# Innovative Technological Progress of Lifetime in Hyperfluorescence™

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## Abstract

***Hyperfluorescence™ (HF) combines TADF and fluorescence to provide narrow emission spectrum with four times higher emission efficiency than fluorescence. TADF acts as excitons generator and transfers excitons to fluorescence by Förster resonance energy transfer (FRET). HF also achieved long enough lifetime for AMOLED applications, such as smartphone not only by durable molecules but also by controlling charge balances in Emissive Layer (EML).***

## Author Keywords

OLED; TADF; Hyperfluorescence; Rare Metal Free; High Efficiency; Narrow Spectrum; Lifetime

## TADF and Hyperfluorescence™

Organic light-emitting diodes (OLEDs) have found wide application in our daily lives over the last few decades. Fluorescence and phosphorescence are currently used in OLED products, but thermally activated delayed fluorescence (TADF) and Hyperfluorescence™ are expected to be used in the next generation of OLED emitters. TADF materials had achieved close to 100% internal quantum efficiency (IQE) by controlling triplet energy level ($T_1$) as high as singlet energy level ($S_1$) without using any rare metals such as iridium.[1]

However, TADF molecules generally emit electro-luminescence, EL, with a broad spectrum, which is not favorable for display applications because a display requires narrow emission spectrum of red, green and blue to achieve a wide color space of images. Hyperfluorescence™ (HF) combines TADF and fluorescence to provide narrow emission spectrum with four times higher emission efficiency than fluorescence. Fig.1 shows the mechanism of HF. TADF acts as excitons generator and transfers excitons to Fluorescence by Förster resonance energy transfer (FRET). Fluorescence receives and emits light with nearly 100% internal quantum efficiency (IQE) [2].

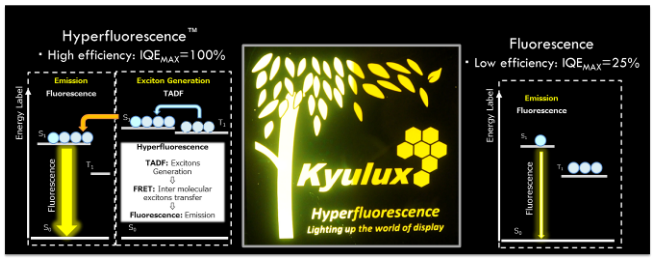


**Fig.1** Mechanism of Hyperfluorescenc™ (left): Excitons up conversion from $T_1$ to $S_1$ in TADF, FRET from TADF to fluorescence and emits light with 100% IQE from fluorescence. (middle): Demonstration panel of Hyperfluorescence™ (left) and conventional fluorescence (right), both side of the panel emit light by the same fluorescence molecule. (Right): Emitting diagram of fluorescence.

The photo of a demonstration panel is also shown in the middle of Fig.1. It demonstrates the difference between HF and conventional fluorescence clearly. The both side of the panel use the same fluorescence molecule as an emitter. Once TADF added as an assistant dopant in the left-hand side of the panel, light intensity became four times or more stronger than that of the right-hand side of the panel which the same fluorescence as an emitter without adding TADF.

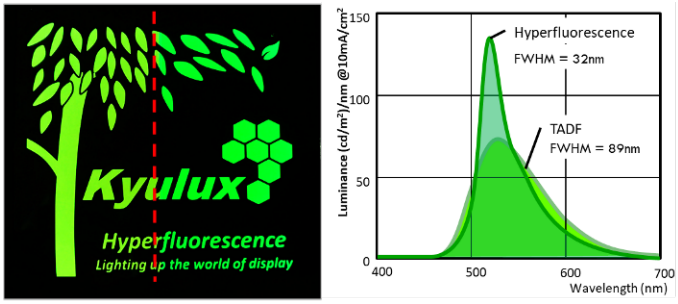


**Fig. 2-1** Comparison of green TADF and Hyperfluorescence™, (left): Demonstration panel, left-hand side; TADF as an emitter, right-hand side; HF, TADF as an assistant dopant. (right): emission spectrum comparison. HF shows higher light intensity and narrower spectrum than those of TADF. FWHM of TADF was 89 nm and that of HF was 32 nm.

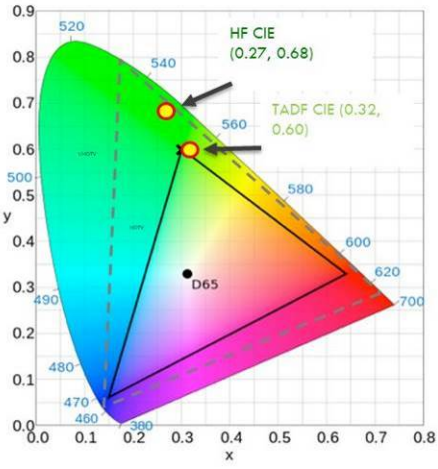


**Fig. 2-2** Comparison of green TADF and Hyperfluorescence™, CIE plots of green HF and TADF.

Fig.2-1 and Fig. 2-2 shows comparison of green TADF and HF. In Fig.2-1left-hand side of the demonstration panel emitted directly from green TADF. Right-hand side panel emitted from green fluorescence. In Fig.2-2 color coordinate of right-hand side panel was CIE(0.32, 0.60) and that of left-hand side panel was CIE(0.27,0.68) respectively. Green HF shows purer color and covers wider color space than green TADF. These differences caused by emission spectrum characteristics. Right figure of Fig. 2-1 shows both HF spectrum and TADF spectrum. Full width half maximum (FWHM) of HF spectrum was 32nm and FWHM of TADF was 89nm. External Quantum Efficiency (EQE) of HF was

18.1% and EQE of TADF was 18.6%. Light intensity at peak top wavelength ($\lambda_{max}$) at 10mA of HF was 1.8 times higher than that of TADF. Small FWHM achieved better CIE for display application and higher light intensity.

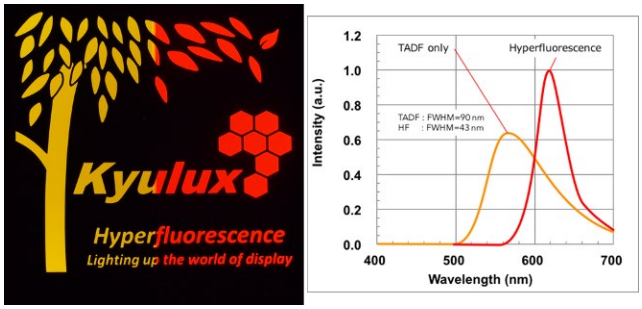


**Fig.3-1** Comparison of orange TADF and red Hyperfluorescence™, (left): Demonstration panel, left-hand side; TADF as an emitter, right-hand side; HF, TADF as an assistant dopant. (right): emission spectrum comparison. HF shows higher light intensity and narrower spectrum than those of TADF. FWHM of TADF was 90 nm and that of HF was 43 nm.

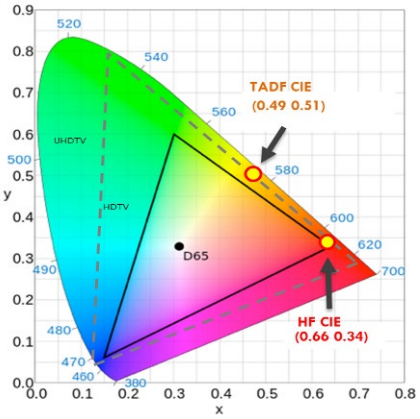


**Fig. 3-2** Comparison of orange TADF and red Hyperfluorescence™, CIE plots of HF and TADF.

Fig.3-1 shows comparison of orange TADF and red HF. Left-hand side of the demonstration panel emitted directly from orange TADF. Right-hand side panel emitted from red fluorescence with using the same orange TADF as an assistant dopant as the left-hand side. In Fig. 3-2 color coordinate of right-hand side panel was CIE (0.49, 0.51) and that of left-hand side panel was CIE (0.66, 0.34). FWHM of TADF was 90nm and that of HF was 43nm. This demonstration proved efficient FRET from orange TADF to red fluorescence and narrow spectrum and high light intensity were achieved. (Fig. 3-1(right))

Blue HF was demonstrated in Fig.4. Left-hand side panel is sky blue TADF. Right-hand side panel is blue HF. $\lambda_{max}$ were 467nm and 463nm respectively, and FWHM were 70nm and 31nm respectively. CIEy of blue HF was 0.15, and that of sky blue TADF was 0.20. Blue HF achieved smaller CIEy by using the same sky blue TADF as an assistant dopant. EQE of blue HF device was 26% at maximum and 22% at 1,000cd/m$^2$. This result showed a benefit of HF to achieve long lifetime. In general, lifetime of TADF decreases as $\lambda_{max}$ of TADF become shorter. HF provides smaller CIEy by using TADF with long $\lambda_{max}$. In other words, in order to achieve the same CIEy by a device using TADF as emitter, shorter $\lambda_{max}$ of TADF is required. Achieving long lifetime, therefore seems difficult in general.

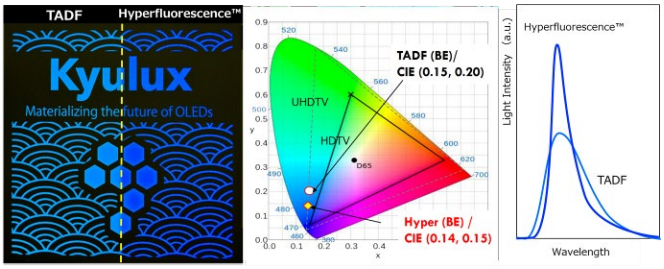


**Fig. 4** Comparison of sky blue TADF and blue Hyperfluorescence™, (left): Demonstration panel, left-hand side; TADF as an emitter, right-hand side; HF, TADF as an assistant dopant. (middle): CIE plots of HF and TADF. (right): emission spectrum comparison. HF shows higher light intensity and narrower spectrum than those of TADF.

## Lifetime improvement

Hyperfluorescence™ is an efficient and pure color emission without using any rare metals. In order to commercialize HF device, we improved the efficiency and lifetime of red TADF devices by expanding the charge recombination zone. (Fig. 5)

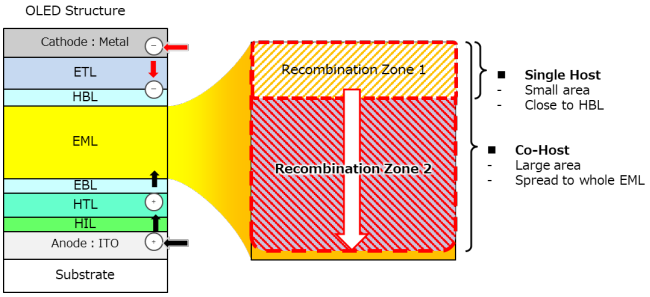


**Fig.5** Schematic diagram of enlarging recombination zone by co-host system

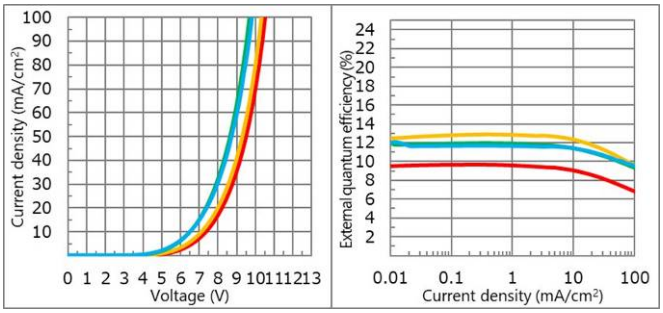


**Fig. 6** The J-V and EQE characteristics of red TADF OLED devices with various n-type host concentrations. Red, yellow, green, and blue lines indicate 0wt%, 20wt%, 40wt% and 50wt% respectively.

The lifetime of a red TADF device was 10-times improved by moving the recombination zone toward the hole-transporting side. Bottom-emission devices with a fixed doping concentration of red TADF material were examined. The charge recombination area was controlled by doping an n-type host into the emissive layer.

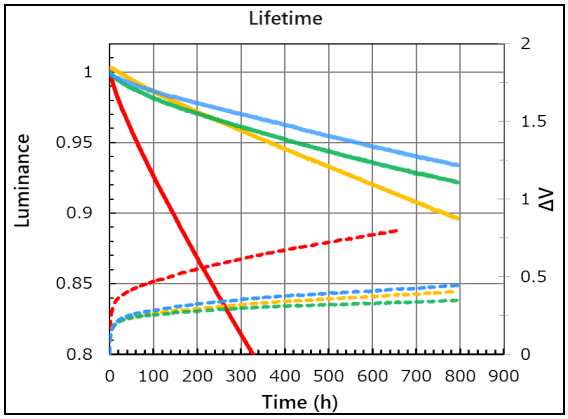


**Fig. 7** Lifetime test results of red TADF OLED devices with various n-type host concentrations. Red, yellow, green and blue lines indicate 0wt%, 20wt%, 40wt% and 50wt% respectively.

**Table 1** The results of EQE, Current efficiency and Lifetime

| @1000 nit | | | | @3000 nit | |
|---|---|---|---|---|---|
| n-type host concentration | EQE (%) | Current efficiency (cd/A) | Peak Spectrum $\lambda_{max}$ (nm) | LT95 (hours) | |
| | | | | measured | improvement |
| 0wt% | 9.4 | 31.9 | 565 | 55.4 | - |
| 20wt% | 12.8 | 46.1 | 560 | 366.6 | 6.6x |
| 40wt% | 11.8 | 40.7 | 563 | 425.4 | 7.7x |
| 50wt% | 11.6 | 38.9 | 564 | 563.4 | 10.2x |

Various n-type host concentrations, 0wt%, 20wt%, 40wt% and 50wt% were examined. EQE and current efficiency were maximized with 20wt% n-type host concentration. Lifetime (LT95@3,000nit) was maximized with 50wt% n-type host concentration. The enhancement of lifetime compared with 0wt% concentration was 10.2 times. The results indicated enlarging the charge recombination zone was one of the key factors to achieve long lifetime of devices.

**Table 2** Performances of Yellow TADF, red HF, green HF and blue HF devices

| Color | $\lambda_{max}$ (nm) | FWHM (nm) | Efficiency (cd/A@10mA) | LT95@1000nit (hours) |
|---|---|---|---|---|
| Yellow | 557 | 90 | 39 | 20,700 |
| Red | 617 | 44 | 32 | 37,000 |
| Green | 519 | 31 | 81 | 9,500 |
| Blue | 470 | 23 | 43 | 250 |

The co-host device structure was also applied to HF devices, and improved initial and lifetime performances as well. Table 2 shows updated performances of yellow TADF, and red, green and blue HF devices. All devices were bottom emission devices fabricated in Kyulux. Lifetime (LT95@1000nit) of yellow TADF device, red HF, green HF and blue HF were 20,700 hours, 37,000hours, 9,500 hours and 250 hours respectively. Lifetime improvement of the yellow, red, green and blue devices compared with the results of May 2019 were 5.6-times, 14.2-times, 4.0-times and 2.1-times respectively. The yellow TADF and red HF achieved long enough lifetime for small and medium size display applications. The lifetime of the blue HF enhanced by a proper combination with TADF assistant dopant and a fluorescence emitter. It is, however, required further development to achieve color and lifetime requirements.

## World's first Hyperfluorescence™ display

As the results of collaboration with WiseChip Semiconductor Inc., a Taiwanese company, the world's first Hyperfluorescence™ display launched. The comparison with a conventional fluorescence display and HF display is shown in Fig. 8.


**Fig. 8** The world's first yellow Hyperfluorescence™ display (left) Hyperfluorescence™, (right) conventional fluorescence

Yellow HF display achieved 2.5-times brighter light intensity than that of fluorescence display using the same fluorescence as an emitter. Continuous operating lifetime was 50,000 hours.

## Conclusion

- Hyperfluorescence™ is the next generation of emission system in OLED:
  - Highly efficient and pure color
  - Expected much lower display cost based on material costs (Iridium-free)
  - Expected to replace current emitting technologies in premium display based on commercial advantages
- Commercialization status:
  - Yellow HF display was commercialized in PMOLED applications
  - Red and Green was close to commercialization
  - Blue performance was improved (CIEy and lifetime improvement planned)

## Acknowledgements

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Development Organization (NEDO).

## References

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2. Hajime Nakanotani; Takahiro Higuchi; Taro Furukawa; Kensuke Masui; Kei Morimoto; Masaki Numata; Hiroyuki Tanaka; Yuta Sagara; Takuma Yasuda; Chihaya Adachi, Nat. Commun., 5, 4016, 2014.