Fabrication Process And Efficiency Analysis of Organic Light-Emitting Diodes (OLEDs)

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This project focuses on new simple solution routes to making of a class of electronic device displays known as organic light-emitting diodes (OLEDs). We investigate impact of design and composition on its ability to emit light. These results show that the light emitted under photo excitation (photoluminescence) were relatively high while the light emitted under electrical stimulation (electroluminescence) needs to be improved. The best result was recorded with a single-layer red OLED design.

I. Introduction

Display technology is one of the markets that has developed significantly and has a strong impact on consumers and the technology industry such as TVs, smartphones, and computer monitors. One of the current research topics in this industry of extensive interest is the development of new organic light-emitting diodes or OLEDs. It is different than LED, which cannot display images by itself and is handled by a transparent LCD or liquid crystal display panel. Since an LCD does not emit its own light, it results that the panel will be black without the backlighting provided by the LED. On the other hand, OLEDs can emit its own light and display images. Its advanced characteristics are expected to be improved and contribute widely to display applications. This will help to lower power consumption, improve image display, and lower costs. However, OLEDs are challenging to fabricate.

This research project seeks to simplify OLED fabrication through simple solution-based routes. Ideally these new OLEDs will perform well at low voltage ranges and maintain good light emission intensity, as evaluated using techniques known as photoluminescence and electroluminescence spectroscopies. Results from single-layer OLED and three-layer OLED devices are analyzed.

Single-Layer OLED

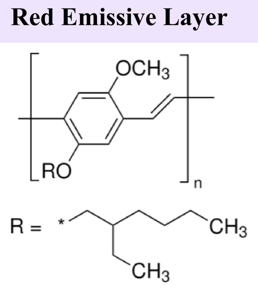
- Emissive Layer
- Interconnect/Cathode
- Anode and substrate: FTO/Glass or ITO/plastic

Three-Layer OLED

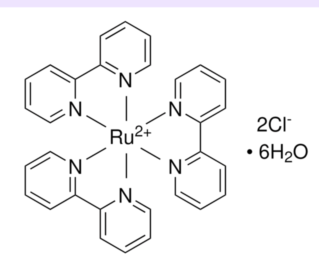
- Interconnect/Cathode
- Electron Transport Layer (ETL)
- Emissive Layer
- Hole Transport Layer (HTL)
- Anode and substrate: FTO/Glass or ITO/plastic

Chemical Structures

MEH-PPV - $(C_{18}H_{28}O_2)_n$
Red Emissive Layer

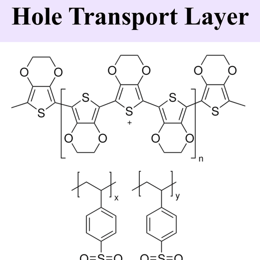


$[Ru(bpy)_3]^{2+}$ - $C_{30}H_{24}Cl_2N_6Ru \cdot H_2O$
Red Emissive Layer

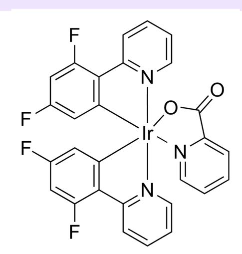


GaIn Eutectic
Interconnect/Cathode

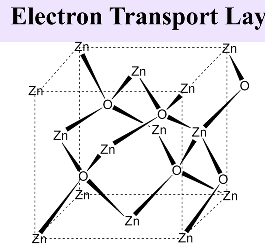
PEDOT:PSS
Hole Transport Layer



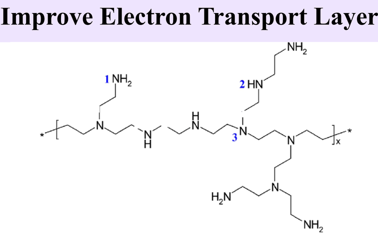
(Picolinato)iridium(III) - $C_{28}H_{16}F_4IrN_3O_2$
Green Emissive Layer



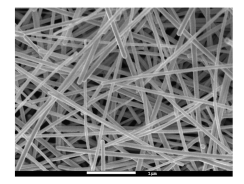
ZnO
Electron Transport Layer



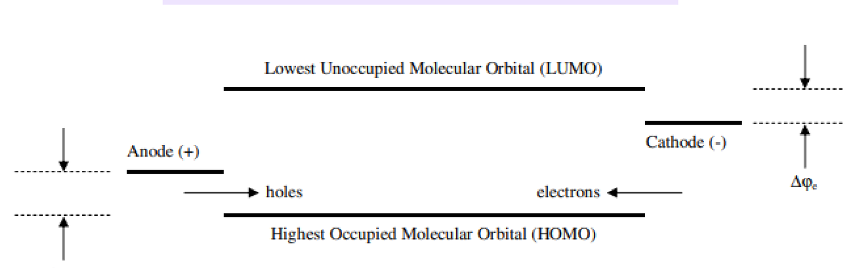
Polyethylenimine
Improve Electron Transport Layer



AgNW
Cathode



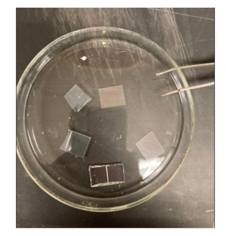
How does an OLED work?



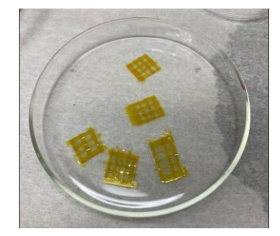
Ross, R., & Murray, M. N. (2011, June), *Fabrication of Organic Light Emitting Diodes in an Undergraduate Physics Course* Paper presented at 2011 ASEE Annual Conference & Exposition, Vancouver, BC. 10.18260/1-2--17977

II. Fabrication Process

1. Clean Substrate Materials



Cut FTO/glass and ITO/plastic into small sizes



Use Kapton tape to create small areas (2 mm x2 mm) on the sample or to cover a side of the sample

Clean FTO with:

1) 10% HCl in H_2O in 1 hour
2) Rinse with DI water
3) Sonicate in acetone in 45 minutes
4) Dry with N_2 gas

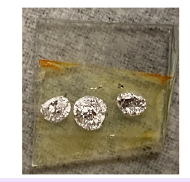
Clean ITO with:

1) 10 minutes in acetone
2) 10 minutes in isopropanol alcohol (IPA)

Caution: Cleaning ITO in aqueous HCl will wash away the anode layer

2. Red OLED

Single-Layer Red OLED



Sngle-Layer Red OLED

- Cathode
- Red emissive Layer
- Substrate and Anode

Structure of Single-Layer Red OLED

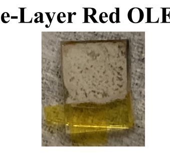
Substrate and anode layer: FTO/glass and ITO/plastic

Kapton tape to cover a side of the sample

Red Emissive Layer: A thin layer of $[Ru(bpy)_3](BF_4)_2$ polyvinyl solution was spread by a cotton applicator on the substrate. The substrate was heated at 95°C for 5 minutes. This step was repeated for 3-4 times

Interconnect/Cathode: A thin layer of Ga-In eutectic was put on top of the emissive layer by using a syringe or silver epoxy was put on top in 95°C for 1 hour

Three-Layer Red OLED



Three-Layer Red OLED

- Cathode
- Electron transport layer
- Red emissive Layer
- Hole Transport Layer
- Substrate and Anode

Structure of Three-Layer Red OLED

Substrate and anode layer: FTO/glass and ITO/plastic

Hole transport layer: PEDOT:PSS was added dropwise and heated in 140°C in 5 minutes

Red emissive layer:

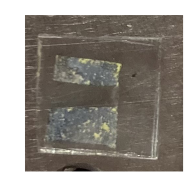
- 3 mg of MEH-PPV was dissolved in 1 ml of toluene
- $Ru[bpy]_3$. PVA (90mg) was dissolved in 30 ml of boiling water, followed by dissolution of 35 mg of $[Ru(bpy)_3](BF_4)_2$ in 3ml of PVA solution.

Electron transport layer: 3 mg of ZnO in 1 ml of ethanol or 1 mg of polyethylenimine was added to 6.7 ml of ZnO ink (concentration of 2.5 mg/1 ml). Then it was heated in 95°C for 10 minutes

Cathode: AgNW was heated in 200°C for 2 hours or silver epoxy in 95°C for 1 hour

3. Green OLED

Three Layer OLED:



Three-Layer Green OLED

- Cathode
- Electron transport layer
- Green emissive Layer
- Hole Transport Layer
- Substrate and Anode

Structure of Three-Layer Green OLED

Substrate and anode layer: FTO/glass and ITO/plastic

Hole transport layer: PEDOT:PSS was added dropwise and heated in 140°C for 5 minutes

Green Emissive layer: 6 mg of Bis[2-(4,6-diflurophenyl) pyridinato-C2,N] (picolinato) iridium (III) 97% was dissolved in 1ml of toluene. It was heated in 95°C for 5 minutes

Electron transport layer: 3mg of ZnO in 1ml of ethanol or 1 mg of polyethylenimine was added to 6.7ml of ZnO ink (concentration of 2.5mg/ml) . Then it was annealed at 50°C and 80°C, each step for 5 minutes

Cathode: AgNW was heated in 200° or silver epoxy in 95°C for 1 hour

Attempt with Perovskite:

Substrate and anode layer: FTO/glass and ITO/plastic

Hole transport layer: 0.2g of titanium isopropoxide was dissolved in 2ml of absolute ethanol, then spin coat at 3000rpm and 20s. The layer was heated at 500°C in 30 minutes

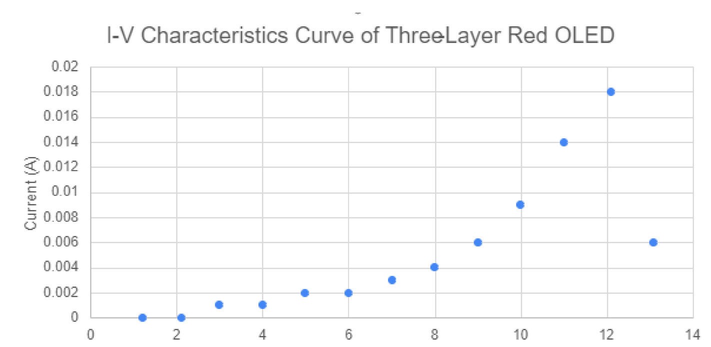
Green emissive layer: Solution of Perovskite layer (emitting at 510nm) was added dropwise and allowed to sit overnight

Electron transport layer: 72 mg of Spiro-ORAD was dissolved in 1ml of chlorobenzene, spin coat at 3000rpm and 20s. The layer was heated in 30 minutes in 95°C

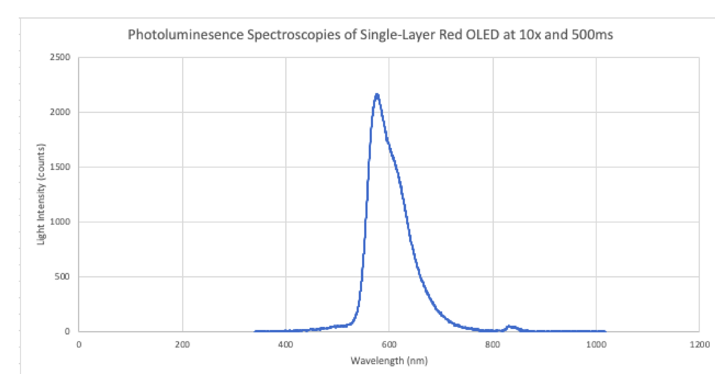
Cathode: AgNW was heated in 200°C for 2hours or silver epoxy in 95°C for 1 hour

III. Results

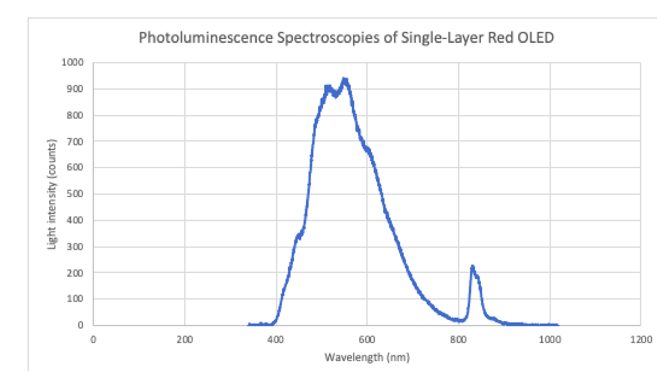
Red OLED



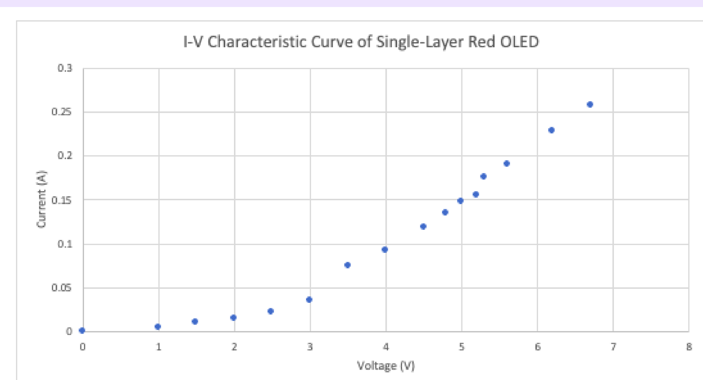
Diode: FTO/glass, PEDOT:PSS, $[Ru(bpy)_3]^{2+}$, (ZnO+ polyethylenimine) and AgNW
Electroluminescence appeared at 9V



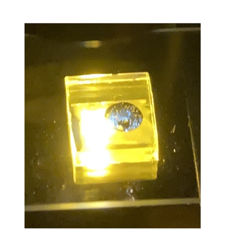
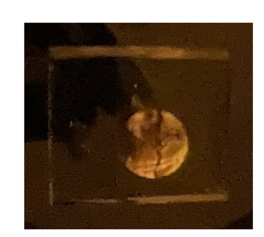
Diode: FTO/glass, $[Ru(bpy)_3]^{2+}$ and Ga-In Eutectic



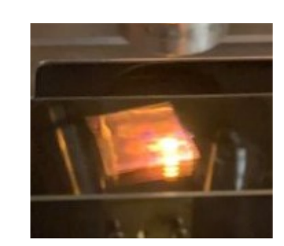
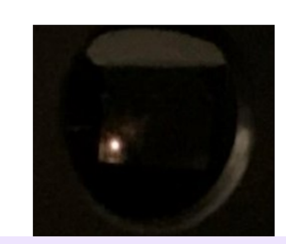
Diode: FTO/glass, MEH-PPV and Ga-In Eutectic



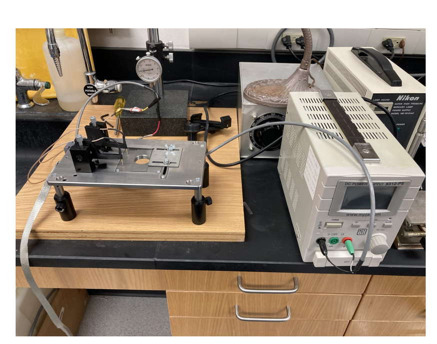
Diode: FTO/glass, $[Ru(bpy)_3]^{2+}$ and Ga-In Eutectic
Electroluminescence appeared at 3.5V

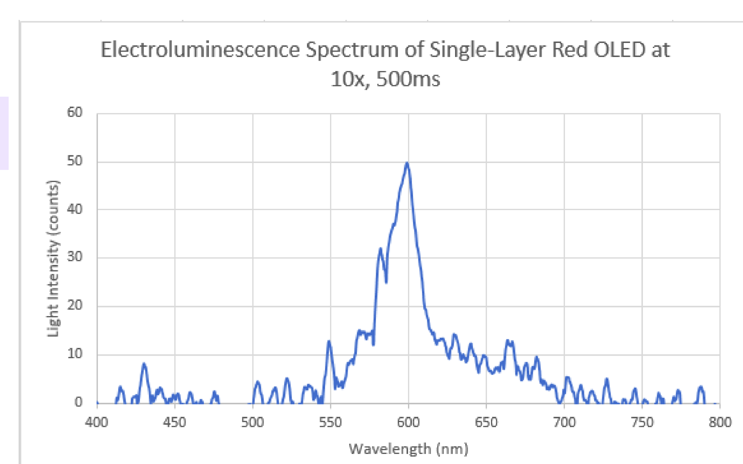
Visible photoluminescence (left) and electroluminescence at 3.5V (right) ($Ru(bpy)_3]^{2+}$ on FTO sample)

Visible photoluminescence (left) and electroluminescence at 8V (right) (MEH-PPV on ITO sample)



Testing Setup - Probe Station and Power Supply

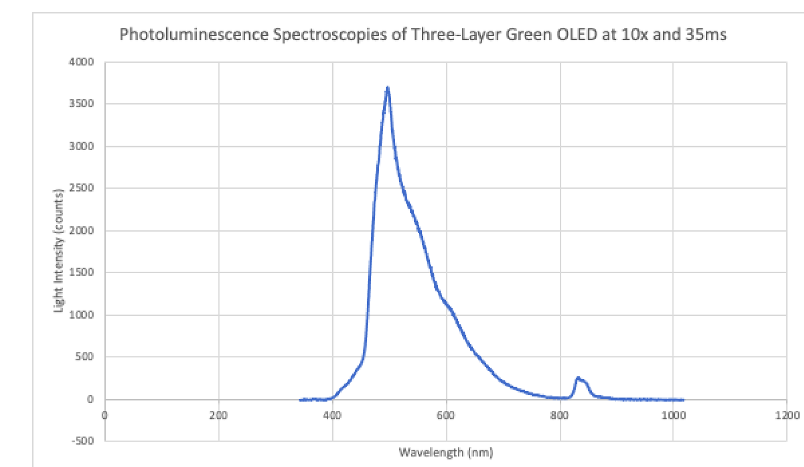


Diode: FTO/glass, $[Ru(bpy)_3]^{2+}$ and Ga-In Eutectic

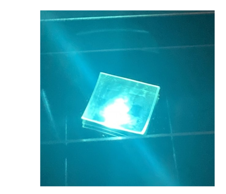
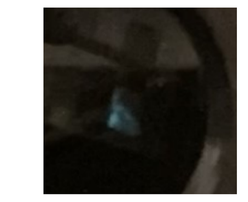
The electroluminescence for three-layer red OLED only lasted for around 1-3 seconds. It did not last long enough to record EL spectrum

III. Results (Continued)

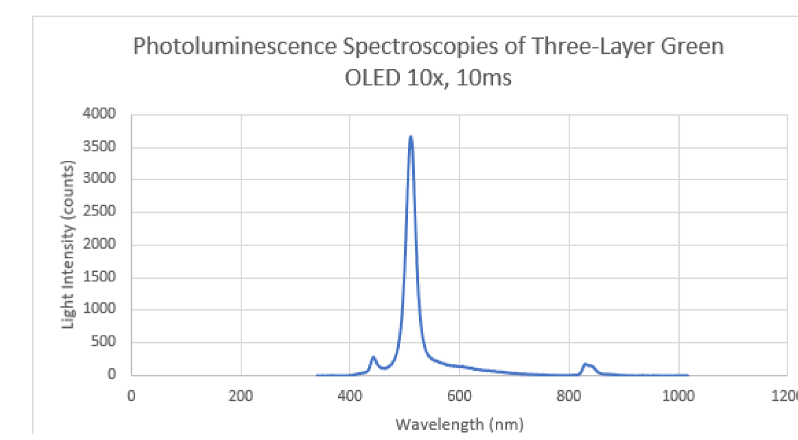
Green OLED



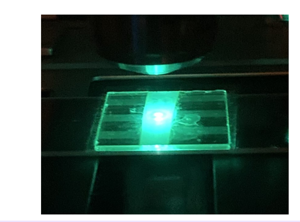
Diode: ITO/plastic, PEDOT:PSS, (picolinato) iridium (97%), ZnO and AgNW

Visible photoluminescence (left) and electroluminescence at 8V (right) (picolinato iridium 97% on ITO sample)



Sample was made following the procedure with green perovskite



Visible photoluminescence (perovskite sample)

The electroluminescence (EL) for a three-layer green OLED only lasted for around 1-3 seconds. It did not last long enough to record an EL spectrum

IV. Overall Conclusion

The photoluminescence and electroluminescence spectra of single-layer red OLED devices can be measured. Visible light emission at low voltages from 3.5V-7V could be observed with the unaided eye under these conditions. However, electroluminescence spectra could not be recorded for three-layer red and green OLED devices. Its photoluminescence spectroscopies and light emission could be observed at very high voltages from 8-10V and only lasted for around 3 seconds. Thus The electroluminescence of both single-layer OLED and three-layer OLED devices need to be improved.

V. References

1) Ross, R., & Murray, M. N. (2011, June), *Fabrication of Organic Light Emitting Diodes in an Undergraduate Physics Course* Paper presented at 2011 ASEE Annual Conference & Exposition, Vancouver, BC. 10.18260/1-2--17977
2) MRSEC Education Group, *''Preparation of an Organic Light Emitting Diode''*, UW-Madison
3) Fei Guo, Andre Karl, Qi-Fan Xue, Kai Cheong Tam, Karen Forberich and Christoph J Brabec, *''The Fabrication of color-tunable organic light-emitting diode displays via solution processing''*, Light: Science & Applications, 17 November 2017
4) Junfeng Wei, Chujun Zhang, Guoqi Ji, Yunfei Han, Irfan Ismail, Hengyue Li, Qun Luo, Junliang Yang, Chang-Qi Ma, *''Roll-to-roll printed stable and thickness-independent ZnO:PEI composite electron transport layer for inverted organic solar cells''*, Solar Energy 193, 2019, pg 102-110
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6) Amitabh Banerji, Michael W. Tausch and Ulrich Scherf, *''Classroom Experiments and Teaching Materials on OLEDs with Semiconducting Polymers''*, 2013, pg. 17-22
7) Juan Zhao, Liu Liu, Jiahao Wu, Junsheng Yu, *''Special variation of solution-processed blue bis[4,6-difluorophenyl) -pyridinato-N,C^2] (picolinate) iridium (III) phosphor''*, Dyes and Pigments, 2014, pg. 234-240

VI. Acknowledgements

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