Stable and Efficient White OLEDs Based on a Single Emissive Material

2017 Building Technologies Office Peer Review

U.S. DEPARTMENT OF ENERGY | Energy Efficiency & Renewable Energy

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Project Summary

Timeline:

Start date: 7/1/15

Planned end date: 6/30/17

Key Milestones

1. EQE of single-doped WOLED of 15% and LT_{50} of 500 hrs @ 1,000 nits (M12)
2. EQE of single-doped WOLED of 20% and LT_{50} of 10000 hrs @ 1,000 nits (M24)

Budget:

Total Project $ to Date:

- DOE: $700 K
- Cost Share: $150 K

Total Project $:

- DOE: $700 K
- Cost Share: $150 K

Key Partners:

ASU
Universal Display Corporation

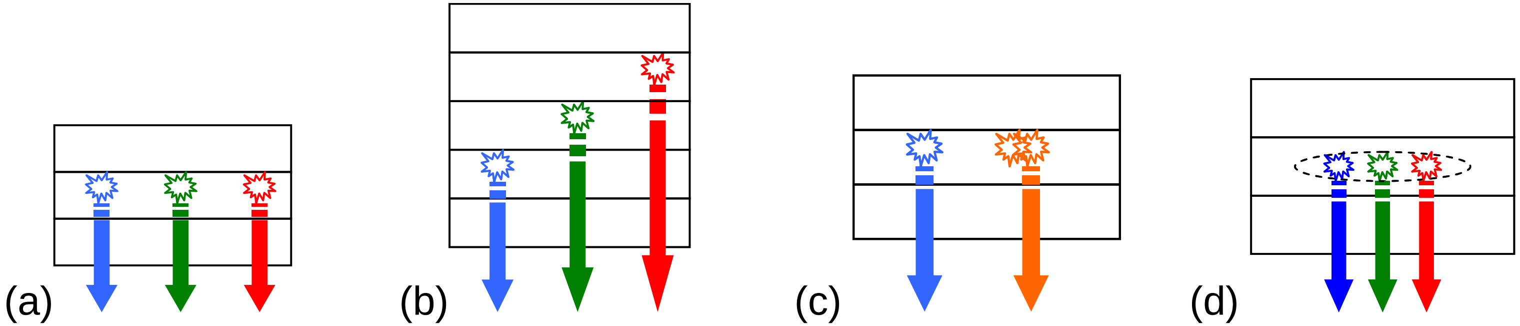
Project Outcome:

This project focus on the development of single-doped WOLEDs, which will provide a solution to lower the fabrication cost of WOLEDs significantly by decreasing the complexity of device fabrication, increasing the robustness of materials and providing more cost-effective alternates to the state-of-the-art Iridium-based phosphorescent emitters. This could help to meet the targeted cost of organic solid state lighting set in the DOE MYPP.

Purpose and Objectives

Problem Statement: The state-of-the art WOLED technology requires the use of multiple emissive materials, which will generate color instability and color aging issues, affecting the performance and operational lifetime of WOLEDs. Moreover, the manufacturing process of white OLED becomes more complicated with the incorporation of multiple emissive layers or a single emissive layer with multiple dopants. In order to prevent the color aging and enhance the color stability, the device structures will become inevitably more complexed.

The **goal** of this project is to demonstrate an efficient and stable white OLED using a single emissive material, which will provide a solution to lower the fabrication cost of white OLEDs significantly by decreasing the complexity of device fabrication.



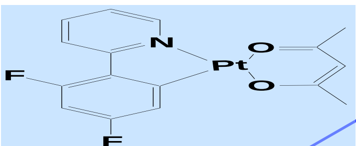
Schemes for 4 possible WOLED architectures: (a) triple-doped emissive layer; (b) multiple emissive layers; (c) emissive layer with monomer and excimer; (d) emissive layer with a single broadband emitter.

Purpose and Objectives

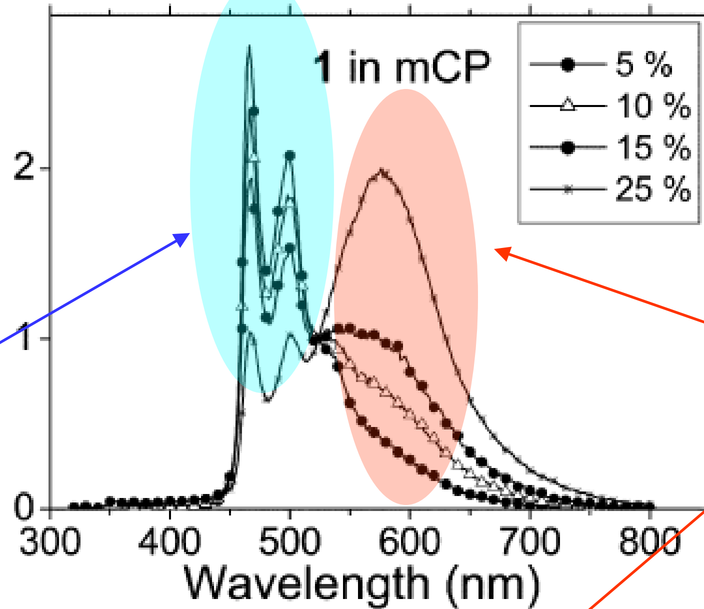
Target Market and Audience: Lighting consumes ~765 trillion Whr of electricity every year in the United States, i.e. 22% of all electricity generated nation-wide. It costs close to $58 billion a year to light the residential, business and manufacture buildings. White organic light emitting diodes (WOLEDs) with high power efficiency (>100 lm/W) are also considered as strong candidates for next generation illumination devices. Especially, WOLEDs use environmentally benign organic materials and their fabrication cost can be significantly reduced with potential roll-to-roll processing technology. Our project focus on developing an efficient and stable WOLED in a simpler device structure, in order to reduce the manufacture cost of WOLEDs.

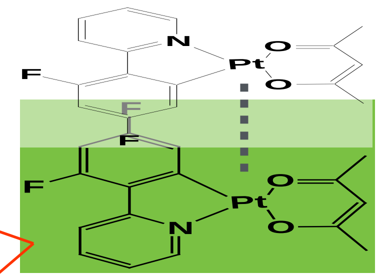
Impact of Project: This project is aiming at providing a solution to lower the fabrication cost of WOLEDs significantly by decreasing the complexity of device fabrication, increasing the robustness of materials and providing more cost-effective alternates to the state-of-the-art Iridium-based phosphorescent emitters. Moreover, a single-doped WOLED will also provide a greater control of emission color by eliminating color aging. This could help to meet the targeted cost of organic solid state lighting set in the DOE MYPP.

Approach

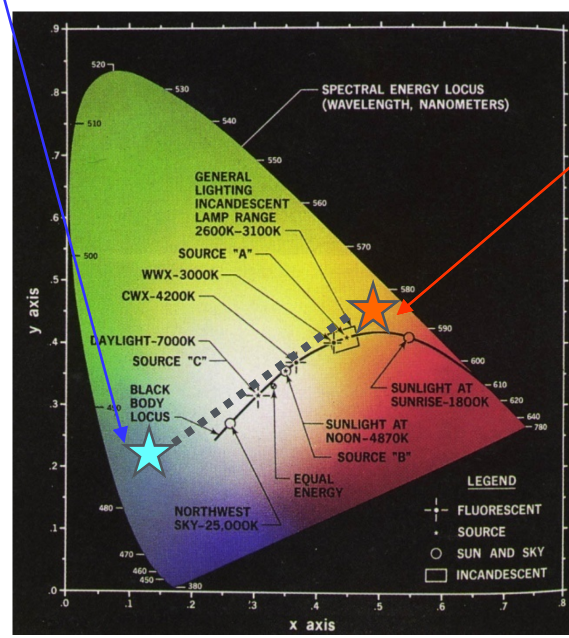


FPt
blue-green like emission





[FPt-FPt]*
orange like emission



Benefits

(a) No problem of energy transfer from blue to red emitters
(b) No problem of Differential Aging
(c) Spectrum is voltage independent
(d) Simple structure
(e) Easy to manufacture

Plus, square metal complexes will be more cost-effective.

Approach

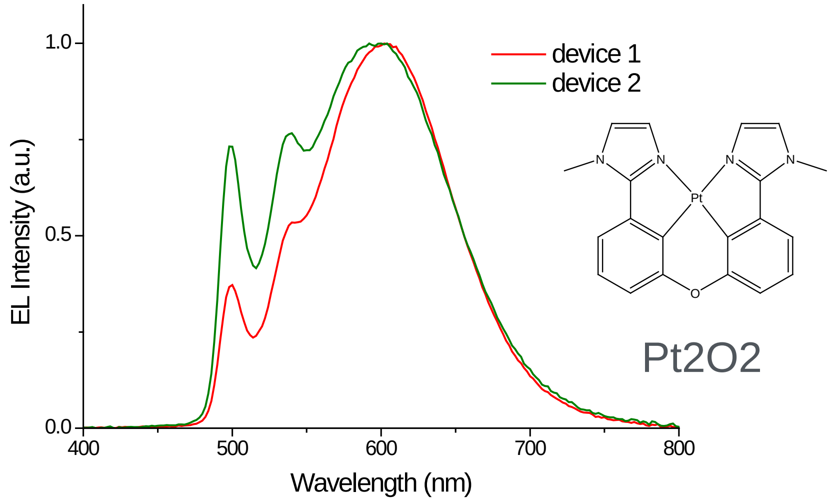
Approach: To deliver this research goal, the project will be focused on two main areas including 1) synthesizing high efficiency stable blue-emitting square planar phosphorescent emitters and 2) fabricating and testing single-doped WOLED and blue devices.

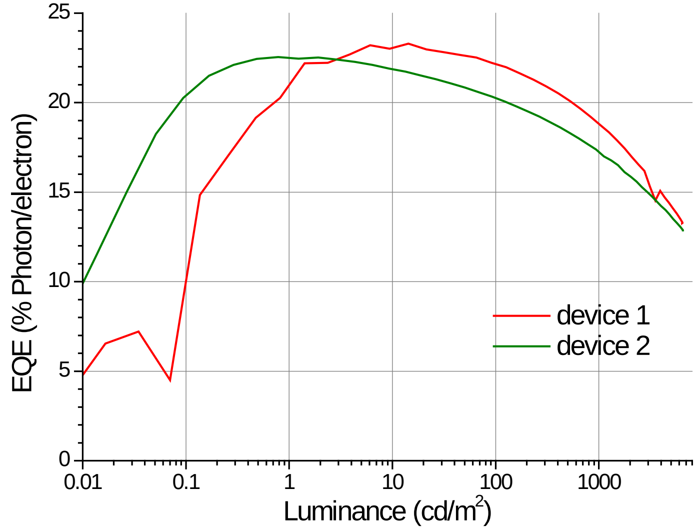
Key Issues: 1) controlling emission color of emitters and their excimers, 2) improving optical and electrical stability of emissive dopants, 3) incorporating transporting and blocking materials to maximize the power efficiency and operational lifetime of WOLEDs at the same time.

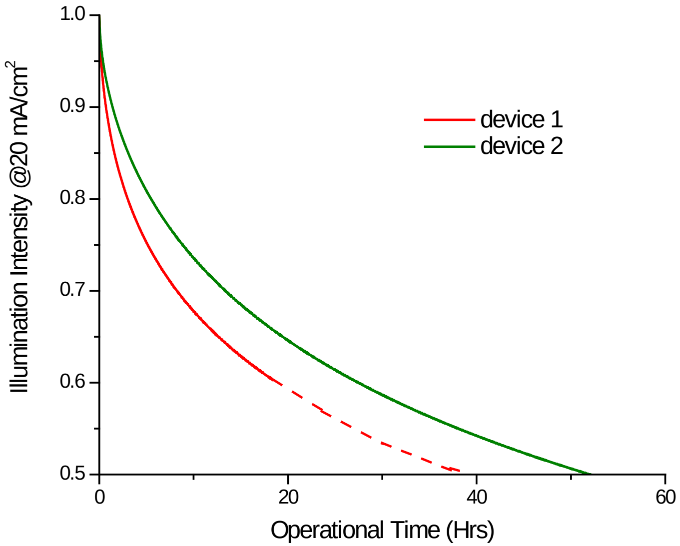
Distinctive Characteristics: First of all, excimer-based WOLEDs can produce a stable emission color independent of the driving voltage. Secondly, the problem of "color aging" can be resolved due to the use of a single emitter. Thirdly, the Pt-based emitters will be more preferable over Ir-analogue for displays and lighting with equal performance, due to its higher natural abundance.

Progress and Accomplishments

device 1: ITO/HATCN/NPD/TrisPCz /14% Pt2O2:mCBP/mCBT/BPyTP/LiF/Al
device 2: ITO/HATCN/NPD/14% Pt2O2:mCBP/BAlq/ BPyTP/LiF/Al







Device type	CRI	EQE	PE (lm/W)	LT_{50} (h) @20 mA/cm^2	EQE(%) @1000 nits	PE @1000 nits	LT_{50} (h) @1000 nits
1	67	23.2	45.7	38	18.7	27.4	891
2	64	22.5	49.5	52	17.0	24.8	1253

With new host, blockers and transporting materials, the device efficiency and operational lifetime improve significantly.

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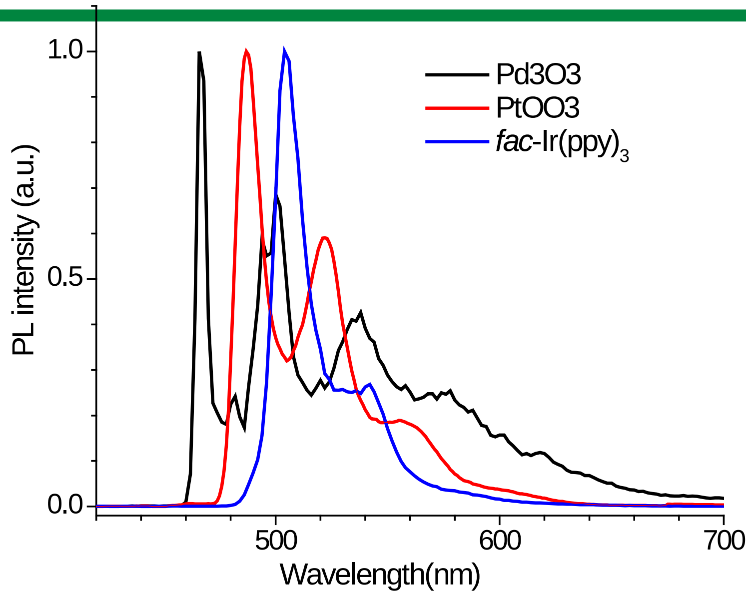
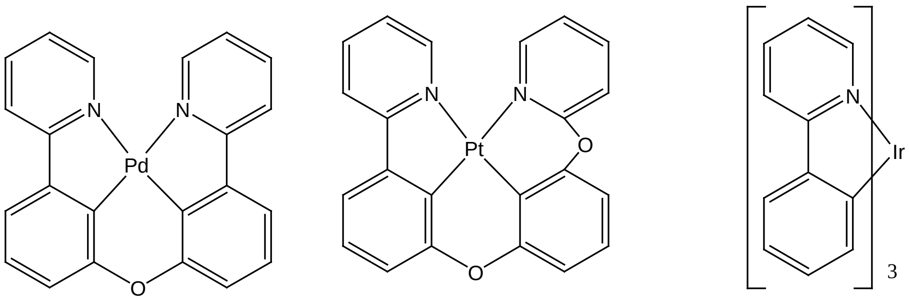
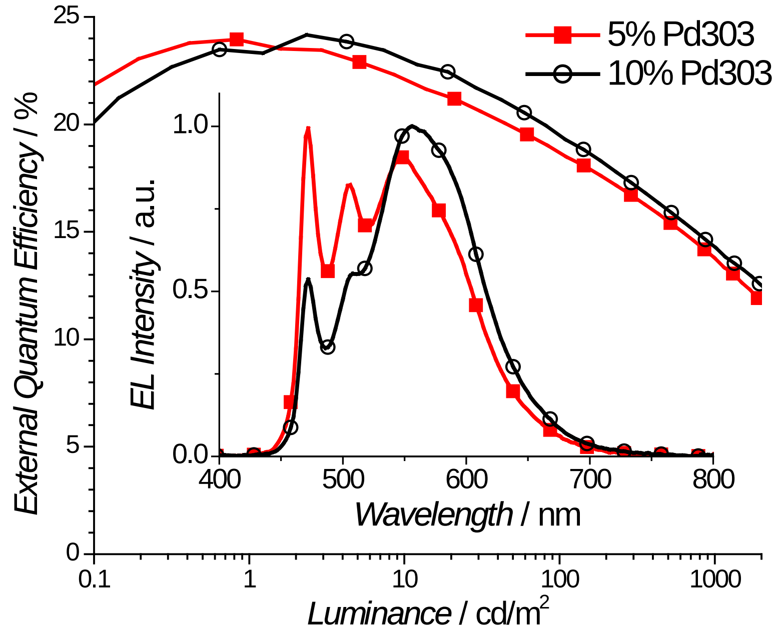
Progress and Accomplishments





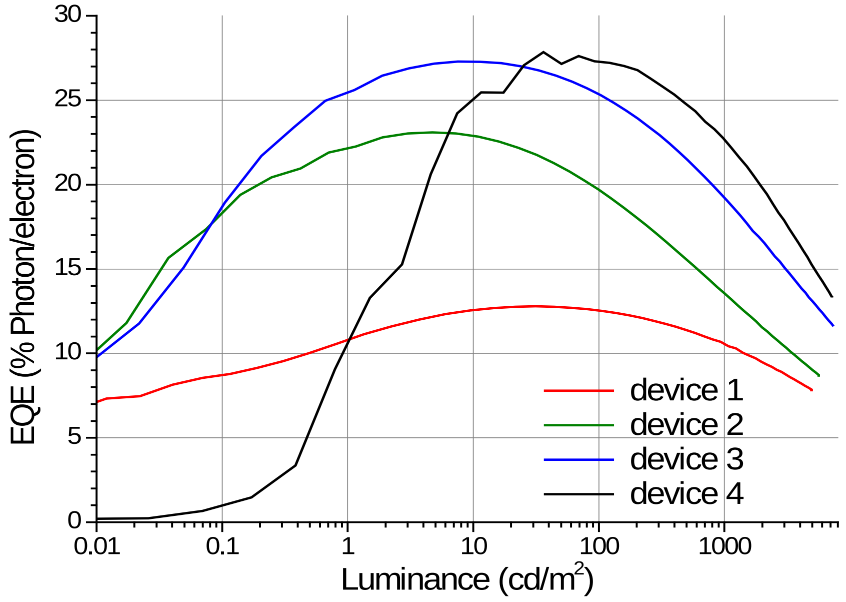
Pd3O3 PtOO3 $Ir(ppy)_3$

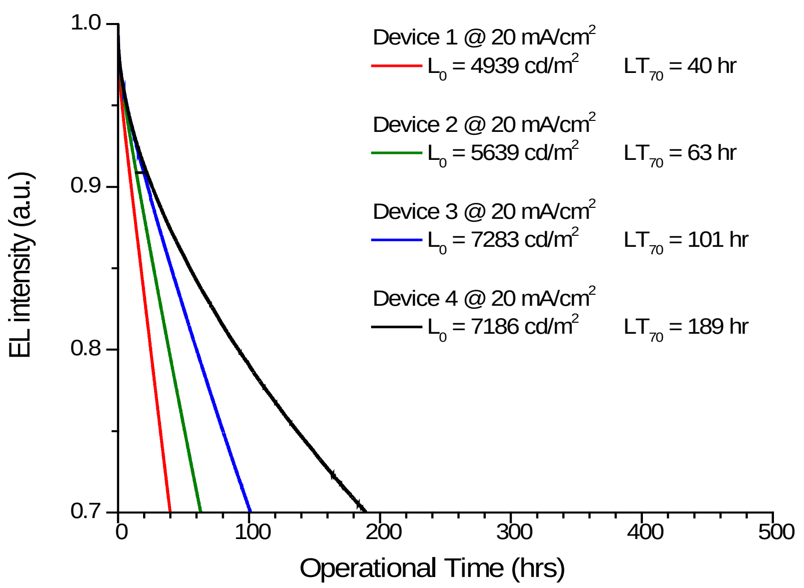
ITO/HATCN(10nm)/NPD(40nm)/TAPc(10nm)/x%Pd3O3:26 mCPy(25nm)/DPPS(10nm)/BmPyPB(40nm)/LiF/Al.

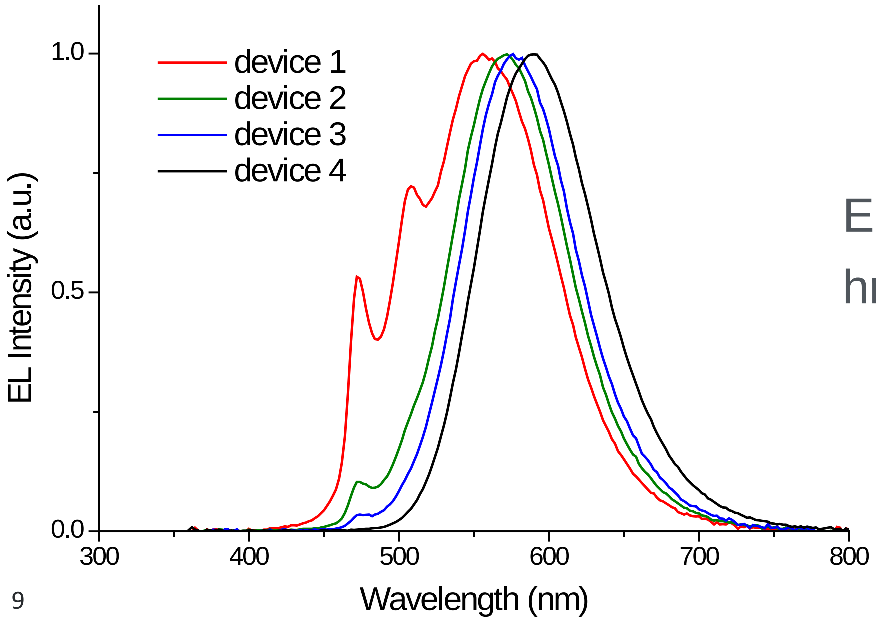


Pd3O3 has the potential to be efficient in both monomer and excimer forms.

Progress and Accomplishments

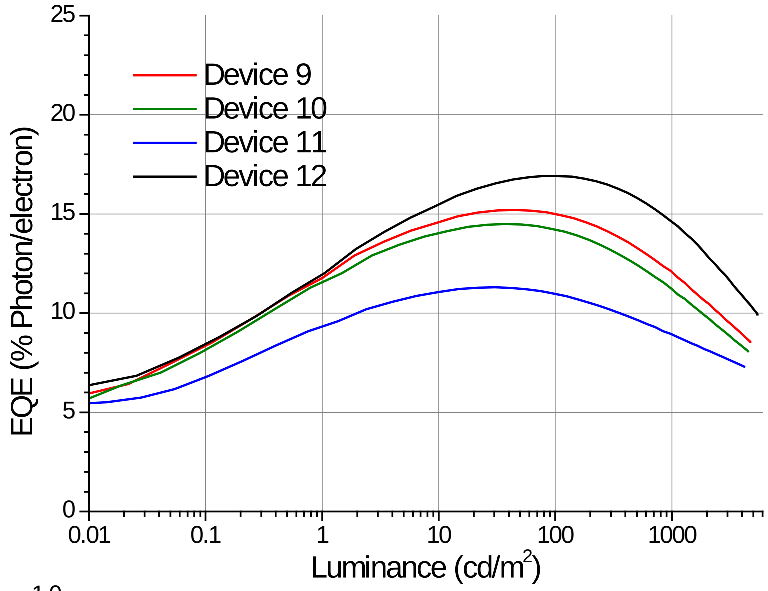


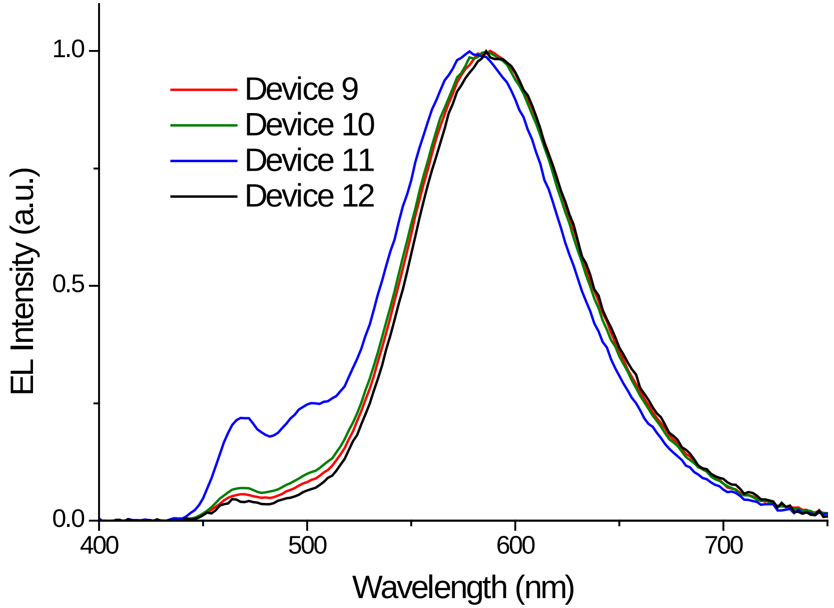


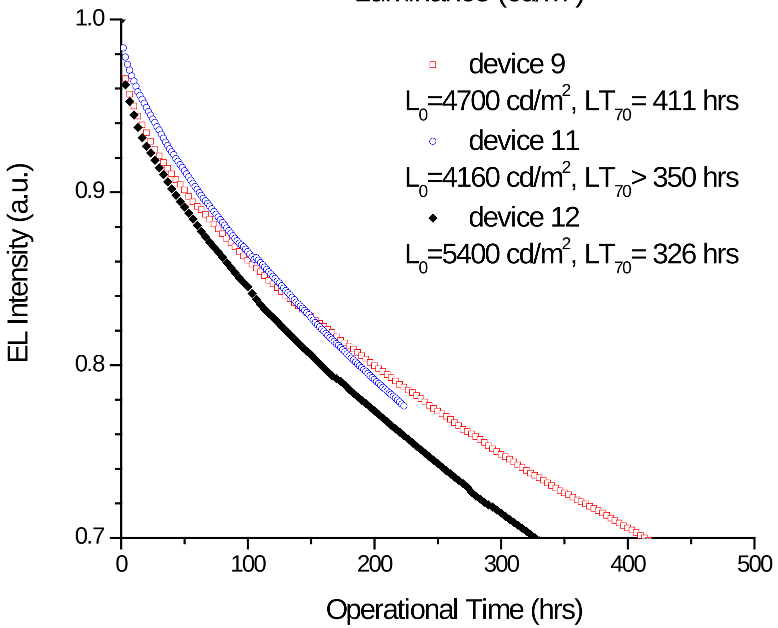


EQE > 22%, LT_{70} >4000 hrs and LT_{50} >13000 hrs @1000 cd/m^2 for efficient Pd3O3 device;

Progress and Accomplishments



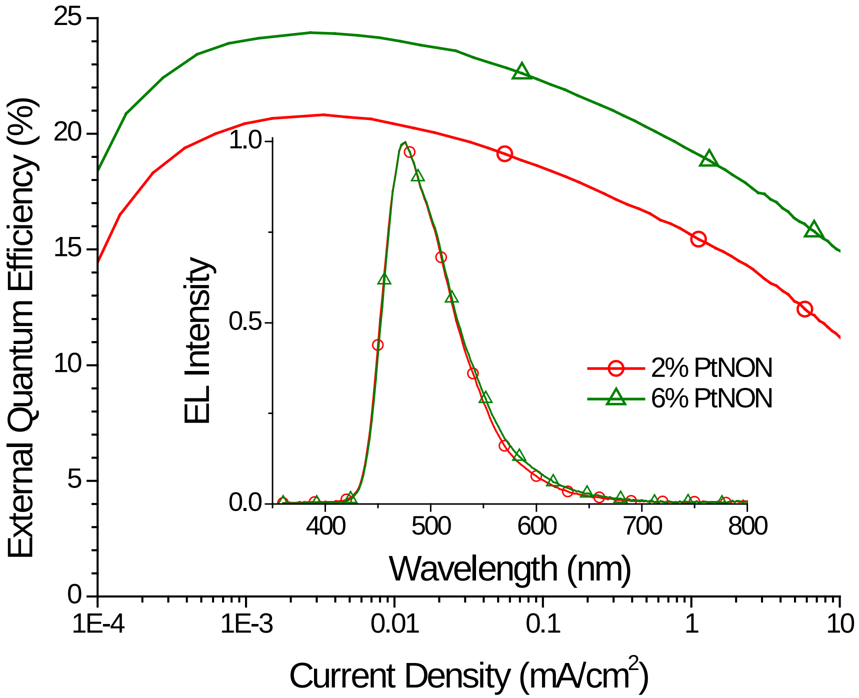


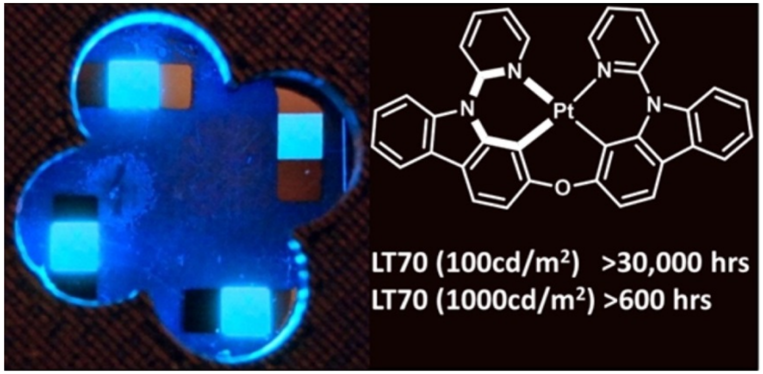


EQE > 10%, LT_{70} >3800 hrs @1000 cd/m^2 for with balanced Pd3O3 monomer/excimer emission.

Progress and Accomplishments

ITO/HATCN(10nm)/NPD(40nm)/TAPc(10nm)/x%PtNON:26mCPy(25nm)/DPPS(10nm)/BmPyPB(40nm)/LiF/Al.





PtNON is the first efficient blue phosphorescent emitters with 6-memebered chelate rings, which has the EQE of over 20% in the devices with strong charge-confinement.

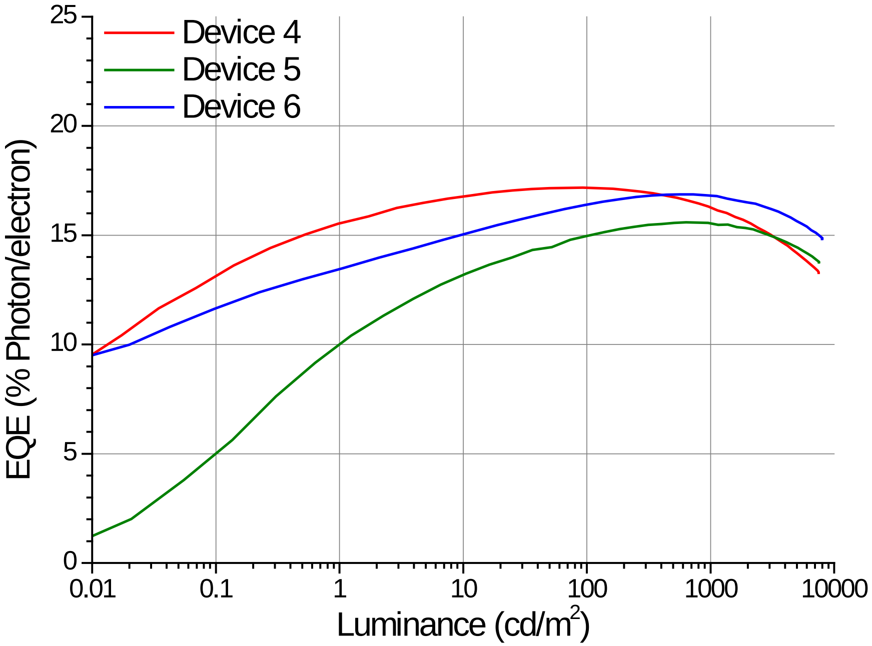
Fleetham et al. Chem. Mater. (2016)

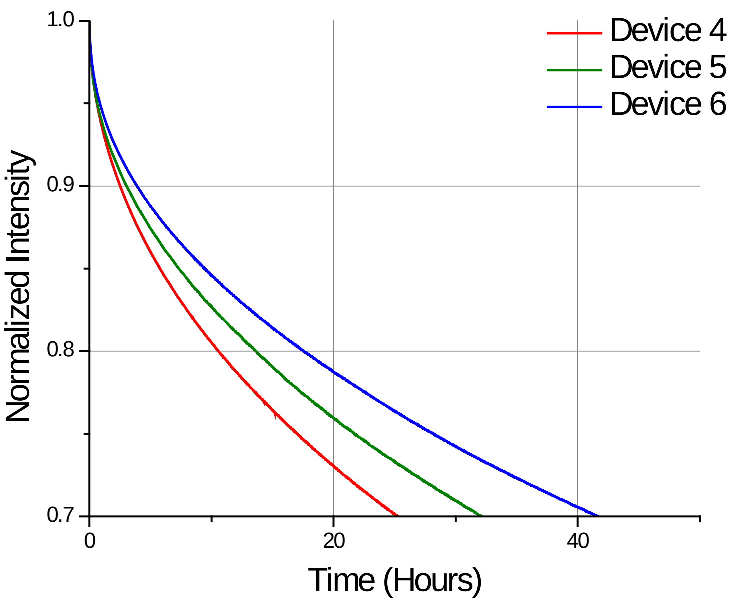
Progress and Accomplishments

Device 4: 20 wt% PtNON (10nm)/6 wt% PtNON (20nm)

Device 5: 20 wt% PtNON (5nm)/16 wt% PtNON (5nm)/12 wt% PtNON (5nm)/10 wt% PtNON (5nm)/8wt% PtNON (5nm)/6 wt% PtNON (5nm)

Device 6: 20 wt% PtNON (10nm)/10 wt% PtNON (10nm)/6 wt% PtNON (10nm)

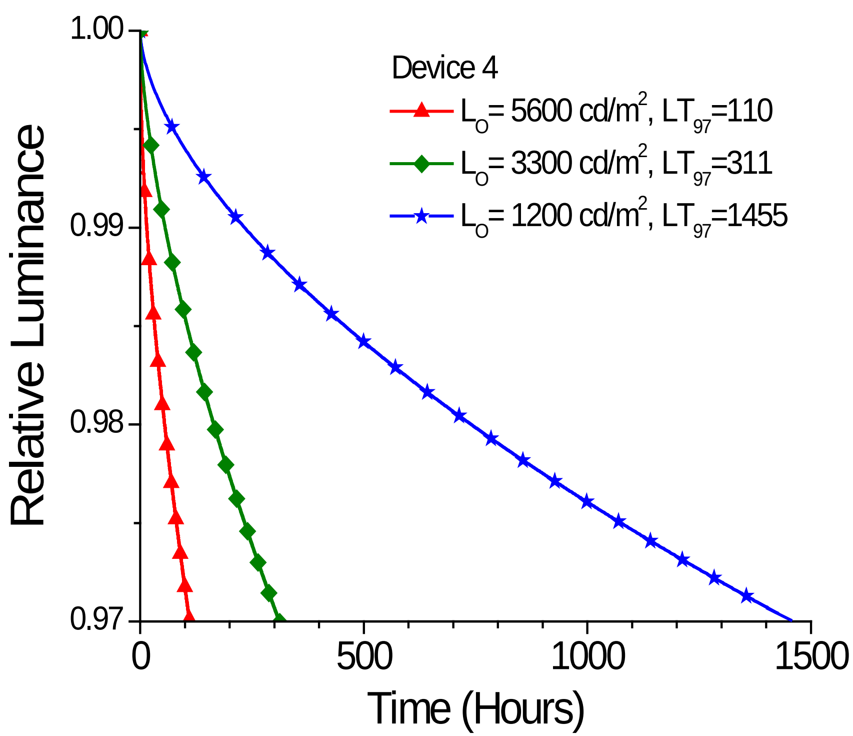


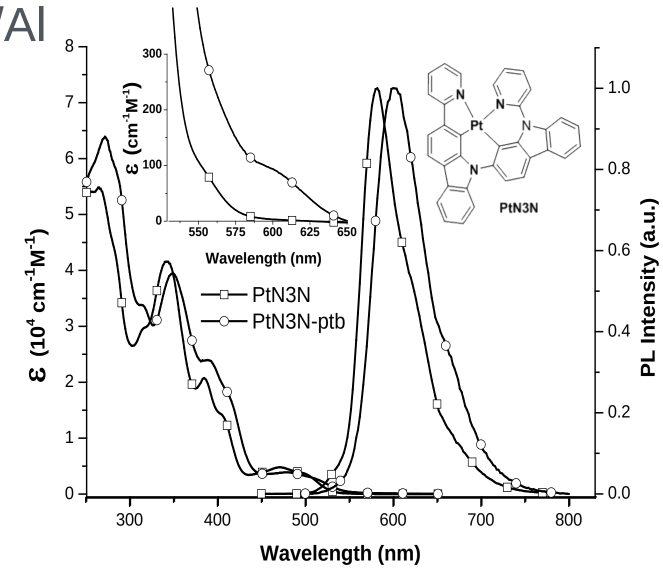


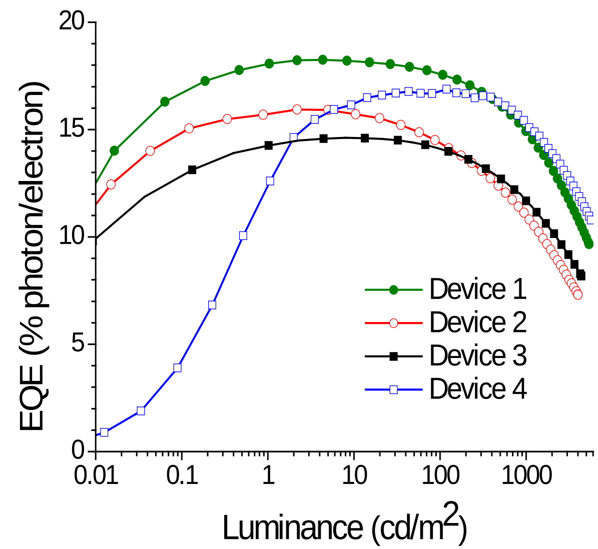
EQE >17% and LT_{50} > 3000 hrs @1000 cd/m^2.

Progress and Accomplishments

ITO/HATCN/NPD/TrisPCz/PtN3N:CBP/Balq/BPyTP/LiF/Al







PtN3N has demonstrated a remarkable operational stability in OLEDs. The LT_{97} is more than 2000 hrs at a 1000 cd/m^2, indicating the potential of such class of emitters as emitters for the stable and efficient blue and white phosphorescent OLEDs.

Li et. al. Advanced Materials, accepted.

Progress and Accomplishments

Accomplishments: 1) demonstrating most efficient and stable excimer-based WOLEDs; 2) demonstrating most efficient and stable Pt-based deep blue phosphorescent OLEDs; 3) demonstrating great operational stability of Pt-based OLEDs, which are comparable to the state-of-the-art Ir-based OLEDs.

Market Impact: we are still on track to achieve the ultimate goal of project. The research progress has been reported in multiple high-profile publications and also presented in various research conferences.

Awards/Recognition: N/A

Lessons Learned: Single-doped WOLEDs can be as efficient as the state-of-the-art WOLEDs employing multiple emissive materials with reasonable operational stability.

Project Integration and Collaboration

Project Integration: PI and one postdoc, two graduate students and one hourly undergraduate student are working on this project.

Partners, Subcontractors, and Collaborators: Co-PI: Michael Weaver, Ph.D., Universal Display Corporation

Communications: this work has been presented in MRS, SPIE, SID annual meetings, as well as DOE SSL R&D workshop and OLED roundtable meetings.

Next Steps and Future Plans

Next Steps and Future Plans: we will optimize the efficacy and performance of the excimer-based WOLEDs by employing the state-of-the-art transporting and blocking materials through collaboration with industrial partners including Universal Display Corporation.

REFERENCE

1) T.B. Fleetham, J. Ecton, Z. Wang, N. Bakkan, and J. Li, "Single-Doped White Organic Light-Emitting Device with an External Quantum Efficiency Over 20%", Adv. Mater., 25, 2573-2576 (2013).
2) Z.-Q. Zhu, K. Klimes, S. Holloway, J. Li, "Efficient Cyclometalated Platinum(II) Complex with Superior Operational Stability", Adv. Mater. DOI: 10.1002/adma.201605002.
3) G. Li, T.B. Fleetham and J. Li, "Efficient and Stable White Organic Light Emitting Diodes Employing a Single Emitter", Adv. Mater., 26 (18), 2931-2936 (2014).
4) T. Fleetham, L. Huang, J. Brooks, J. Li, "Tetradentate Pt(II) Complexes with 6-membered Chelate Rings: A New Route for Stable and Efficient Blue OLEDs", Chem. Mater. 28, 3276-3282 (2016).
5) T. Fleetham, G. Li, J. Li, "Phosphorescent Pt(II) and Pd(II) Complexes for Efficient, High Color Quality and Stable OLEDs" (Short Review), Adv. Mater. DOI: 10.1002/adma.201601861.

Project Budget

Project Budget: DOE share - $700,000, ASU share - $175,000
Variances: N/A
Cost to Date: close to 70% budget has spent at the end of 2016.
Additional Funding: N/A

Budget History					
7/1/16– FY 2016 (past)		FY 2017 (current)		FY 2018 – N/A (planned)	
DOE	Cost-share	DOE	Cost-share	DOE	Cost-share
339,939	84,985	360,061	90,015		

Project Plan and Schedule

Project Schedule												
Project Start: 7/1/15		Completed Work										
Projected End: 6/30/17		Active Task (in progress work)										
		Milestone/Deliverable (Originally Planned) use for missed										
		Milestone/Deliverable (Actual) use when met on time										
	FY2015				FY2016				FY2017			
Task	Q1 (Oct-Dec)	Q2 (Jan-Mar)	Q3 (Apr-Jun)	Q4 (Jul-Sep)	Q1 (Oct-Dec)	Q2 (Jan-Mar)	Q3 (Apr-Jun)	Q4 (Jul-Sep)	Q1 (Oct-Dec)	Q2 (Jan-Mar)	Q3 (Apr-Jun)	Q4 (Jul-Sep)
Past Work												
Milestone 1: EQE of Pt-based blue OLED of 15% and LT50 of 500 hrs @ 1,000 nits												
Milestone 3: EQE of single-doped WOLED of 15% and LT50 of 500 hrs @ 1,000 nits												
Current/Future Work												
Milestone 4.4: EQE of Pt-based blue OLED of 18% and LT50 of 500 hrs @ 1,000 nits												
Milestone 4.5: EQE of single-doped WOLED of 18% and LT50 of 500 hrs @ 1,000 nits with CRI of 70 and above												
Milestone 2: EQE of Pt-based blue OLED of 20% and LT50 of 10000 hrs @ 1,000 nits												
Milestone 4: EQE of single-doped WOLED of 20% and LT50 of 10000 hrs @ 1,000 nits												
Milestone 5: EQE of single-doped WOLED of 50% with light-outcoupling enhancement and LT50 of 20000 hrs @ 1,000 nits												

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