Energy Transfer Mechanisms in White OLEDs

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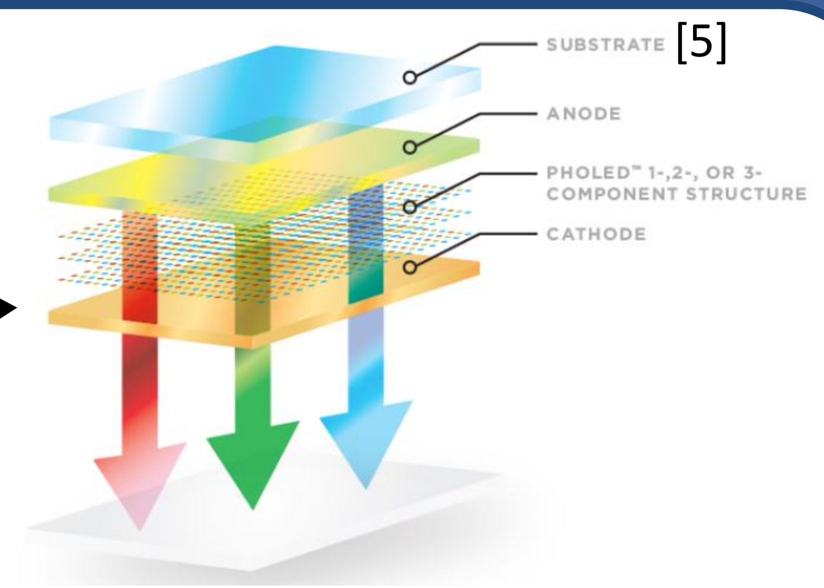
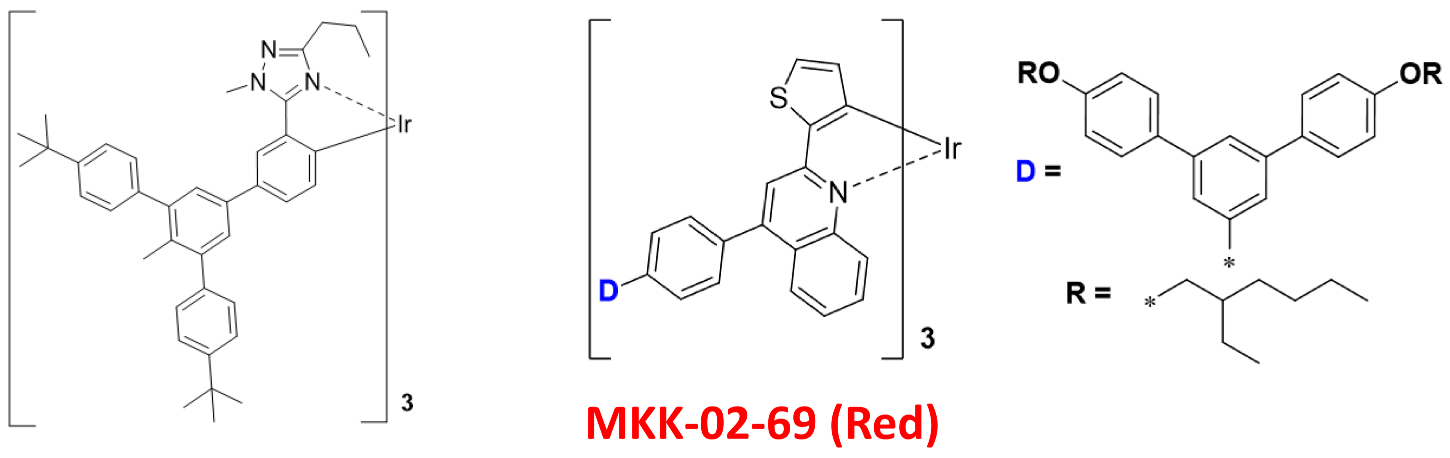
White OLEDs are of interest and importance for lighting applications and as backlights for displays. The simplest way to create a white OLED is to combine multiple (narrow band) emitters (blue, green and red) into a single emissive layer. Energy transfer between the emitters will cascade energy from higher (blue) to lower energy emitters (green and red). As such, only a small amount of red emitter is needed. The energy transfer process is not well understood as phosphorescent emitters are typically used and so Förster, Dexter or a combination of both may be present. *(White OLED Device)*

The aim of this project is to characterise the photoluminescence from blends of blue and red emitters for white OLEDs to identify the energy transfer process.



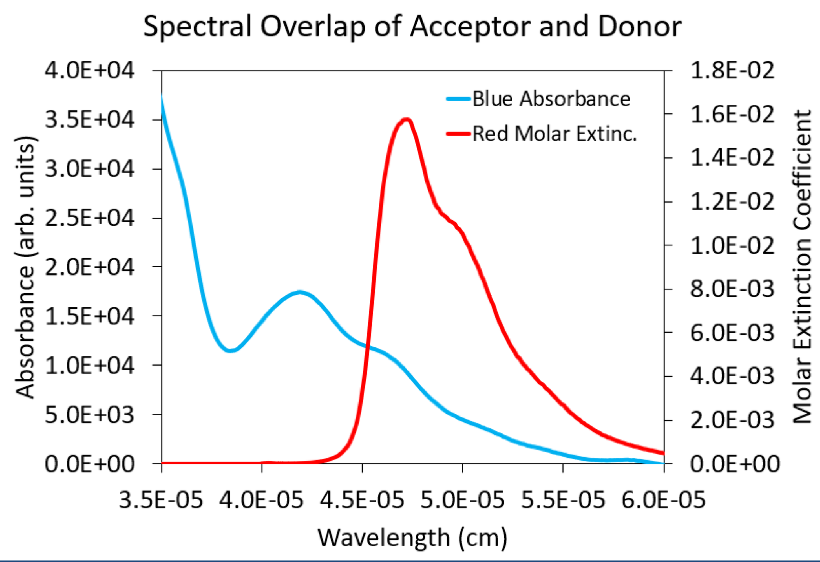
Materials System



MKK-04-12 (Blue)

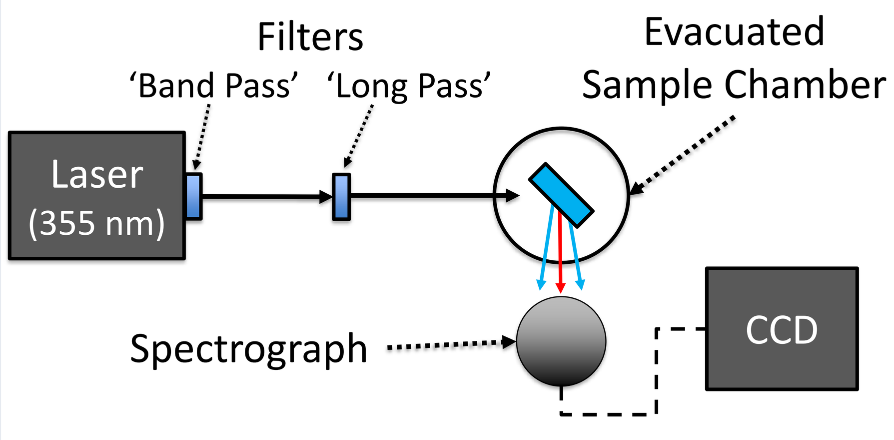
MKK-02-69 (Red)

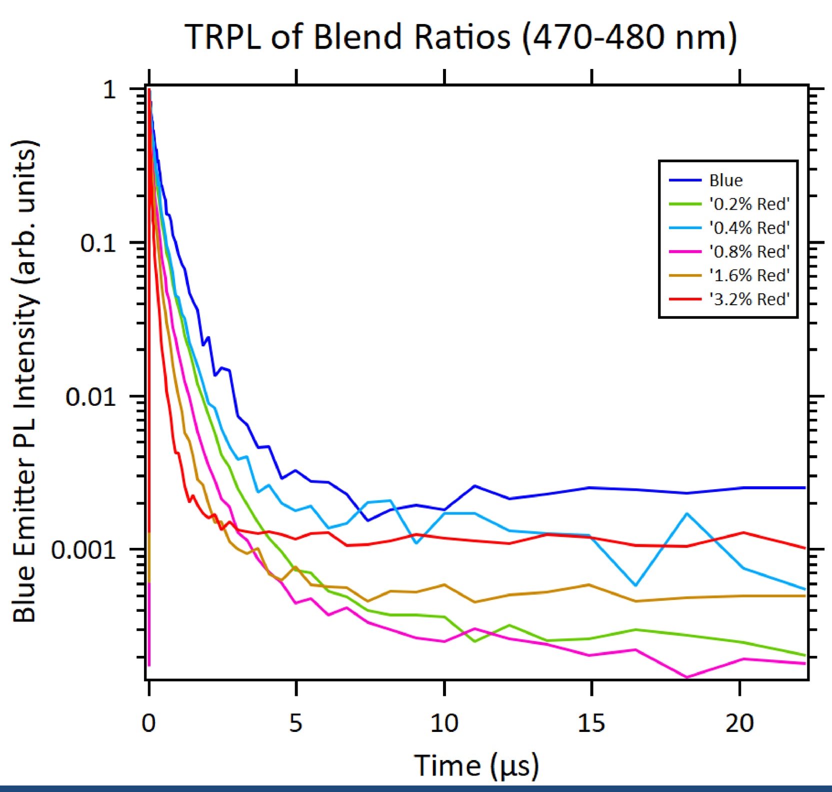
- Blue and Red compounds are phosphorescent emitters for OLEDs
- Both emitters are solution processable and compatible with a TCTA host
- Good spectral overlap indicates energy transfer will occur



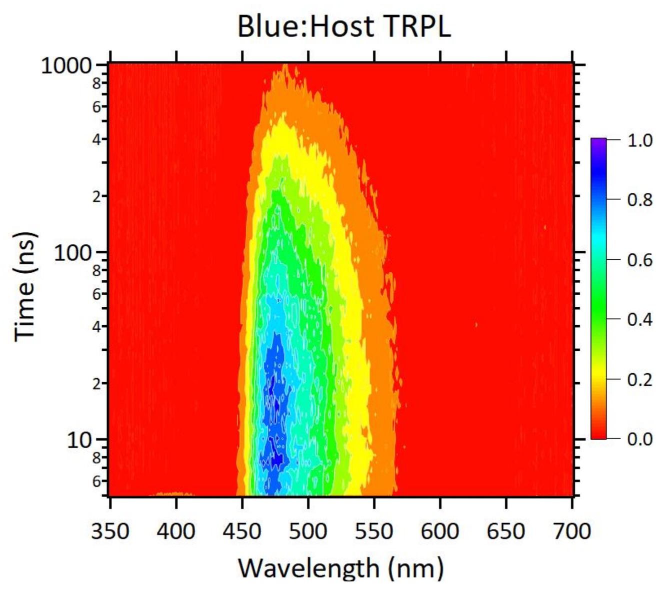
Time Resolved Photoluminescence

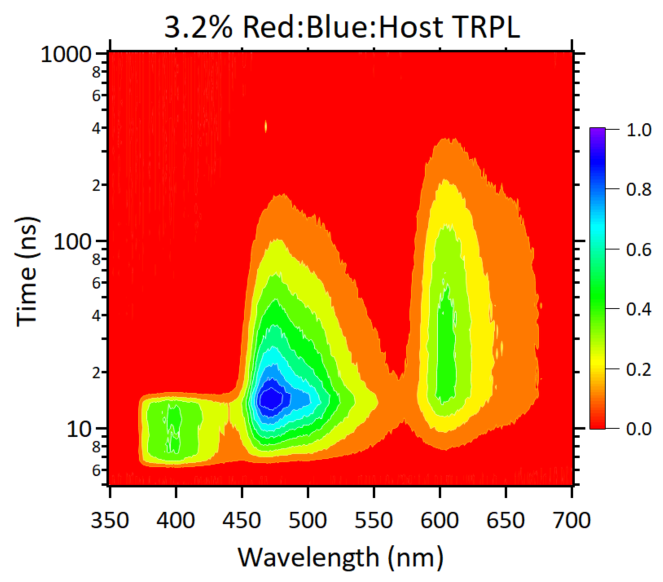
- Thin-film samples were prepared through spin-coating solutions in toluene onto fused silica substrates
- Blue fixed at 20 wt%, Red varied (0.2, 0.4, 0.8, 1.6 and 3.2 wt%)[4]





- **TRPL spectroscopy performed on each blend ratio (contours below)**
- **Increasing Red:Blue ratio reduces the blue emitter lifetime**
- **Consistent with energy transfer from Blue to Red emitter**





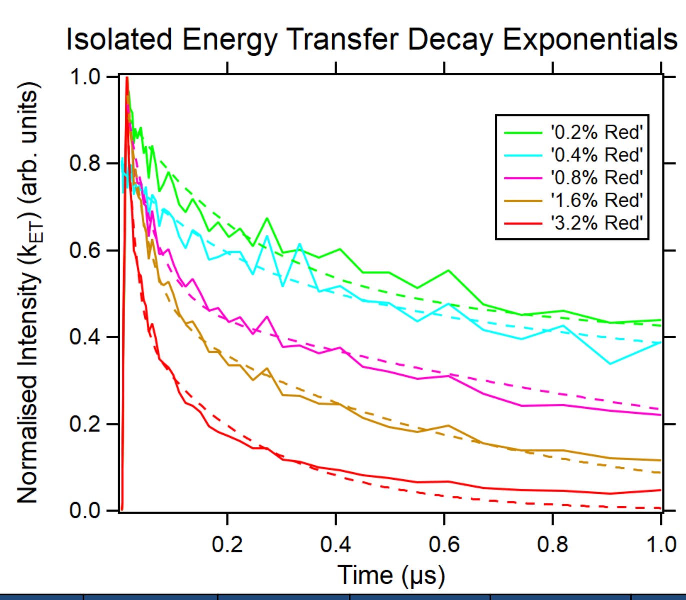
Data Processing

- The PL intensity of the Blue emitter in the presence of Red emitter can be described by

$$I_{br}(t) = I_0 e^{-(k_R+k_{NR}+k_{ET})t}$$

- The component of the PL decay corresponding to the energy transfer rate k_{ET} can be isolated by dividing by the Blue-only PL decay

$$\frac{I_{br}(t)}{I_b(t)} = \frac{e^{-(k_R+k_{NR}+k_{ET})t}}{e^{(k_R+k_{NR})t}} = e^{-(k_{ET})t}$$



Red %	3.2	1.6	0.8	0.4	0.2
Average Rate (s^{-1})	$(3.5\pm0.4) \times 10^7$	$(1.4\pm0.1) \times 10^7$	$(1.0\pm0.1) \times 10^7$	$(1.8\pm0.5) \times 10^6$	$(2.2\pm0.3) \times 10^6$

(Weighted average rates of double exponential fit)

Analysis of Energy Transfer Rate

- Förster energy transfer is a long-range (several nanometres) dipole interaction with a characteristic 1/r^6 dependence (distance sensitive)
- Dexter energy transfer is a short-range (~1 nanometre) electron exchange interaction with a characteristic exponential dependence on the separation

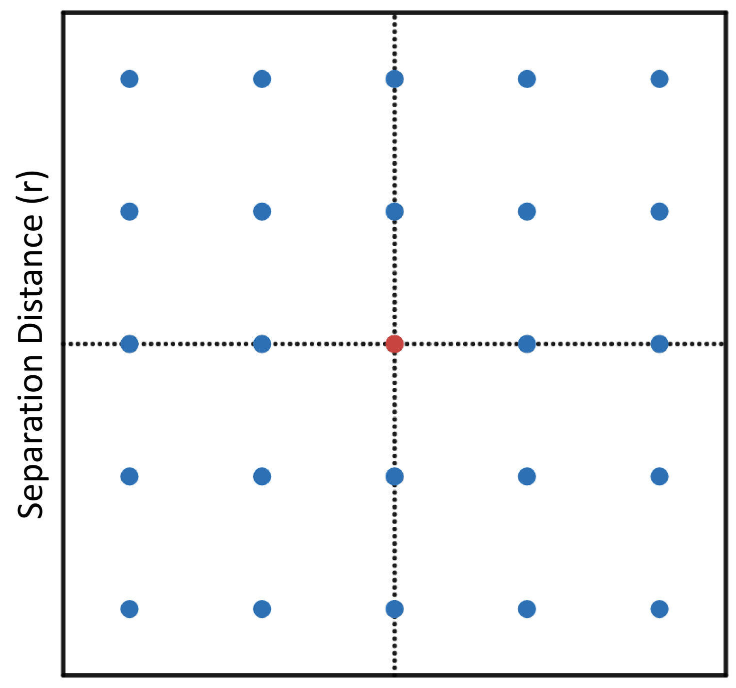
The dependence of the Förster energy transfer rate (k_{ET}) on the distance r between the donor and acceptor pair is

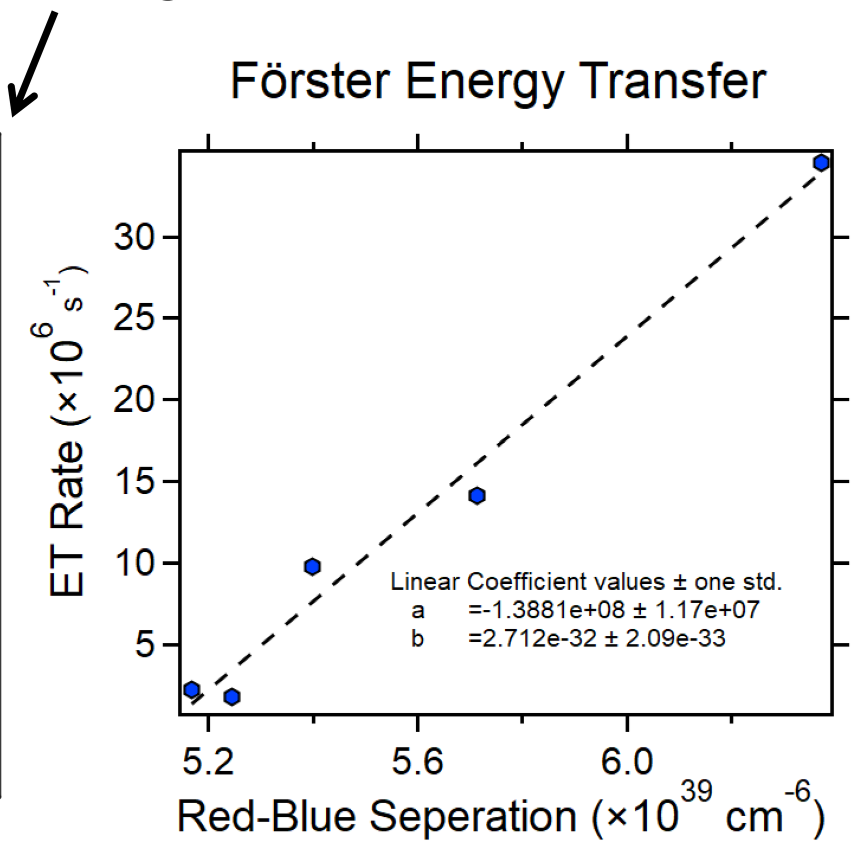
$$k_{ET} = \frac{1}{\tau_D}\left(\frac{R_0}{r}\right)^6$$

where τ_D is the lifetime of the donor (blue emitter), and R_0 is the Förster radius.

- **The average blue-red separation was estimated as the side length of the volume per emitter in the cube containing one red emitter**

Red Emitter Free Volume Diagram





- **The data is consistent with the Förster energy transfer mechanism when plotting k_{ET} against r, giving an R_0 of 4.3 ± 0.2 nm**
- **Comparing this with a solution based calculated R_0 of 3.8 nm gives a physically reasonable result consistent with Förster energy transfer**

Conclusions

Summary of Project:

- **The addition of the red emitter to the blend shows clear evidence of energy transfer from the blue chromophore**
- **TRPL data is consistent with the Förster mechanism with a Förster radius of 4.3 ± 0.2 nm**

Improvements of Analysis:

- **Better approximation of separation distance by using molecular dynamics simulations to predict morphology and distribution of emitter separations [1][2]**
- **Full modelling of the PL decays rather than using average rates**

References

[1] Gao, M.; Lee, T.; Burn, P. L.; Mark, A. E.; Pivrikas, A.; Shaw, P. E. Revealing the Interplay between Charge Transport, Luminescence Efficiency, and Morphology in Organic Light-Emitting Diode Blends. Advanced Functional Materials 2019, 30 (9), 1907942.

[2] Lee, T.; Sanzogni, A. V.; Burn, P. L.; Mark, A. E. Evolution and Morphology of Thin Films Formed by Solvent Evaporation: An Organic Semiconductor Case Study. *ACS Applied Materials & Interfaces* **2020**, *12* (36), 40548–40557.

[3] Ruseckas, A.; Shaw, P. E.; Samuel, I. D. Probing the Nanoscale Phase Separation in Binary Photovoltaic Blends of Poly(3-Hexylthiophene) and Methanofullerene by Energy Transfer. *Dalton Transactions* **2009**, No. 45.

[4] Saghaei, J.; Koodalingam, M.; Burn, P. L.; Pivrikas, A.; Shaw, P. E. Light-Emitting Dendrimer:Exciplex Host-Based Solution-Processed White Organic Light-Emitting Diodes. *Organic Electronics* **2022**, *100*.

[5] White Oleds (WOLEDS) https://oled.com/oleds/white-oleds-woleds/ (accessed Jan 21, 2023).