

MAKING STUFF GLOW

THERMALLY ACTIVATED DELAYED FLUORESCENCE (TADF) IN LIGHT EMITTING ELECTROCHEMICAL CELLS (LECs)

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Outline

In the modern world, artificial lighting is an absolute necessity. An estimated 3500 terawatt hours were consumed by the lighting sector in 2012, expelling almost 1900 megatonnes of CO₂ into the atmosphere.¹ It follows that increasing the efficiency of light emitting technologies is of paramount importance if this is to be reduced. LECs are a relatively new technology, first reported in 1995,² which represent a potentially huge saving for the lighting industry. Their simple device architecture and solution-processable manufacture make them a possible replacement for OLEDs. If equivalent luminance is achieved, then a **tenfold decrease in production cost** per lumen is expected, compared with projected future costs of OLEDs.³ Mainstream integration of LECs has so far been limited due to the lack of efficient, stable, long-lived deep-blue emitters.⁴ The aim of this project was to synthesise and characterise a new deep-blue TADF emitter (shown in Figure 1) to try and bring the advantages of TADF to LECs.

(Structure will be added after Winter break)

Figure 1: TADF emitter to be synthesised

What is an LEC?

LECs are one of the simplest electroluminescent (EL) devices. They contain just a single, thick active layer, whose EL performance is proportional to the concentration of mobile ions within it.⁴ They are industrially appealing as they use electrodes which are stable in air; this makes their encapsulation requirements much less stringent than for OLEDs and consequently they are **considerably more fault tolerant**.⁴ The structural differences between LECs and OLEDs can be seen in Figure 2 (Ref.⁴). LECs are well suited to backing on flexible substrates, and **operate efficiently at low voltages**, unlike OLEDs.³ Light emission from LECs is a direct response to the physical movement of ions in the active layer; response times range from milliseconds to hours.⁴

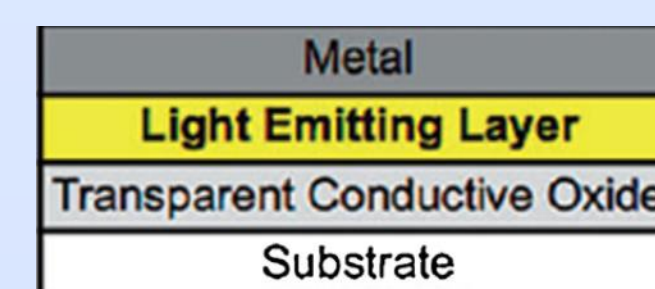
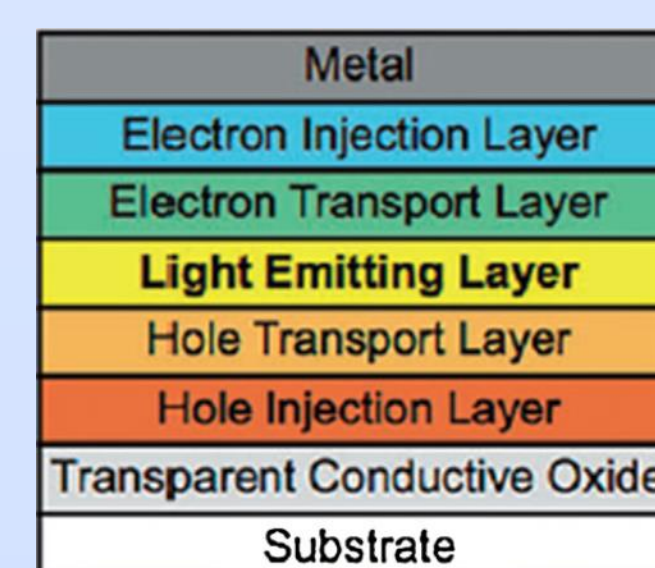


Figure 2: The structure of an LEC (above) vs. an OLED (below)



Synthesis

TO BE COMPLETED AFTER WINTER BREAK

What is TADF?

Traditional **fluorescence** is inherently limited by its max theoretical internal quantum efficiency (IQE) of 25%. Light emission involves radiative decay of an **exciton** (a bound electron-hole pair) from the first singlet (S₁) state to the ground (S₀) state, but only 1/4 of produced excitons are singlets. **Phosphorescence** uses 100% of excitons. After energy input excites electrons (dark blue arrow), from the S₁ state, an **intersystem crossing** (orange arrow) allows conversion to the T₁ state. From here, a spin forbidden electronic relaxation occurs back to the ground state, emitting light. This requires substantial spin-orbit coupling which limits it to expensive and often toxic heavy metal compounds. TADF also boasts 100% IQE, but doesn't require heavy metals. It combines prompt and delayed fluorescence (DF). DF is achieved by the up-conversion of triplet (T₁) states (which are electrically generated 75% of the time) to singlet (S₁) states using thermal energy. This is **reverse intersystem crossing**, which results in radiative decay of all excitons from S₁ back to S₀.⁵

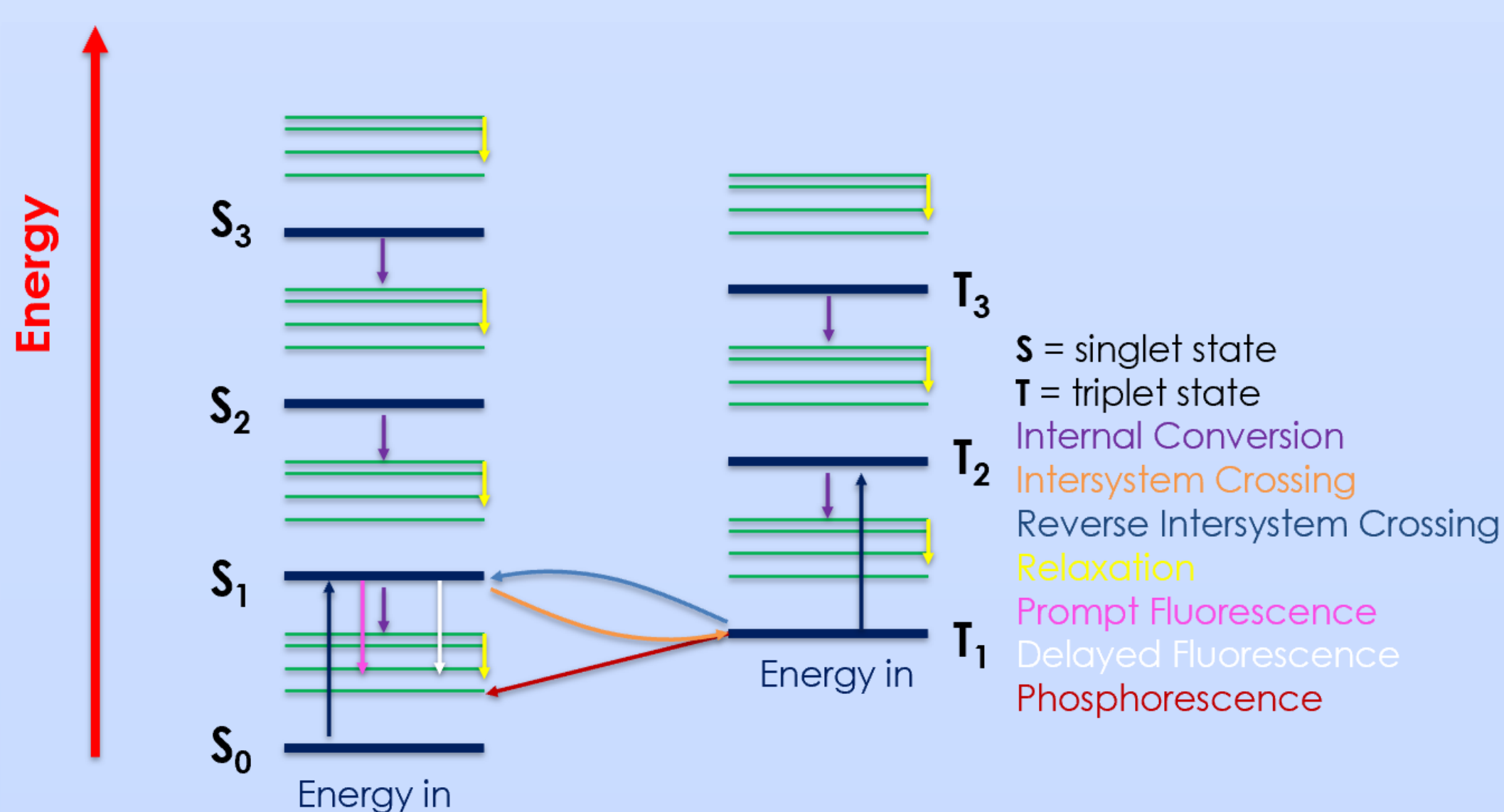


Figure 3: Jablonski diagram illustrating the various radiative and non-radiative decay processes in photoluminescence. TADF occurs after prompt fluorescence (pink arrow) when RISC (blue curved arrow) is followed by delayed fluorescence (white arrow)

Methods

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Results

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Future Work

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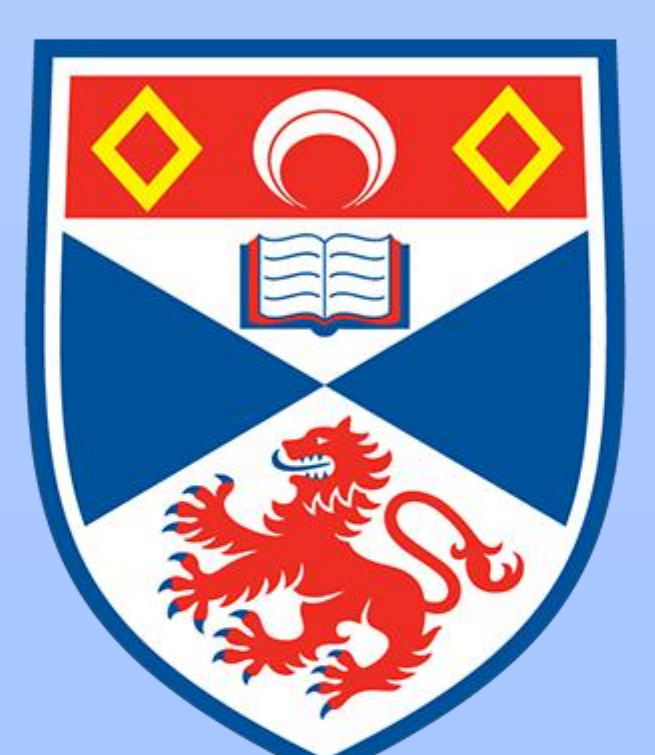
References

- ¹ International Energy Agency, Light's Labours Lost, <http://www.iea.org/>, accessed August 2020
- ² Q. Pei, G. Yu, C. Zhang, Y. Yang, A.J. Heeger, *Science*, 1995, **269**, 1086
- ³ S. van Reenen and M. Kemerink, in *Light Emitting Electrochemical Cells: Concepts, Advances and Challenges*, ed. R. D. Costa, Springer, Cham, 1st edn, 2017, vol. 1, ch. 1, pp 3-48
- ⁴ S.B. Meier, D. Tordera, A. Perregás, C. Roldán-Carmona, E. Orfí and H. J. Bolink, *Materials Today*, 2014, **17**, 217-223
- ⁵ C. Adachi, 2014, *Jpn. J. Appl. Phys.*, **53**, 060101

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