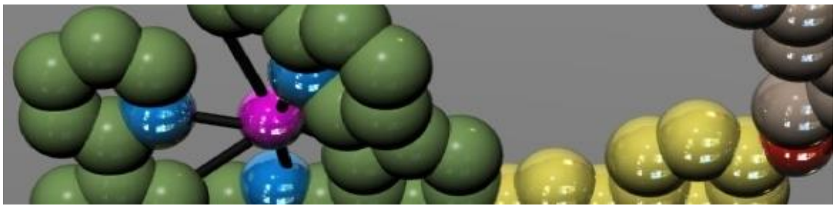
Institution: PHYESTA (Physics at Edinburgh and St Andrews)

Unit of Assessment: UoA 9 - Physics

Title of case study: Light-emitting Dendrimers

1. Summary of the impact

Impact: Economic



The light-emitting dendrimers are a new class of materials for organic light-emitting diodes, a major display technology. They have been commercialised by Cambridge Display Technology (CDT), the leading developer of polymer light-emitting diodes.

Significance

Light-emitting dendrimers provided a breakthrough in the efficiency of organic light emitting diode (OLED) materials deposited from solution. This enabled the convenience of solution-processing to be combined with high efficiency, and enabled solution-processed materials to compete with evaporated materials.

Beneficiaries

CDT, display manufacturers around the world and display users.

Attribution

The research was performed by Professor Samuel in collaboration with Professor Burn of the University of Oxford.

Reach

Materials based on light-emitting dendrimers are manufactured by Sumitomo Chemical in Japan and supplied to global displays manufacturers.

2. Underpinning research

Light-emitting dendrimers were a major part of the extensive research programme on organic optoelectronic materials and devices led by Professor Samuel at the University of St Andrews since 2000. The research was seeking to understand how optical and electrical properties of organic semiconductors relate to their structure, and then apply this understanding to developing improved materials for organic light-emitting diodes (OLEDs). The idea of light-emitting dendrimers was developed jointly with Professor Paul Burn (University of Oxford.) This technology was an alternative to light-emitting polymers and evaporated small molecules that were the dominant OLED materials at the time. A dendrimer is a highly branched molecule, and the idea was to have a core which would define key electronic properties such as the colour of light emission, dendrons to keep the cores apart, and surface groups around the outside of the macromolecule to confer solubility and favourable processing properties. By using such a modular molecular architecture, it was hoped that better OLED materials could be made.

By 2000, we had made some light-emitting dendrimers, but the efficiency of OLEDs made from them was very low (around 0.1%) whilst polymer LEDs had efficiencies of a few percent. The research programme identified the reasons for the limited efficiency – low photoluminescence quantum yield, hole-dominated charge transport and losses to the formation of triplet states. We then set about developing materials to overcome these problems. Our focus, like much of the UK was on solution-processed materials i.e. materials that can be deposited from solution – a simpler process than evaporation in high vacuum. Although it was known that phosphorescence could potentially increase the efficiency, there were not successful examples of efficient solution-processed phosphorescent OLEDs.

We therefore explored whether dendrimers could address this challenge by incorporating a phosphorescent chromophore into the core and using the dendrons and surface groups to make it solution-processable. Accordingly we developed the first phosphorescent light dendrimer OLED [R1], though its efficiency was also low. Subsequently, we developed an iridium-cored dendrimer which gave a dramatic leap in the external efficiency of devices to 8% [R2]. This was a world record by a large margin for a solution-processed LED.

The first Ir-cored dendrimer OLEDs were very efficient but we realised the charge transport was dominated by holes, so that the efficiency could be further improved by improving the charge balance. This was achieved by introducing an electron-transporting layer and led to an outstanding external quantum efficiency of 16% [R3] - three times higher than light-emitting polymers at the time.

Subsequent light-emitting dendrimer research aimed at simplifying the device structure by making "host-free" materials, and making a full range of colours for displays [R4]. Hence we adjusted the core to give red light emission [R5], and then worked on the very challenging problem of deep blue phosphorescence. We made considerable progress at understanding chromophore design for deep blue and then showed how this could give efficient deep-blue phosphorescence [R6],

This research led to approximately 70 refereed journal papers on light-emitting dendrimers, and a string of patent applications (more than 10) for efficient light-emitting dendrimers in the period 2000-2010. The light-emitting dendrimer research was recognised by Prof Samuel winning the Ben Sturgeon award of the Society for Information Display in 2008, showing the quality of the research and its influence on the user community. The dendrimer research was a substantial part of the research portfolio recognised by the award of the Beilby Medal to Prof Samuel and the Academic R&D prize at Printed Electronics USA, the world's largest printed electronics meeting.

Personnel

Key PHYESTA researchers involved were Professor Ifor Samuel (2000 - Present), Dr Ebinazar Namdas (PDRA 2001-2004), Dr Thomas Anthopoulos (PDRA 2001-2003) and Dr Ruth Harding (PDRA 2004-2007).

3. References to the research

The quality of the underpinning research is best indicated by R2, R3 and R5 *[Number of citations]*

[R1]	J.M. Lupton, I.D.W. Samuel, M.J. Frampton, R. Beavington, and P.L. Burn, "*Control of electrophosphorescence in conjugated dendrimer light-emitting diodes*", Advanced Functional Materials **11**, p. 287 (2001), DOI: 10.1002/1616-3028(200108)11:4<287::AID-ADFM287>3.0.CO;2-Z, URL: tinyurl.com/kjjxm8x, *[74]*
[R2]	J.P.J. Markham, S-C. Lo, S.W. Magennis, P.L. Burn and I.D.W. Samuel , "*High efficiency green phosphorescence from spin-coated single-layer dendrimer light-emitting diodes*", Applied Physics Letters **80**, p. 2645, (2002), DOI: 10.1063/1.1469218, URL: tinyurl.com/kyqmcng, *[172]*
[R3]	S.C. Lo, N.A.H. Male, J.P.J. Markham, S.W. Magennis, P.L. Burn, O.V. Salata and I.D.W. Samuel "*A green phosphorescent dendrimer for light-emitting diodes*", Advanced Materials, **14**, p. 975 (2002), DOI: 10.1002/1521-4095(20020705)14:13/14<975::AID-ADMA975>3.0.CO;2-D URL: tinyurl.com/mfqg55v, *[250]*
[R4]	S.C. Lo, T.D. Anthopoulos, E.B. Namdas, P.L. Burn and I.D.W. Samuel, "*Encapsulated cores: host-free organic light-emitting diodes based on solution-processible*

	electrophosphorescent dendrimers", Advanced Materials **17**, p. 1945 (2005), DOI: 10.1002/adma.200500020, URL: tinyurl.com/l9cm2mx, *[96]*
[R5]	T.D. Anthopoulos, M.J. Frampton, E.B. Namdas, P.L. Burn and I.D.W. Samuel , "*Solution-processable red phosphorescence dendrimers for light-emitting device applications*", Advanced Materials, **16**, p. 557 (2004), DOI: 10.1002/adma.200306095, URL: tinyurl.com/klefyf2, *[130]*
[R6]	S.C. Lo, R.E. Harding, C.P. Shipley, S.G. Stevenson, P.L. Burn and I.D.W. Samuel , "High triplet—energy dendrons: enhancing the luminescence of deep blue phosphorescent iridium (III) complexes", Journal of the American Chemical Society, **131**, p. 16681 (2009), DOI: 10.1021/ja903157e, URL: tinyurl.com/k9ahcum, *[70]*

4. Details of the impact

The above research changed the development of OLED materials by showing that highly efficient solution-processed materials could be made. Several patents were filed, and the materials were licensed to Cambridge Display Technology (CDT), the leading developed of light-emitting polymers. In 2007, CDT was purchased by Sumitomo Chemical of Japan for $285M [S1, S2]. This allowed Sumitomo to take a major stake in the OLED business.

The materials have been developed for commercialisation via three channels: (i) a CDT-funded research programme at St Andrews and Oxford (ii) an internal research programme at CDT (iii) a joint development programme with Sumitomo Chemical. The link to Sumitomo Chemical is extremely important both because of their skills in scaling up materials production and because of their credibility and proximity to major display manufacturers. The last point is very important as display manufacture is capital intensive and the major electronics companies need to be certain of the reliability of materials supply in order to build the factories to make the displays.

In 2005 the CEO of CDT explained [S3] "*the work on phosphorescent emission from dendrimers opens up new possibilities for the application of OLEDs to practical applications and this work complements our work on fluorescent polymer OLEDs, especially as the technologies potentially can be combined in one device without any increase in complexity of the structure.*" Innovations in display technology are commercially sensitive and so there is very limited publicly available information about the subsequent development of the dendrimers and the impact of the research. Our primary source of information is therefore a recent letter from [text removed for publication].

Hence the light-emitting dendrimers have had a major influence on one of the world's largest chemical companies, and its customers who are some of the world's largest electronics companies.

5. Sources to corroborate the impact

[F1]	Factual statement [text removed for publication].
[S1]	optics.org/article/30789 *Corroborates details of CDT acquisition by Sumitomo Chemical Corporation.*
[S2]	www.eetimes.com/document.asp?doc_id=1166722 *Corroborates details of CDT acquisition by Sumitomo Chemical Corporation.*
[S3]	www.electronicsweekly.com/news/components/led-lighting/emitter-life-boost-opens-red-oled-door-2005-10/ *Corroborates quotes from Chief Executive of CDT about the potential of phosphorescent dendrimer materials.*