SUMITOMO CHEMICAL Co., Ltd.

C|D|T

Excited state interaction in P-OLEDS – implications for efficiency and lifetime

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10% EQE deep blue with long lifetime

- Efficiency
- Lifetime
- Strategies
- Current Performance

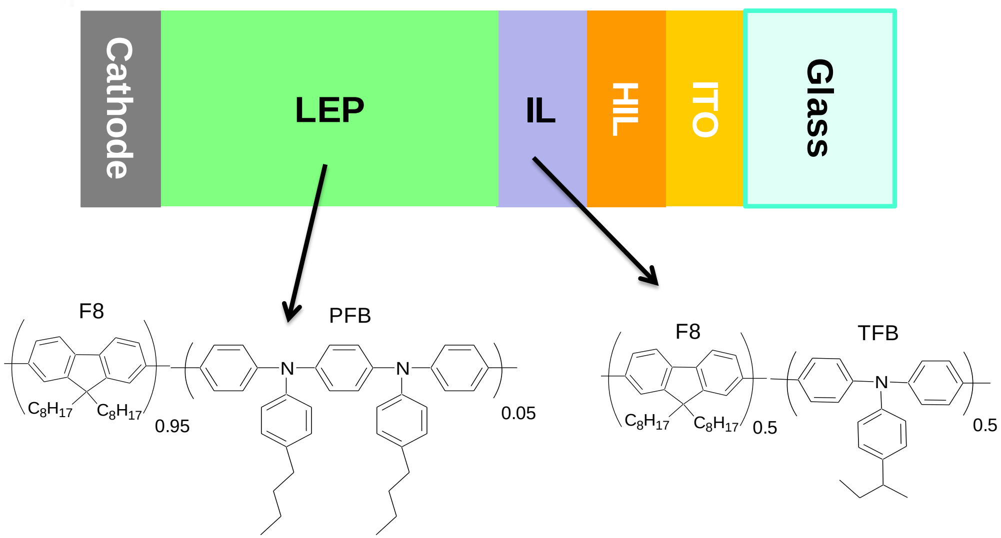
Excited state interaction in POLEDs

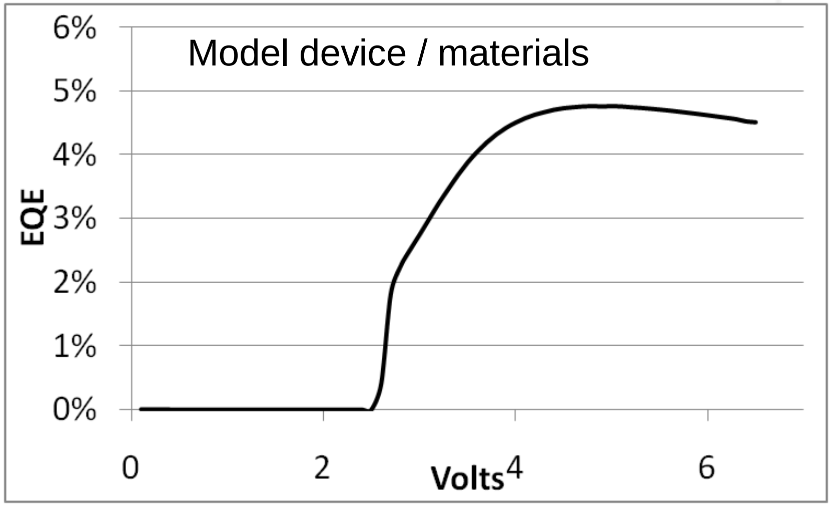
- Efficiency
- Lifetime
- Strategies
- Current Performance

Expected EQE of fluorescent OLED

CDT

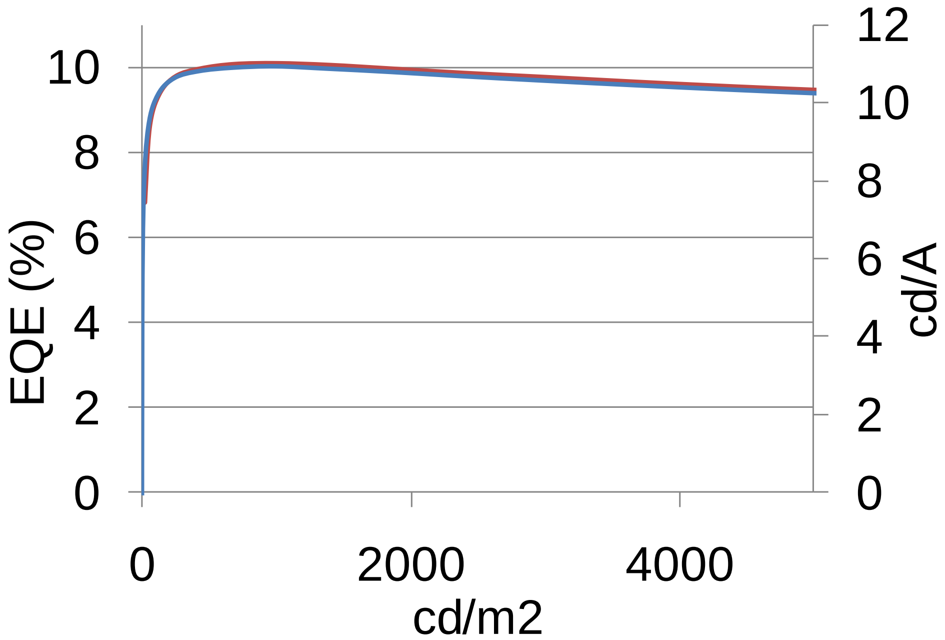
	'charge balance'	'S:T ratio'	'PLQE'	'outcoupling'	
EQE =	$\eta_{\text{exciton formation}}$ ×	$\eta_{\text{singlet formation}}$ ×	$\eta_{\text{photon emission}}$ ×	$\eta_{\text{photon escape}}$	
	100%	25%	70%	30%	~ 5%

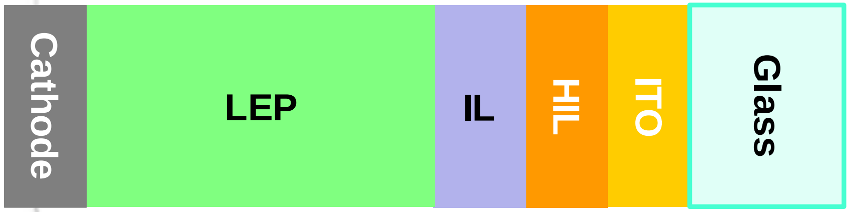


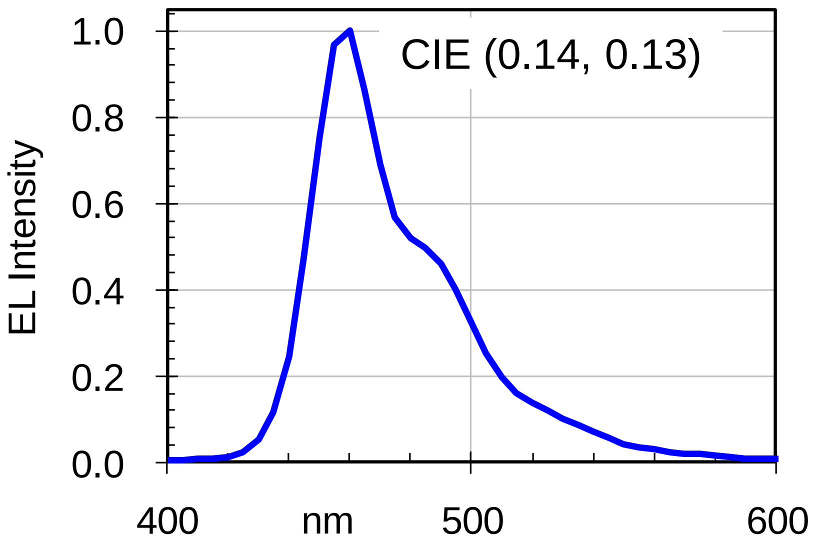


10% EQE at CIEy=0.13

CDT







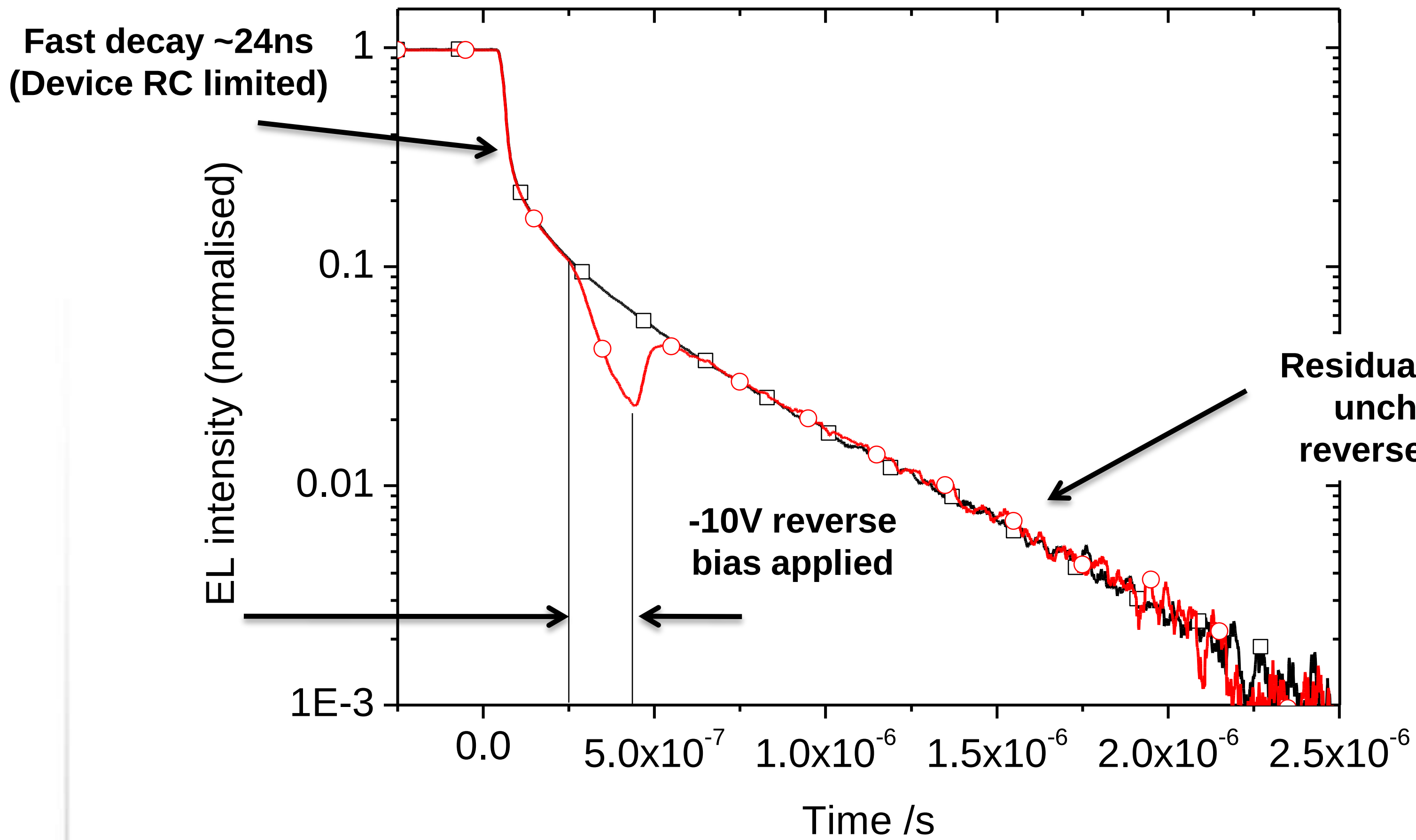
How can we explain 10% EQE?

	‘charge balance’	‘Singlet Yield’	‘PLQE’	‘outcoupling’	
EQE =	$\eta_{\text{exciton formation}}$ x	$\eta_{\text{singlet formation}}$ x	$\eta_{\text{photon emission}}$ x	$\eta_{\text{photon escape}}$	
	100%	25%	70%	30%	~ 5%

Most likely cause of discrepancy

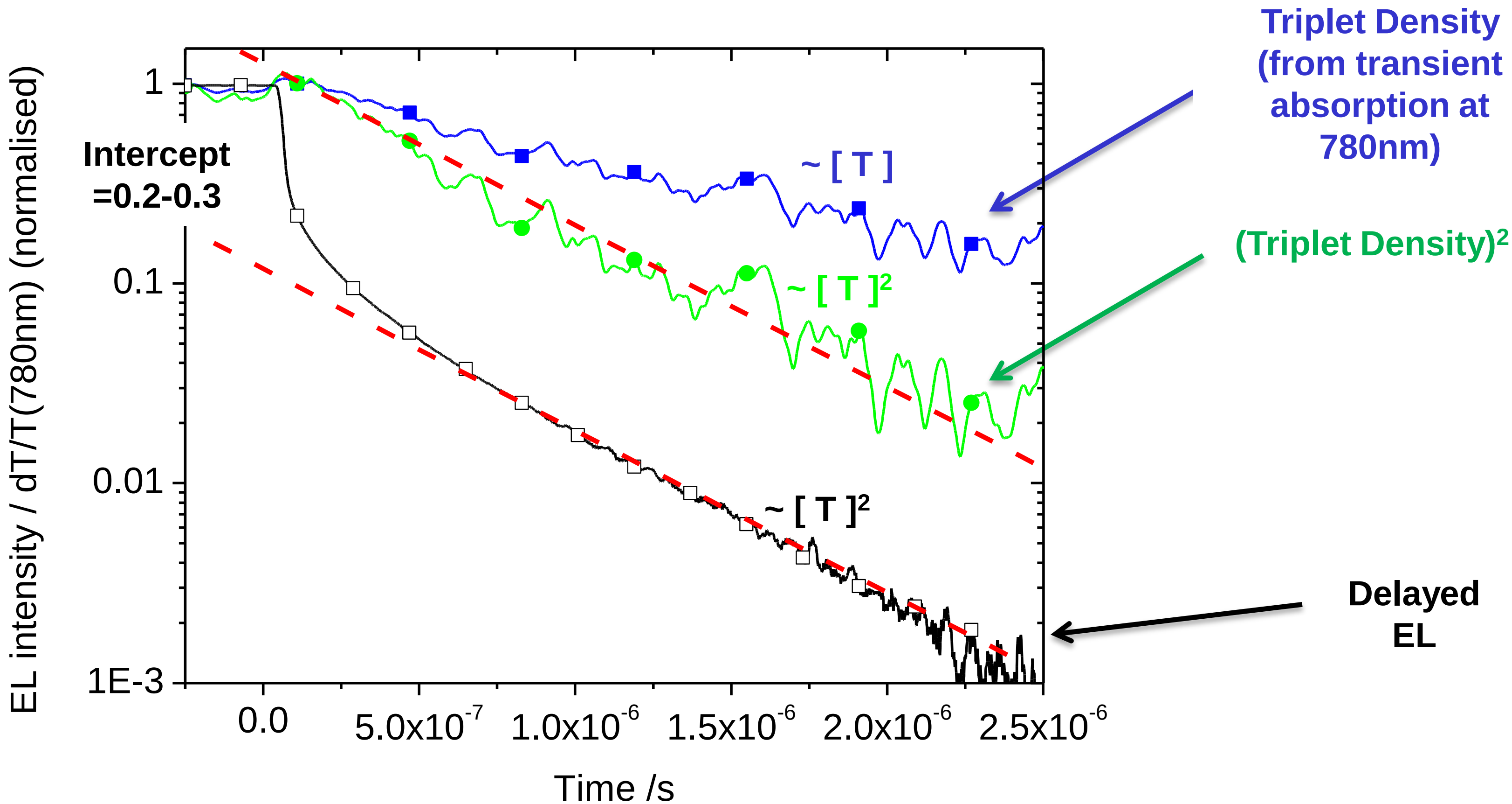
- S:T ratio > 25% for polymers?
- Triplet harvesting via TTA?

Delayed Electroluminescence



Delayed fluorescence does not originate from trapped charges

Triplet Triplet Annihilation (TTA)



- **Origin of delayed fluorescence is TTA :** $T_1 + T_1 \rightarrow S_1 + S_0$
- **Triplets make up 20-30% of efficiency**

Including TTA in EQE expression

	‘charge balance’	‘Singlet+Triplet Yield’	‘PLQE’	‘outcoupling’	
EQE =	$\eta_{\text{exciton formation}}$ x	$\eta_{\text{singlet formation}}$ x	$\eta_{\text{photon emission}}$ x	$\eta_{\text{photon escape}}$	
	100%	50%	70%	30%	**~10%**

$$\Phi_{s:t} + (1 - \Phi_{s:t})\,\chi_t$$

$\Phi_{s:t}$ = S:T ratio →

χ_t = triplet yield →

2 strategies for improving EQE in fluorescent systems

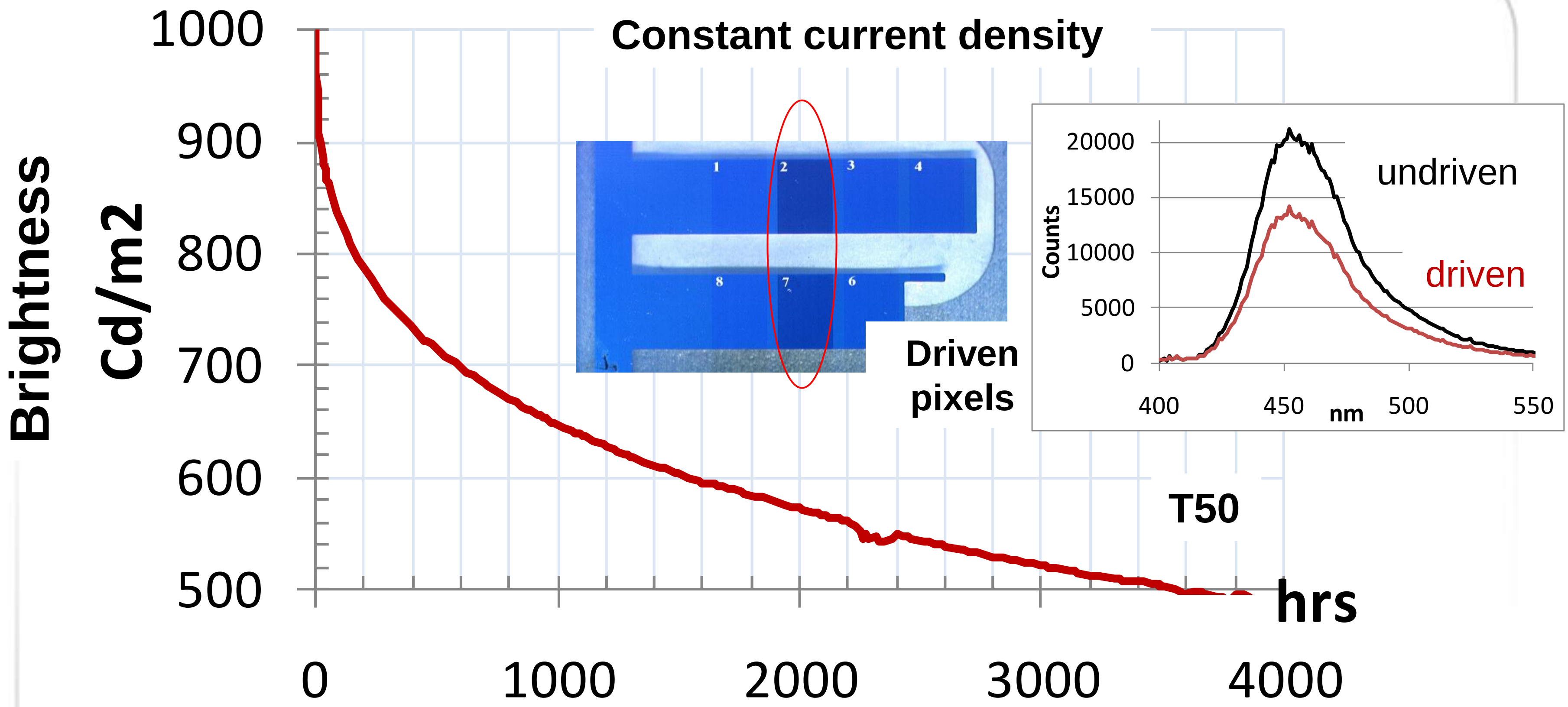
Review

- **10% EQE @ CIEy=0.13 demonstrated**
- **TTA process is key to achieving this EQE**

Excited state interaction in POLEDs

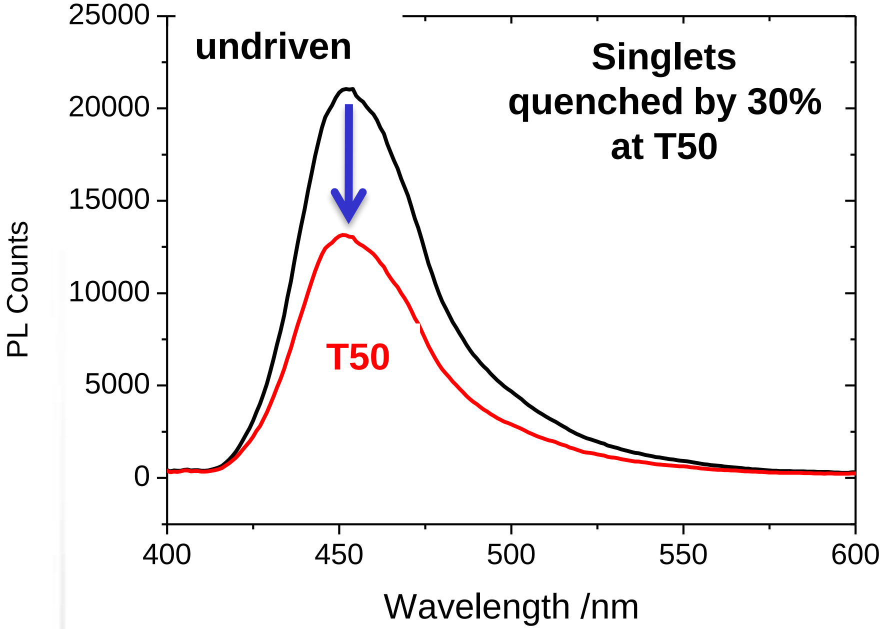
- Efficiency
- Lifetime
- Strategies
- Current Performance

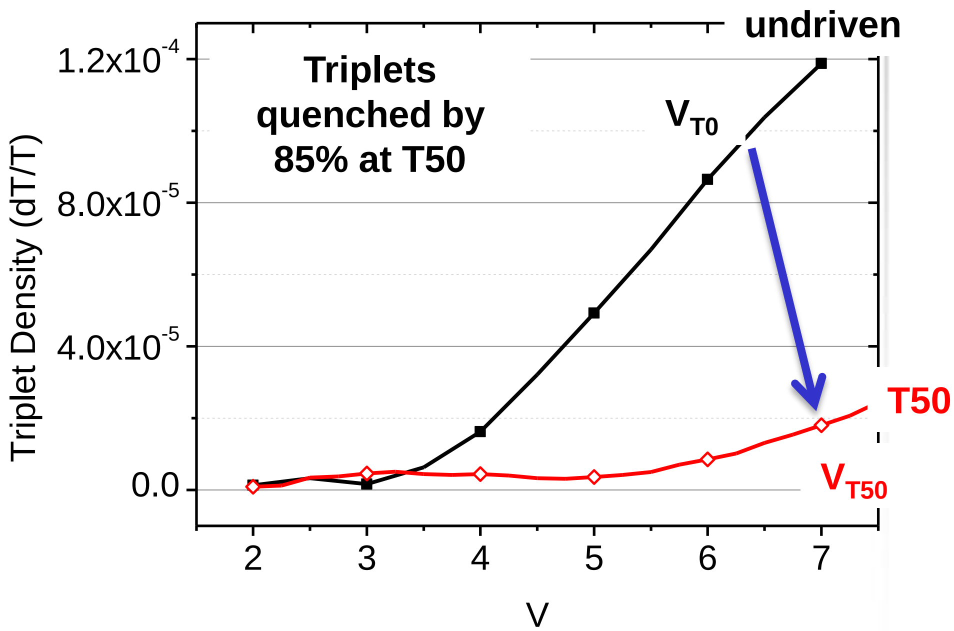
Lifetime testing of P-OLED devices



- PL efficiency drop is a major cause of efficiency loss
- How stable is the TTA contribution?

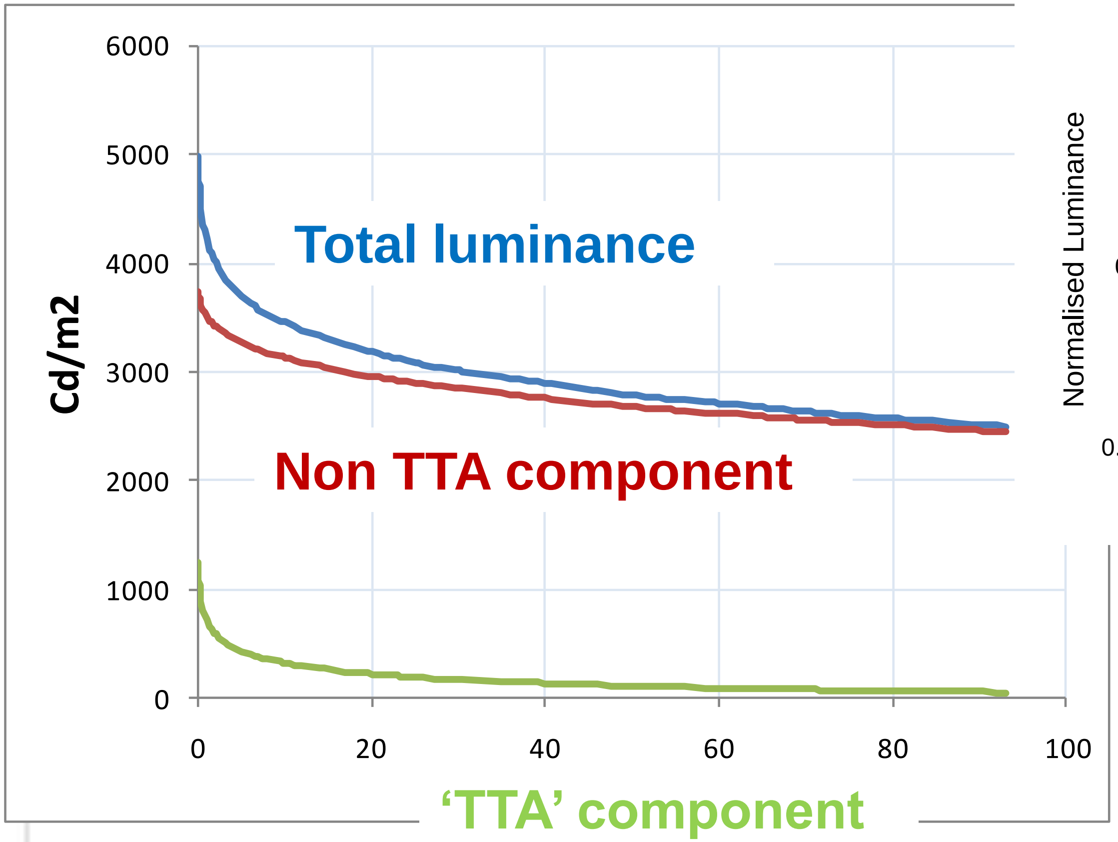
Driving Effect on Triplet Density

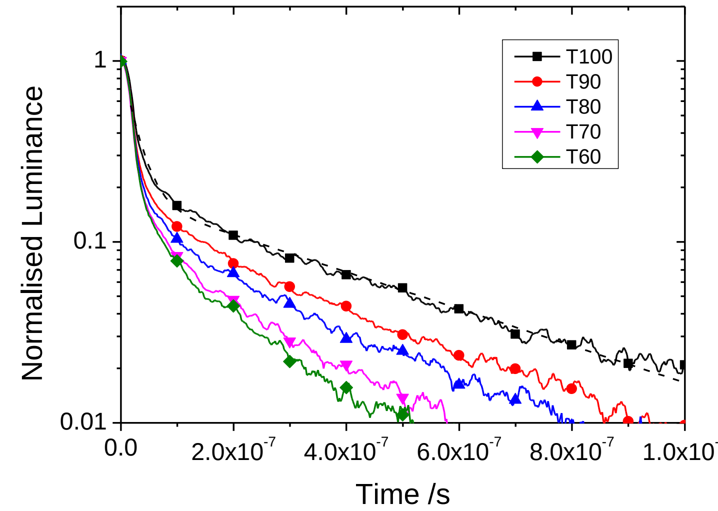




- Triplets are quenched very effectively in a driven device

TTA component is unstable





- TTA contribution can limit lifetime and give rapid initial decay

Review

- 10% EQE @ CIEy=0.13 demonstrated
- TTA process key to achieving this EQE
- TTA contribution can be relatively unstable

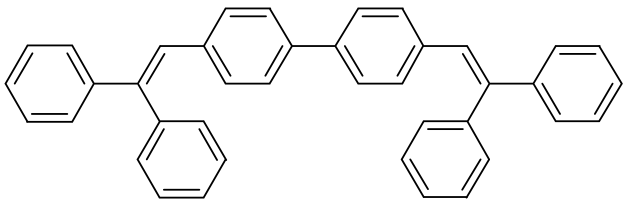
Excited state interaction in POLEDs

- Efficiency
- Lifetime
- **Strategies**
- Current Performance

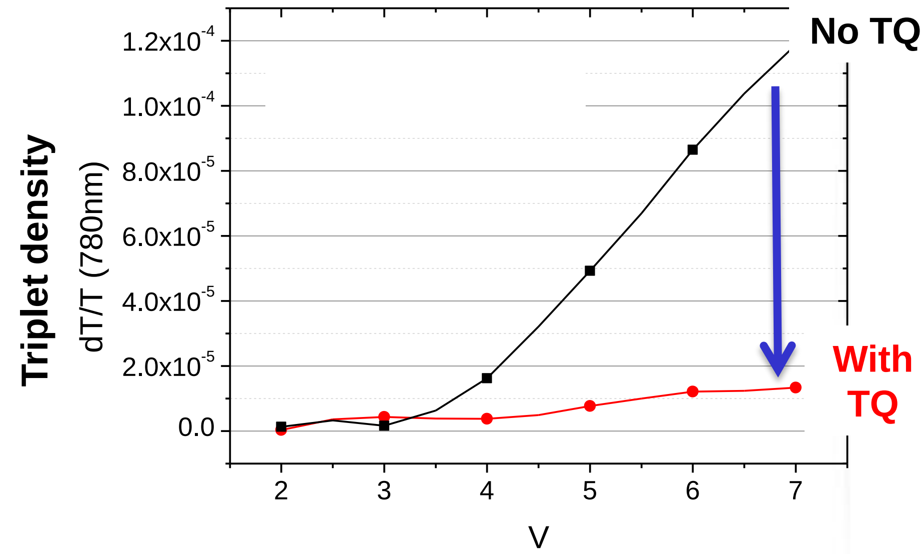
Strategy 1 : Remove triplets

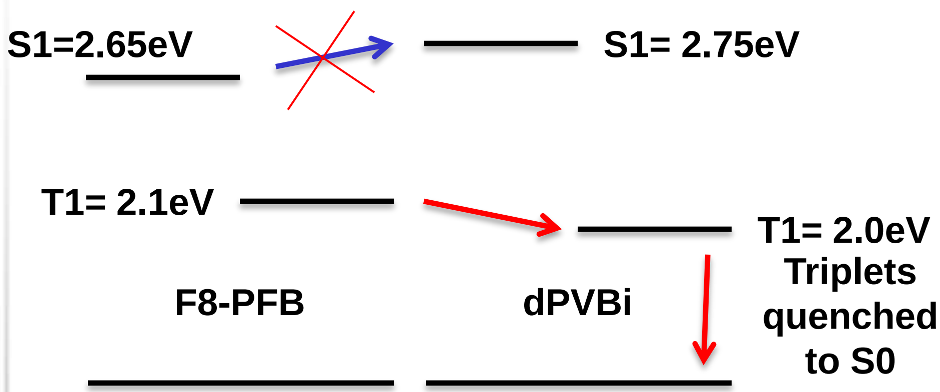
Triplet Quenching unit

- Efficiently removes triplets from system

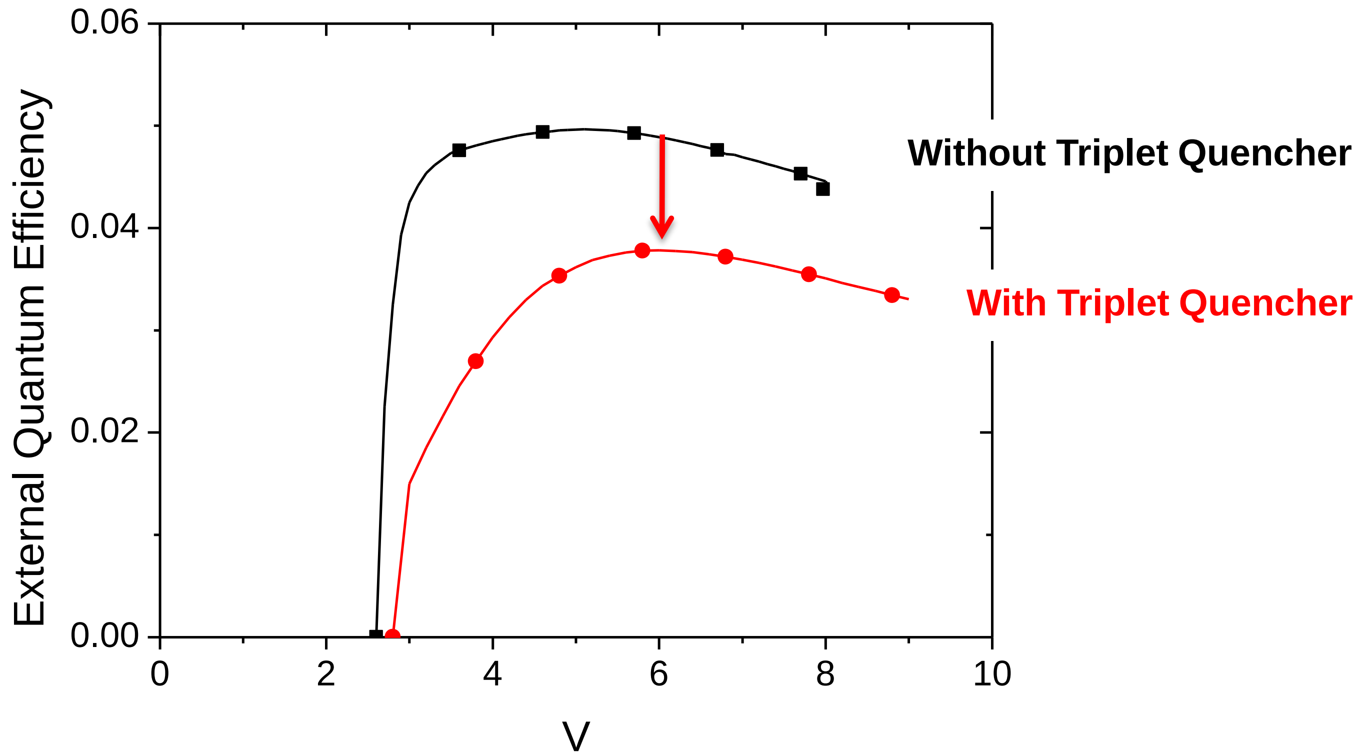


dPVBi (1% mol ratio)



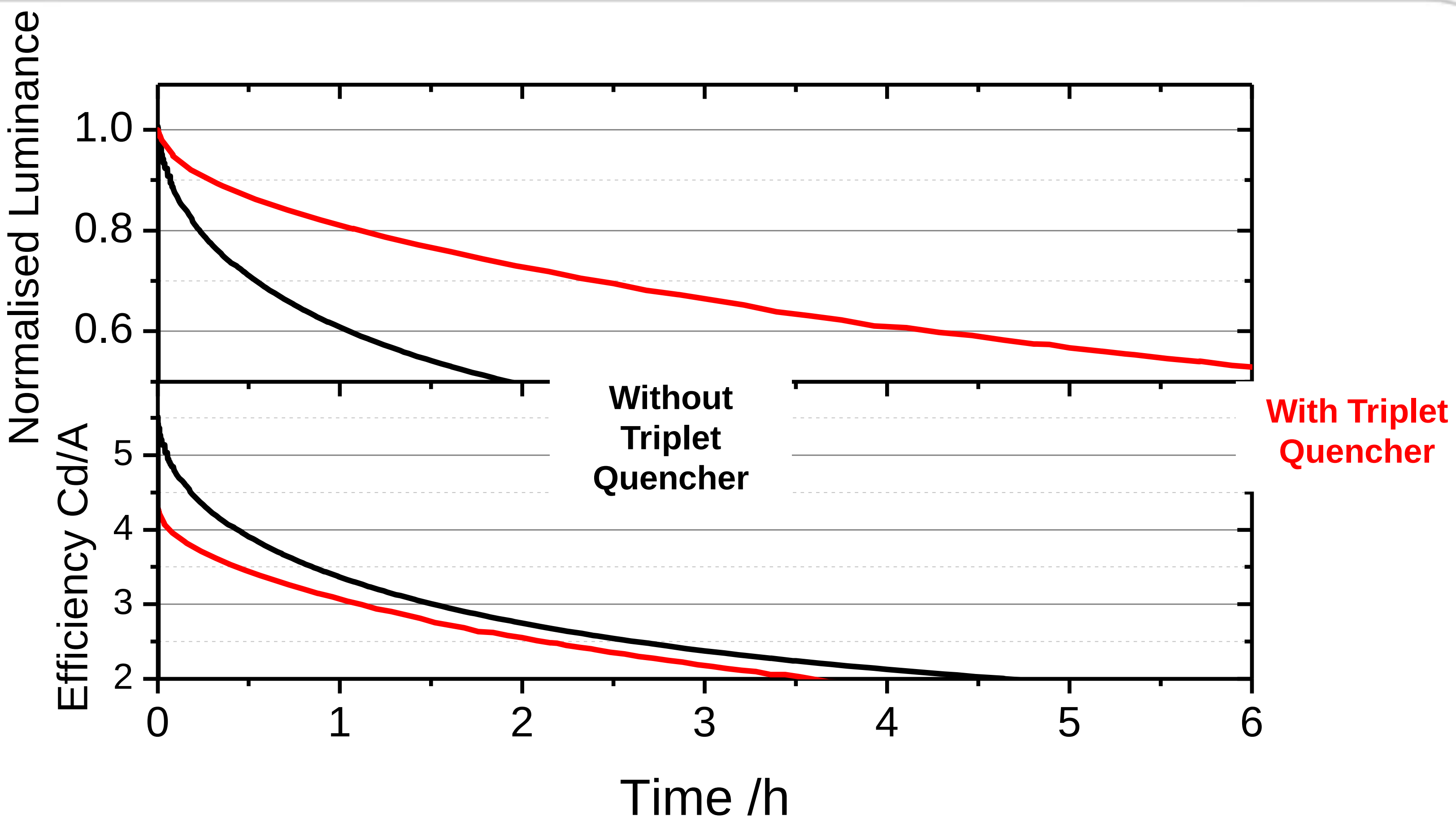


Strategy 1 : Remove triplets



- 20% drop in EQE consistent with loss of TTA contribution

Strategy 1 : Remove triplets

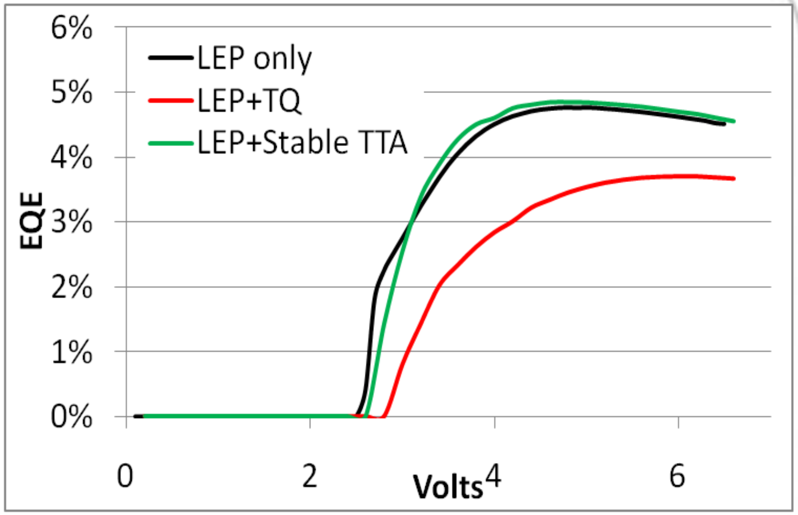


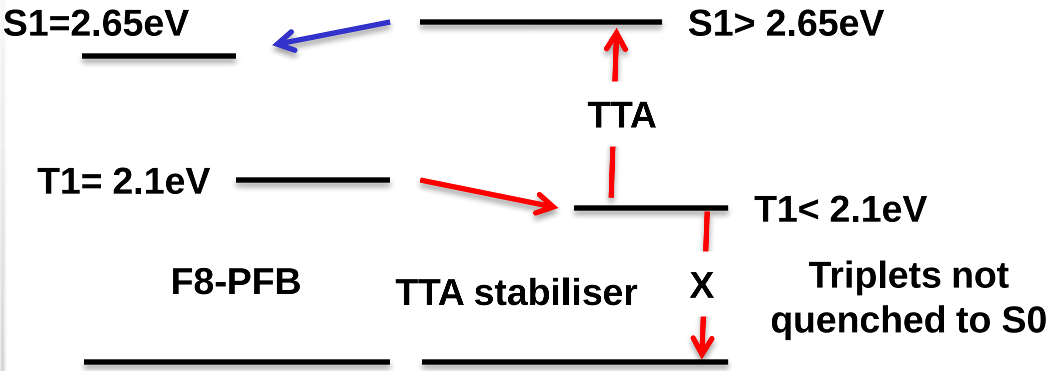
- Triplet quenchers can significantly improved T90 and T50 – but at expense of efficiency

Strategy 2 : Stabilise TTA

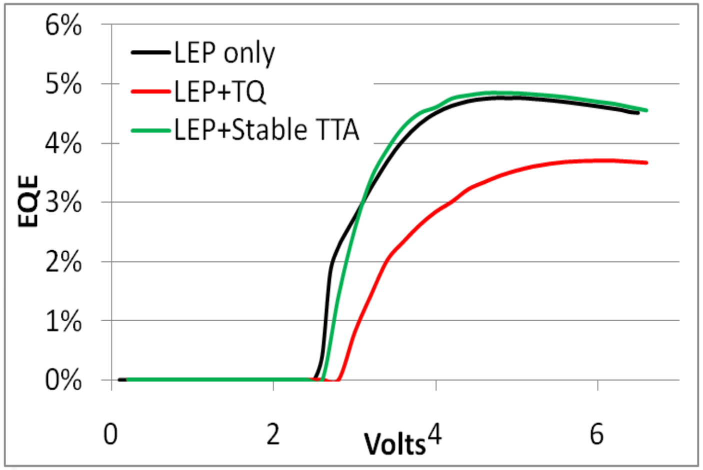
TTA stabilising unit

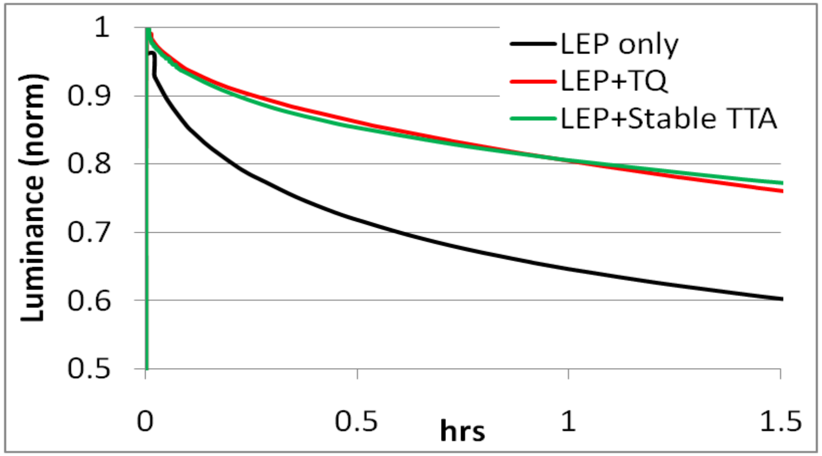
- Maintain TTA efficiency boost
- Prevent triplets from being quenched





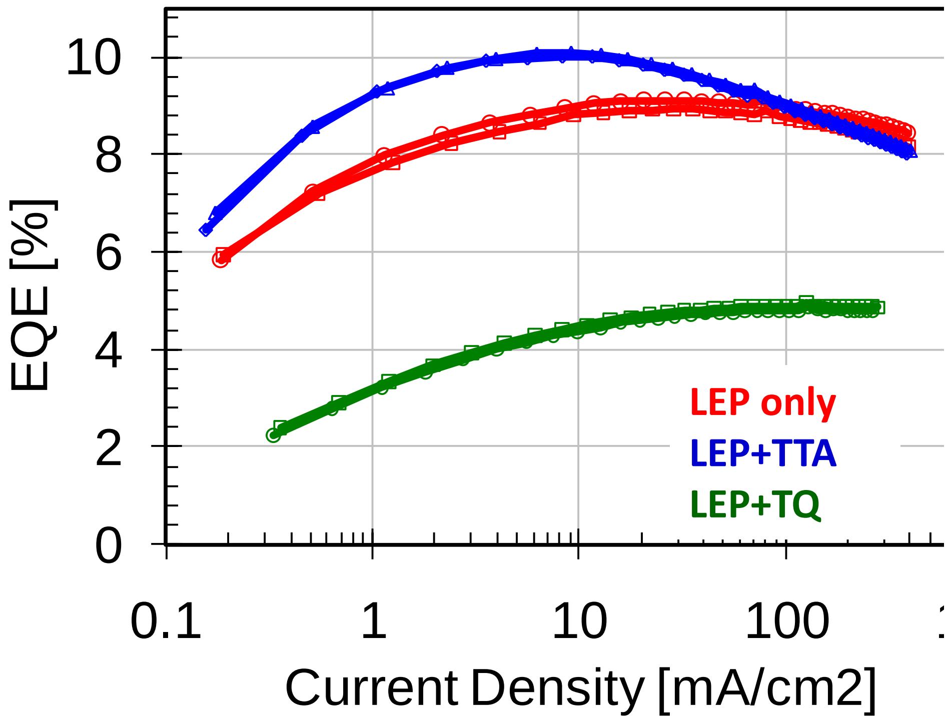
Strategy 2 : Stabilise TTA

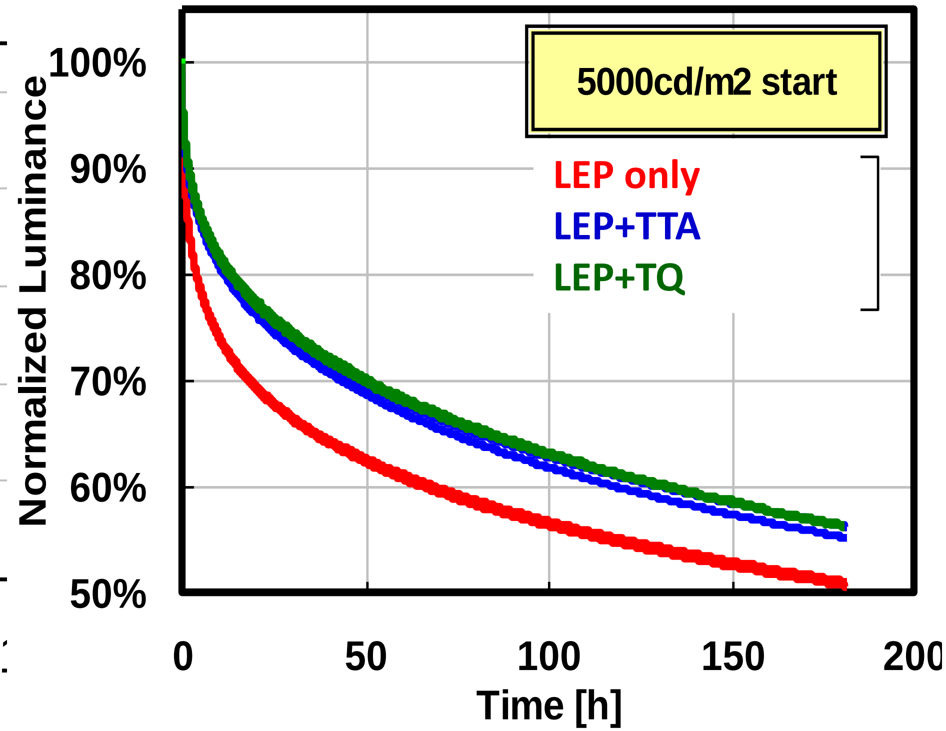




- Stable TTA units allow both high efficiency and long lifetime

EQE and lifetime in 10% EQE system





- Long lifetime + High efficiency can be achieved by stabilising the TTA contribution

Review

- **10% EQE @ CIEy=0.13 demonstrated**
- **TTA process key to achieving this EQE**
- **Stable TTA units can give combination of good lifetime and high efficiency**

Excited state interaction in POLEDs

- Efficiency
- Lifetime
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Latest PLED performance data 2011/Spring

CDT

High efficiency + good lifetime

Spin/BE data @1000cd/m2	Red			Green		Blue			
Efficiency [cd/A]	11	16	31	28	54	9.0	5.2	6.3	9.2
Colour (C.I.E.)	x=0.67 y=0.32	x=0.65 y=0.35	x=0.63 y=0.37	x=0.35 y=0.60	x=0.31 y=0.63	x=0.14 y=0.22	x=0.15 y=0.13	x=0.15 y=0.12	x=0.14 y=0.14
Lifetime [hrs]	200k	170k	350k	200k	190k	34k	21k	14k	15k
Vd [V]	6.0	5.2	5.7	4.4	5.6	5.0	4.8	4.8	4.5

Device structure

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

✓ RGB common and simple layer structure

✓ Organics are fully solution-processed

Appendix

TTA yield

TTA PROCESSES AVAILABLE	SINGLET YIELD FROM TTA	INTERNAL QE FOR 25% S:T	INTERNAL QE FOR 50% S:T
$T_1 + T_1 \rightarrow$ 5 x (S_0 + Q) 3 x ($S_0 + T_n$) 1 x ($S_0 + S_1$)	1/18 + 3/18x1/18 + 3/18x3/18x1/18 +..~ 5% Ch. E. Swenberg and N. E. Geacintov, in *Organic Molecular Photophysics, edited by J. B. Birks ~ John Wiley and Sons, NY,* 1973, p. 489	25%+0.05*75% = 30%	50%+0.05*50% = 52.5%
$T_1 + T_1 \rightarrow$ 3 x ($S_0 + T_n$) 1 x ($S_0 + S_1$)	1/8 + 3/8x1/8 + 3/8x3/8x1/8 +… ~20%	25%+0.2*75% = 40% Kondakov, J. Soc. Inf. Disp. 17, 137 (2009)	50%+0.2*50% = 60%
$T_1 + T_1 \rightarrow$ 1 x ($S_0 + S_1$)	1/2 = 50%	25%+0.5*75% = 62.5% Kondakov JAP 106, 124510 (2009)	50%+0.5*50% = 75%

Combination of S:T>25% and high TTA yields now established as promising routes to higher efficiency fluorescent POLEDs