Supplementary information

High-Performance Bifunctional Near-Infrared Diode Enabled by Intentional Manipulation of Energy Transfer and Carrier injection with a Hetero-Active-Layer

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Experimental Section

Materials. Lead iodide (PbI_2, 99.9% purity), Formamidine iodide (FAI, 99.9% purity) were purchased from Xi'an Yuri Solar. 5-aminovaleric acid (5AVA, 97% purity) was purchased from Greatcell Solar. CdSe (CdSe/CdS/CdZnS) QDs and ZnO nanoparticles were purchased from Poly Optoelectronics. TFB (Mw < 60000) was purchased from American Dye Source. N,N-dimethylformamide (DMF) and chlorobenzene (CB) were purchased from Adamas-beta. All materials are used directly without any purification treatment.

Preparation of Perovskite Precursor Solution. 46.1 mg of PbI_2, 41.3 mg of FAI and 8.2 mg of 5-AVA were weighed in a nitrogen glove box and dissolved in 1.35 mL of DMF. The solution was heated and stirred on a hot plate at 60 ^oC for 2 hours and then prepared for use.

Device fabrication. The ITO glasses were cleaned with detergent, and sonicated sequentially with Isopropyl alcohol, and Ethanol for 15 mins, respectively. Then the ITO substrates were treated with oxygen plasma for 20 mins. The ZnO solution was filtered through a 0.2 μm filter and spin coated onto ITO substrates at 4000 rpm for 45 s, and then annealed at 150 ^oC for 25 mins. The device substrates were then transferred into a N_2-filled glove box, and the PEIE solution (0.1 wt%, 2-methoxyethanol as solvent) was spin coated at 5000 rpm for 60 s, then baked at 150 ^oC for 2 mins. The perovskite precursor solution was spin-coated at 3000 rpm for 45s and subsequently annealed at 100 ^oC for 16 mins. The CdSe QDs dispersion (20 mg/mL in chlorobenzene) was spin-coated at 4000 rpm for 60 s and subsequently annealed at 100 ^oC for 5 mins. Afterwards, the TFB (12 mg/mL in m-xylene) was spin-coated at 2000 rpm for 60s. Finally, 5.8 nm MoO_3 and 100 nm Al electrodes were deposited using a thermal evaporation system under a high vacuum of 2×10^{-6} Torr, respectively.

Characterizations. Femtosecond Transient-Absorption spectroscopy was based on a Ti:sapphire regenerative amplifier system (Spectra-Physics Inc.) that produces 800-nm pulses with a 100-fs pulse width and 1000-Hz repetition rate. The UV-visible

absorption spectra were measured using UV-Visible spectrophotometer (Shimadzu, SolidSpec-3700). The fluorescence spectra were obtained on an Edinburgh Instruments FLS980 spectrometer. Confocal PL images and fluorescence lifetime imaging microscopy images were collected using a Leica TCS SP8 nasoscope. The photoluminescence (PL) decay curves were measured with an Edinburgh Instruments FS5 Spectrofuorometer. The on-off and LDR properties were performed on a Zennium system (Zahner, Germany). The current-luminance-voltage (I-L-V) characteristic curve of the EL device was measured by the EL measurement system (Enlitech, LQ-100). J-V characteristics under light and dark conditions were measured by a solar simulator (Enlitech, SS-F5-3A).

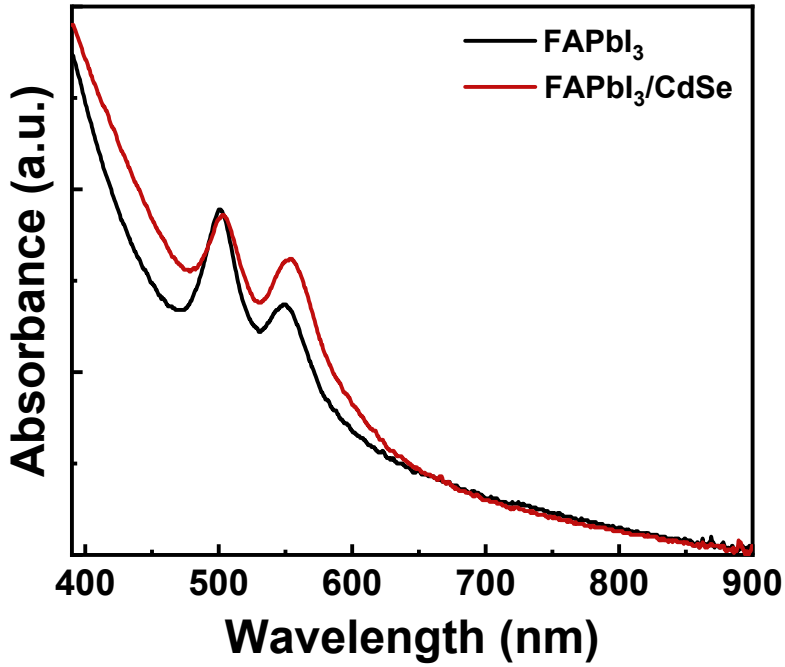

Figure S1. The UV–vis spectra of the $FAPbI_3$ and $FAPbI_3$/CdSe films.

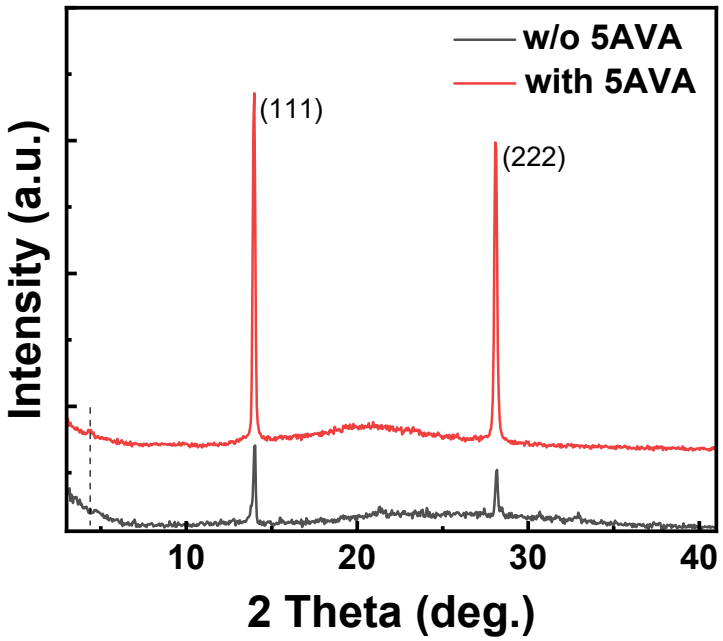

Figure S2. The X-ray diffraction (XRD) patterns of the perovskite films (with or without 5AVA).

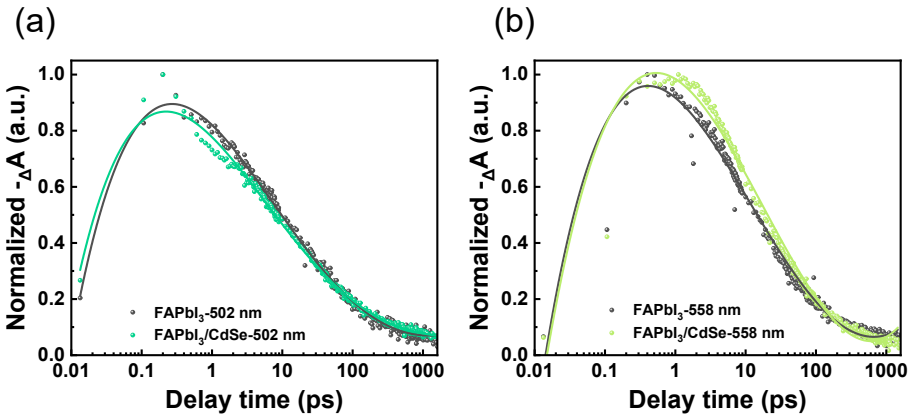

Figure S3. The decay kinetics at the characteristic absorption peaks of $FAPbI_3$ at (a) 502 nm and (b) 558 nm.

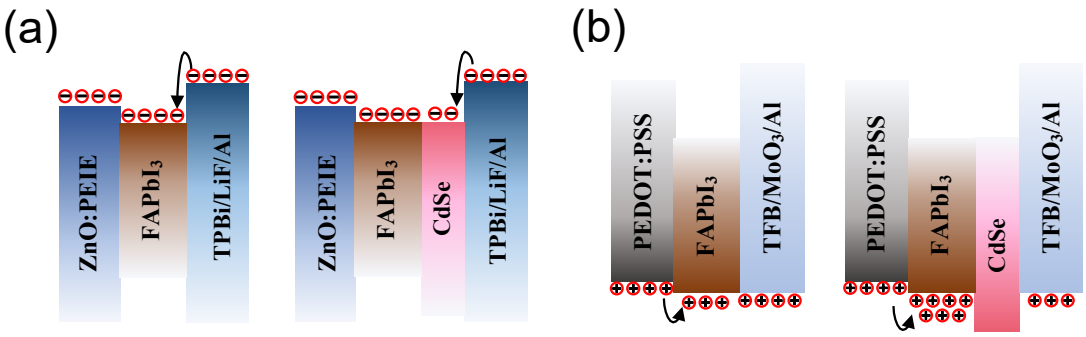

Figure S4. Schematic diagram of (a) electron-only and (b) hole-only devices.

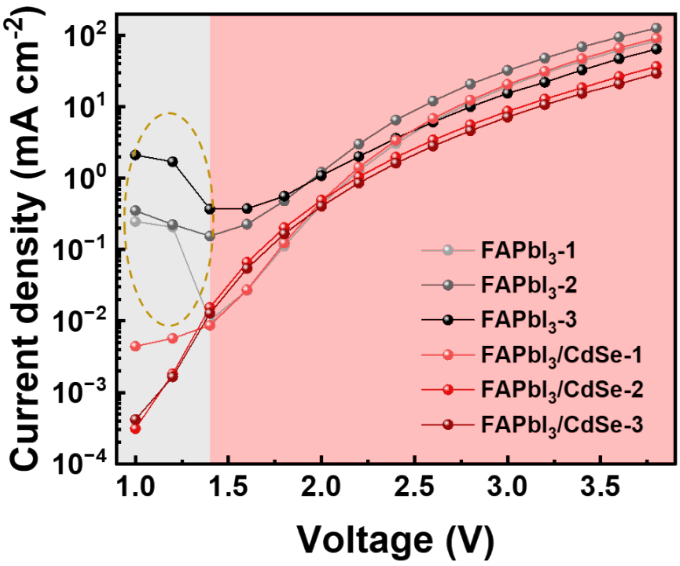

Figure S5. The current density versus voltage characteristic curves of three $FAPbI_3$ and $FAPbI_3$/CdSe devices. The grey area represents the situation when the device is not lit.

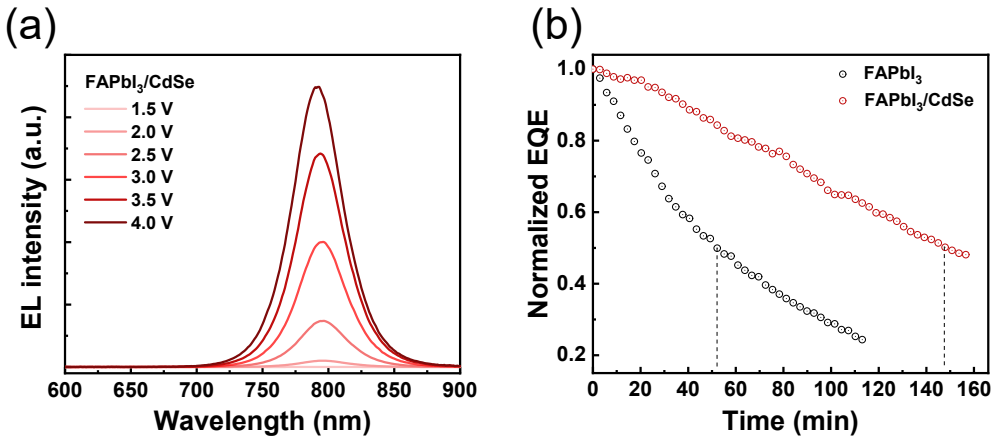

Figure S6. (a) EL spectra of the $FAPbI_3$/CdSe device. (b) Lifetime measurements of the devices under a constant current density of 100 mA/cm^2.

Table S1. Fitting results of time-resolved PL decay curves.

Sample	A1	τ_1(ns)	A2	τ_2(ns)	τ_{ave} (ns)
$FAPbI_3$/CdSe (792 nm)	6869.7	90.2	1466.7	500.0	312.3
$FAPbI_3$ (792 nm)	7114.8	29.4	1162.1	189.7	111.7
$FAPbI_3$/CdSe (618 nm)	5266.1	1.7	4951.8	6.7	5.6
CdSe (618 nm)	6928.9	8.6	3159.4	16.5	12.3