Charge Balance in OLEDs: Optimization of Transport Materials

DOE SSL R&D Workshop

Tampa, FL

January 29, 2014

All references to “Merck” refer to Merck KGaA, Darmstadt, Germany.
In North America Merck operates under the name EMD.

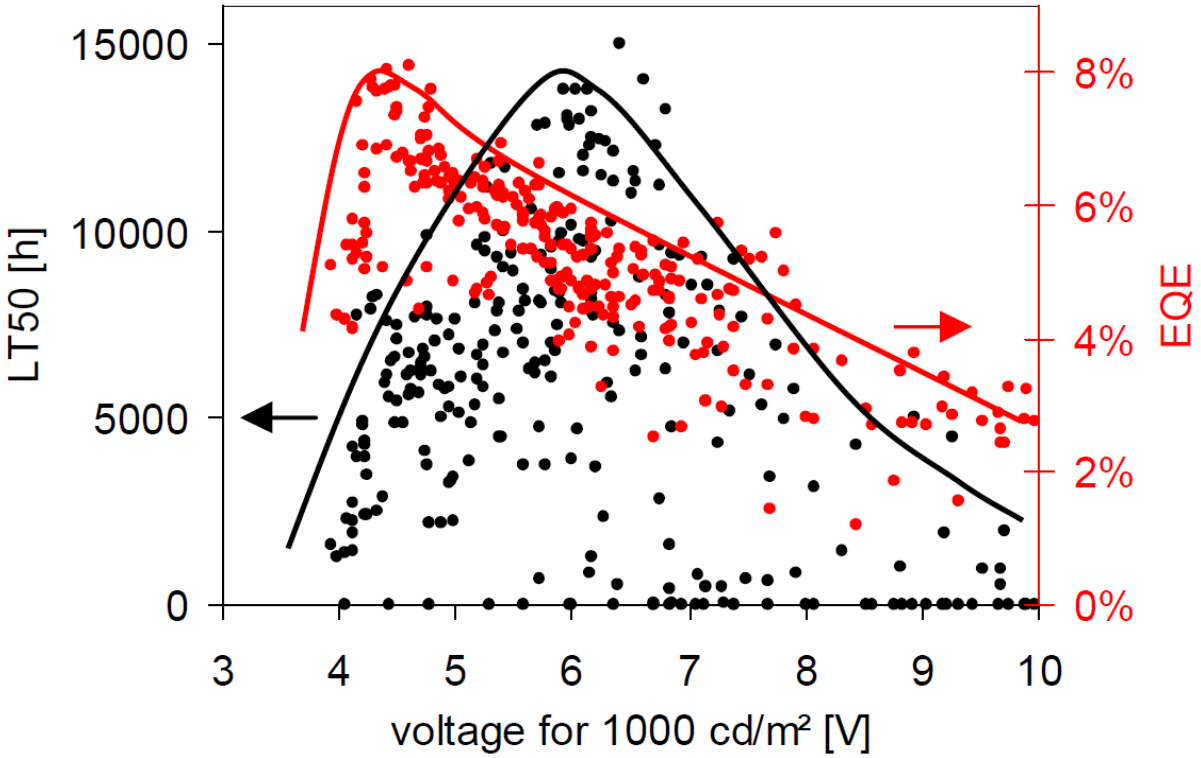
Transport Materials are Critical Components in High-Performance OLED Devices

- Enable key performance characteristics
  - Low voltage
  - Long lifetime

- Voltage and lifetime typically trade-off in devices. Charge balance is key to maximize both properties.

- Reducing drive voltage to ~ 3V is a challenge. Can this be done with a single material or is p/n doping the best approach?

Trade-off between Lifetime and Efficiency



E. Böhm, C. Pflumm, F. Voges, M. Flämmich, H. Heil, A. Büsing, A. Parham, R. Fortte, T. Mujica, IDW'09, OLED1-2, p.431 (2009).

This behavior is well-established, particularly for fluorescent blue OLEDs

Tuning Charge Balance with Mixed Host

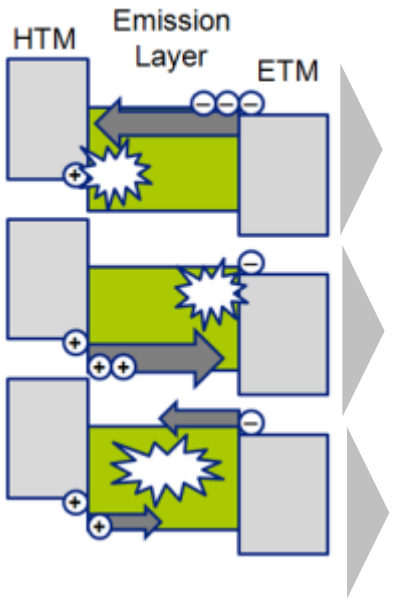
Mixed host systems

Two host components are used to adjust charge balance

- Lifetime improvement by a factor of two
- Low roll-off
- Low voltage

compared to single host system

Emission Zone



e-type TMM shifts luminance zone to the HTM layer

h-type TMM shifts luminance zone to the ETM layer

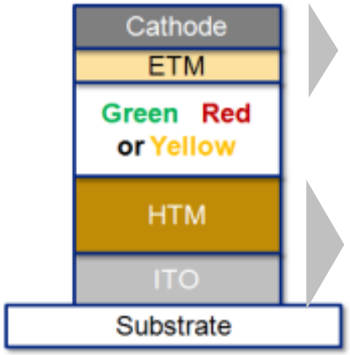
Mixed or bipolar TMM can lead to a luminance zone in the middle of the EML

Host materials (TMMs) are key to optimize & control charge balance in the device

Tuning Charge Balance with Mixed Host

Requirements

- Balance can be tuned by adjusting the host mixing ratio: e-type TMM + h-type TMM
- Customized for customer device



Cathode and ETM control electron supply

ITO (+ treatment) and HTMs control hole supply

- Merck addresses triplet Green, Yellow & Red OLEDs

Balance Adjustment

Example : combination of
- h-type (material A and B) with
- e-type (material 1 and 2)

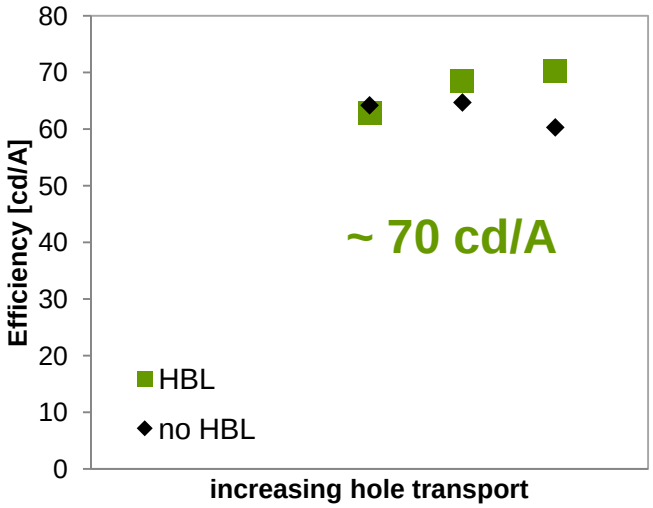
h-type

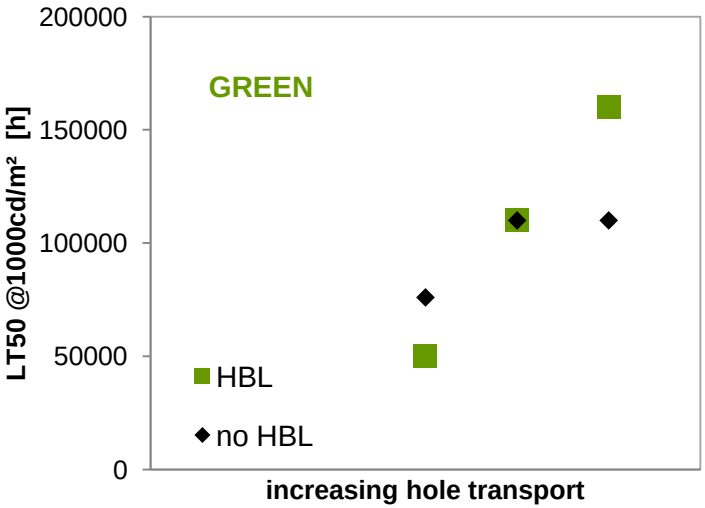
e-type

e-type:	h-type:	A	B
1	**Best co-host ratio**	**>10%**	**47%**
	LT50 [h]	100%	180%
	Eff. [cd/A]	100%	120%
	V [V]	3.8	3.9
2	**Best co-host ratio**	**32%**	**>63%**
	LT50 [h]	150%	110%
	Eff. [cd/A]	120%	105%
	V [V]	3.7	4.5

Charge Balance Optimization through the Introduction of an HBL

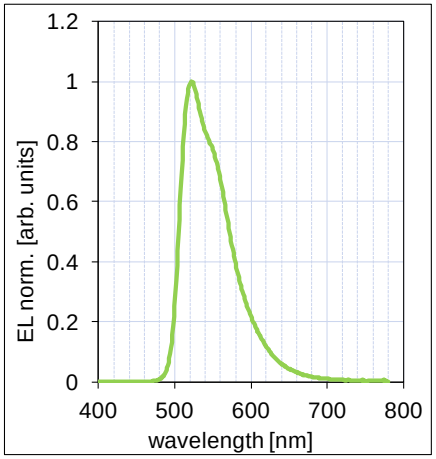
With a hole-rich EML mixture, we need to adjust the charge balance by introducing an HBL

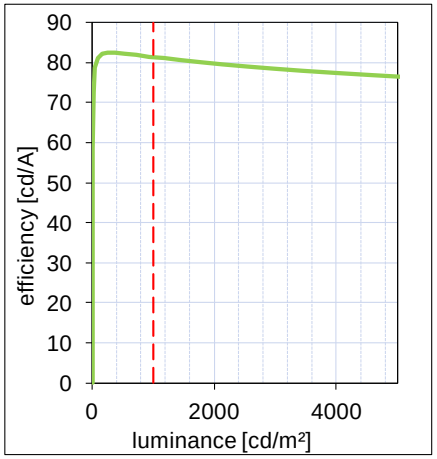


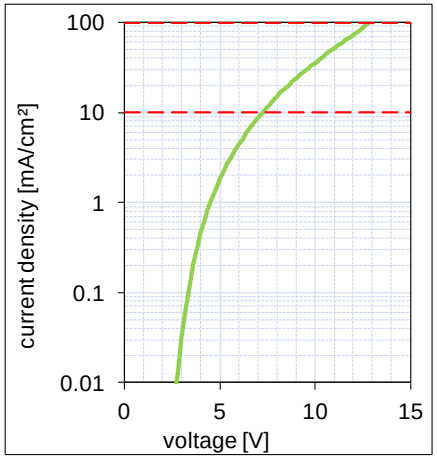


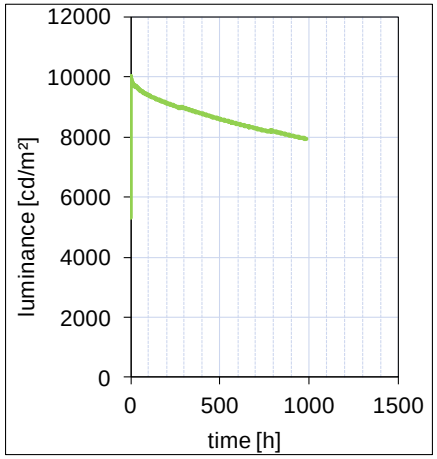
Lifetime and efficiency are further improved with the introduction of an HBL

A Winning Strategy Leading to Impressive Results in Solution Processed Devices









CIE x,y	Eff [cd/A] @1000cd/m²	Voltage [V] @1000cd/m²	EQE [%] @1000cd/m²	Est. LT50 [h] @1000cd/m²
0.33, 0.63	81.3	4.7	21.8	320.000

Record efficiency & LT in phosphorescent green with more hole-injecting HTL. The gap between solution and vapor processing is closed?

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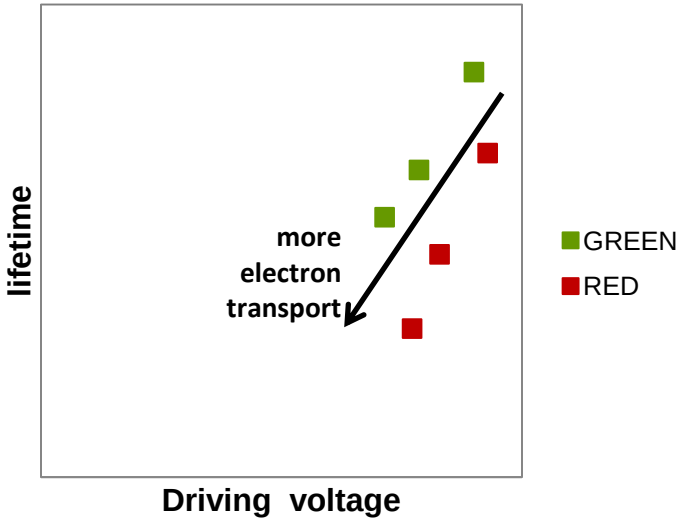
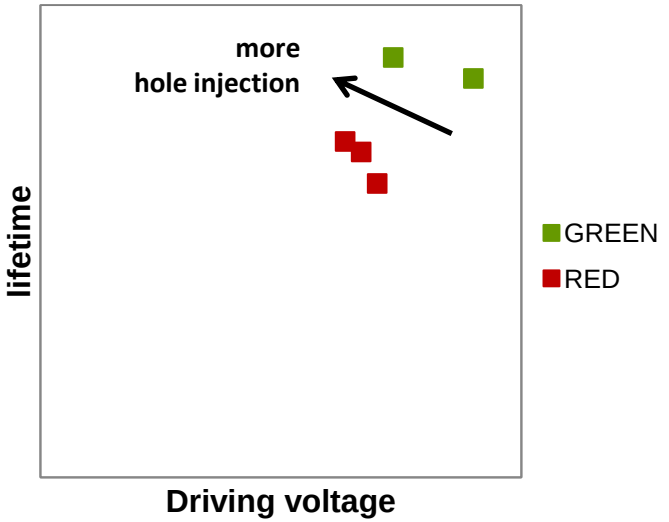
Charge Balance Optimization





Adding more electron transportting materials to EML mixtures results in lower voltage, but reduced lifetime

→ Not enough holes to counterbalance the electrons!

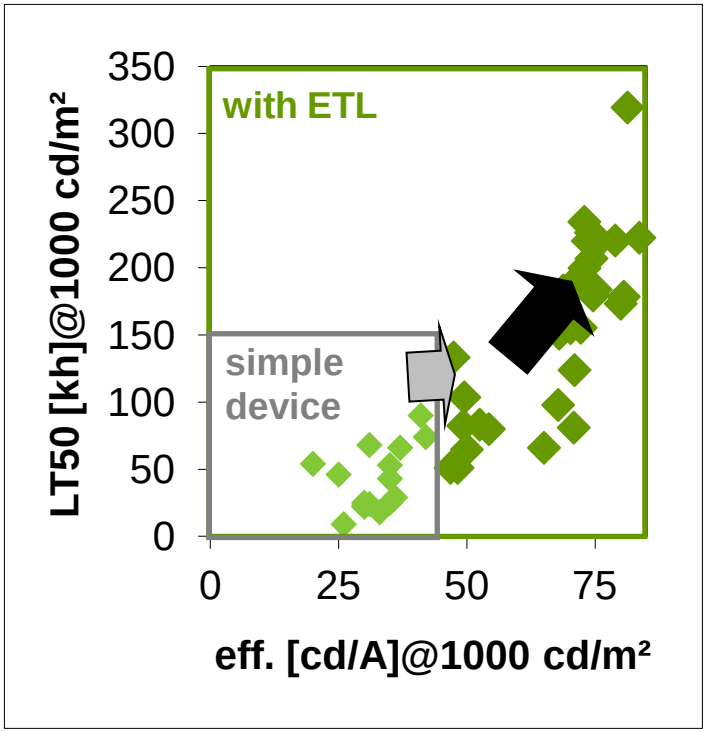
For a given EML mixture, vary the hole injection properties of the HTL.

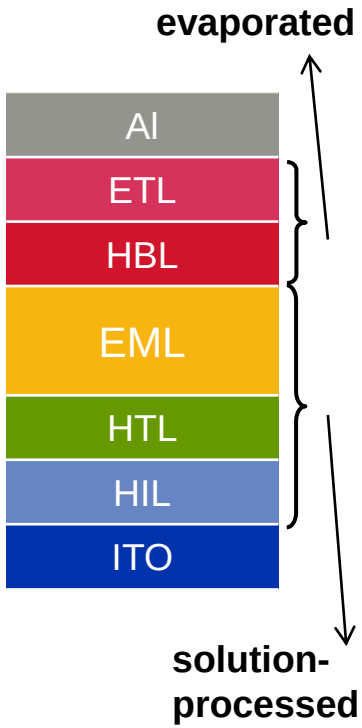
→ HTL with strong hole injection can improve voltage and lifetime simultaneously!

Introduction of more hole-injecting transport layers significantly improves lifetime

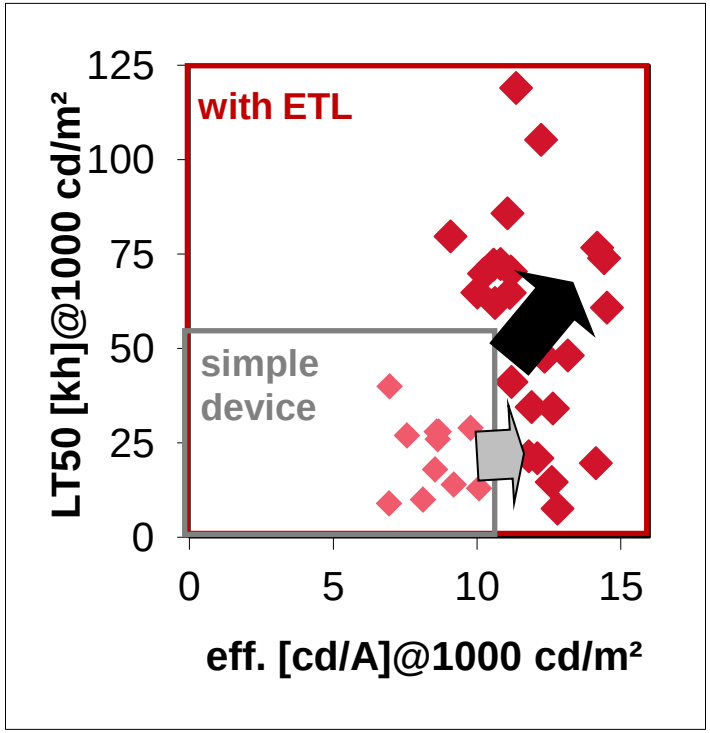
Performance Progress – Solution Processing

Triplet Green



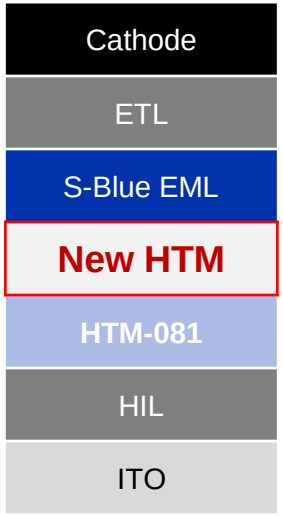


Triplet Red



Huge performance improvement with new materials in optimized devices

Novel HTMs with Electron Blocking Capability



HTM	CIE x/y	Efficiency [cd/A] @ 1000 cd/m²	Voltage [V] @ 1000 cd/cm²	EQE [%] @ 2000 cd/m²	LT_{50} [h] @ 1000 cd/m² (based on n=2)
HTM-081	0.14/0.14	9.2	4.1	8.4	21 000
New HTM	0.13/0.14	13.2	4.1	11.6	44 000

→ Further improvement compared to HTM-081 based device

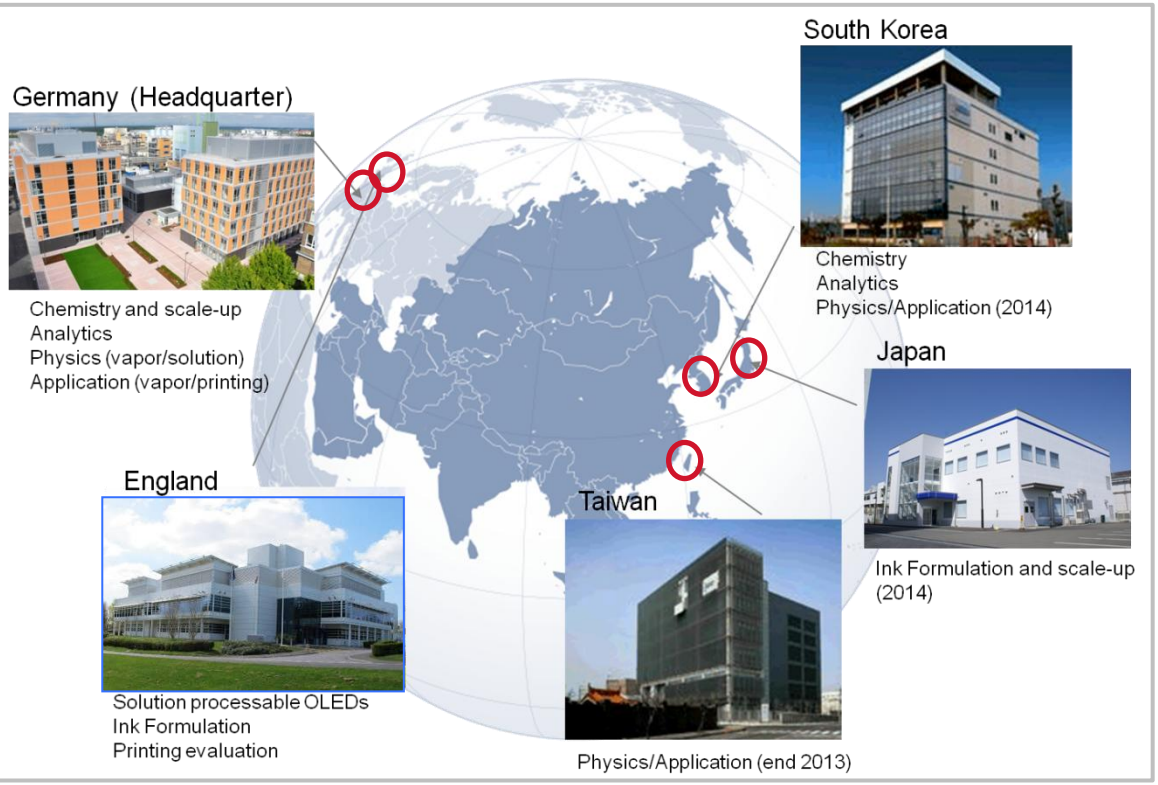
- EMD / Merck have developed a variety of new HTMs, for use as hole transporting layers with high triplet level & electron blocking capability
- New stack configurations provide excellent lifetime, efficiency and voltage for fluorescent & phosphorescent devices

EMD: OLED Solution Provider

R&D experts | **M&S experts** | **~1,400 patents**

Commitment to OLED

- New investment of MRC Darmstadt (2009), extensions in 2013 and 2014
- Extension of OLED scale-up and production in DA in 2013
- Setup of OLED formulation in Germany and UK 2012/13
- Continuous Investment in laboratories in Korea, Taiwan and Japan



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