Polariton Enhancement of the Purcell Effect for Extending Blue Phosphorescent Organic Light-Emitting Diode Lifetime

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Introduction

Phosphorescent organic light-emitting diodes (PHOLEDs) feature high efficiency, vivid color and flexible color-tunability. However, blue PHOLEDs are short-lived due to severe triplet-polaron annihilation (TPA) and/or triplet-triplet annihilation (TTA) due to from long triplet lifetime and high triplet density.

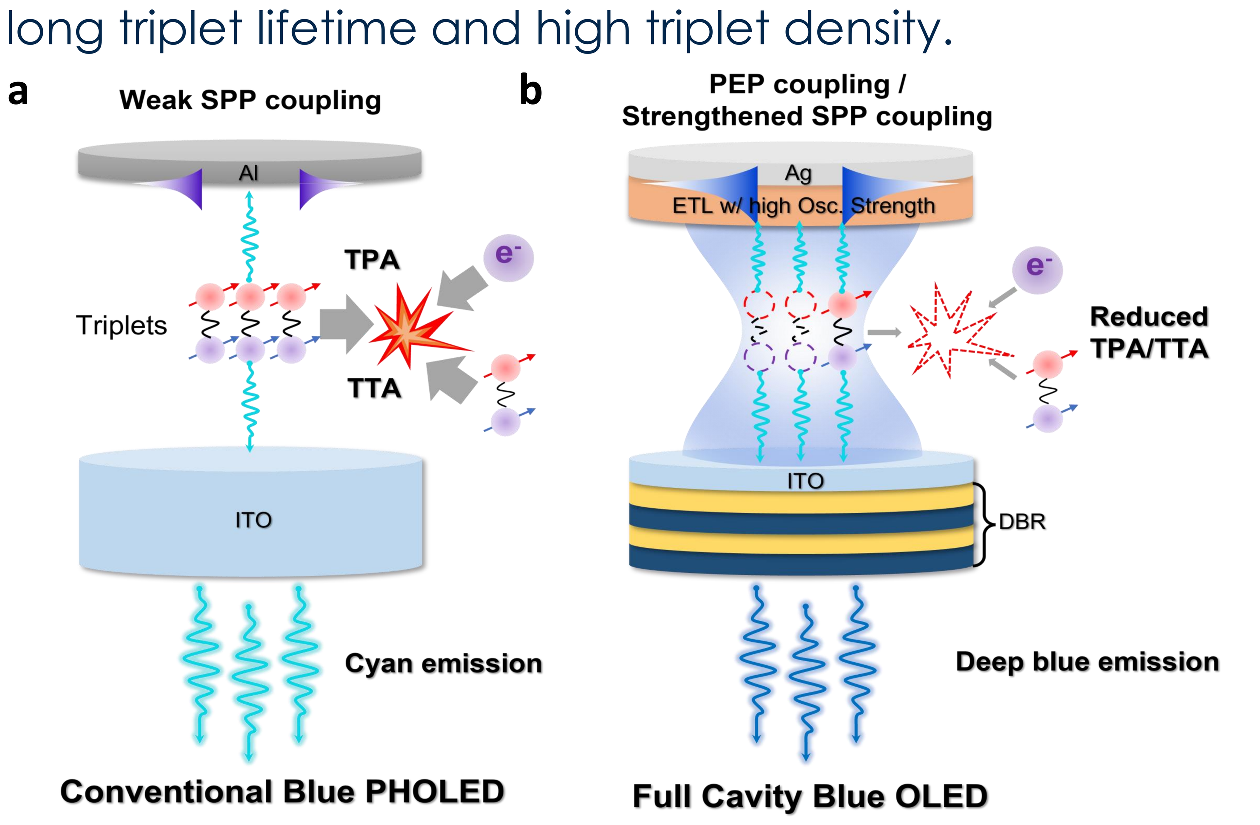

Fig. 1. a, Conventional devices with weak optical coupling. The weak radiative decay results in a high triplet density, and thereby a high probability of defect generation by TPA/TTA. **b**, Devices with polariton-enhanced Purcell effect. Plasmon-exciton-polaritons (PEPs) are formed using an electron transporting layer (ETL) with high oscillator strengths. Ag can strengthen the coupling to PEPs or surface plasmon polaritons (SPPs) to enhance Purcell effect, thereby reducing triplet density and consequently TPA/TTA rate. For a cyan emitter, the full cavity devices employing metal/distributed Bragg reflector (DBR) narrow the emission spectrum and increases outcoupling of blue photons.

- **Purcell effect**: the control of radiative decay rate in a microcavity, can be used to reduce the triplet density in the device and prolong the device lifetime.
- **Plasmon-exciton-polaritons (PEPs)**: we use the strong-coupled quasiparticle between excitons in electron-transporting layer (ETLs) and metal surface plasmon polaritons (SPPs). PEPs can enhance the Purcell effect due to their highly tunable dispersion relations and large optical density of states (ODoS).

Design

- **Microcavity devices achieves the full, independent control of device lifetime, EQE and color.**

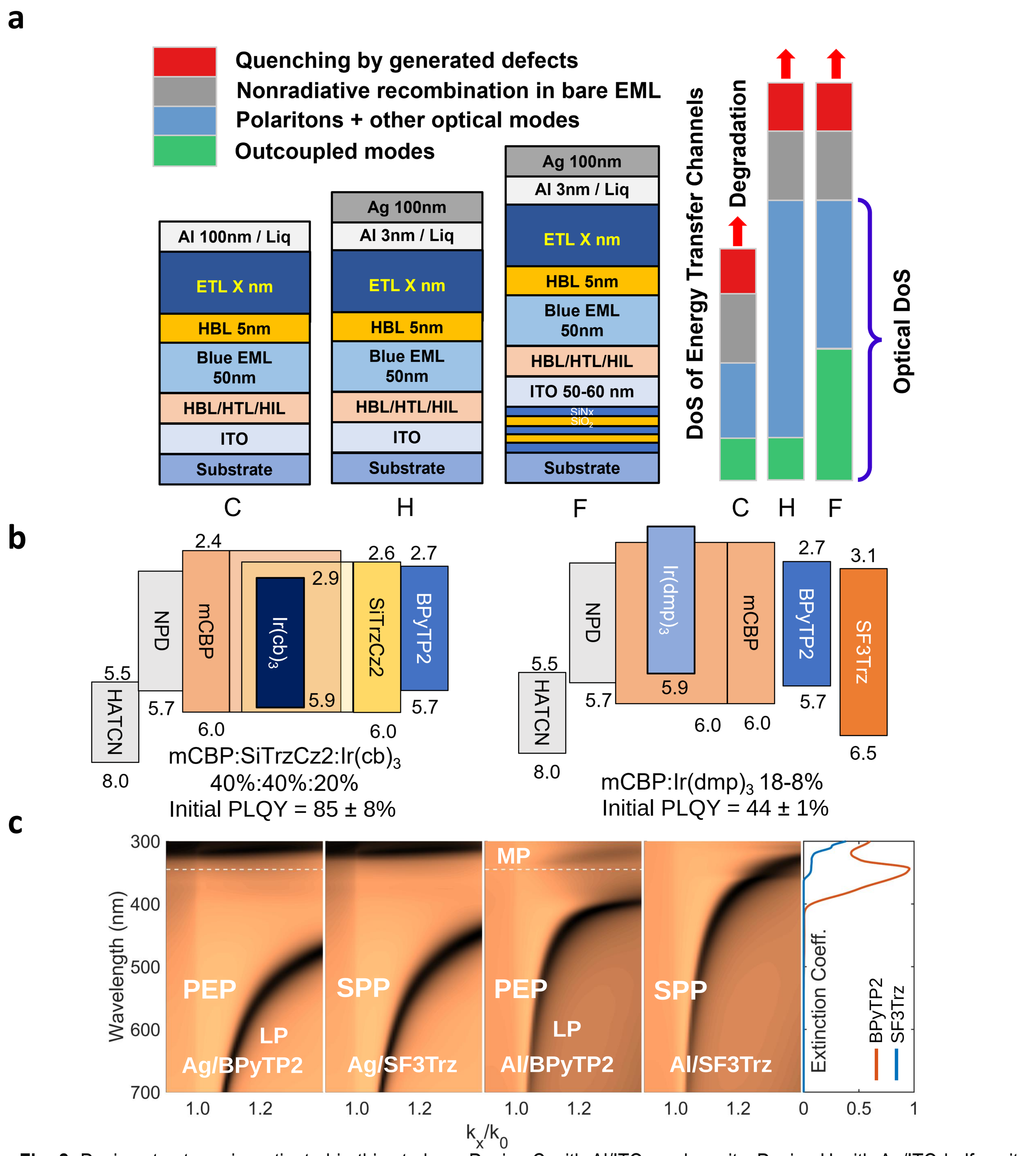

Fig. 2. Device structures investigated in this study. **a**, Device C with Al/ITO weak cavity. Device H with Ag/ITO half cavity. Device with Ag/DBR full cavity. The main energy transfer channels and their density of states (DoS) in devices C, H, F are plotted on the right. **b**, Organic structures of device studied employing $Ir(cb)_3$ (left) and $Ir(dmp)_3$ (right). **c**, Simulated angle-resolved reflectance of PEPs and SPPs for four metal/ETL combinations. Right panel: the extinction coefficient of ETLs.

Results

- **Observation of PEPs in an OLED**
- **Purcell Factor: Ag PEPs > Ag SPPs > Al PEPs > Al SPPs**
- **4x device lifetime enhancement + high EQE**
- **Color shift from cyan to deep blue for the lonest-lived device**

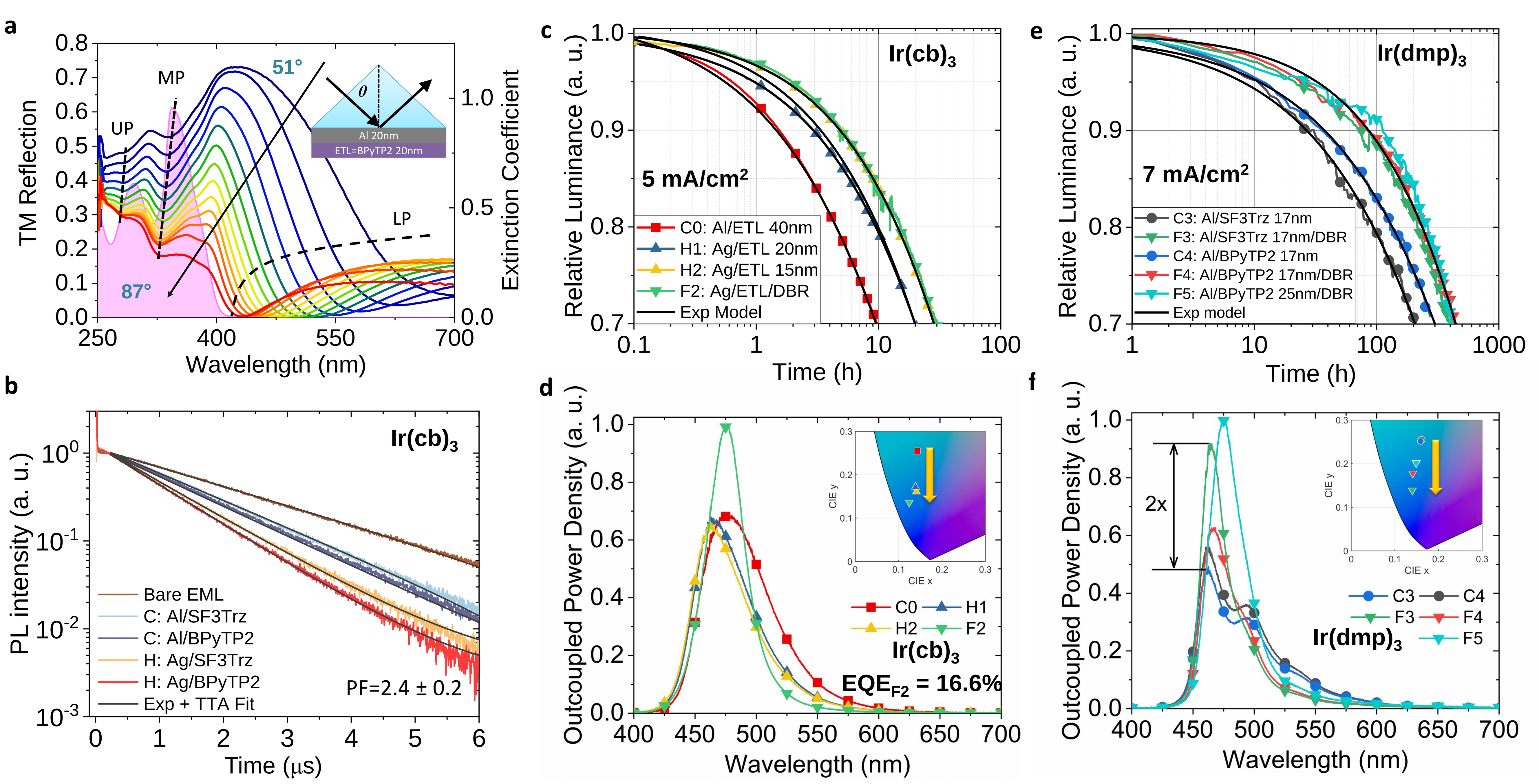

Fig. 3. a, Angle-resolved reflectance showing the presence of PEPs on an Al/BPyTP2 surface. The anti-crossing of strong coupling results in upper (UP), middle (MP) and lower polariton (LP) branches. Inset: Ellipsometry geometry. **b**, Measured PL lifetime of the 50 nm Ir(cb)3 EML in half cavity H vs. weak cavity C. A Purcell factor of PF = 2.4 ± 0.2 is achieved. **c-d,** Device lifetime and outcoupled power density for $Ir(cb)_3$ devices C0, H1, H2, F2. ETL= BPyTP2. measured at 5 mA/cm^2, initial luminance is 1350 cd/m^2 for C0. Inset: emission coordinates in Commission Internationale d'Eclairage (CIE) space. **e-f**, Device lifetime and outcoupled power density for $Ir(dmp)_3$ devices C3, F3, C3, F4, F5. Measured at 7 mA/cm^2, initial luminance is 500 cd/m^2 for F3. Inset: emission coordinates in CIE space.

Results (cont.)

- **Deep blue devices have the shortest lifetime**
- **Purcell effect and cavity devices reverse this trend.**
- **LT vs. PF follows a power law m = 2.2-1.4 from LT90-70**
- **Longest LT90 for Ir-based PHOLEDs up to date.**
- **14x and 10x enhancement vs. similar Ir-based devices.**

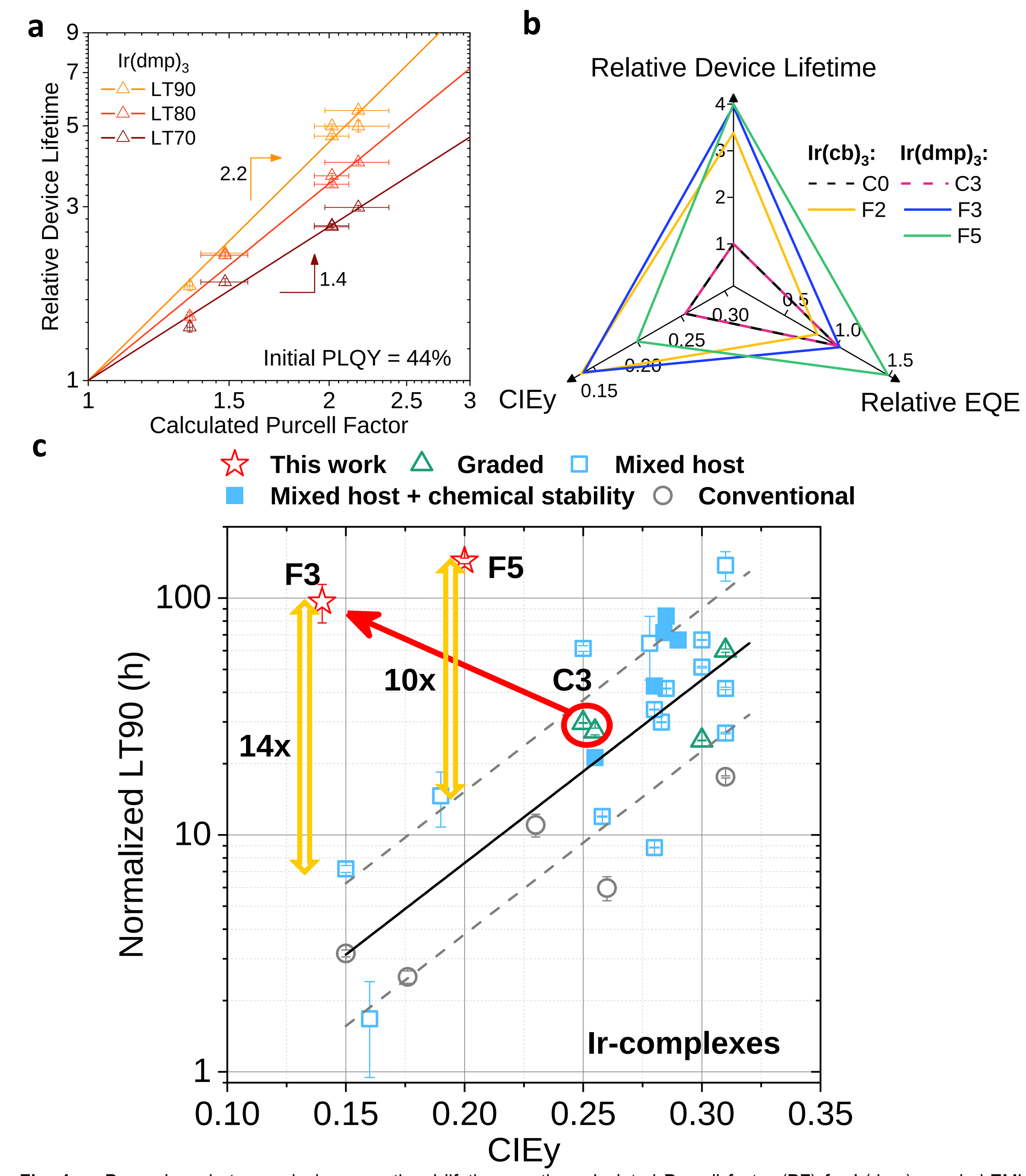

Fig. 4. a, Power laws between device operational lifetime vs. the calculated Purcell factor (PF) for $Ir(dmp)_3$ graded-EML devices. Three lifetime standards LT90, LT80 and LT70 (the time to reach 90%, 80%, and 70% of initial luminance, respectively) are shown, and all data extracted from devices C3, C4, H3, H4, F3, and F4 with the same ETL thickness are normalized to the same origin. The power laws are m = 2.2 ± 0.3, 1.8 ± 0.2 and 1.4 ± 0.1 for LT90, LT80 and LT70, respectively. **b**, Comparison of relative device lifetimes, relative external quantum efficiency (EQE) and CIEy coordinates. **c**, Normalized LT90 versus CIEy of Ir-complex-based devices reported for this work and the literature. The conventional devices C3 and C4 in this work are labeled by triangles in the red solid circle. Operational lifetimes are normalized by a standard photon exitance $M_{p,0}$, equivalent to a device with EQE = 25% and J = 2 mA/cm2. An aging acceleration factor of 1.8 ± 0.2 is adopted from literature. Black solid line shows the linear regression of the scattered data (except for the polariton devices in this work), with the upper/lower bound denoted by the dashed lines.

Conclusions

- We observed plasmon-exciton-polariton in the OLEDs.
- Using polariton-enhanced Purcell effects, we have achieved a PF = 2.4 ± 0.2 and extended device lifetime by 4x at same aging conditions.
- Shifting to deep blue CIE = (0.14, 0.14) from (0.16, 0.26), we obtain a high EQE = 10.7% for the initial PLQY = 44%.
- These leads to a 10-14x increase in LT90 compared to similar devices - longest normalized LT90 = 144 ± 4h for Ir-complex up to date.

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References

This work: H. Zhao, D. Fan, C. E. Arneson, B. Qu and S. R. Forrest, submitted (2023).

[1]H. Zhao, S. R. Forrest, *Proc. SPIE PC12418, Organic Photonic Materials and Devices XXV*, PC1241802 (2023)

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