U.S. DEPARTMENT OF ENERGY

Office of ENERGY EFFICIENCY & RENEWABLE ENERGY

Stable and Efficient White OLEDs Based on a Single Emissive Material

Arizona State University

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Project Summary

Timeline:

Start date: 7/1/15

Planned end date: 6/30/18

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.

Team

The research team for this program consists of two PIs, Dr. Jian Li, from ASU and Dr. Mike Weaver from the Universal Display Corporation (UDC). Li is responsible for the design, synthesis and evaluation of phosphorescent excimers and Weaver will be responsible for device fabrication and characterization. Phosphorescent excimers are synthesized by Li and initial devices will be made for the purpose of materials screening. Subsequently, materials will be sent to UDC where the final device processing and optimization will be done.

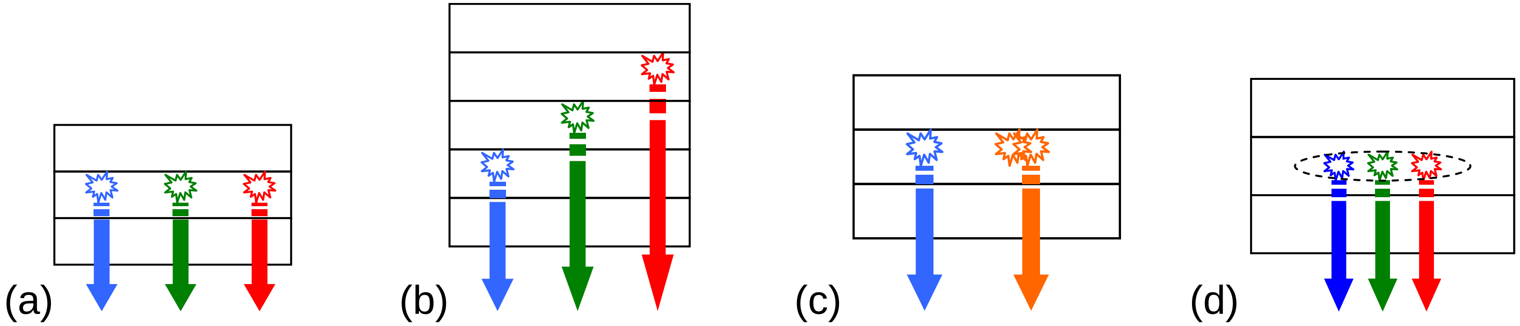
Li has led the recent effort in exploring cyclometalated Pt and Pd complexes for lighting and displays applications, including 1) the first demonstration of single-doped white OLEDs to have an EQE of over 20% and produce ideal white light; 2) the first demonstration of efficient single-doped white OLEDs with reasonable device operational stability; 3) the first demonstration of efficient and stable excimer-based white OLEDs employing Pd complexes. Currently, he has about over 100 issued and pending patent applications on OLED phosphorescent emitters and related materials.

Weaver led the UDC team that focuses on improving the lifetime and efficiency of phosphorescent OLEDs (PHOLEDs), which led directly to the commercialization of PHOLEDs into various applications like mobile displays, TVs, lighting.

Challenge

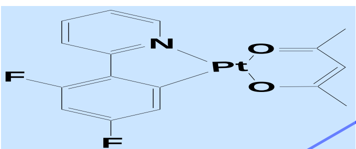
Problem Statement: The state-of-the art WOLED technology requires the use of multiple emissive materials, which will generate color instability and color aging issues, affecting the performance and operational lifetime of WOLEDs. Moreover, the manufacturing process of white OLED becomes more complicated 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.

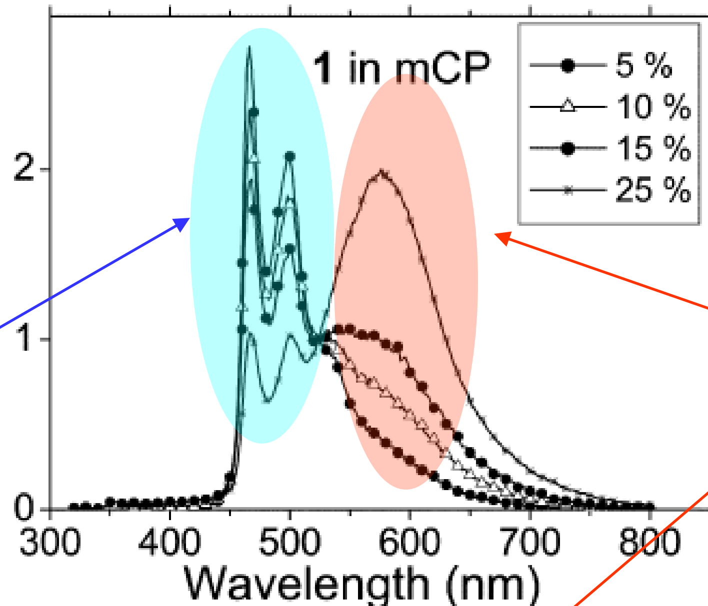


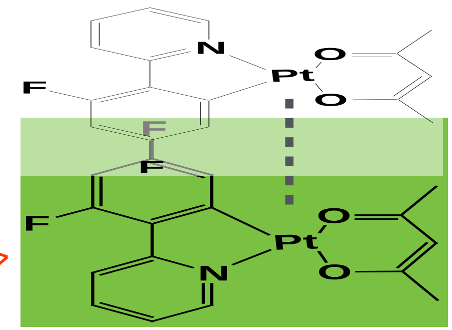
Schemes for 4 possible WOLED architectures: (a) triple-doped emissive layer; (b) multiple emissive layers; (c) emissive layer with monomer and excimer; (d) emissive layer with a single broadband emitter.

Approach

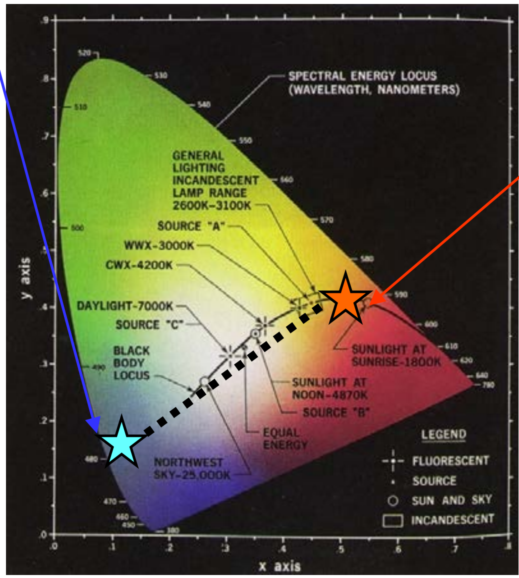


FPt
blue-green like
emission





[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.

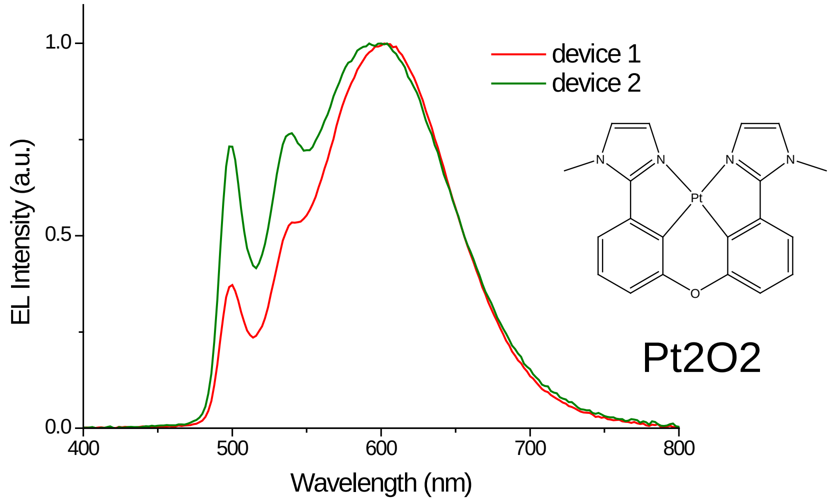
Impact

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.

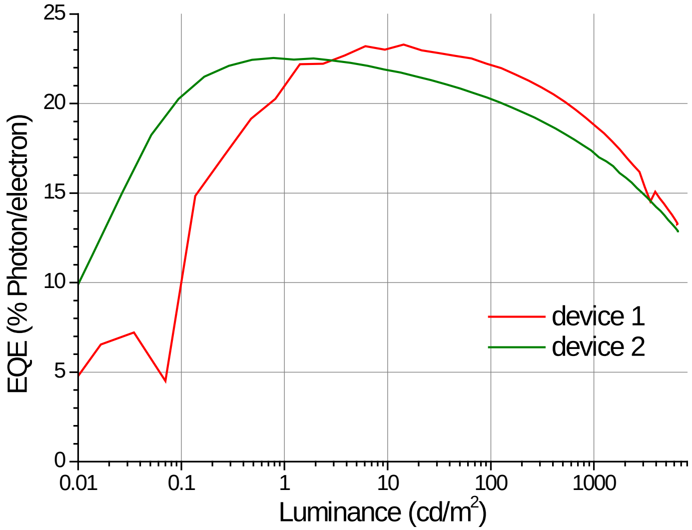
Impact of Project: This project is aiming at providing a solution to lower the fabrication cost of WOLEDs significantly by decreasing the complexity of device fabrication, increasing the robustness of materials and providing more cost-effective alternates to the state-of-the-art Iridium-based phosphorescent 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.

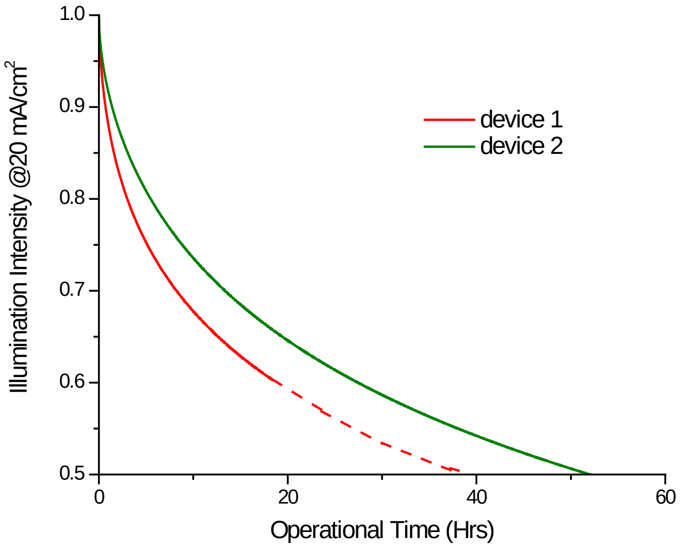
Progress

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



Pt2O2

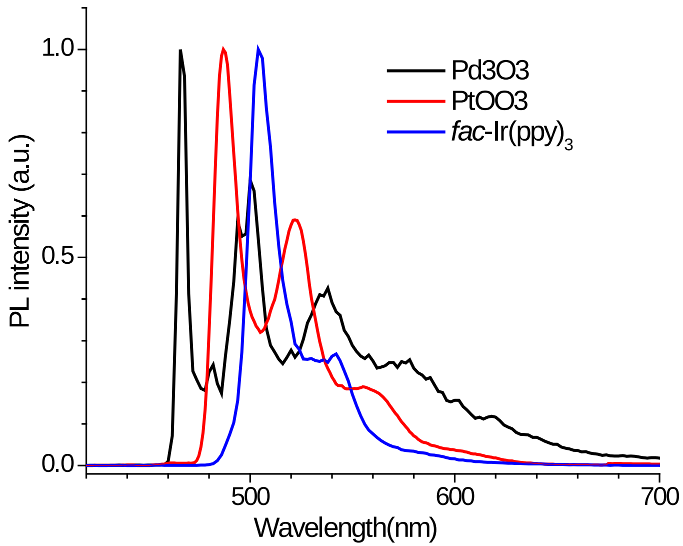


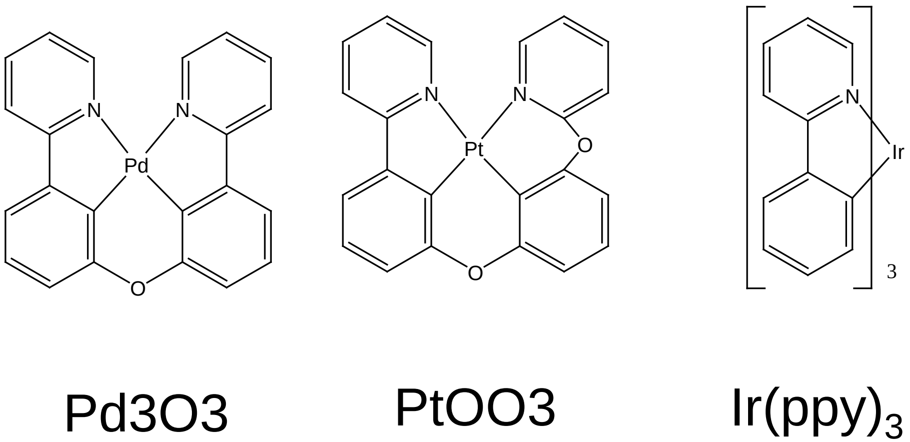


Device type	CRI	EQE	PE (lm/W)	LT_{50} (h) @20 mA/cm^2	EQE(%) @1000 nits	PE @1000 nits	LT_{50} (h) @1000 nits
1	67	23.2	45.7	38	18.7	27.4	891
2	64	22.5	49.5	52	17.0	24.8	1253

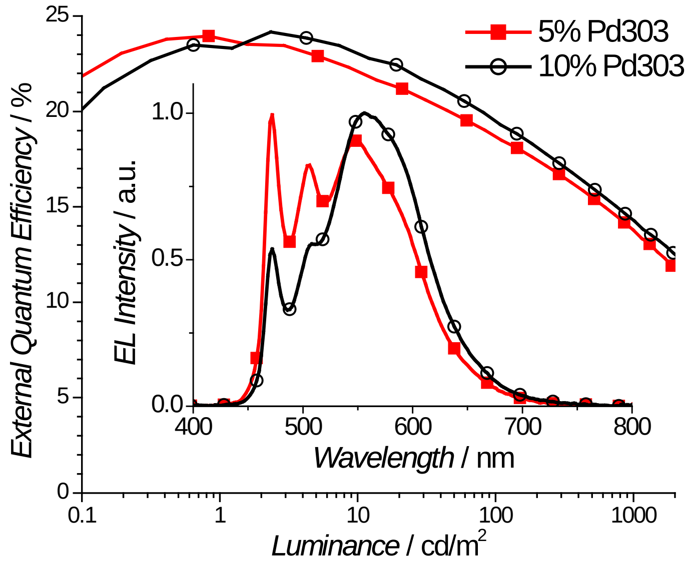
With new host, blockers and transporting materials, the device efficiency and operational lifetime improve significantly.

Progress



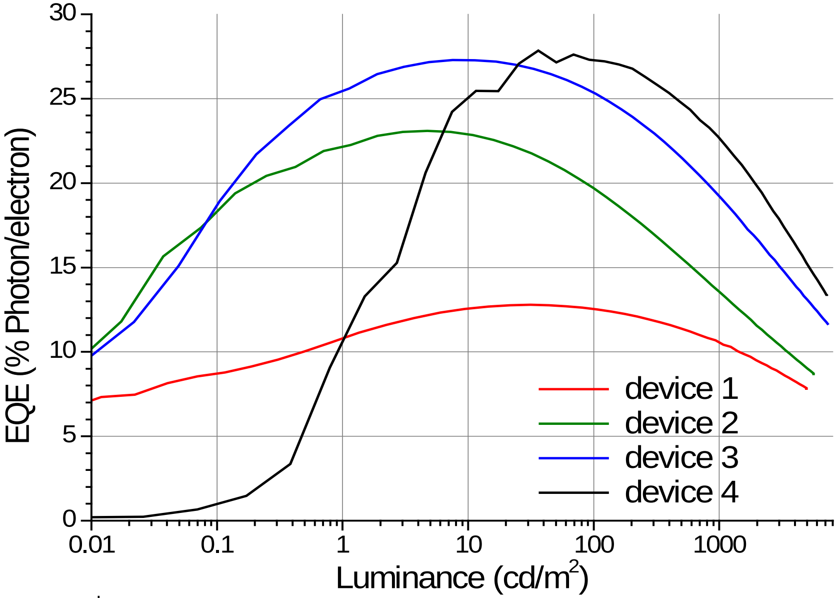


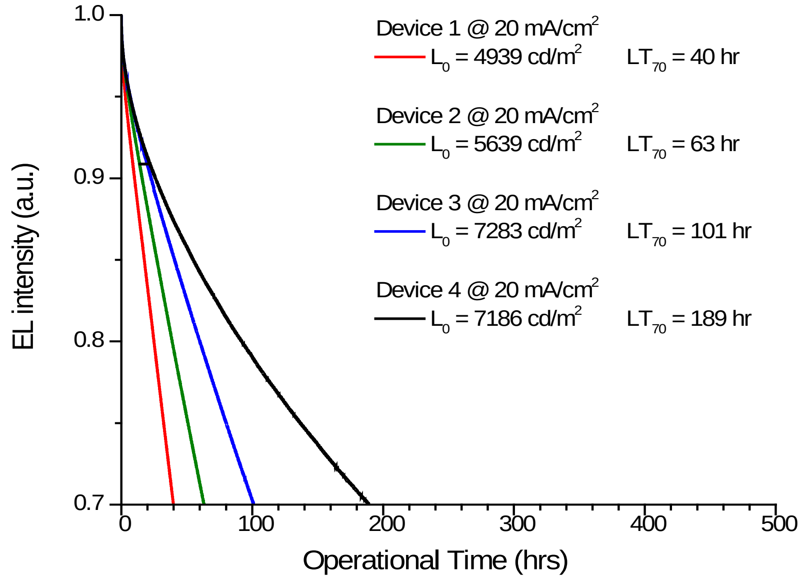
ITO/HATCN(10nm)/NPD(40nm)/TAPc(10nm)/x%Pd3O3:26 mCPy(25nm)/DPPS(10nm)/BmPyPB(40nm)/LiF/Al.

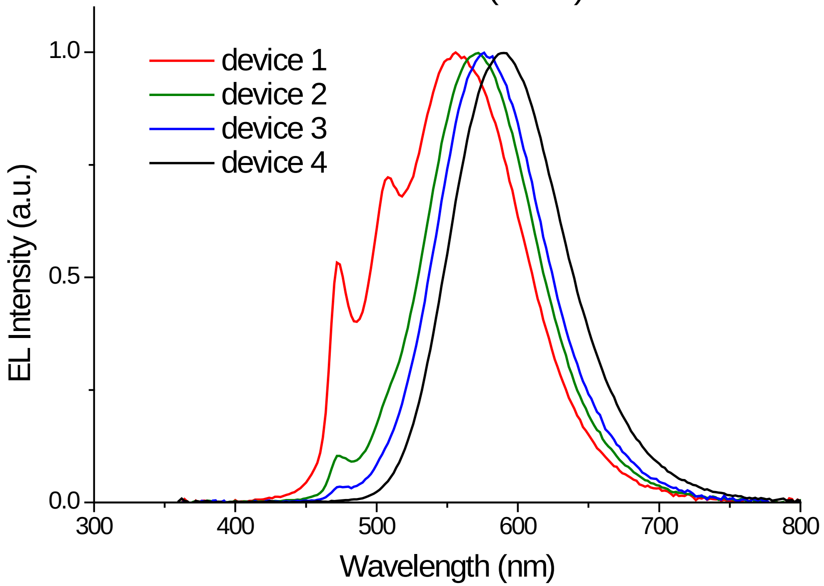


Pd3O3 has the potential to be efficient in both monomer and excimer forms.

Progress

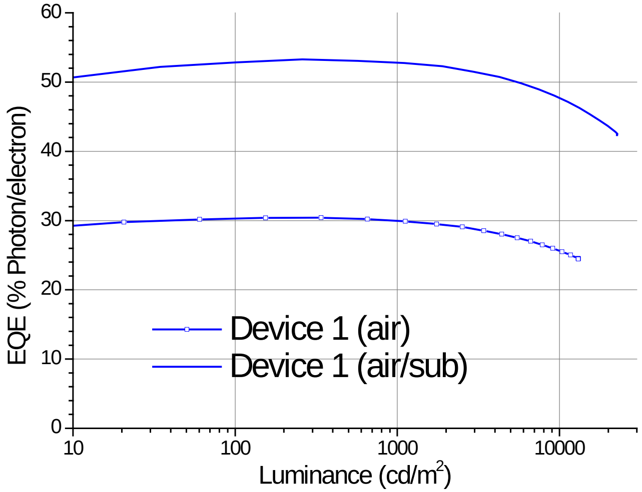


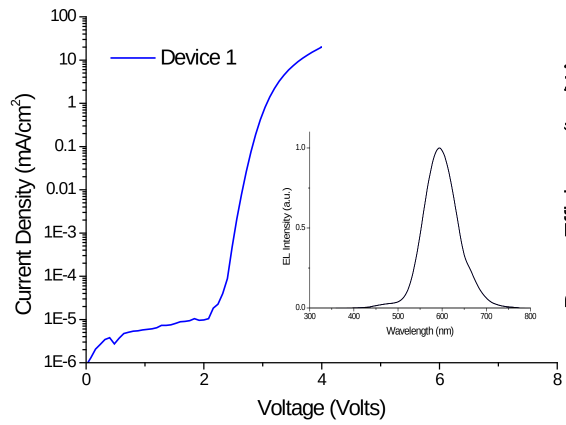


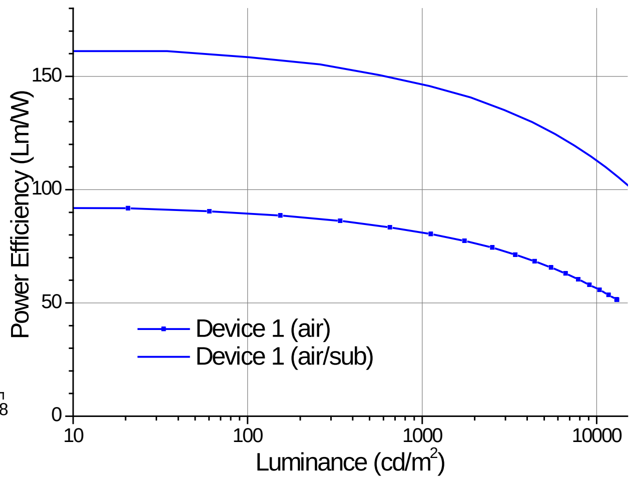


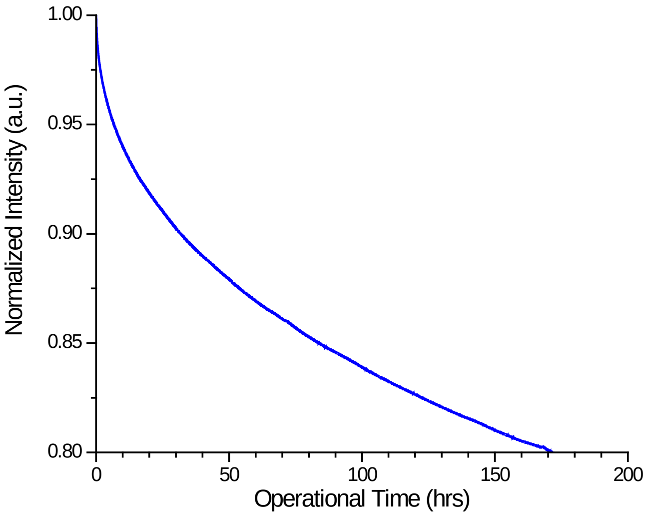
EQE > 22%, LT_{70} >4000 hrs and LT_{50} >13000 hrs @1000 cd/m^2 for efficient Pd3O3 device;

Progress



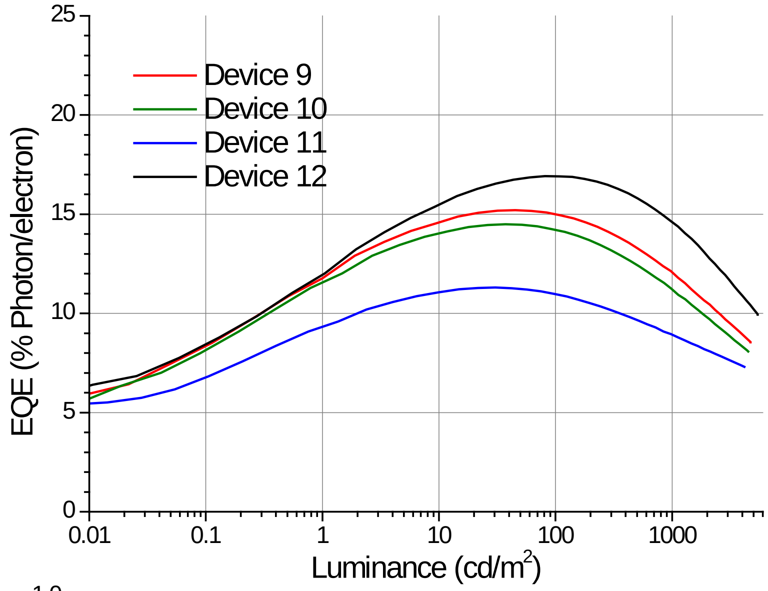


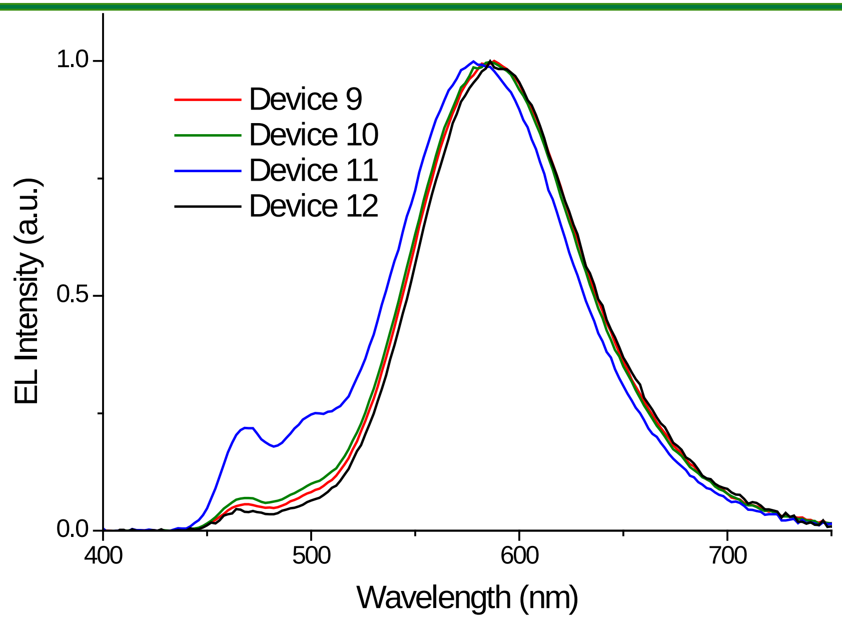


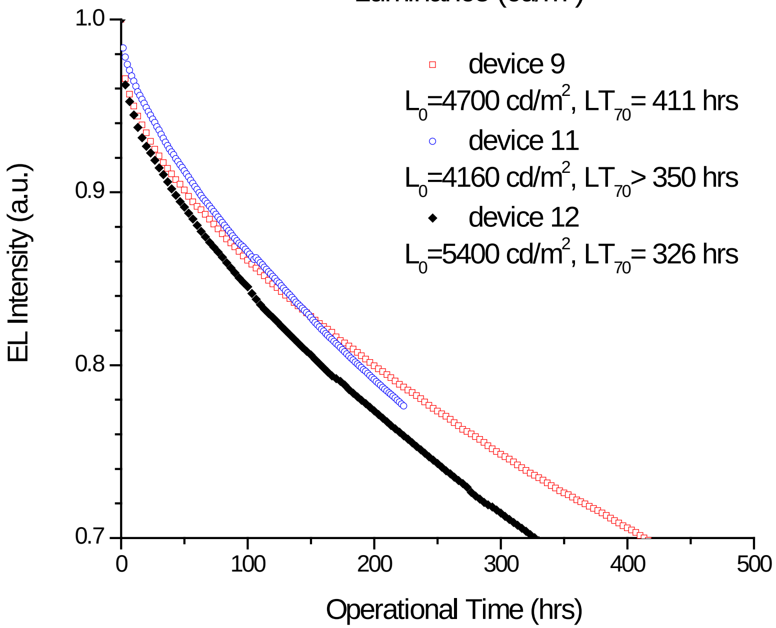


EQE > 30%, LT_{80} >17000 hrs and PE >80 lm/W @1000 cd/m^2 for efficient Pd3O3 device without light outcoupling enhancement technique;

Progress





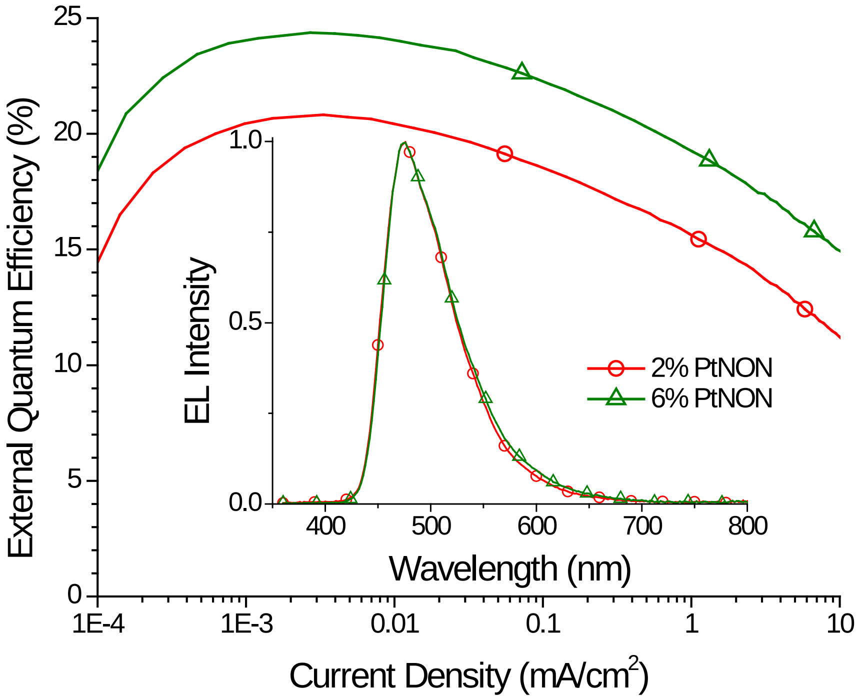


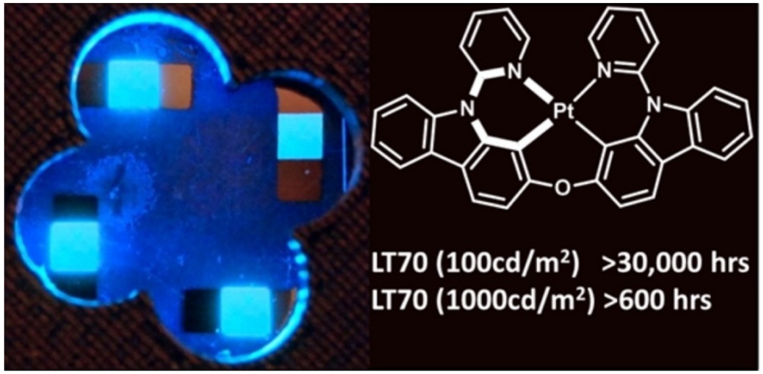
EQE > 10%, LT_{70} >3800 hrs @1000 cd/m^2 for with balanced Pd3O3 monomer/excimer emission.

In collaboration with UDC team,
EQE > 22%, LT_{80} > 2900 hrs and LT_{50}>20000 hrs @1000 cd/m^2 for Pd3O3 devices with modestly balanced monomer/excimer emission

Progress

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.

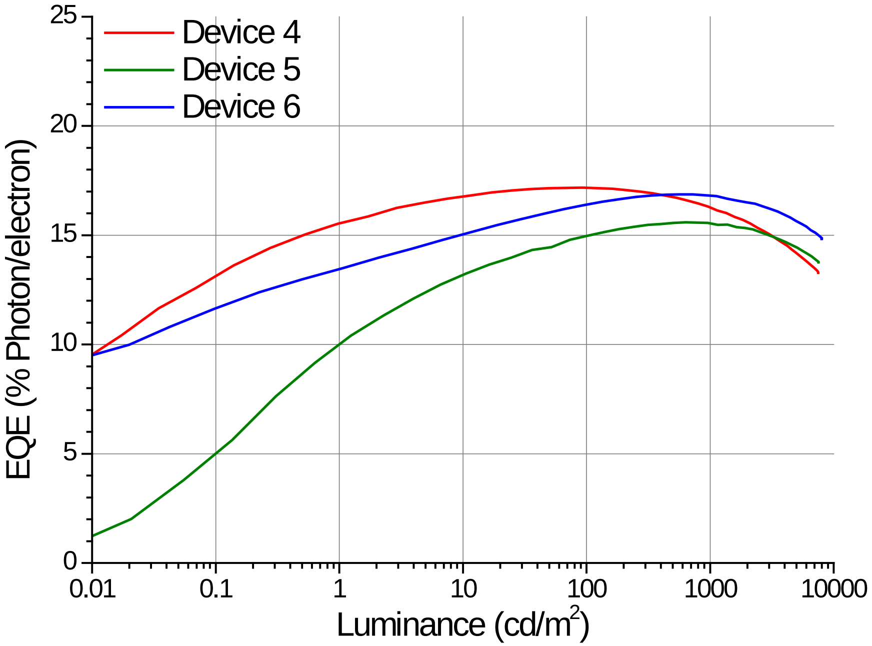
Fleetham et al. Chem. Mater. (2016)

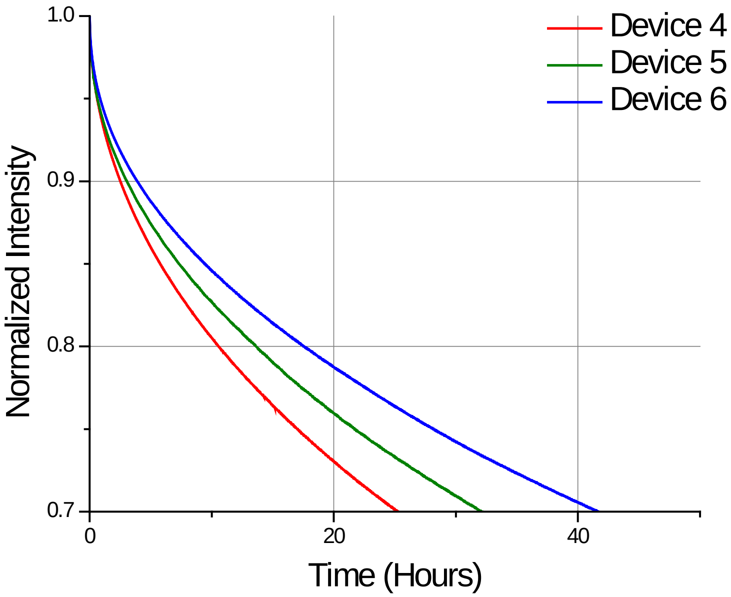
Progress

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

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.

Stakeholder Engagement

Project Integration: PI and 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.

Remaining Project Work

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.

Thank You

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REFERENCE

(1) T. Fleetham, Y. Ji, L. Huang, T. Fleetham, J. Li*, “Efficient and Stable Single-Doped White OLEDs Using a Palladium-Based Excimer Emitter”, Chem. Science, 8(12), 7983-7990 (2017).

(2) G. Li, A. Wolfe, J. Brooks, Z.Q. Zhu, J. Li*, “Modifying Emission Spectral Bandwidth of Phosphorescent Platinum(II) Complexes Through Synthetic Control”, Inorg. Chem. 56 (14), 8244-8256 (2017).

(3) Z.-Q. Zhu, K. Klimes, S. Holloway, J. Li*, “Efficient Cyclometalated Platinum(II) Complex with Superior Operational Stability”, Adv. Mater. 29, 1605002, (2017).

(4) 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. 29, 1601861 (2017).

(5) 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).

Project Budget

Project Budget: DOE share - $700,000, ASU share - $175,000
Variances: N/A
Cost to Date: close to 90% budget has spent at the end of 2017.
Additional Funding: N/A

Budget History					
7/1/17– FY 2017 (past)		FY 2018 (current)		FY 2019 – N/A (planned)	
DOE	Cost-share	DOE	Cost-share	DOE	Cost-share
360,061	90,015	0	0		

Project Plan and Schedule

Project Schedule		
Project Start: 7/1/15		Completed Work
Projected End: 6/30/18		Active Task (in progress work)
		Milestone/Deliverable (Originally Planned) use for missed
		Milestone/Deliverable (Actual) use when met on time

	FY2015				FY2016				FY2017				FY2018		
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)	Q1 (Oct-Dec)	Q2 (Jan-Mar)	Q3 (Apr-Jun)
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															