Hybrid White Inorganic/Organic LEDs using Organic Colour Converters

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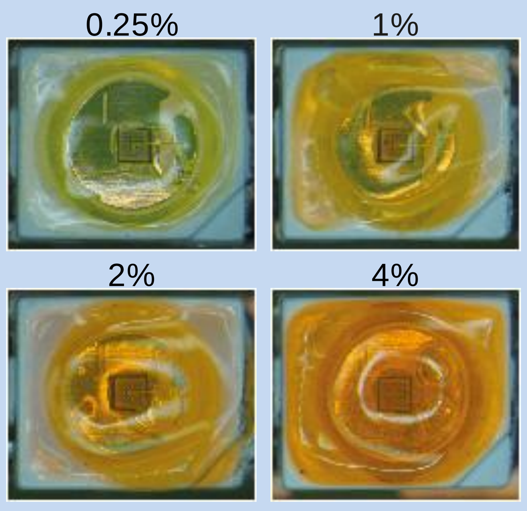
Introduction and motivation

- White light-emitting diodes (LEDs) are an integral part of solid-state lighting (SSL) to replace conventional light sources
- Currently the majority of high-power white LEDs consist of an *inorganic* blue LED pumping a yellow-emitting phosphor to produce white light
- However, there is still scope for improved wavelength converters for optimising the quality of the white light
- In this work, white LEDs are fabricated by combining novel *organic* colour converters with commercial, *inorganic* blue LEDs
- These organic compounds offer low-cost manufacturing, solution processability, tuneable emission and absorption properties by manipulation of the chemical structure and high speed of response (light communication)

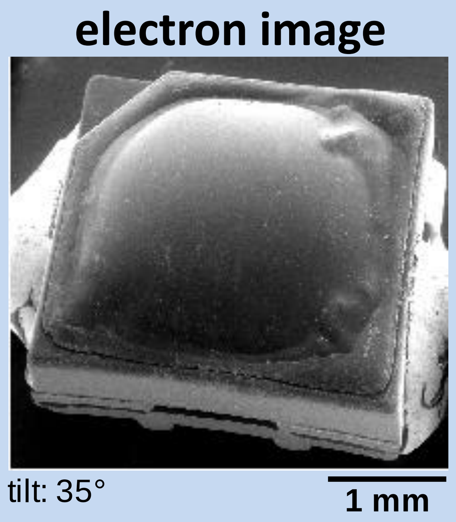
Smith, *Nano Letters* **13**, 3042 (2013); Findlay, *J. Mater. Chem. C* **1**, 2249 (2013)

The organic converter/transparent matrix solutions are deposited onto the LED package using a drop-cast method. Curing the mixture using UV light forms a solid dome.

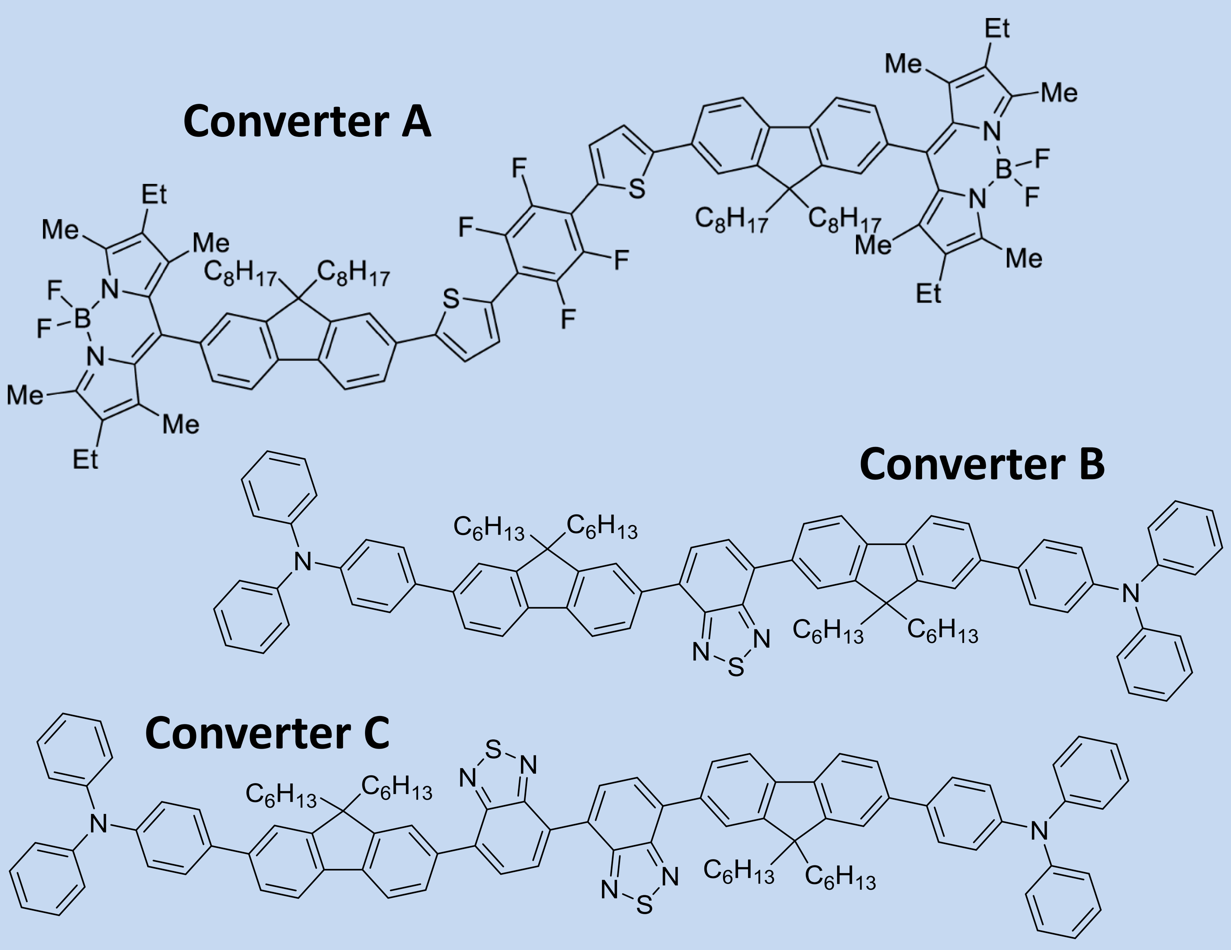
Photographs



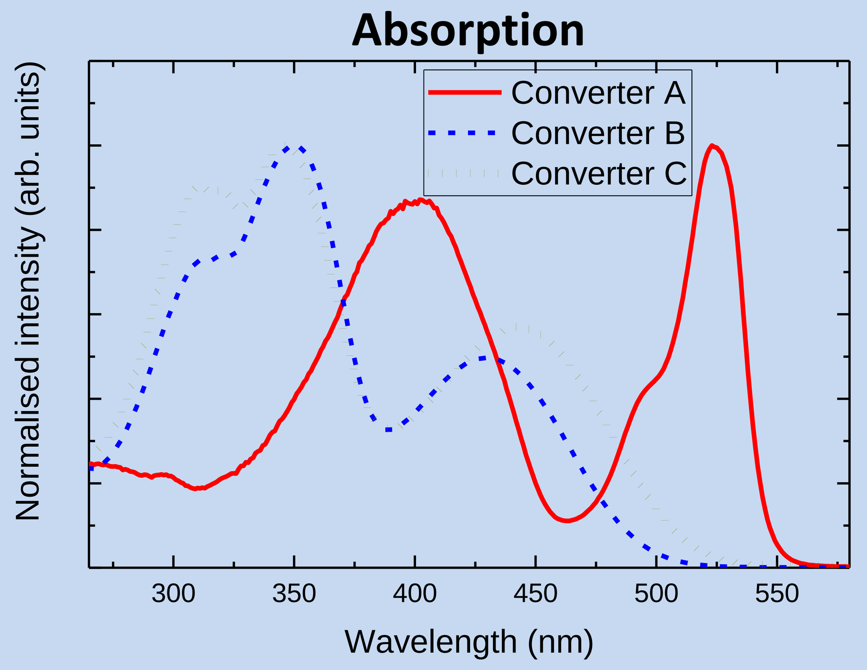
Secondary electron image



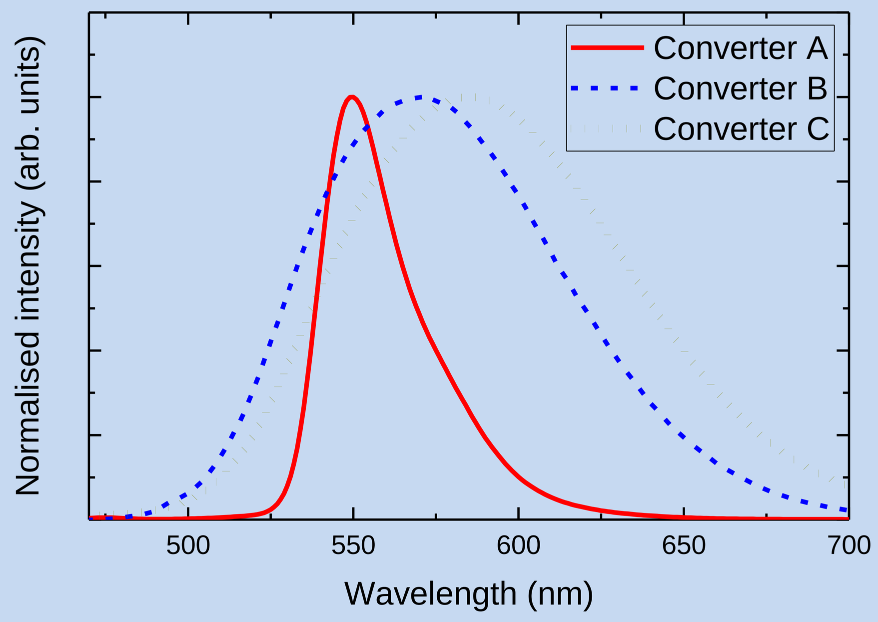
Photophysical properties of the organic colour converters



Absorption



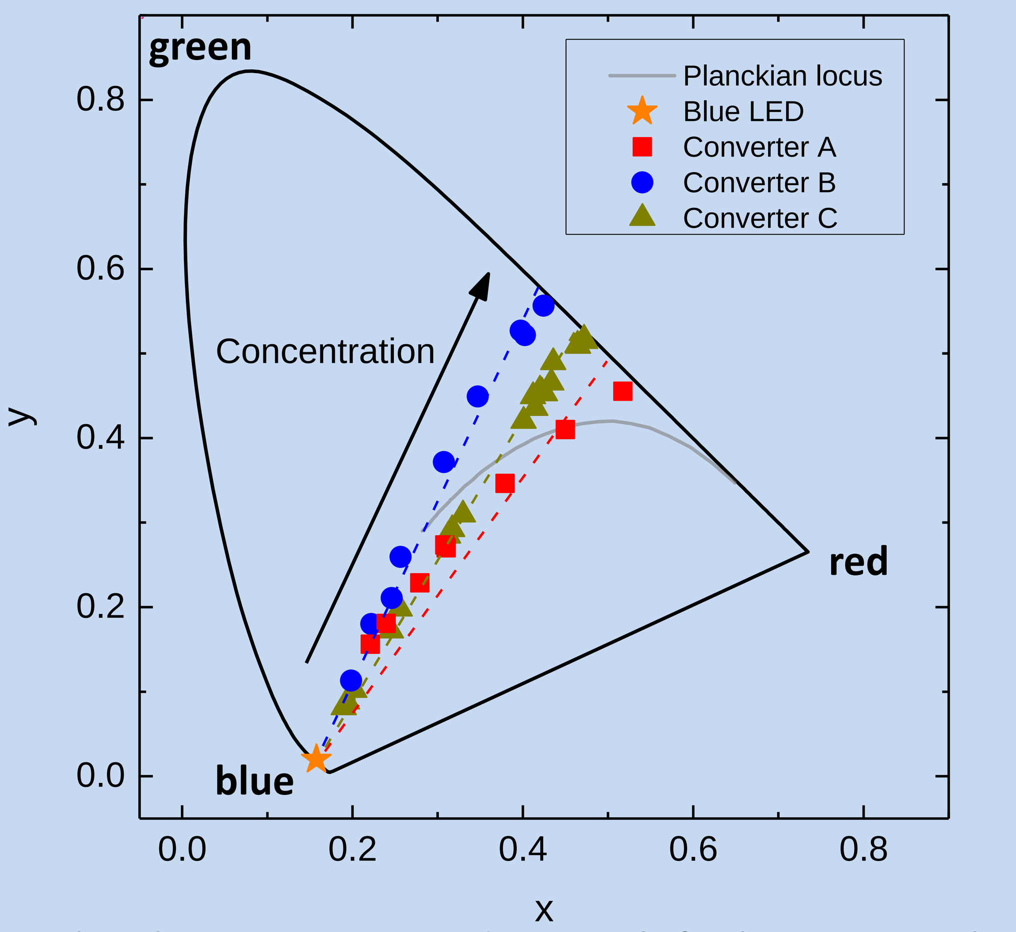
Emission



- The converter molecules consist of a core unit absorbing around 400-450 nm and an emissive unit emitting around 550-590 nm in the yellow-orange spectral region
- For ease of deposition on the LEDs, prevention of aggregation and use of low concentrations the molecules were incorporated into a transparent matrix, which also retains the optical properties of the solution state

Kuehne, *Adv. Mater.* **21**, 781 (2009); Findlay, *Adv. Mater.* **26**, 7290 (2014); Taylor-Shaw, submitted (2016)

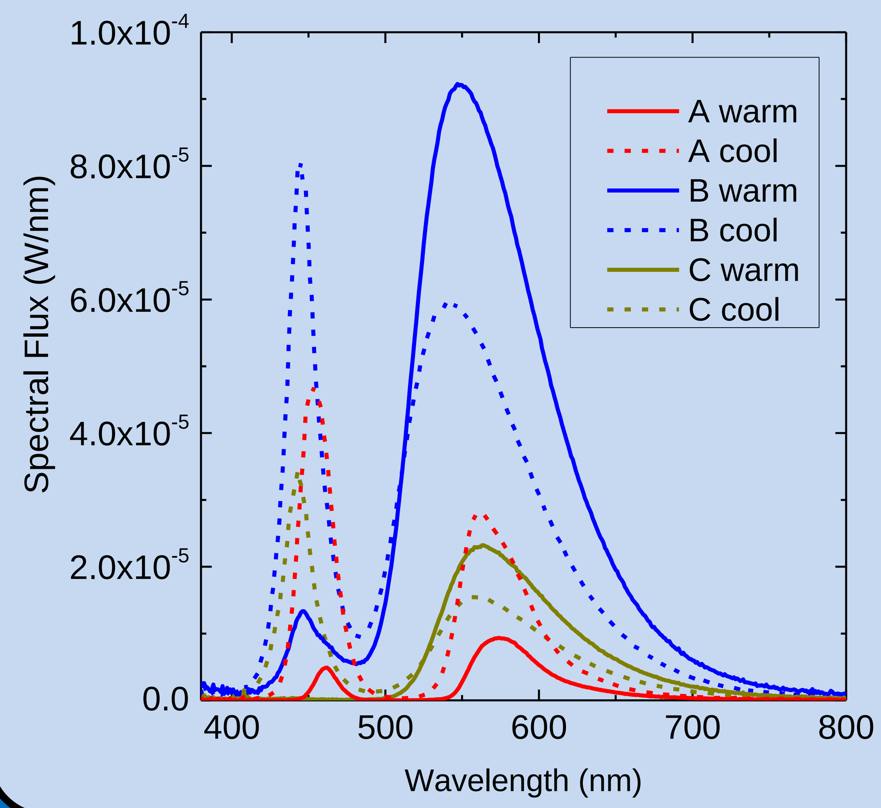
Influence of concentration

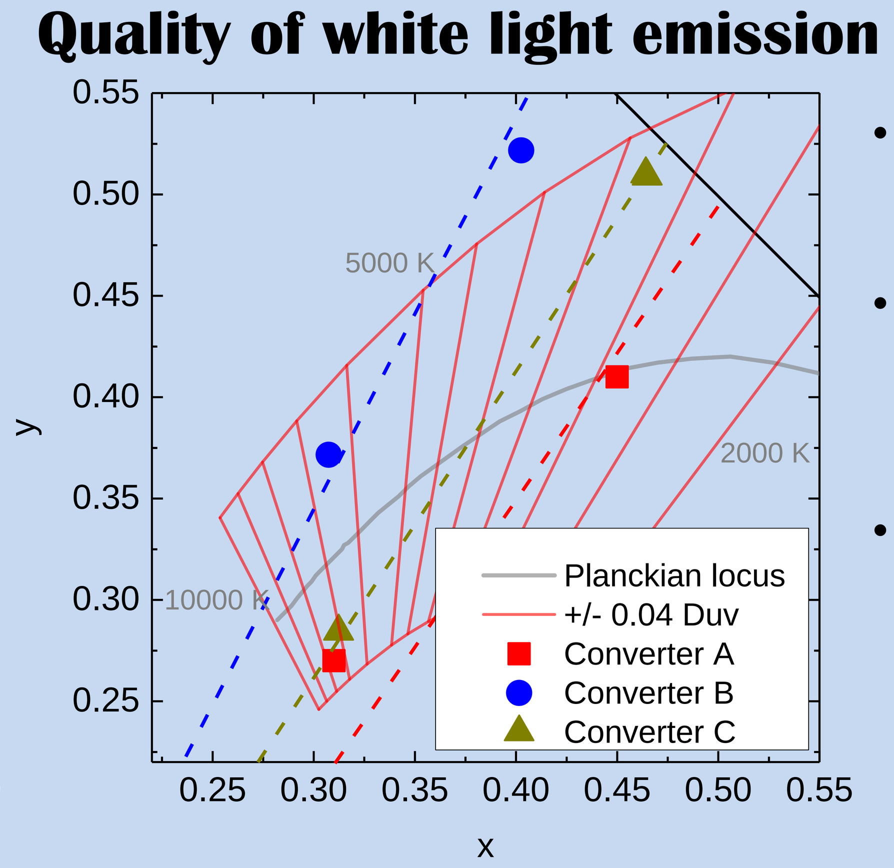


- The chromaticity coordinates shift along a straight line from blue to yellow-orange with increasing concentration
- The yellow emission from the organic material quenches with increasing concentration
- Differences in emission from the organic material lead to different gradients of the straight line

Bruckbauer, *J. Phys. D* **49**, 405103 (2016)
Taylor-Shaw, submitted (2016)

Quality of white light emission





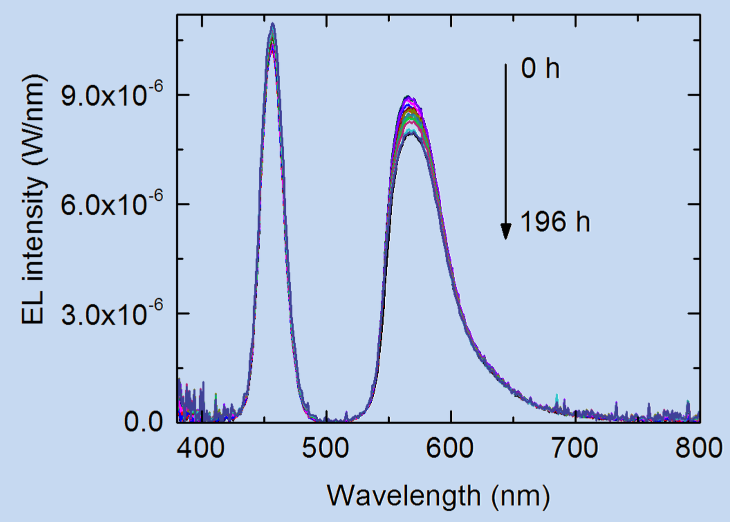
- By adjusting the concentration of the organic material warm and cool white light can be realised
- Converter B and C have a larger colour rendering index (CRI>60) due to broader yellow emission compared with converter A
- This has been achieved by manipulating the chemical structure in order to improve the photophysical properties of the organic colour converter

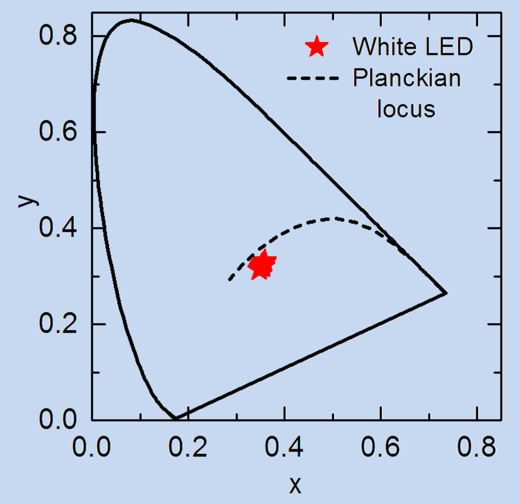
Taylor-Shaw, submitted (2016)

Lifetime testing

- Yellow emission intensity decreases drastically when the organic material is in close contact with LED chip
- Separation leads to the protection of the organic material
- Correlated colour temperature (CCT) and chromaticity coordinates are almost unaffected
- Luminous efficacy decreased by about **15%** after 750 h of continuous operation

→ Heat from the LED appears to cause degradation of the organic material or transparent matrix.





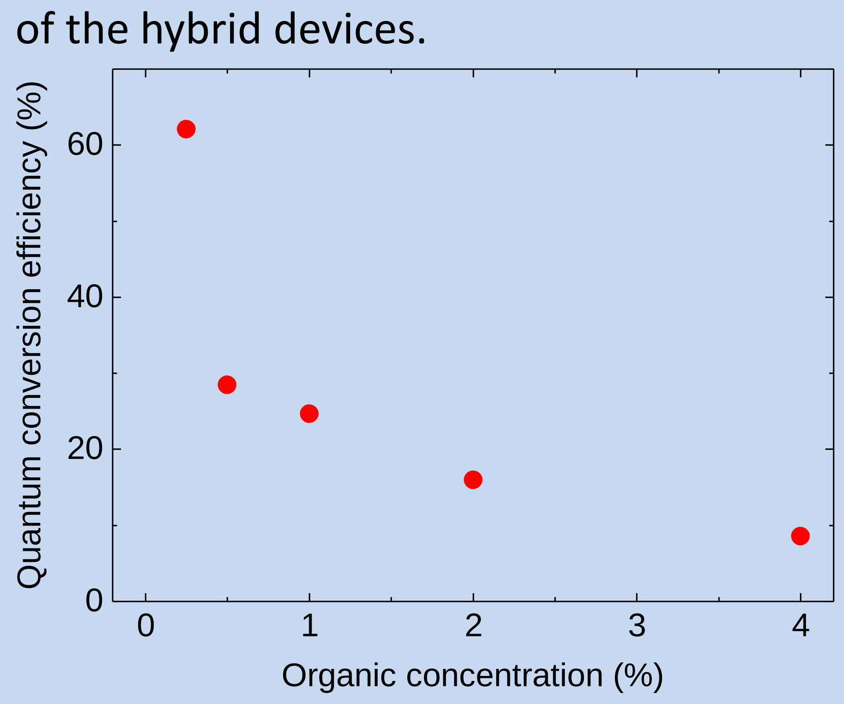
Device efficiencies

Estimations were made of the quantum conversion efficiency, photoluminescence quantum yield (PLQY), Blue-to-white efficacy (B-W) and luminous efficacy (LE) of the hybrid devices.

$$\eta_{\mathrm{conv}} = \frac{N_{\mathrm{converted}}}{N_{\mathrm{absorbed}}} = \frac{N_{\mathrm{yellow}}}{N_{\mathrm{blue}}^{\mathrm{before}} - N_{\mathrm{blue}}^{\mathrm{trans}}}$$

$$\eta_{\mathrm{B-W}} = \frac{\mathrm{lum.\ flux\ (white\ LED)}}{\mathrm{rad.\ flux\ (blue\ LED)}}$$

$$LE = \frac{\mathrm{lum.\ flux\ (white)}}{\mathrm{electrical\ power\ (white)}}$$

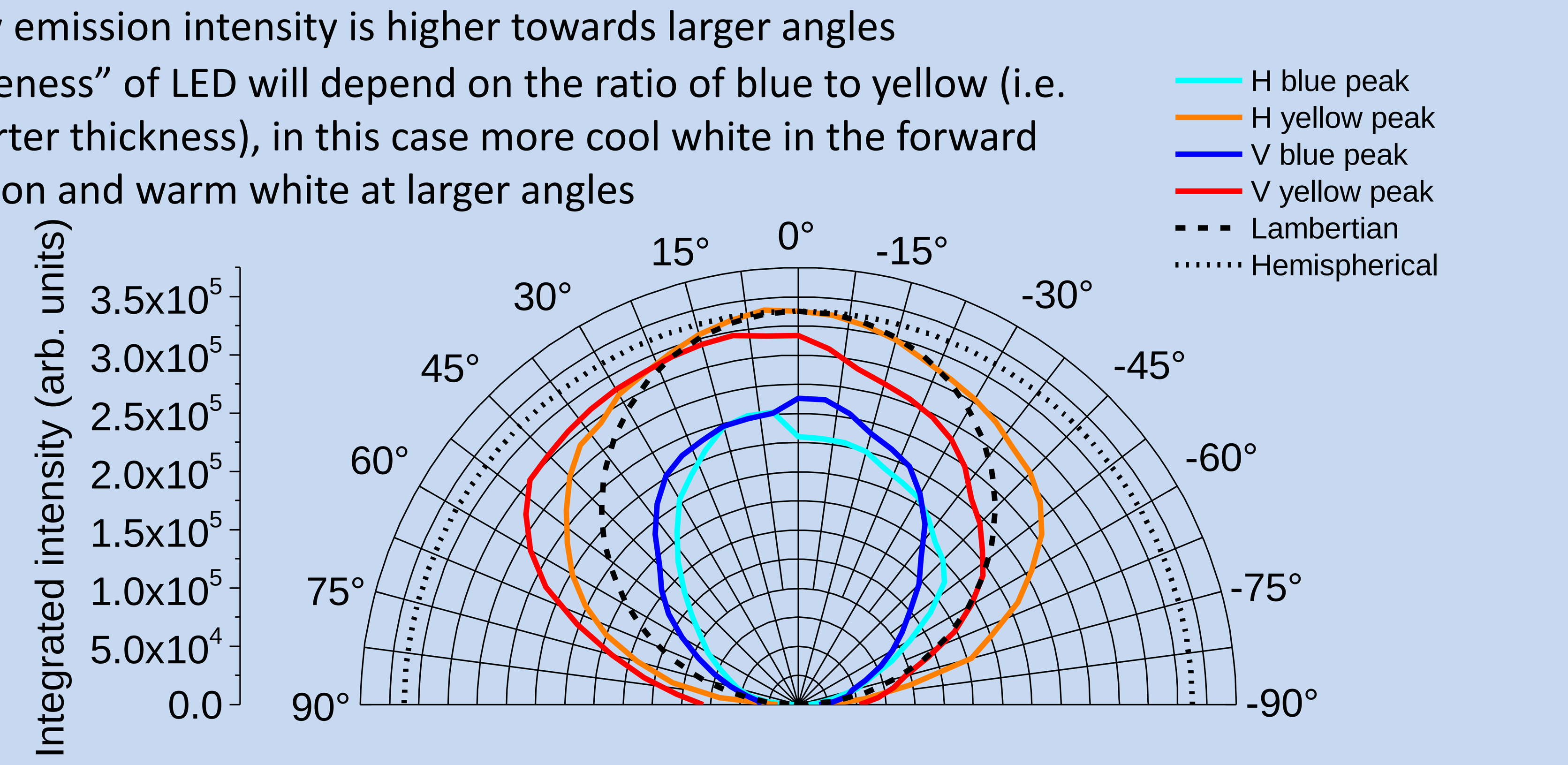


	PLQY (%)	B-W (lm/W)	LE (lm/W)
A	60	100-120	14
B	61	368	41
C	17	116	10

B-W efficacy of phosphor LEDs: >200 lm/W

Angular dependence

- Blue and yellow emission close to Lambertian emission pattern
- Blue emission intensity is slightly elongated in the forward direction, whereas the yellow emission intensity is higher towards larger angles
- "Whiteness" of LED will depend on the ratio of blue to yellow (i.e. converter thickness), in this case more cool white in the forward direction and warm white at larger angles



Summary

- White light was achieved using novel *organic* colour converters combined with *inorganic* blue LEDs
- Characteristics of warm and cool white hybrid LEDs are presented

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Acknowledgements

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EPSRC Engineering and Physical Sciences Research Council