Enhancing the Stability of Deep Blue Phosphor-Sensitized Fluorescent OLED Using Polariton-Enhanced Purcell Effect

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Abstract

The stability of efficient, deep blue organic light-emitting diodes (OLEDs) remains a major challenge in organic electronics and industry. The poor device stability originates from the high probability of non-radiative triplet exciton annihilation. Phosphor-sensitized fluorescence (PSF) has been proposed to reduce triplet exciton density and enable deep blue emission by efficient energy transfer to fluorophores. Recently, the polariton-enhanced Purcell (PEP) effect has been introduced to decrease the triplet radiative lifetime, thereby reducing reduce triplet density resulting an increase in blue phosphorescent OLED lifetime. Here, we introduce the PEP effect to enhance the stability of the PSF-OLEDs. Applying a full PEP cavity to the device using Pt-complex phosphor and a so-called multi-resonance (MR) fluorescent emitter, we observe a 3.1-fold lifetime increase at a current density of $J = 10$ mA/cm^2, reduced EQE roll-off and a deep blue color with Commission Internationale de l'Eclairage coordinates of (0.13, 0.09).

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High stability, efficiency and color purity of blue organic light-emitting diodes (OLEDs) are a well-known problem for the past 20 years [1]. A unity internal quantum efficiency (IQE) is normally achieved by harvesting triplet exciton radiative states [2,3]. However, due to the long lifetimes of triplets, the high probability of triplet annihilation processes (e.g. triplet-triplet and triplet-polaron annihilations, TTA and TPA) leads to device degradation [4–6]. These processes are energy driven and, therefore, are most harmful to deep blue emitters. One promising solution is phosphor-sensitized fluorescence (PSF) where efficient Förster and Dexter energy transfer processes enable triplet harvesting while reducing triplet annihilation [7]. However, an intrinsically stable, efficient, deep blue OLED is yet to be reported.

Recently, the polariton-enhanced Purcell (PEP) effect has led to increased phosphorescent OLED (PHOLED) stability by reducing triplet radiative decay lifetime and density. The large optical density of states (ODoS) of plasmon-exciton-polaritons [8] and surface plasmon polaritons (SPPs) [9] can increase the radiative coupling of nearby emitters with resonant wavelengths. Particularly, plasmon-exciton-polaritons formed within the metal electrode and the adjacent organic charge transporting layer enable a larger Purcell factor in the emissive layer (EML) than excitation of simple surface plasmons [8]. Here, we show that the PSF-OLED stability can also be enhanced by the PEP effect.

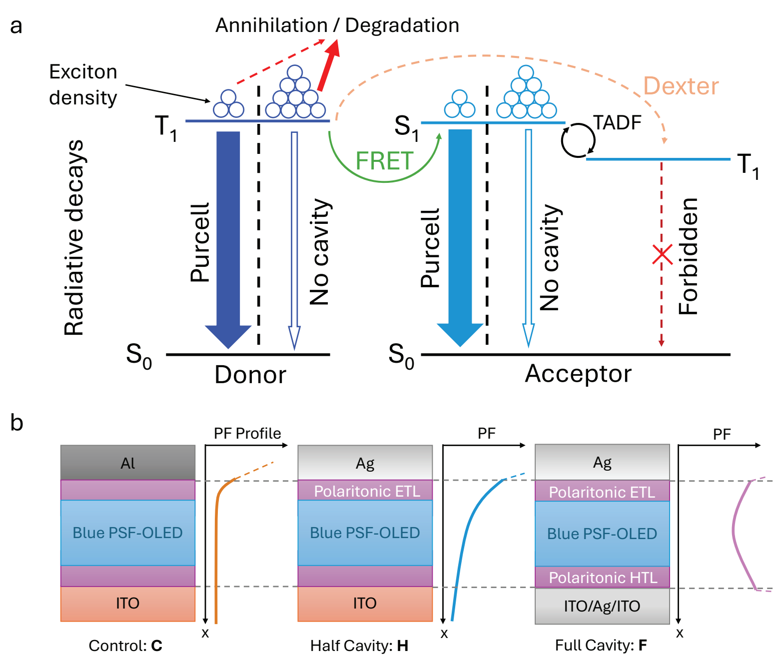

Figure 1.(a) Proposed Purcell effect enhancement on phosphor-sensitized fluorescent (PSF) OLED stability. Purcell effect increase the radiative decay of the optically allowed transitions, including the phosphor triplet and fluorophore singlet emission. Triplet annihilation and device degradation are suppressed due to the reduced exciton density. (c) Studied device structures and their Purcell factor (PF) spatial profile. ***C****: Al-ITO control, weak cavity device.* ***H****:Ag-ITO half-cavity.* ***F****: Ag-ITO/Ag/ITO (IAI) full cavity.*

To investigate the PEP effect on the PSF-OLED stability, we investigated three PtON-TBBI-sensitized PSF-OLED structures with increasing Purcell effects containing a so-called multi-resonance-type (MR) deep blue fluorophore emitter, v-DABNA. From the weakest Al-ITO control cavity, moderate Ag-ITO half cavity to the strongest Ag-Ag full cavity, we demonstrate a 3.1-fold device lifetime increase, from LT70 = 63 ± 1h to 197 ± 3h at a current density of J = 10 mA/cm^2. The EQE roll-off is reduced from 35% to 17% at a current density of J = 100 mA/cm^2. The PSF-OLED has a deep blue emission with a standard Commission Internationale de l'Eclairage coordinates of CIExy = (0.14,0.15). Owing to the Fabry-Pérot cavity effects, the full cavity emits in a deep blue color of CIExy = (0.13, 0.09), compared to the phosphor-only device whose CIExy = (0.15, 0.20). To our knowledge, this is the first demonstration of PSF-OLED stability enhancement utilizing Purcell effect, paving the way for intrinsically stable, efficient deep blue OLEDs for display applications.

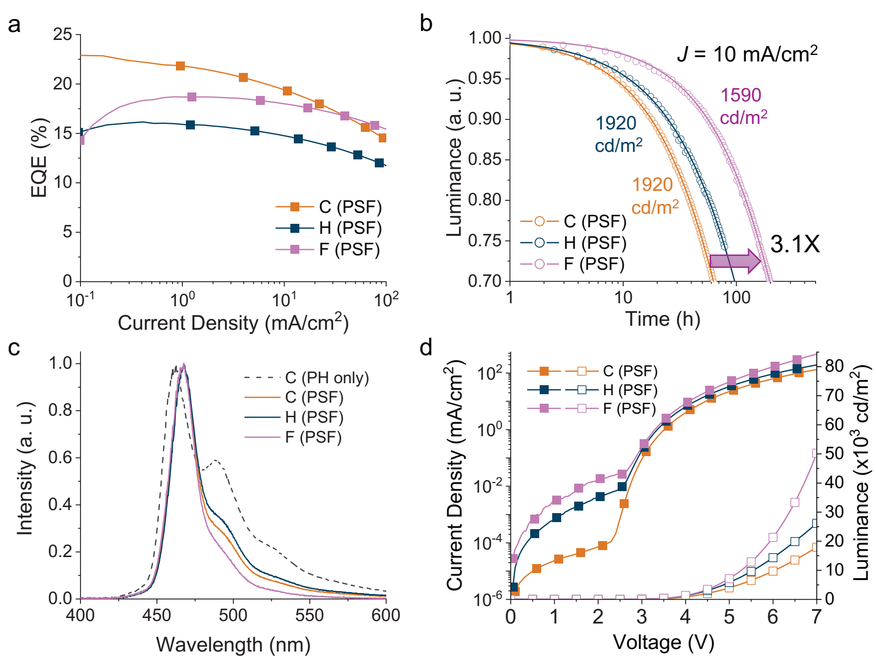

Figure 2.(a) External quantum efficiency of PSF-OLEDs. (b) PSF-OLED operational lifetime at 10 mA cm^{-2}. Initial luminance is labeled beside each curve. (c) Electro-luminescence (EL) spectra at 10 mA cm^{-2}. PSF-OLED and phosphor-only devices are labeled in solid and dashed curves, respectively. (d) Current-voltage-luminance characteristics of PSF-OLEDs.

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