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Polymer OLED Technology – Materials Development for Display & Lighting Applications

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Presentation Outline

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- The Choice to be made
- Remaining Polymer Blue Development through fundamental degradation understanding
- IJ Printing – Current Development
- Polymer Materials Development for Lighting Applications
- Closing remarks

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Comparison between SM- and polymer-OLED

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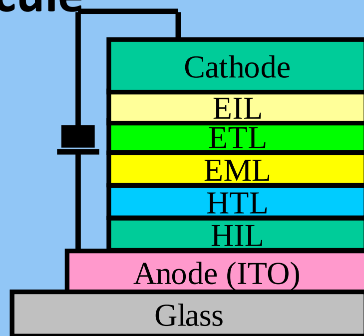
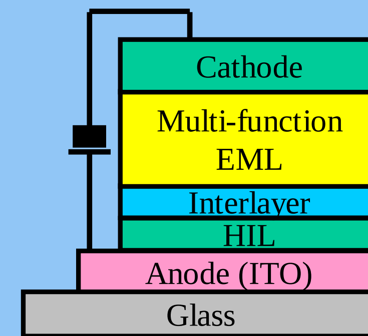
<table>
<tr><th></th><th>Small Molecule

</th><th>Polymer

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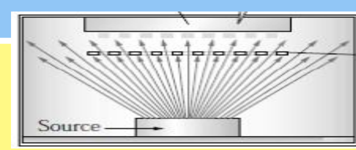
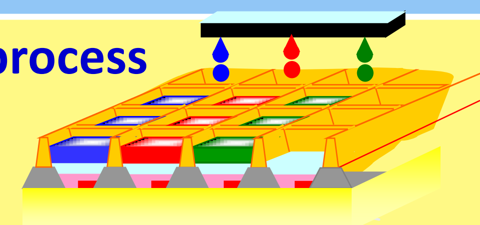
<tr><td>Process</td><td>Dry process (Vacuum evaporation)

</td><td>Solution process
</td></tr>
<tr><td>Patterning</td><td>Shadow mask</td><td>Printing (IJ etc.)</td></tr>
<tr><td>Structure</td><td>Complex layer structure (5-6)
→Complex process</td><td>Simple layer structure (2-3)
→Simple process, scalable</td></tr>
<tr><td>Material</td><td>Separated function</td><td>Integrated function</td></tr>
<tr><td>Issue</td><td>Layer structure complexity
Difficulty in mask patterning</td><td>Performance (esp. LT)
Patterning technology</td></tr>
</table>

The Choice

- Solution processed small molecule OLED
- Solution processed polymer OLED

Polymer-OLED Chemistry

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- Molecular weight control and high molecular weights achievable
- Polymerization generally robust with respect to reaction conditions
- Process suitable for various molecular architectures
  - Random
  - Alternating
  - Block
- High purity achieved to meet the needs of semiconductor industry
- Scalable to >20 litre reactors

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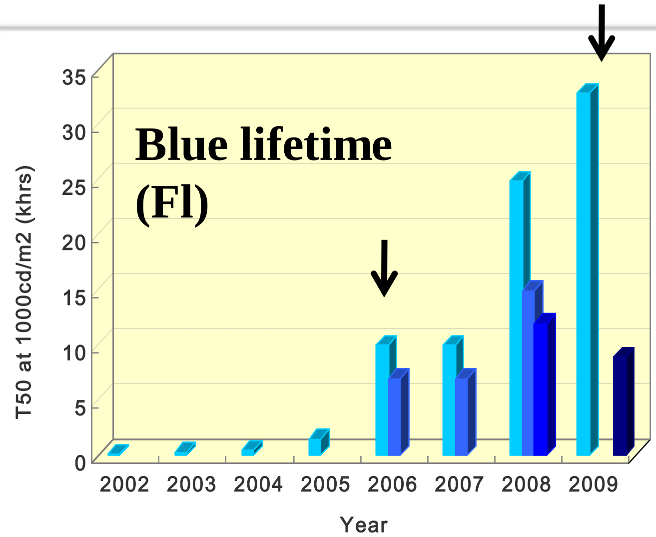
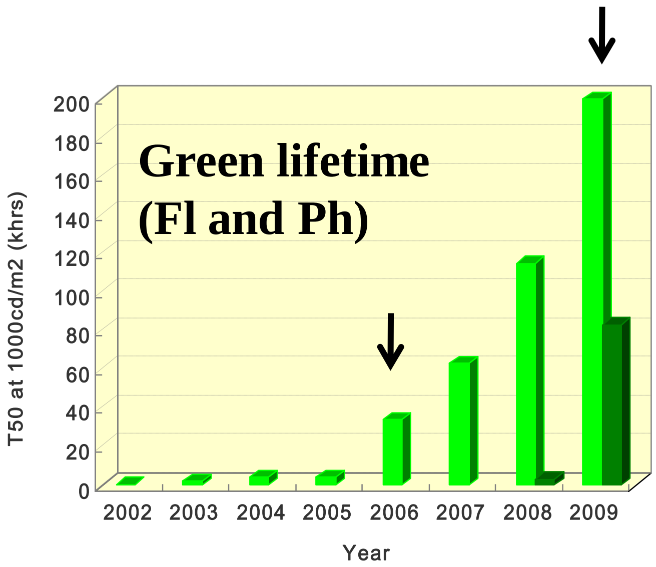
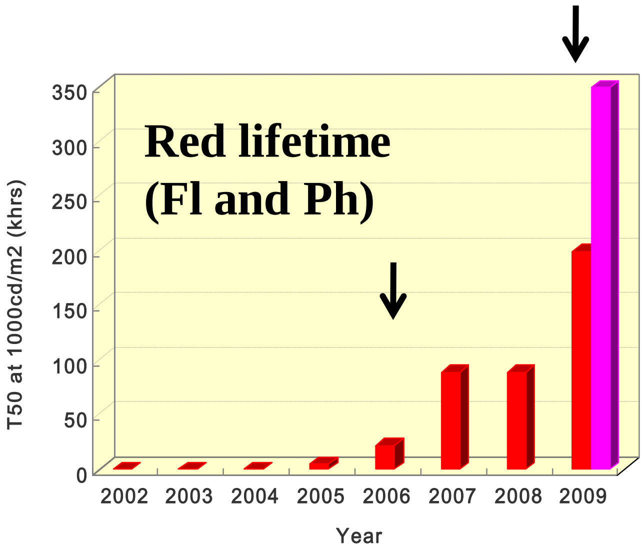
Sumitomo/CDT's lifetime growth 2002-2009







- Boost around 2006 and 2009
- Blue LT enhanced at early 2010
- Blue LT still the key issue

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Remaining POLED Materials Challenges

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- **Blue lifetime**
  - Colour point challenges
    - Lifetime challenges

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Conjugated polymers for LEPs

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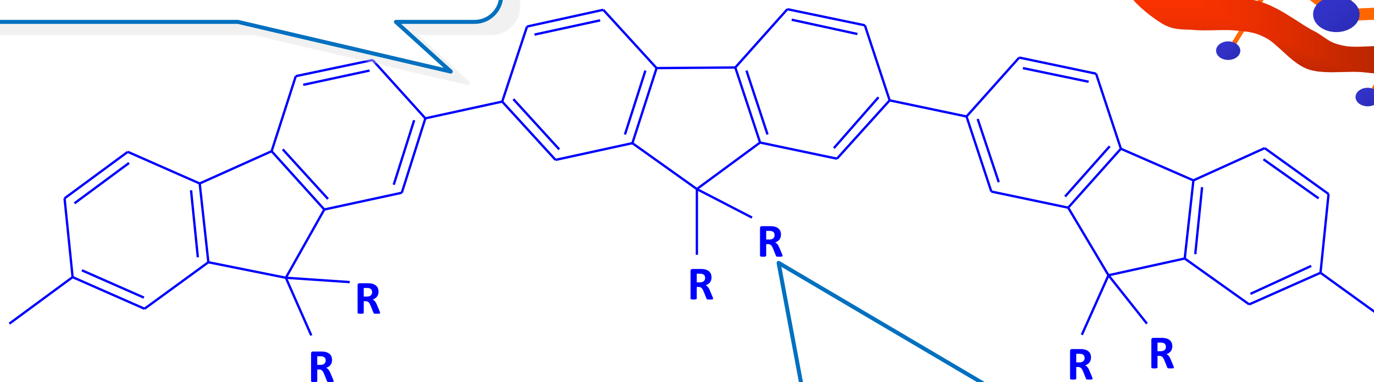
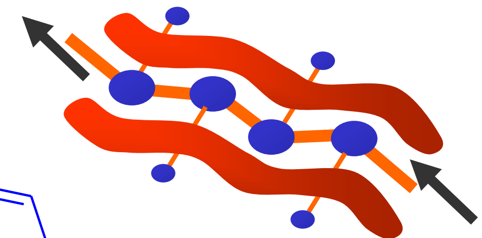
Electro-luminescence Technology based on conjugated polymers

Electronic properties determined by backbone





Physical properties determined by side-chains (R) and Mw
-Solubility,Tg, Rheology etc.

- Electrons are delocalized over molecules
- Charge is transported along the chain (and inter-chain)
- Polymers behave as semiconductors

Injected holes and electrons combine to emit light

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Single Component Polymers

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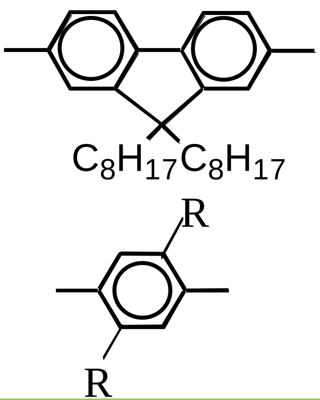
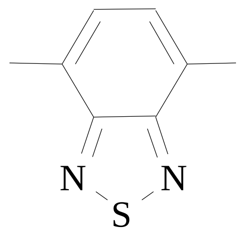
Integration of all functions using copolymer system

Copolymerization with each functional unit

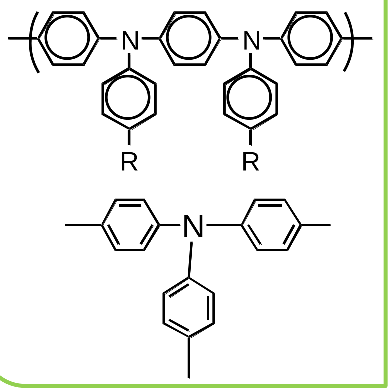
Backbone



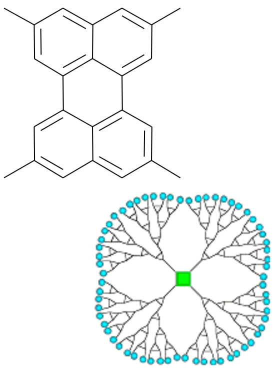
Electron affinitive



Hole affinitive



Emission



Optimize monomer ratio
- carrier-charge balance
- quantum yield

Controlled unit-sequence
Controlled molecular weight

Device structure of Polymer-OLED (PLED)

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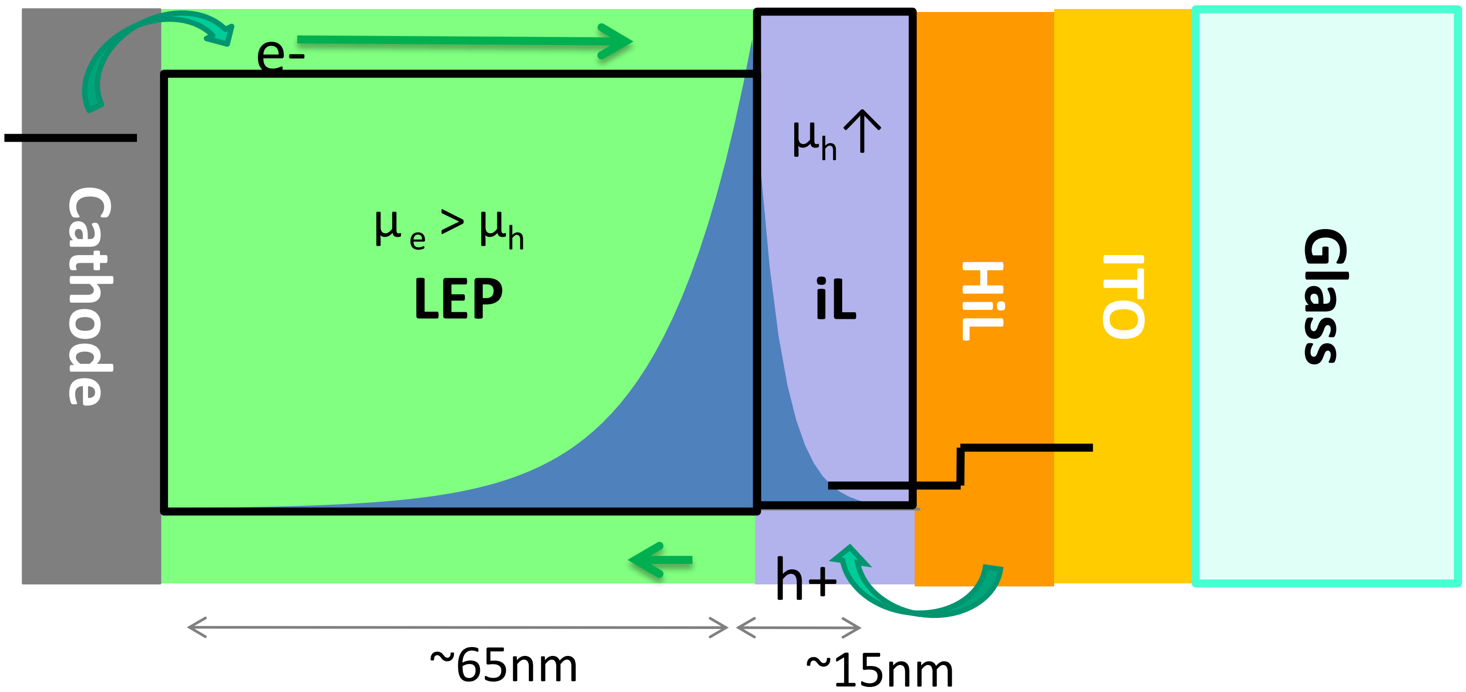

1. LEP thickness and carrier mobilities → Optimum RZ and outcoupling
2. Introduction of iL → Hole injection, efficiency and lifetime
3. HIL and ITO thicknesses → Colour and outcoupling
4. Electrodes / charge injection layers → Stable electron/hole injection

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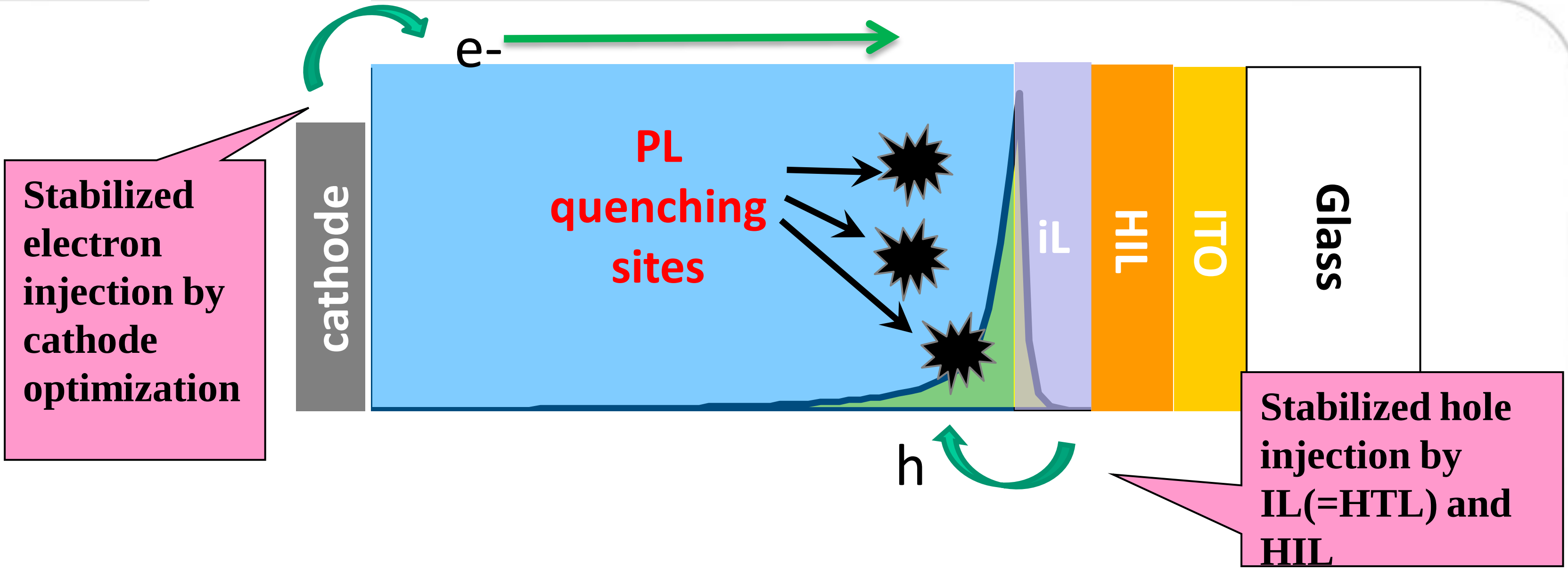
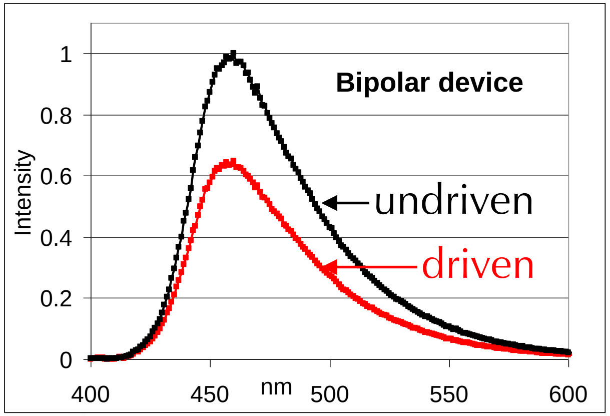
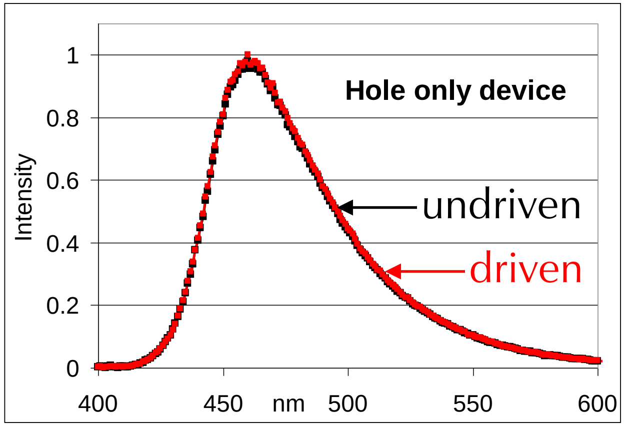
Current Elucidation of PLED degradation

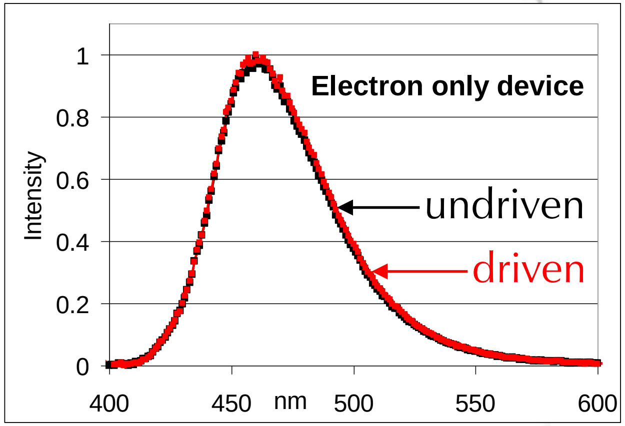


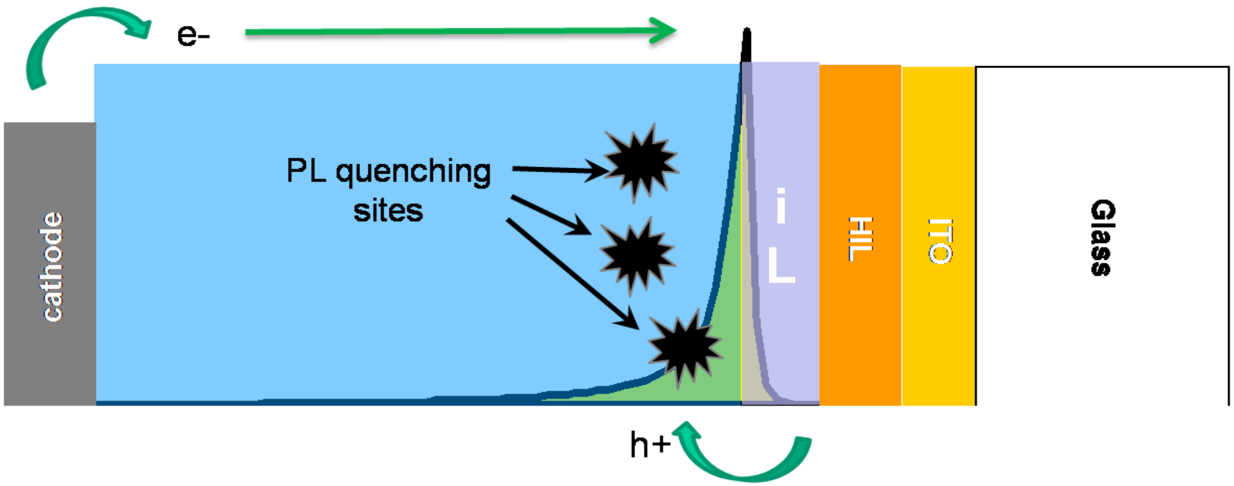
- Possible causes of luminance decay are :
  1. Loss of Charge Balance
  2. Decay of Photo Luminescent Quantum Efficiency (PLQE)
- Without iL/HIL, loss of hole injection is responsible for the degradation.
- Decay of PLQE becomes main issue after stabilizing hole and electron injections by IL and HIL, and cathode optimizations, respectively.

Cause of PL decay









→ Excitons required to generate PL quenching sites

Improved Materials Set

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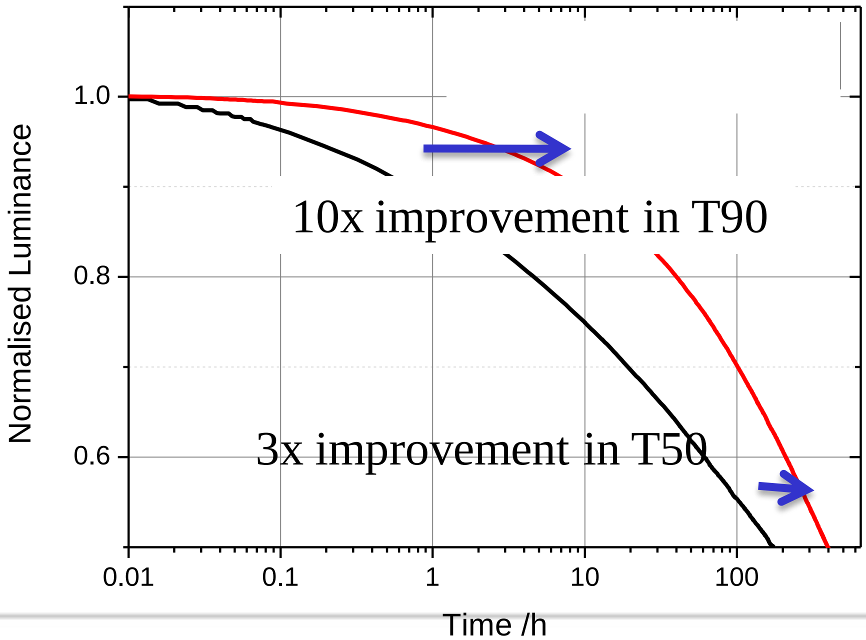
- Modern materials set where other degradation mechanisms are removed still yields ~ 3x increase in lifetime (T50).
- ~10x improvement in initial decay (T90) as other initial degradation mechanisms are suppressed.



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Blue – Summary of Progress

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- P-OLED degradation understanding was obtained :
  1. Stable charge-carrier injection was investigated and achieved.
  2. Governing process of degradation was found to be PL decay.
  3. Exciton itself is a main origin of PL decay.

- From these observations, we have designed molecular structures to slow-down PL decay with controlled TTA.
- We have achieved longer lifetime for RGB, maintaining simple device structures.

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Current Material Status

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Latest PLED performance data 2010/Autumn

Spin/BE data @1000cd/m2	Red		Green		Blue	
Efficiency [cd/A]	11	31	28	50	9.0	6.0
Colour (C.I.E.)	x=0.67 y=0.32	x=0.63 y=0.37	x=0.35 y=0.60	x=0.30 y=0.63	x=0.14 y=0.22	x=0.15 y=0.14
Lifetime [hrs]	200k	350k	200k	140k	34k	21k
Vd [V]	6.0	5.7	4.4	6.0	5.0	~5.0

Device structure

ITO (45nm)/ spin-coated HIL (50-65nm)/ Interlayer (20nm)/ LEP (60-75nm)/ low-WF cathode

- ✓ RGB common, simple layer structure.
- ✓ Organics are fully solution-processed.

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IJ Printing – Current Development

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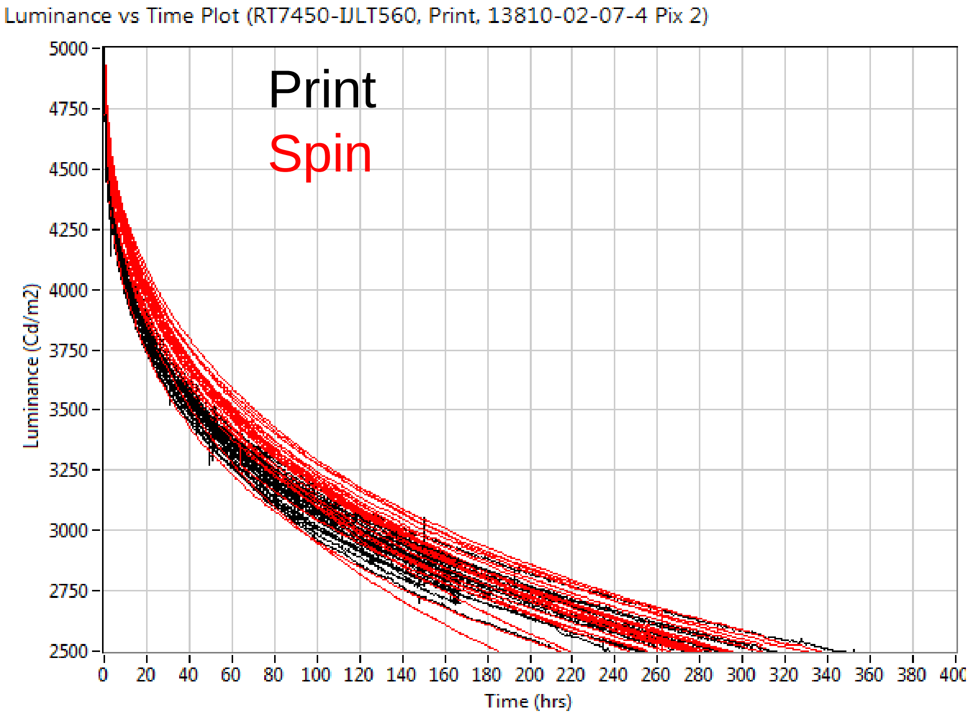

Previous generation blue Printed devices demonstrate 7,500 hrs from 1000 cd/m2 CIEy ~0.23

Similar lifetime to SC devices (CIEy~0.2)

We are demonstrating very good printed performances and lifetimes.

New materials are being evaluated on a printed platform

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IJ Printing – Current Development

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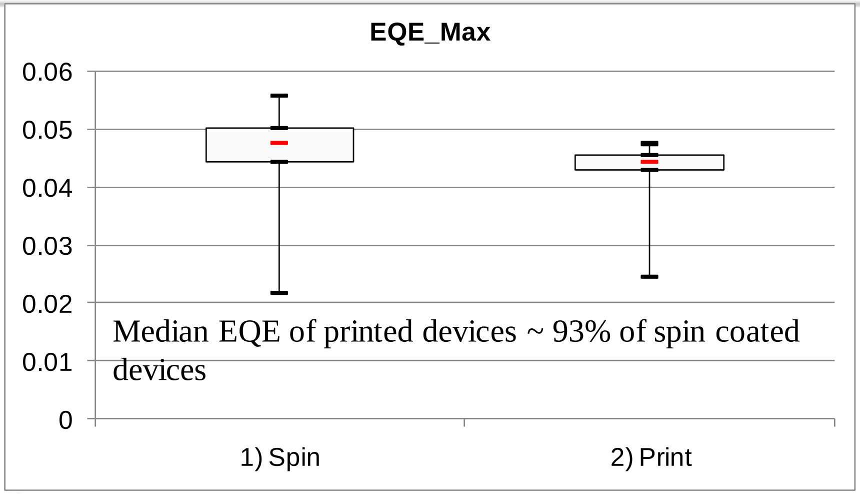

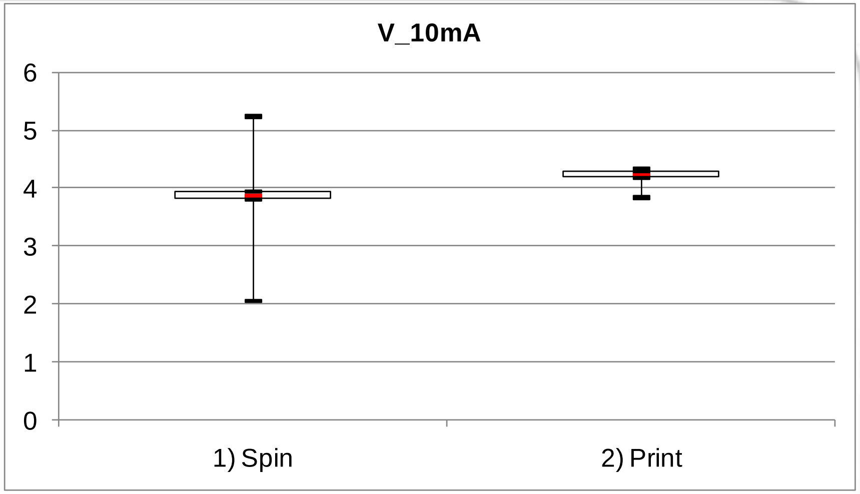

- LEP can be patterned by IJP

This process has now been developed to an extent that efficiencies and conductivities are similar to what is measured in spin coated devices that we use for general material evaluation and development

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Swathe Joins

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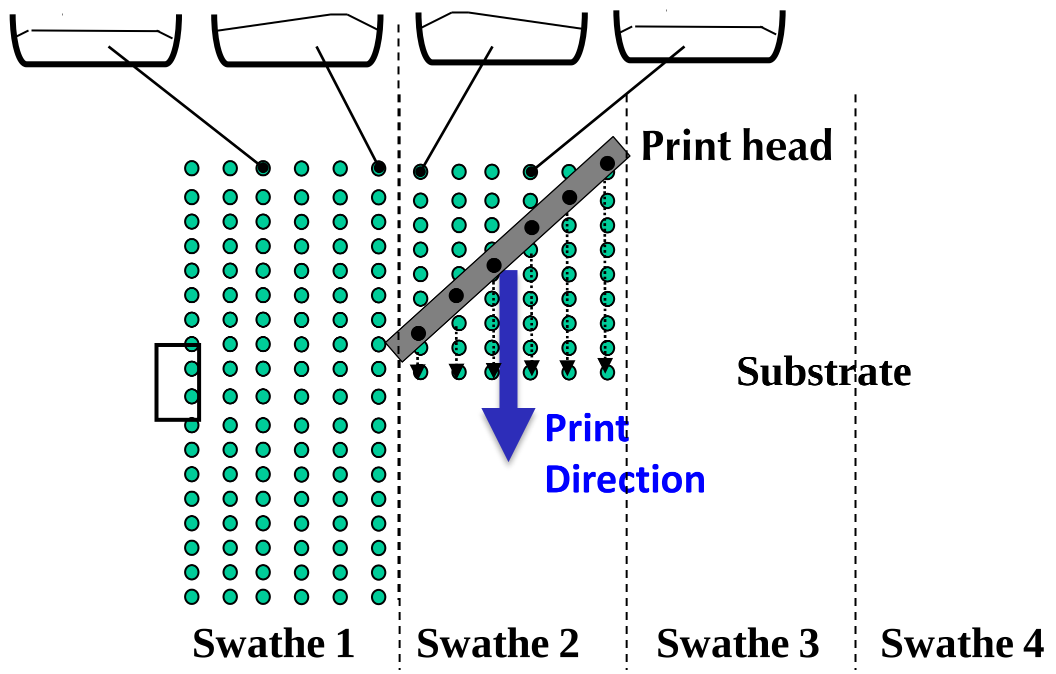
- With a single inkjet head, the substrate is printed in a series of passes (swathes)
- Joins between swathes can be seen as emission non-uniformities
- Swathe joins improved by formulation and print process



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Eliminating Swathe Joins

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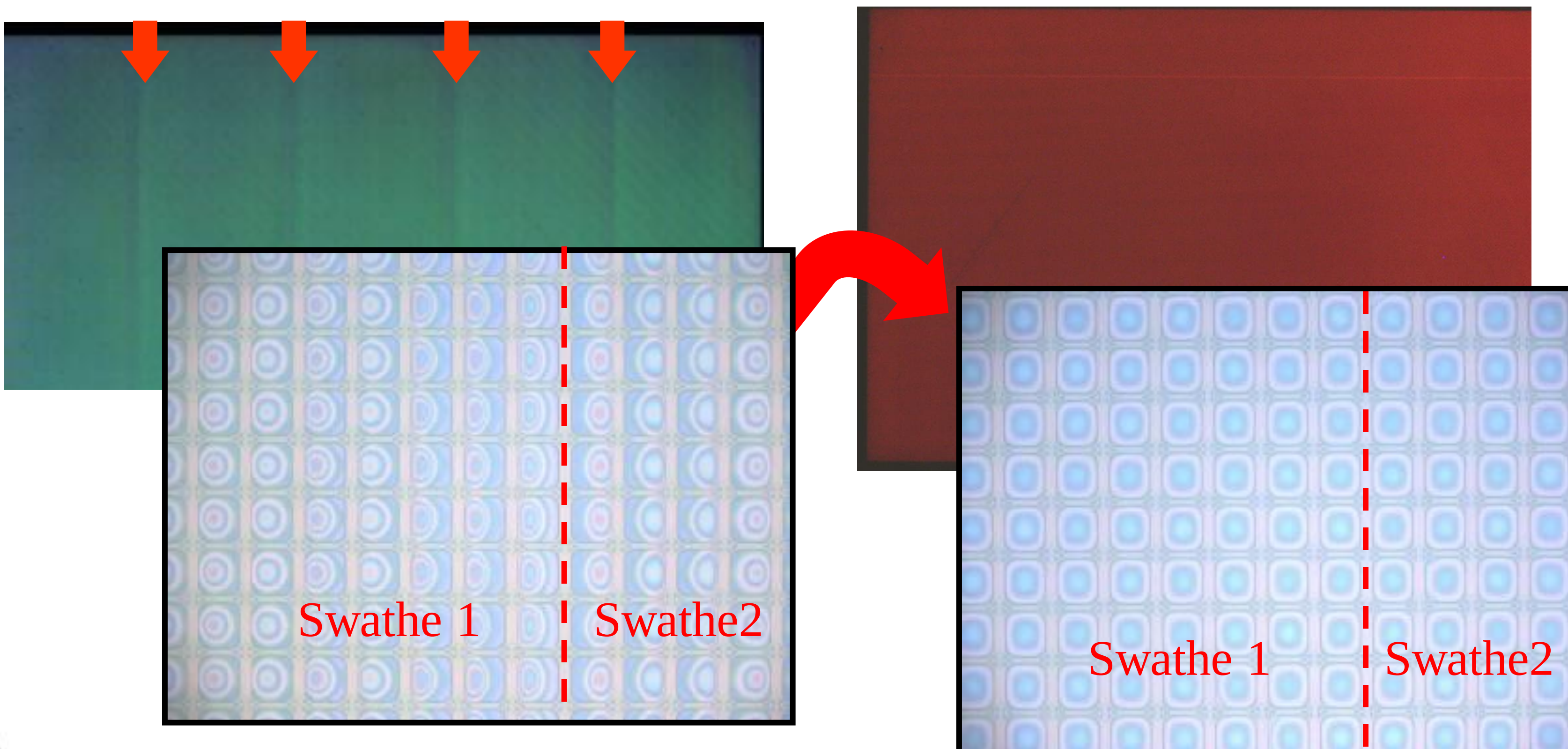
- New HIL formulations have been developed to improve display printing and significantly reduce swathe effects
- One-pass, multi-head approach probably the ultimate answer



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How to achieve the required Efficiency

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- Increasing number of Phosphorescent colours used
- Improving the out-coupling of light from the device

Blue	Green	Red	Lm/W (no outcoupling enhancement) *
Fluorescent	Fluorescent	**Phosphorescent**	**18-20**
Fluorescent	**Phosphorescent**	**Phosphorescent**	**~30**
Phosphorescent	**Phosphorescent**	**Phosphorescent**	**40-50**

With simple out-coupling ~45Lm/W

* Based on spectral calculations for given EQE & V

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Combination of emitters

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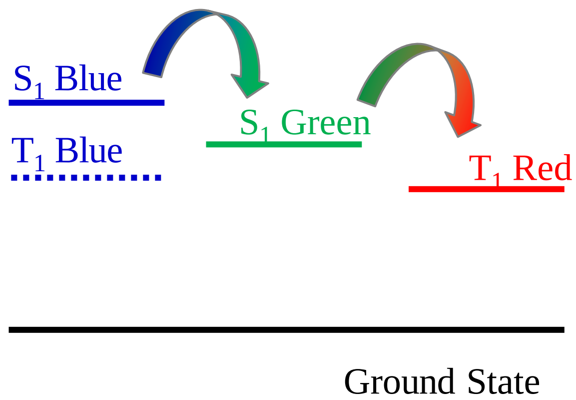
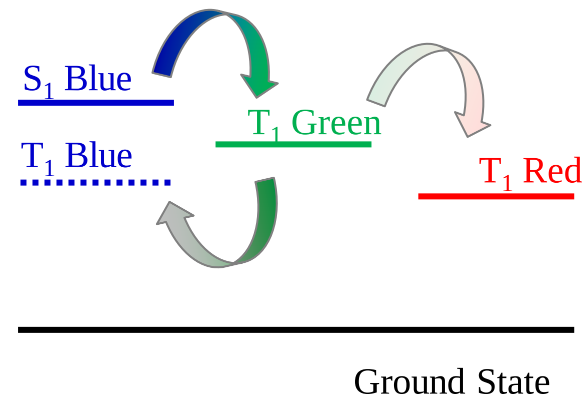
Fluorescent Green



Phosphorescent green single layer



In single component White materials energy cascades from blue to green and red

Replacing fluorescent green with phosphorescent green leads to quenching of emission

It is necessary to separate phosphorescent green and fluorescent blue emitters

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Initial attempt at separation

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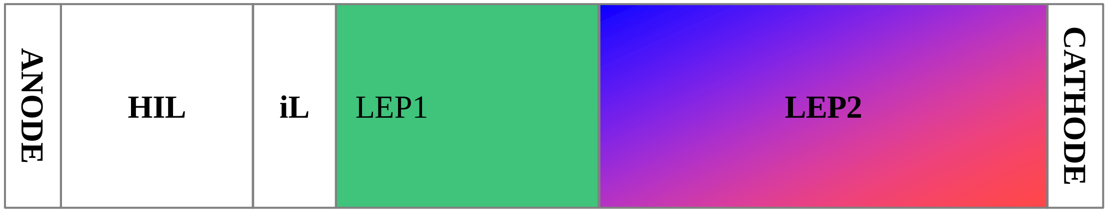

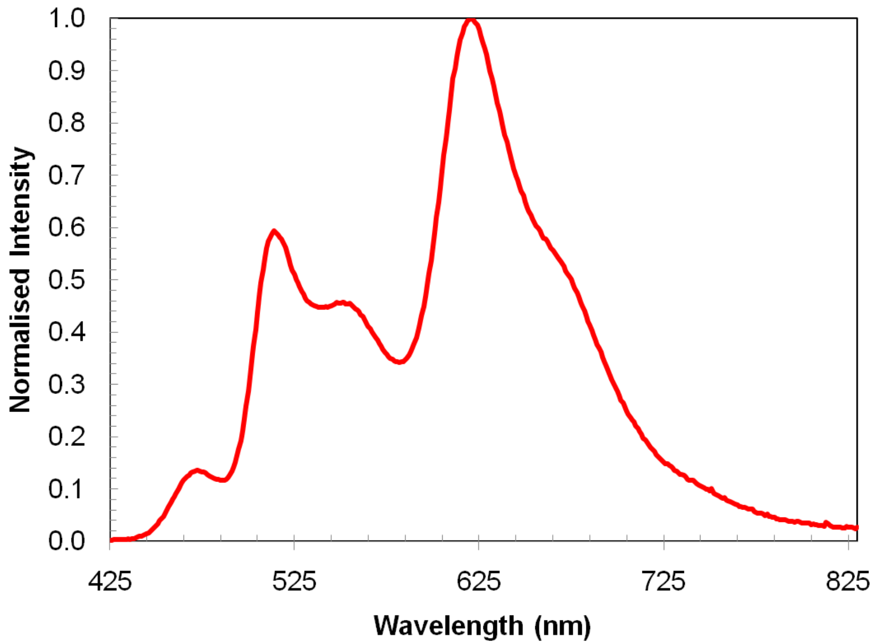

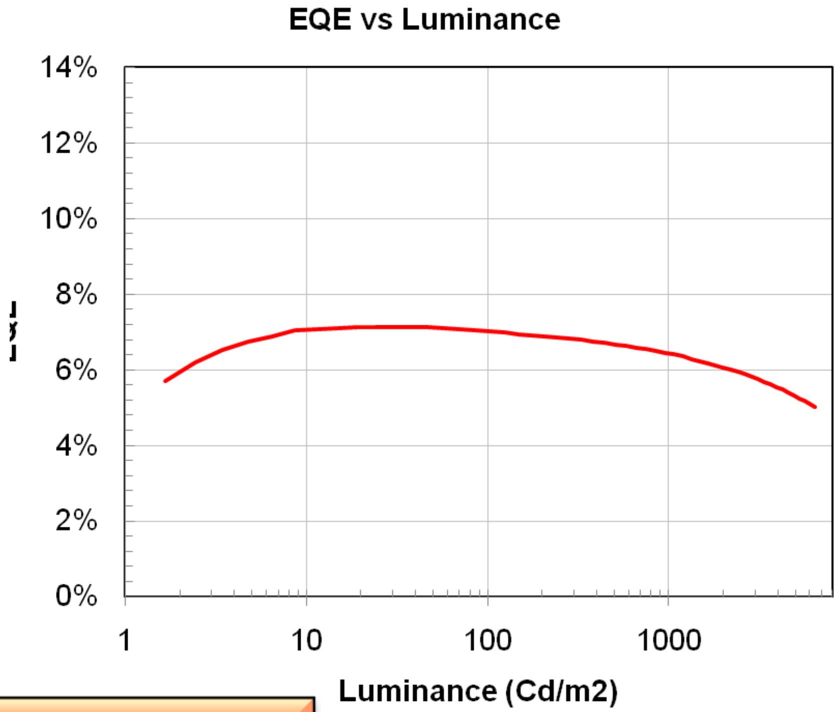

Three colour emission observed
EQE@1000 Cd/m^2 6.5%

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Prevention of quenching

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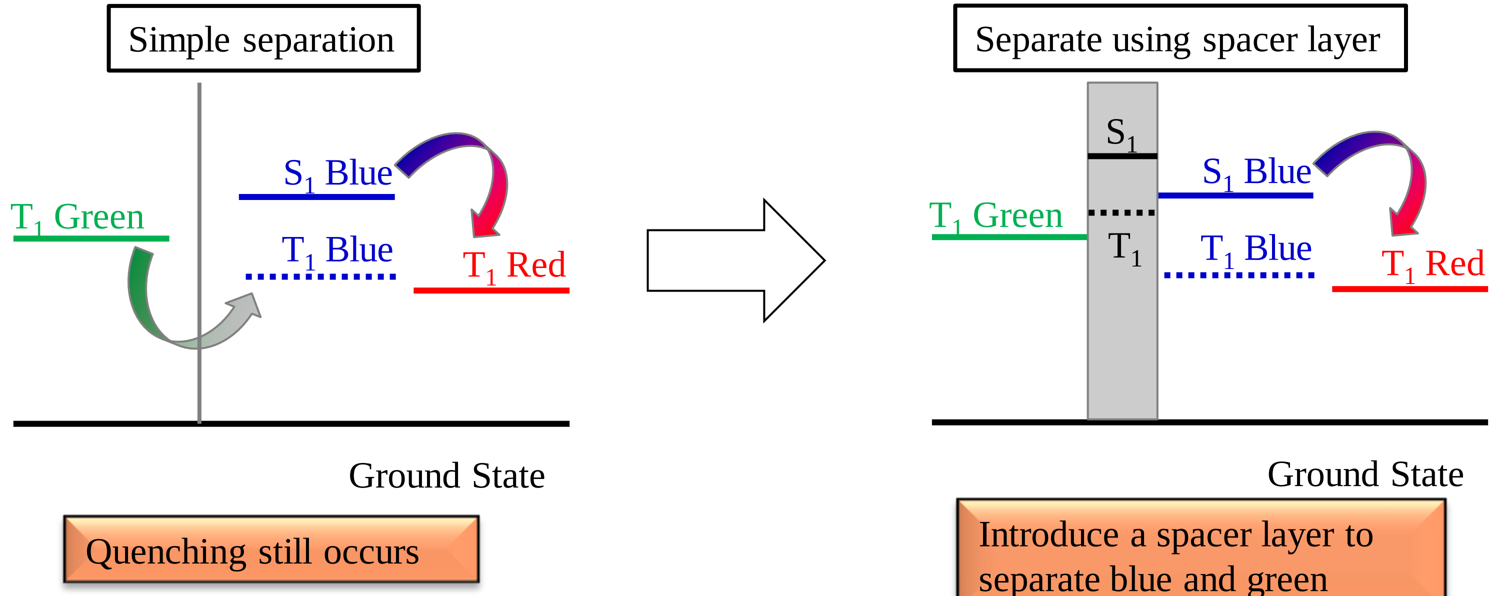

Design of the materials to control the recombination zone is key

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4 layered White - Result

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Blue	Green	Red	Lm/W (no outcoupling enhancement) *
Fluor.	Phos	Phos.	~30

add external outcoupling → × ~1.5

Lm/W (external outcoupling)
~45-50

add internal outcoupling → × ~2

Lm/W (*FULL* outcoupling)
~90

*Calculations based on achieving certain EQE, V and at (0.4,0.4) with CRI >85

- 22Lm/W efficiency achieved with in colour specification
- Theoretical calculations suggest with out-coupling ~ 65 Lm/W achievable

- Current Research Focus
  - Enhancing fundamental knowledge of key degradation mechanism(s)
  - Transferring fundamental learning to improve Lifetime
  - New Materials

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All Phosphorescent White

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- Phosphorescent versus fluorescent emitters
  - Approx. 8-10% EQE achievable for fluorescent emitters
  - > 20% EQE for phosphorescent emitters

  → Significant increase in efficiency when moving to phosphorescent system

Blue	Green	Red	Lm/W (no outcoupling enhancement) *
Fluor.	Fluor.	Phos.	18-20 (14 achieved)
Fluor.	Phos.	Phos.	~30
Phos.	Phos.	Phos.	40-50

× ~1.5

add external outcoupling

Lm/W (external outcoupling)
~30-35
~45-50
~60-80

× ~2

add internal outcoupling

Lm/W (*FULL* outcoupling)
~60
~90
~120-150

Calculations based on achieving certain EQE, V and at (0.4,0.4) with CRI >85

All-phosphorescent White to deliver +100Lm/W POLED lighting

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The Choice

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- Printable OLED is THE future and quietly acknowledged by most major players to be so – vacuum processed small molecules is a transitional technology, and colour filter-on-white will not fly on efficiency considerations
- **The Choice:**
  - Solution processed small molecule OLED
  - Solution processed polymer OLED

Closing remarks

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- For P-OLED , there is a LOT of covert activity behind the scenes by major players as materials performance improves rapidly
- OLED Displays will drive materials development and expand the OLED supply chain for the benefit of both display and lighting players
- With the P-OLED lead in solution processing, the winds are shifting in its direction

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