An add-on organic green-to-blue photon-upconversion layer for organic light emitting diodes

Electronic Supplementary Information

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1. Preparation of the gelled upconverter

For photon-upconversion, the sensitizer palladium tetraphenylporphyrin (PdTPP, from Frontier Scientific, 0.5 mM) and the emitter 9,10-diphenylanthracene (DPA, Merck KGaA, 10 mM) were dissolved in tetralin (99 %, Sigma-Aldrich). Then the upconverter solution was gelled by adding 1,3:2,4-bis(3,4-dimethylbenzylidene) sorbitol (DMDBS, from Chemos, 3 g/L) and by heating the mixture at 150°C for 10 min. Upon cooling down to room temperature, the DMDBS gelled the solution by forming a fibrillar network. Then the gel was spread between two cavity glasses to form a homogeneous layer with a thickness of 1.1 mm which was then encapsulated with epoxy glue (edge-sealing). To avoid contamination with oxygen and hence quenching of triplet states, the gel was prepared in a glovebox filled with dry nitrogen.

2. Design and optoelectronic properties of the tandem-OLED

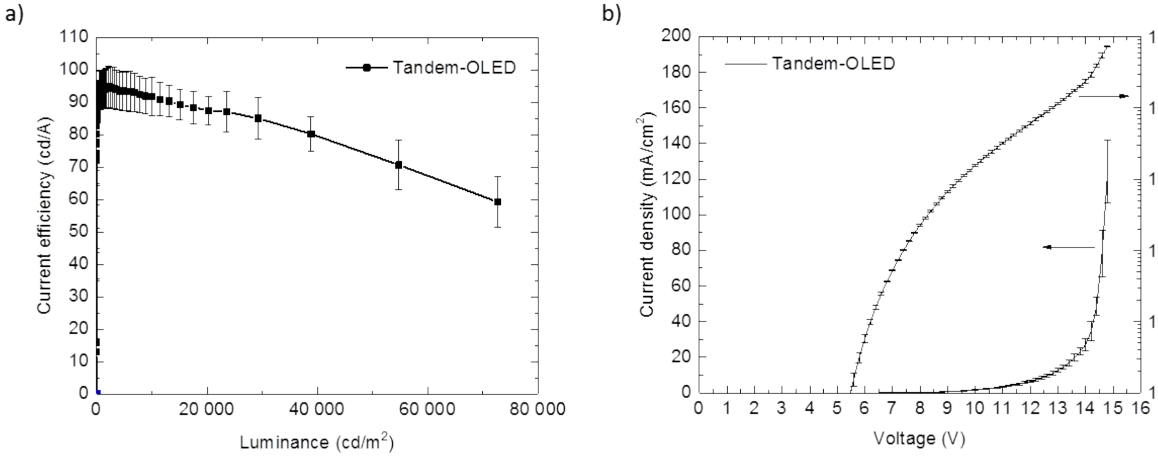

Figure S1: a) Current efficiency *versus* luminance of three tandem OLEDs built in three different experiments. b) *J*-*V*-*L* characteristics.

The OLEDs that were used to pump the photon-upconverter, were fabricated by thermal evaporation in a home-built six-chamber evaporation system (cluster tool) with a base pressure of $1 \cdot 10^{-7}$ mbar atop pre-structured indium tin oxide electrodes on glass substrates. The substrates were cleaned in 2-propanol using an ultrasonic bath (2 min), followed by an oxygen plasma treatment (2 min, 100 W). Tris(4-carbazoyl-9-ylphenyl)amine (TCTA), 8-hydroxyquinolinolatolithium (Liq) and tris[2-phenylpyridinato-

C2,N]iridium(III) (Ir(ppy)$_3$) were purchased from Lumtec. 4,7-diphenyl-1,10-phenanthroline (BPhen) and molybdenum tris(1,2-bis(triuoromethyl)ethane-1,2-dithiolene) (Mo(tfd)$_3$) were supplied by Sigma-Aldrich. All materials were used as received. Weight ratios and thicknesses of the OLED layers: ITO (100 nm); Mo(tfd)$_3$ (2 nm); TCTA (20 nm); TCTA : Ir(ppy)$_3$ 90:10 (20 nm); TCTA : BPhen : Ir(ppy)$_3$ 45:45:10 (20 nm); BPhen : Ir(ppy)$_3$ 90:10 (20 nm); BPhen (20 nm); BPhen : Liq 70:30 (20 nm); Al (1nm); Mo(tfd)$_3$ (4 nm); TCTA (20 nm); TCTA : Ir(ppy)$_3$ 90:10 (20 nm); TCTA : BPhen : Ir(ppy)$_3$ 45:45:10 (20 nm); BPhen : Ir(ppy)$_3$ 90:10 (20 nm); BPhen (20 nm); BPhen : Liq 70:30 (20 nm); Aluminum (100 nm). The samples were unloaded into the attached glove box and glass-encapsulated using epoxy glue.

The optoelectronic properties of the tandem-OLED are depicted in Figure S1, including the current density-voltage-luminance and the current efficiency-luminance curve. The tandem-OLEDs were designed for high luminance beyond 70 000 cd/m^2 in order to efficiently pump the upconverter. High luminance inherently requires high current efficiencies to reduce the dissipated energy and hence to allow stable device operation. Both are enabled by employing a tri-layer mixed host comprising the hole transport material TCTA and the electron transport material BPhen. The central emission layer comprises both hosts and the emitter Ir(ppy)$_3$. The outer two emission layers comprise only either of the two hosts, TCTA or BPhen to gradually improve the transport of one charge carrier species while hindering the transport of the other. The tri-layer mixed host is sandwiched between neat layers of TCTA and BPhen, altogether enforcing charge carrier confinement in the center of the emission layer.

3. Color coordinates of the DPA fluorescence

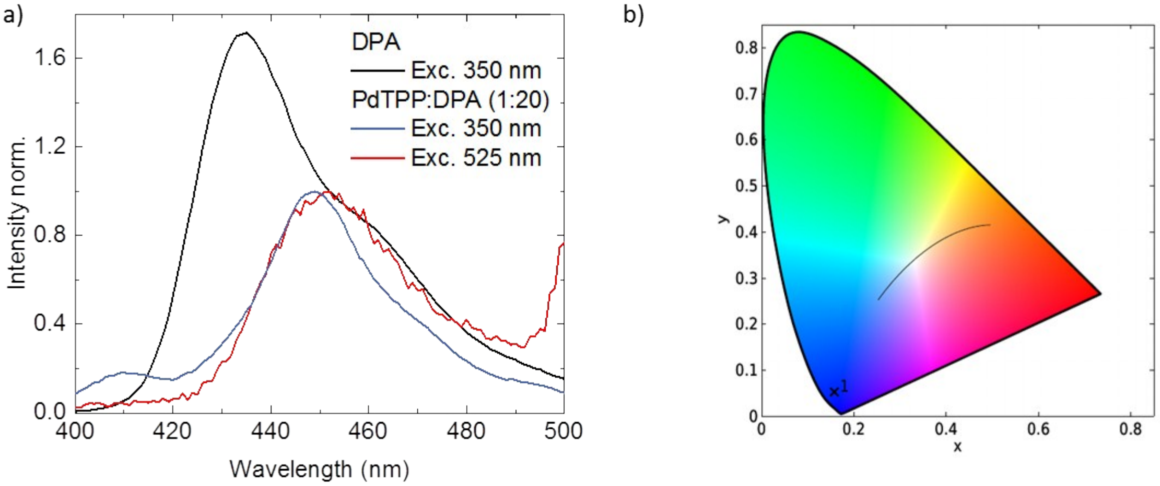

Figure S2: a) Photoluminescence spectra of DPA and DPA:PdTPP (1:20) measured with a Cary Eclipse photoluminescence spectrometer (source: Xenon flashlamp with monochromator) and normalized to the PdTPP:DPA emission (excitation: 525 nm) maximum. b) CIE1931XY Color coordinates (x,y) = (0.16,0.05) of the upconverted DPA emission. The black line marks the Planckian locus.

The photoluminescence spectrum of DPA mixed with PdTPP is redshifted due to absorption in the Soret band of PdTPP (black line compared to blue line). The DPA emission of the upconverter is overlaid by the short-wavelength tail of the green pump-light, as visible in Figure S2a (red line), which renders the determination of the color coordinates of the DPA emission difficult. To avoid the overlay with the pump-light, the upconverter was optically excited at a wavelength of 350 nm and the photoluminescence spectrum was measured (Figure S2a, blue line). Then the CIE1931XY color coordinates (x,y) = (0.16,0.05) were calculated from the photoluminescence spectrum (Figure S2b). Importantly, the photoluminescence spectrum of the upconverter under excitation of the sensitizer as implemented in the OLED/upconverter assembly and the photoluminescence of DPA under 350 nm excitation coincide, validating this approach.

4. Dichroic filter characteristics

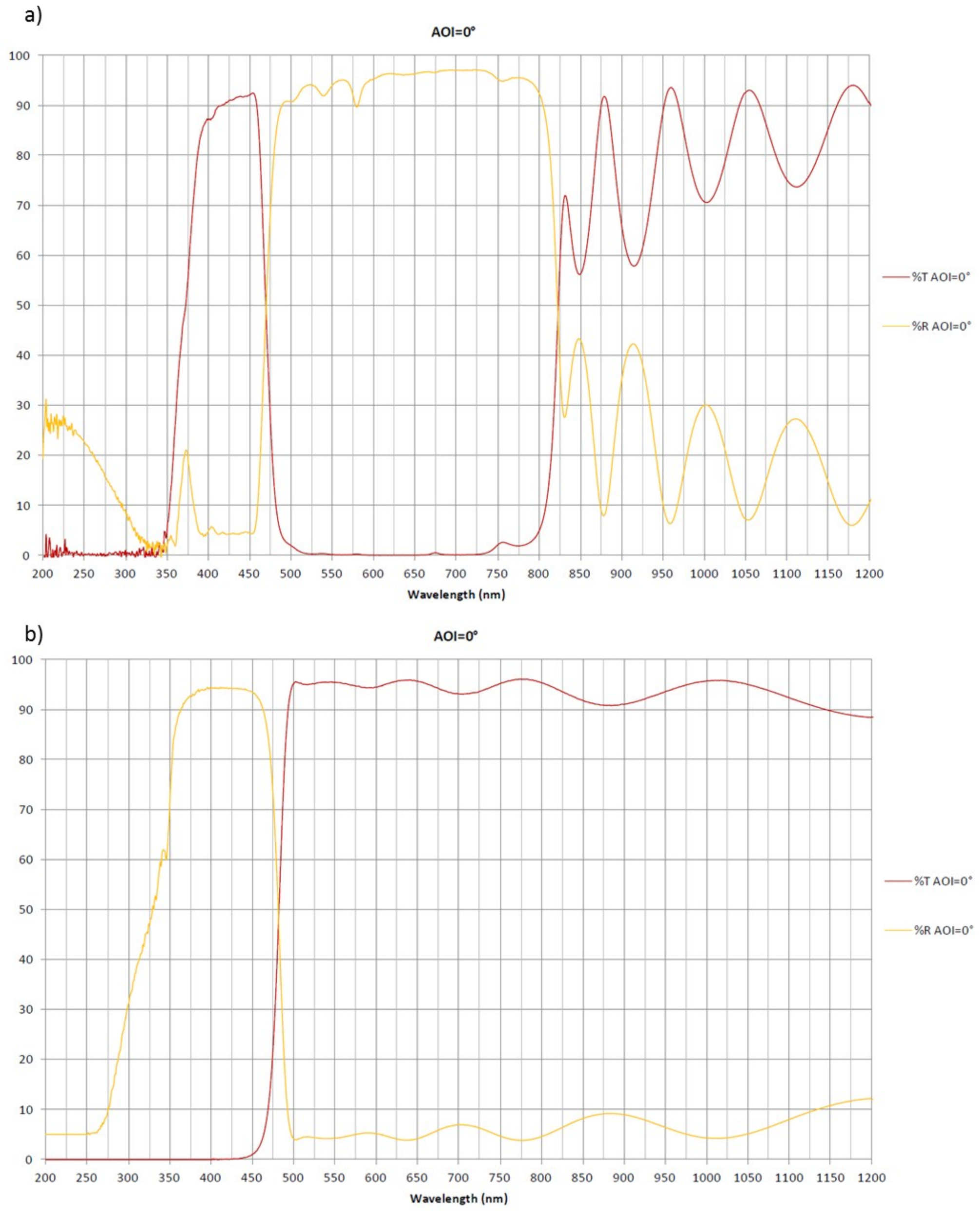

Figure S3: a) Transmission and reflection of the 470 nm short-pass filter (Knight Optical 470FDS). b) Transmission and reflection of the 480 nm long-pass filter (Knight Optical 480FDL).[1]

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[1] www.knightoptical.com Knight Optical (UK) Ltd.