materials.
(D. Cahen and A. Kahn, "Electron Energetics at Surfaces and Interfaces: Concepts and Experiments", *Advanced Materials* vol. 15 (2003) p. 271.)

Main Issues in Organic Top-Emitting Diodes :

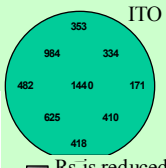
- **Semi-transparent cathodes with low work-functions:**
Most of the top-emitting diodes have a laminated cathode, which consists of a thin/low work-function metal and a thick/transparent metal. In our case, the thin/low work-function metal is calcium (Φ=2.87eV), and the thick/transparent metal is ITO.
- **Plasma damage onto light-emitting polymers while depositing the cathode:**
In most of cases, calcium is thermally evaporated and followed by ITO sputtering, which causes a significant damage onto the light-emitting polymer (PPV). In order to reduce the plasma bombardment, low power sputtering is required, as well as the optimized ratio of Ar/O_2 flow.
- **Weaker oxygen/moisture resistance:**
Unlike the bottom-emitting diode, the top-emitting diode does not have a thick cathode as the protective/reflective layer on the top, but only a thin calcium and a 1500Å ITO. That calcium/ITO cathode is resistive neither to the oxygen nor the moisture, so that a good encapsulation process and materials are required.
- **High work-function and reflective anodes:**
In order to result in efficient hole-injection, anodes with high work-functions are adopted. In bottom-emitting diodes, ITO is always the anode. Several different anodes are being investigated in our top-emitting diodes.
- **Processing temperature is limited to the Tg of polymers after they are spun:**
Post-anneal or any heating process is almost prohibited after the polymers are coated, owing to the glass-transition temperature.
- **Anodes surface roughness:**
The anode surface roughness has been found to contribute to the device life-time and the degradation. Atomic Force Microscope (AFM) technique is employed to analyze the surface roughness.

Transmittance and Sheet Resistance of ITO :

ITO was sputtered at 100W RF. After optimizing the physical configuration of the sputter, ITO is sputtered at 50W RF.

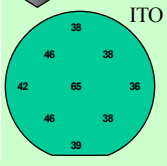


ITO was…



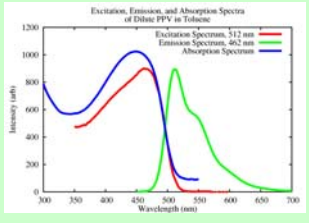
Rs is reduced in the same thickness.

ITO is…



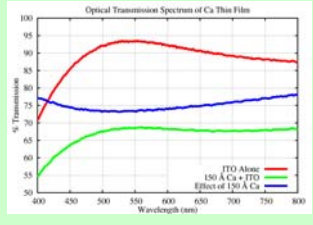
- The deposition rate (D.R.) is lowered down to 0.86Å/s. One believes that the D.R. is proportional to the plasma damage. It was 1.98Å/s before.
- The optimized ITO has much less sheet resistance below 100ohm/□ all over the wafer, as well as better uniformity.
- The transmission of a blank glass is around 92%, mostly due to the refraction rather than the absorption. The optimized ITO (green curve) has a great transmission, around 85%, at 550nm wavelength, which is the same wavelength as our PLEDs emitting.
- According to the previous statement, one can obtain a transmission higher than 92% by means of optimizing the film thickness.

Optical Properties of PPV in a Dilute Toluene Solution :



PPV Properties:
EL Peak Wavelength: 550 nm
PL Peak Wavelength: 512 nm

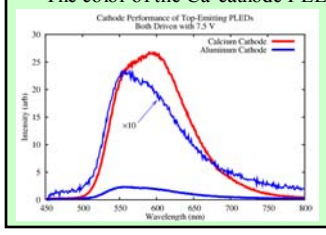
Transparency of Calcium Cathodes :

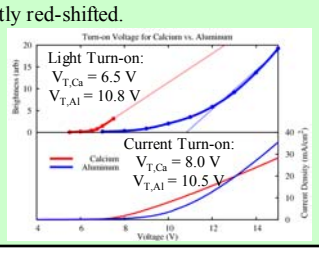


The thin metal cathode absorbs only about 20−30% of the generated light.
The traditional bottom-emitting PLEDs lose up to 50−80% of the light to the glass substrate and ITO anode [M.-H. Lu, *et al.*, *Appl. Phys. Lett.* **81** (2002) 3921].
Top-emitting PLEDs can be just as efficient as their bottom-emitting counterparts.

Effect of Cathode on Color and Brightness :

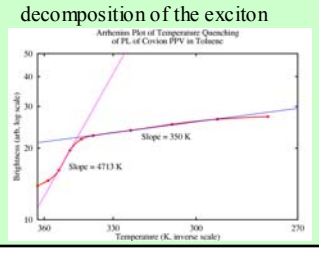
- Aluminum has a high work function (Φ = 4.28 eV) and produces low-efficiency PLEDs, but it is more resistant to degradation.
- The Calcium cathode has a better work function (Φ = 2.87 eV) to make low-voltage, bright, high-efficiency PLEDs.
- The color of the Ca-cathode PLEDs is slightly red-shifted.





Temperature Quenching of Photoluminescence in PPV :

- Measurements taken from 5 to 90 °C with Peltier heater/cooler.
- At higher temperatures, the photo-excited exciton is more likely to degrade before it collapses and emits light.
- Slope on the Arrhenius Plot gives the Activation Energy for decomposition of the exciton



Reverse-Bias Quenching of Photoluminescence in PPV :

- In an electric field, the photo-excited excitons are torn apart before fluorescent emission.