OLEDWorks

# *Material Development for OLED Lighting Panels*

*Made by Vacuum Deposition*

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2021 DOE Lighting R&D Workshop

# OLED Lighting Market Segments

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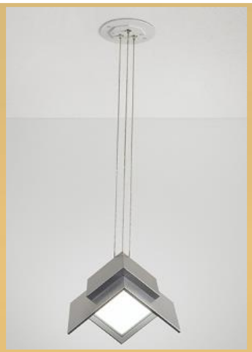
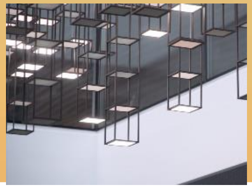
## General Lighting

Hospitality
Office and Corporate
Healthcare
Education
Retail

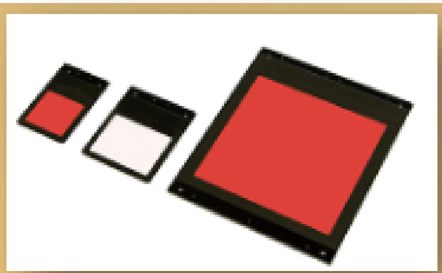
Museums/ Galleries
Residential



## Custom

Bendable,
Logo, & Colors



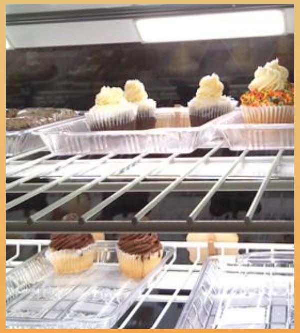
## OLED Lighting = Design Freedom



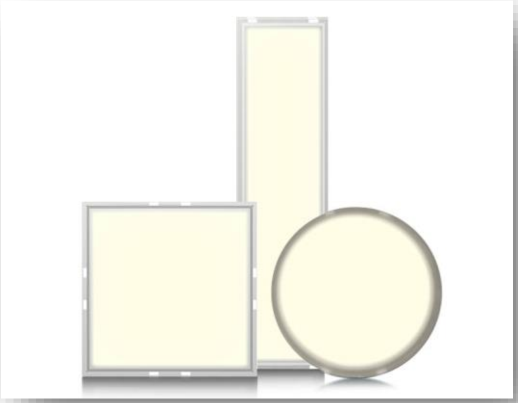
## Embedded Lighting

Automotive
Rail & Marine
Appliances
Medical
Furniture



# **OLEDWorks Brite 3 Panels** for White OLED Lighting



## Brite3 Family

- The brightest commercial OLED panel with up to 300 lumens and 75-85 lm/W
- Warm white (3000K) and neutral white (4000K) , CRI of > 90 and R9 >50
- **Meets performance expectations (output, efficacy, LT, robustness) for many applications**
- Light for all interior applications that desire high performance lighting
- Wider market opportunities available if cost can be lowered and efficacy increased

Matrix Wall Surface

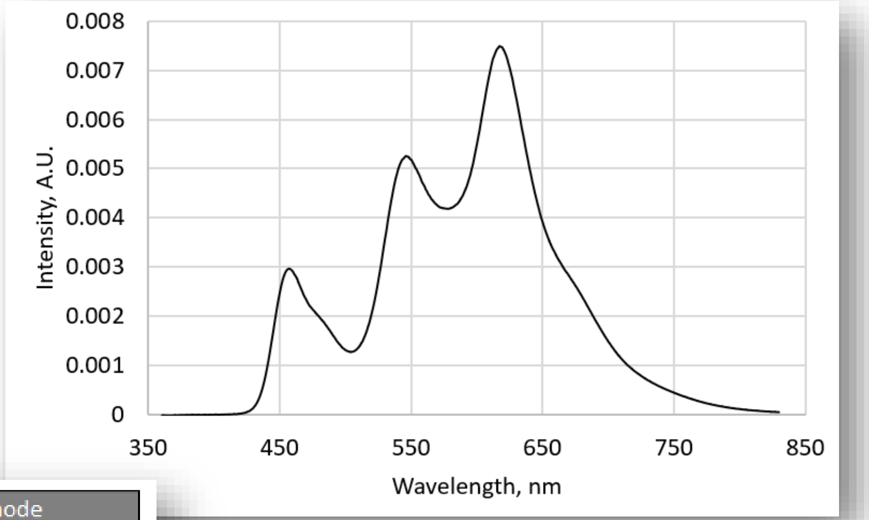
YOLED2481

Olessence

Gravity dual pendant

# **OLEDWorks Brite 3 Panels** for White OLED Lighting

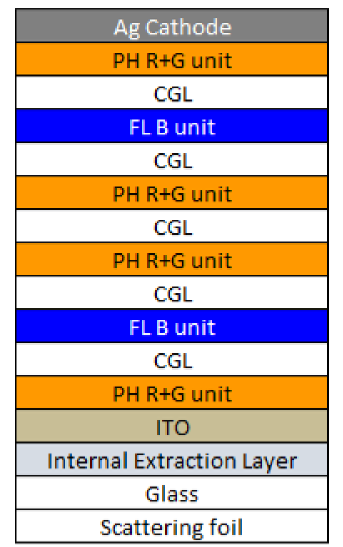
Spectral Power Distribution, 3000K

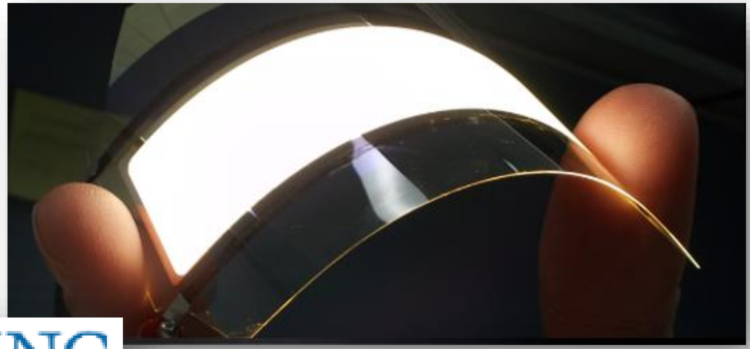



*J. Spindler, et al. SID2018, 84.1*

## Brite3 Family

- Multi-stacked hybrid OLED structures
  (FL blue, phosphorescent green/red emitters)
- Internal and external light extraction
- Rigid 0.7mm glass substrate
- LumiCurve Wave: Corning Willow® glass (0.1 mm)
  panel thickness 0.5 mm
- >30 organic materials across products



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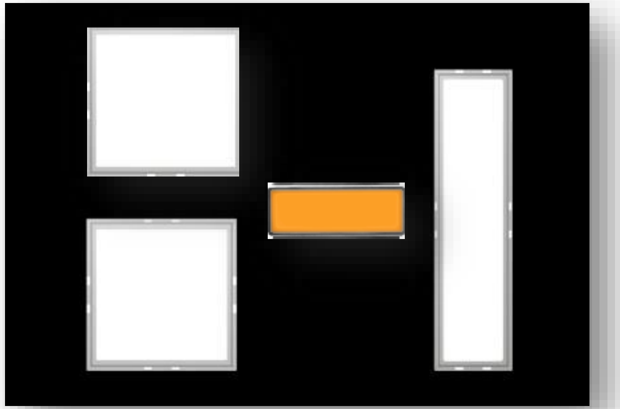
# Next Generation of OLED Panels



| Panel Generation | Brite 3 | | Brite 4 target | |
|---|---|---|---|---|
| Brightness (cd/m$^2$) | 3000 | 8000 | 3000 | 8000 |
| Flux (lumens) | 100 | 300 | 100 | 300 |
| Efficacy (LPW) | 85 | 75 | 120 | 100 |
| LT70 (khr) | 100 | 30 | >100 | 50 |

**Brite 4 target: >100 LPW**

- **Power efficiency $\eta_P$**
- **Internal quantum efficiency $\eta_{IQE}$**
- **Outcoupling efficiency $\eta_{OUT}$**
- **Device voltage V**

$$\eta_p \propto \frac{\eta_{IQE}\,\eta_{out}}{V}$$

Maximize: $\eta_{IQE}$, $\eta_{out}$

Minimize: $V$

**To achieve >100 lm/W and longer lifetime:**

- Advanced OLED materials for vacuum deposition
- More stacks, lower voltage per stack, improved CGL
- Improved thermal stability
- Highly efficient light extraction
- Lower light absorption (transparent TCO, ILE, organic layers)

**OLED Challenges**:

- Efficient and stable blue emitter with right spectrum.
- Phosphorescent efficiency improvement
- Stable host material(s) and materials for blocking layers.
- Low voltage transport materials.

# Blue Emitter Development – Fluorescence

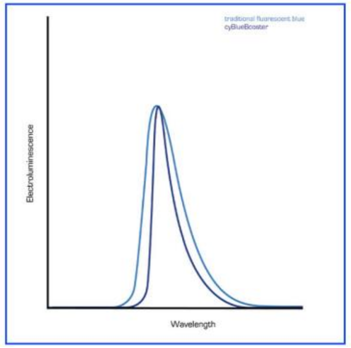
**Fluorescence**
x Insufficient harvesting of triplet excitons
- ✓ Low cost
- ✓ Deep blue color, narrow spectrum, works for lighting
- ✓ OLED lifetime

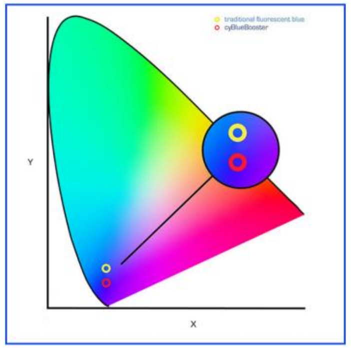
Currently ~ 10%EQE
Further improvement by OLED engineering ( EBL, HBL, etc)
Device structure optimized for TTA
  IQE ≤ 25% before mid'00s
  IQE ≤ 40% before *ca.* 2008
Molecular orientation
Reduction of spectral width

**Performance of blue fluorescent devices, Idemitsu Kosan materials**
10 mA/cm$^2$

| Device | Device Type | Emitter | V | CIEx | CIEy | cd/A | EQE,% | nm | LT95, hrs | Ref |
|---|---|---|---|---|---|---|---|---|---|---|
| 1 | BE | BD1 | 3.4 | 0.136 | 0.100 | 9.5 | 10.7 | 458 | | IDK, SID2018, 6.3 |
| 2 | BE | BD2 | 3.8 | 0.136 | 0.099 | 9.0 | 10.3 | 457 | | IDK, SID2018, 6.3 |
| 3 | TE | BD2 | 3.8 | 0.142 | 0.043 | 8.4 | | 458 | 770 | IDK, SID2018, 6.3 |
| 4 | BE | BD3 | 3.7 | | | | 9.8 | 460 | | IDK, SID2020, 48.2 |
| 5 | TE | BD3 | 3.7 | 0.138 | 0.049 | 9.9 | | 460 | 811 | IDK, SID2020, 48.2 |

**Cynora: cyBlue Booster**
15% more efficient than comparative emitters




cynora.com/technology-and-products/cyblueboosterr/

# Blue Emitter Development

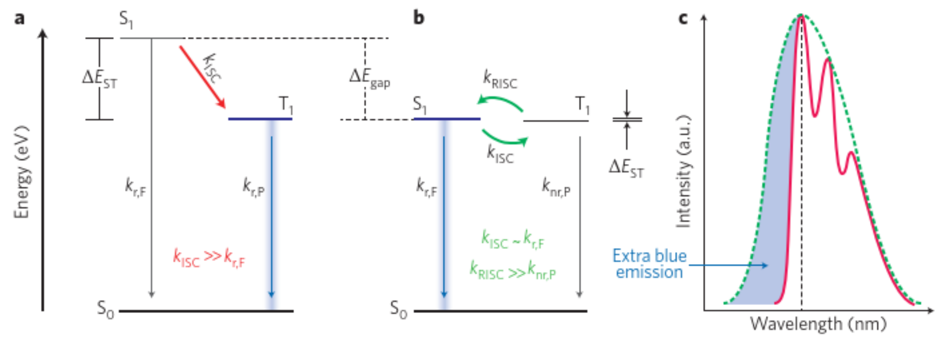



**Figure 1 |** Key photophysical differences between phosphorescent and TADF-type emitters. **a**,**b** Simplified Jablonski diagrams for phosphorescent (**a**) and TADF-based (**b**) emitters. Important rates $k_i$ are indicated. r, radiative; nr, nonradiative; F, fluorescence; P, phosphorescence; ISC, intersystem crossing; RISC, reverse ISC; $\Delta E_{ST}$, singlet–triplet splitting. **c**, Schematic showing the difference between the spectral distributions of phosphorescence (red curve) and TADF (dashed green curve) emissions.

Reineke, Nature Photonics, 2004, 269

**Phosphorescence**
- ✓ 100% Exciton harvesting
- ✓ Color tuning via ligand design
- ✓ Wider spectrum, works well for lighting
- ✓ OLED lifetime for PH green and red
- x Higher voltage compared to FL device
- x Blue PHOLED lifetime

→

Blue emitters with < 470 nm max
Blue PHOLED lifetime improvement?
Band gap ~ 1/LT
Need (Host + Emitter) EML system

**TADF**
- ✓ 100% Exciton harvesting
- ✓ Organic materials, potentially cheap
- ✓ Broad spectrum
- x Emitter development ongoing
- x OLED Lifetime

→

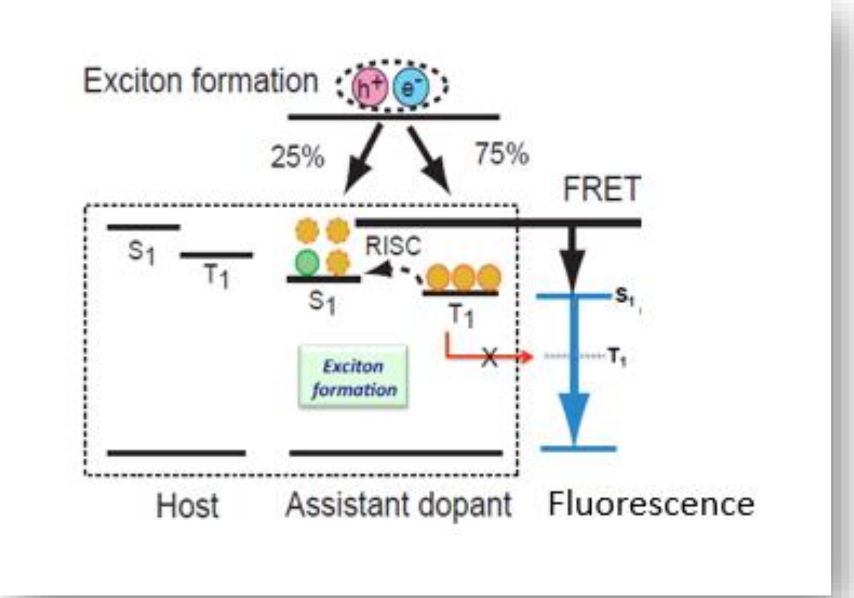
Technology was introduced in 2010-2012
Short lifetime for blue TADF OLEDs
(Host +TADF emitter) EML system
*The absence of stable hosts complicates development of the emitters*

# Blue Emitter Development - Hyperfluorescence

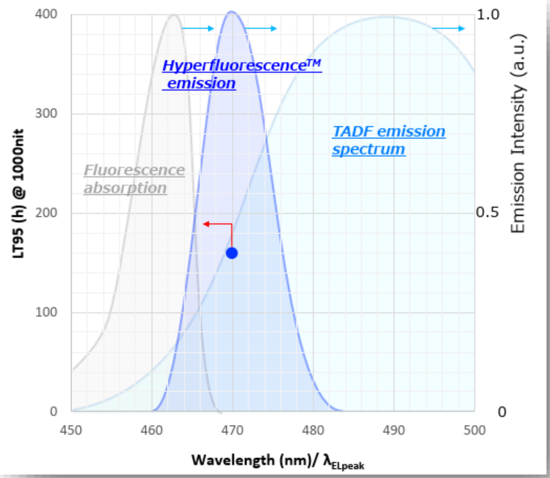
**Hyperfluorescence (HF)**
- ✓ 100% Exciton harvesting
- ✓ Deep blue color
- x 3 component complex system
- x OLED lifetime

Simultaneous development of TADF-assistant dopant and fluorescent emitter.
LT improvement required.

**LT improvements in HF OLED vs classic TADF:**
Further reduction of exciton residence times;
Exciton energies of TADF co-dopants are reduced , less excited-state chemistry/instability;
High efficiency devices operate at reduced current.




Nakanotani, et al. Nature communications, 5:4016,2014.




Latest achievement blue HF ( SID2020)

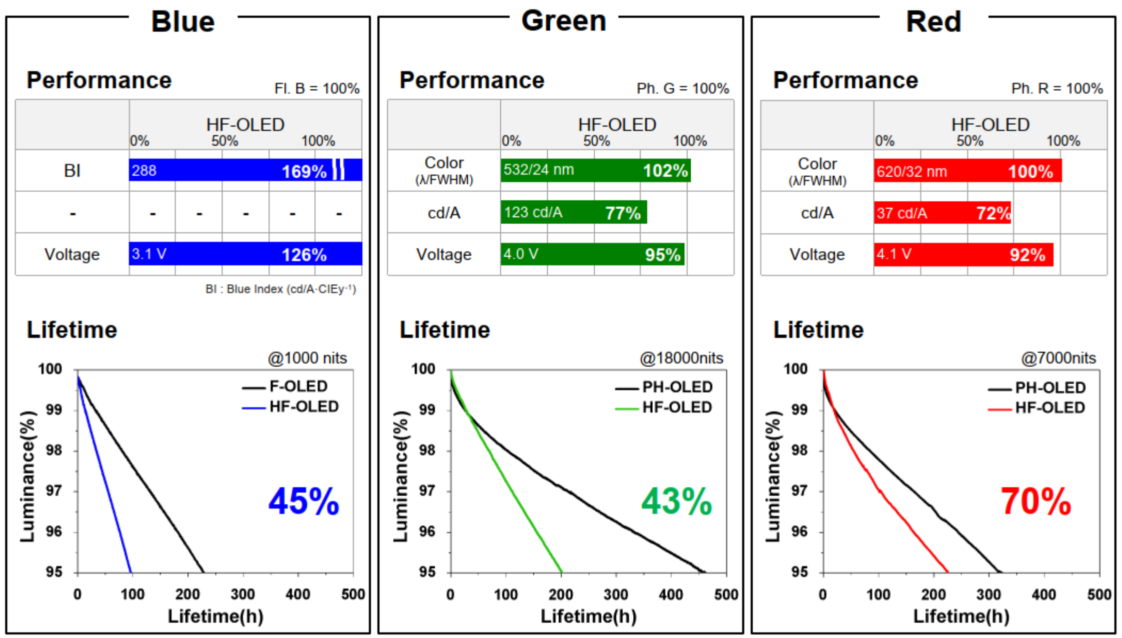
| Color | Peak, nm | FWHM | cd/A | LT95 at 1000 nits, hrs |
|---|---|---|---|---|
| Blue | 470 | 23 | 43 | 250 |

Kyulux, SID2020, 6.2

# Performance of Hyperfluorescent OLED Devices

Kim et al, LG Display, SID 2020, 6.1

Top-emitting OLEDs




Bottom-emitting OLEDs

| | Device | V | CIEx | CIEy | nm | FWHM, nm | EQE,% | LT95*, hrs |
|---|---|---|---|---|---|---|---|---|
| 1 | F-OLED, 2% | 4 | 0.11 | 0.12 | 472 | 16 | 9.4 | 650 |
| 2 | TADF-OLED | 3.7 | 0.2 | 0.44 | 494 | 74 | 22.7 | 300 |
| 3 | HF-OLED,FD_0.5% | 3.9 | 0.18 | 0.36 | 474 | 36 | 20 | 300 |
| 4 | HF-OLED,FD_2% | 3.9 | 0.16 | 0.27 | 474 | 20 | 13 | 30 |

*at 300 nits

>2X LT improvement for blue HF devices required.
**Today development of hyperfluorescent blue EML seems the most promising for LT and EQE.**
Combination of ( TADF assist+ FL dopant) is needed.
New materials should be tested in advanced OLED structures.

# Blue Stack Performance Improvement

New emitters are tested in a single stack OLEDs

**Luminous efficacy of blue emitters**

- Objective: Achieve required CCT (3000K, 4000K) with using as few blue units as possible
- Choose a material providing highest blue index , i.e., tristimulus Z value at a certain current J

$$Z/J = ([1-CIEx-CIEy]/CIEy) * (L/J)$$

L = Luminance ($cd/m^2$)

J = Current density ($A/m^2$)

| Merit | Priority |
|---|---|
| Blue index (Z/J) | High |
| Lifetime | High |
| Impact on CRI for white OLED | Medium |
| Cost | High |

Alternatively, BI = (L/J)/CIEy
Both BI give same relative score for the blue emitters

**Blue stack improvement for Lighting panels:**
450 nm - 465 nm emission maximum.
At least 25% improvement of Z/J.
IEL extracts blue light less efficiently compared to green and red .
50% LT improvement ( LT95>400 hours at 1000 nits)

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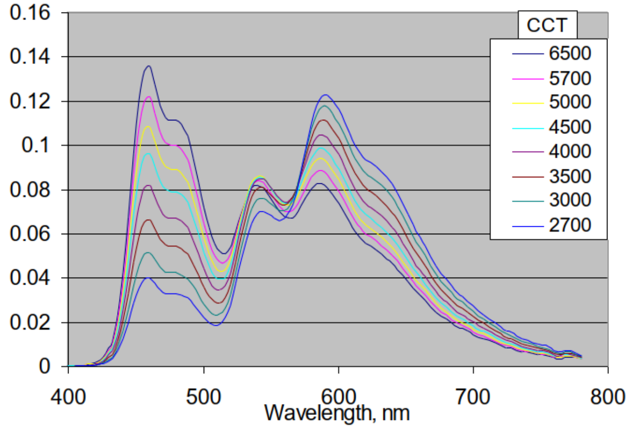
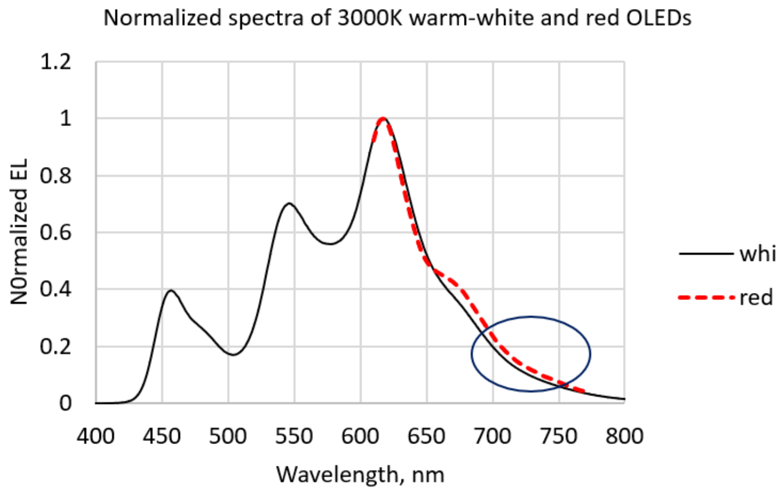
# Phosphorescent Stack Improvement - Emitters

*Phosphorescent effciency and stability improvement*
*Materials needed: host/emitters/ EBL/HBL*

**Emitters:** 520-550 nm **green-yellow** emitter with longer LT
620-626 nm **red** phosphorescent emitter with FWHM <45 nm
phosphorescent **amber** emitter with CIEx,y (0.56, 0.43) for healthcare, accent and wayfinding lighting




Tyan, OLED Lighting seminar, SID 2013



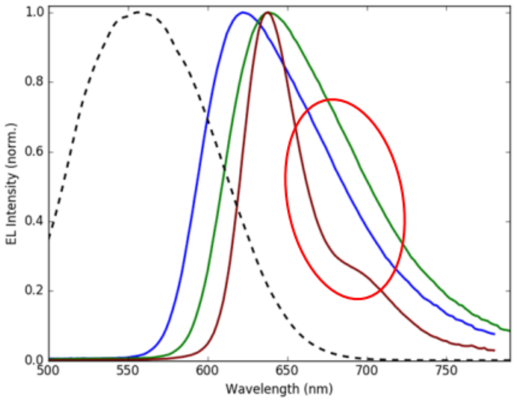




**Figure 4:** Normalized bottom emission device EL spectra for an advanced narrow deep red emitter (red) vs. a conventional red (blue) and the same emitter red-shifted to the peak wavelength of the narrow emitter (green). The photopic response function (black, dashed) is also shown.

Margulies et al. SID2019, 65.1

30-40% improvement of LE with narrow-spectrum red

Latest achievement Red HF

| Color | Peak, nm | FWHM | cd/A | LT95 at 1000 nits, hrs |
|---|---|---|---|---|
| Red | 617 | 44 | 32 | >37,000 |

Kyulux, SID2020, 6.2

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# Phosphorescent Stack Improvement - Host

*Materials needed: host/EBL/HBL*

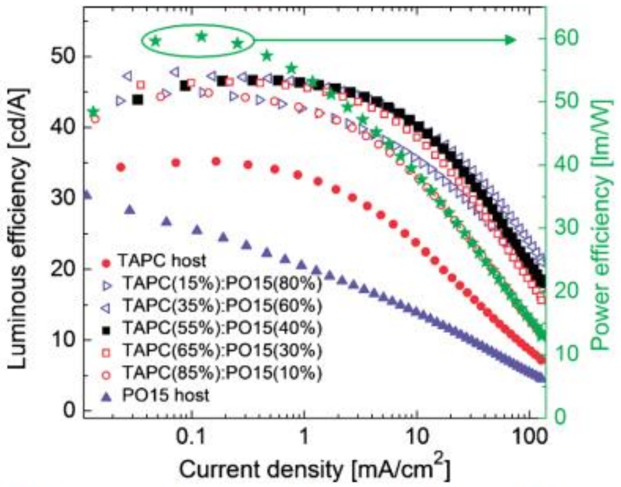


FIG. 3. (Color online) Luminous efficiency roll-off characteristics for devices with varying mixed host composition. The OLED with 55 wt % TAPC:40 wt % PO15 mixed host was considered the optimized device with respect to a combination of low operation voltage and stable roll-off. Hence, the representative power efficiency for the optimized device is included (solid stars).

Chopra et al, Appl. Phys. Lett., 2010, 97, 033304

**Host:** Single host material preferable but can be **pre-mixed**

**Mixed host:**
Results in **voltage reduction**, lower effciency roll-off with current density, improved effciency and LT

- Consists of hole- and electron-transporting components
- High HOMO and low LUMO are compatible with high triplet energy
- Improves charge injection and transport
- Eliminates/reduces internal charge accumulations at or near interfaces

*Stability of pre-mixed host composition during several cycles of evaporation at high rates is required.*

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# Summary

- Development of hyperfluorescent blue materials seems most promising to achieve high efficiency and sufficient stability among blue OLED technologies. TADF co-dopant and fluorescent emitter need to be developed in parallel for the best performance.  Host development is also needed.
- Phosphorescent efficiency in white OLEDs can be improved by use of red dopants with narrow spectra.
- Development of new phosphorescent host materials is needed to improve OLED efficiency and LT.
- All new materials must be cost effective.
- **Any new materials need to be tested in combination with the state-of-the-art materials used in advanced OLED lighting structures to verify their performance.**