

Electronic supplementary information

Solution processed flexible and bending durable heterojunction colloidal quantum dot solar cell

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Experimental details

Materials preparation: PbS QDs were synthesized according to the method reported by Sargent.¹

² The obtained PbS QDs were dispersed in octane (~50 mg mL⁻¹) and stored in an argon-filled glovebox until use. ZnO NPs with a size of ~5 nm were synthesized according to the literature with modification.³ Briefly, zinc acetate dihydrate (932 mg) was dissolved in methanol (40 mL) in a three necked flask, and then heated at 60 °C for 30 min under magnetic stirring. Potassium hydroxide (467 mg) was dissolved in methanol (20 mL), of which was slowly added to the zinc acetate solution (~15 min) under stirring and the mixed solution was kept at 60 °C for 150 min. ZnO NPs were separated using centrifugation and washed several times with methanol and finally were dispersive in chloroform getting a concentration ~10 mg mL⁻¹.

Solar cell fabrication: ITO covered PET with a thickness of 0.2 mm was cleaned with water, acetone, and iso-propanol, respectively, and dried with nitrogen. The PET substrate was mounted on a glass substrate during the solar cell fabrication. For the solar cell with the regular architecture, a ZnO NP layer was firstly deposited on the PET substrate by spin-coating ZnO NP chloroform solution at 3000 rpm for 30 s. PbS QD layer was deposited on the ZnO NP layer using layer-by-layer spin-casting method under ambient condition. The PbS QD solution was dispensed on the ZnO NP layer and spun at 2500 rpm for 15 s. 1 % 3-mercaptopropionic acid (MPA) in methanol (v/v) was dropped on the QD film for ligands exchange and following also spun at 2500 rpm. The QD film was washed with methanol and spun at 2500 rpm for two times. The above procedures were repeated until the desired QD film thickness was reached. The hole

conductor layer was covered on the QD film by spin-coating a mixture solution of P3HT (20 mgmL⁻¹), bis(trifluoromethane)sulfonimide lithium salt (LiTFSI, 64 mM), 4-tert-butylpyridine (TBP, 198 mM) and chlorobenzene at 3000 rpm for 60 s. An Ag counter electrode with a thickness of ~150 nm was finally deposited on the hole conductor layer using a thermal evaporator (LEICA EM MED020) in a vacuum of 4×10^{-5} Torr, forming the complete solar cell with a regular architecture. For the solar cell with the inverted architecture, PEDOT:PSS solution was firstly spin-coated on PET substrate at 4000 rpm for 60 s, and subsequently annealed at 140 °C for 30 min. PbS QD layer was deposited on the PEDOT:PSS layer using above demonstrated procedures. A ZnO NP layer was spin-coated on the QD layer, and finally a counter electrode Al with a thickness of ~100 nm was deposited on ZnO NP layer forming the complete solar cell with an inverted architecture. The solar cell based on the glass substrate was fabricated on an ITO covered glass substrate using above procedures.

Solar cell characterization: A light intensity of 100 mWcm⁻² AM1.5 illumination was provided using a Newport solar simulator (model 91160) that was calibrated using a certified reference Si solar cell (Fraunhofer ISE). The *J-V* curves were recorded by means of a Keithley model 2400 digital source meter. A black mask with a capture area of 7 mm² was applied during photovoltaic measurement. IPCE spectra were recorded using a computer-controlled setup consisting of a xenon lamp (Spectral Products ASBXE 175), a monochromator (Spectral Products CM110), a LabJack U6, and a potentiostat (PINE, AFRDE 5). The setup was calibrated using a certified reference solar cell (Fraunhofer ISE) prior to measurement. The bendable solar cell was mechanically bent with a diameter of 40 mm for bending stability test. The performance of the solar cell under the bent state was measured by fixing the flexible solar cell on the tube with a diameter of 15-105 mm.

Materials characterization: Light absorption and transmission spectra were measured using an Ocean Optics HR2000 spectrometer with a Micropack DH-2000-BAL light source. SEM images were collected using a scanning electron microscopy (SEM, Zeiss LEO1550) at an accelerating voltage of 5 kV, and TEM images and electron diffraction patterns were performed using a transmission electron microscope (JSM 2100) at an accelerating voltage of 200 kV.

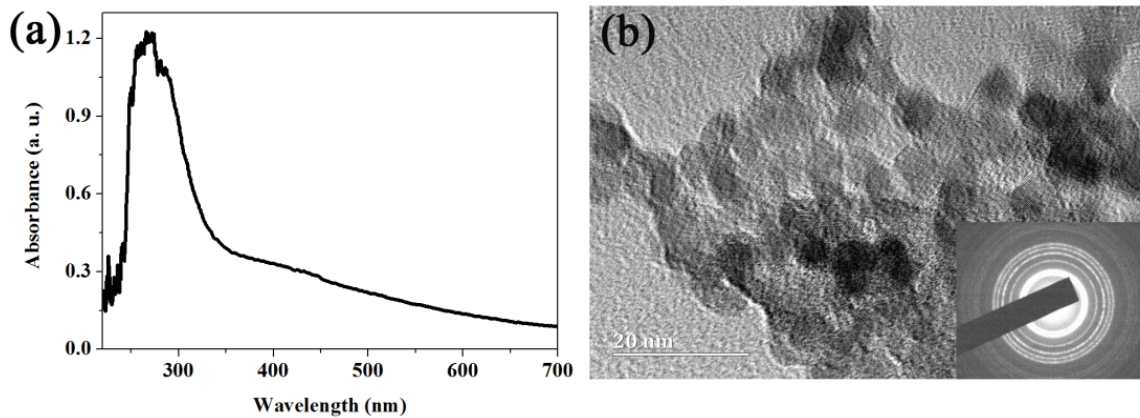


Fig. S1 (a) Light absorption spectrum and (b) TEM image of ZnO nanoparticles. Inset is electron diffraction pattern.

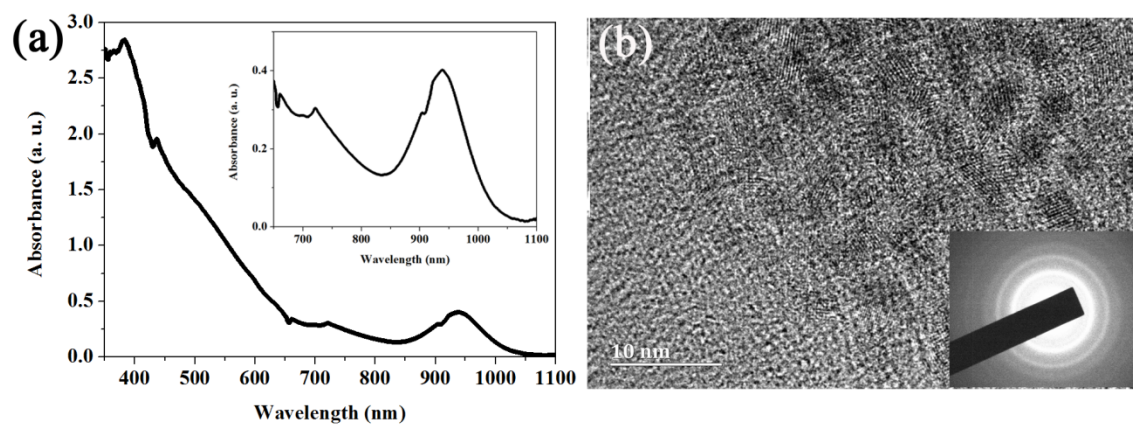


Fig. S2 (a) Light absorption spectrum of PbS QDs. Inset is magnified light absorption in a range of 650-1100nm. (b) TEM image of PbS QDs. Inset is electron diffraction pattern.

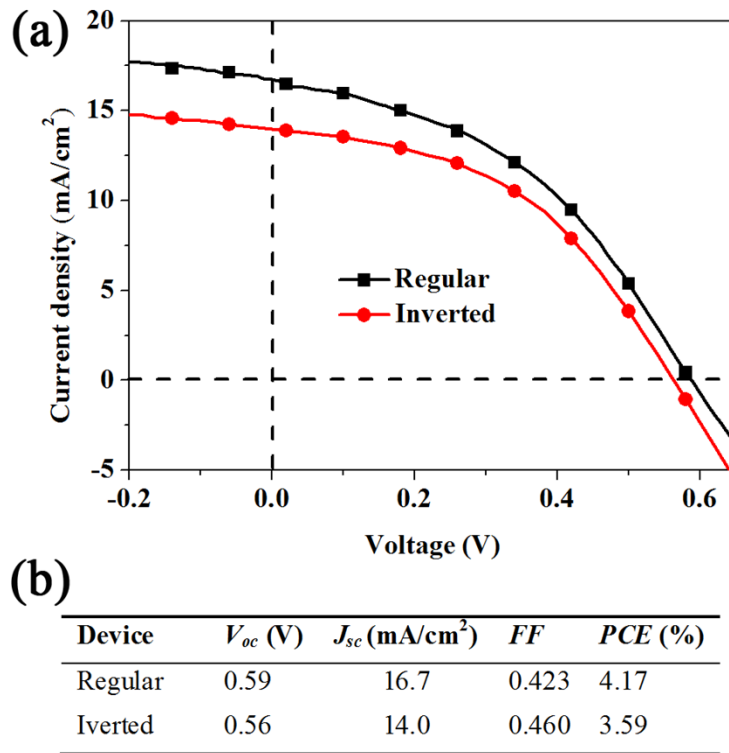


Fig. S3 (a) J - V characteristics curves of the solar cell with a regular architecture and an inverted architecture, respectively. The solar cells were fabricated on an ITO covered glass substrate. The measurements were performed under a light intensity of 100 mWcm^{-2} (AM 1.5) and ambient atmosphere condition. (b) Photovoltaic parameters of above solar cell.

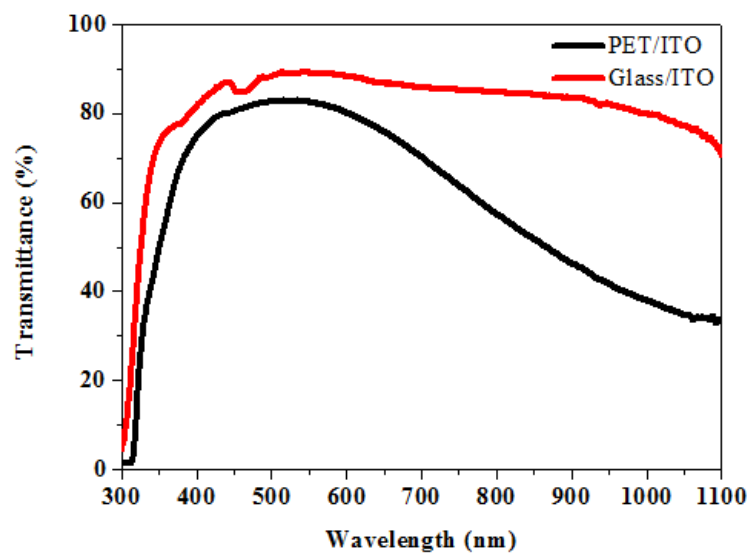


Fig. S4 Light transmission spectra of ITO covered PET substrate and glass substrate.

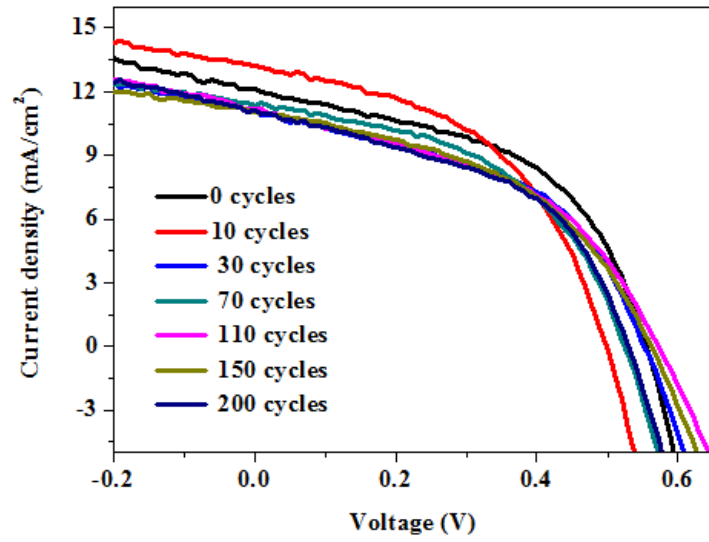


Fig. S5 J - V characteristics curves of bendable solar cell after mechanical bending various cycles with a diameter of 40 mm.

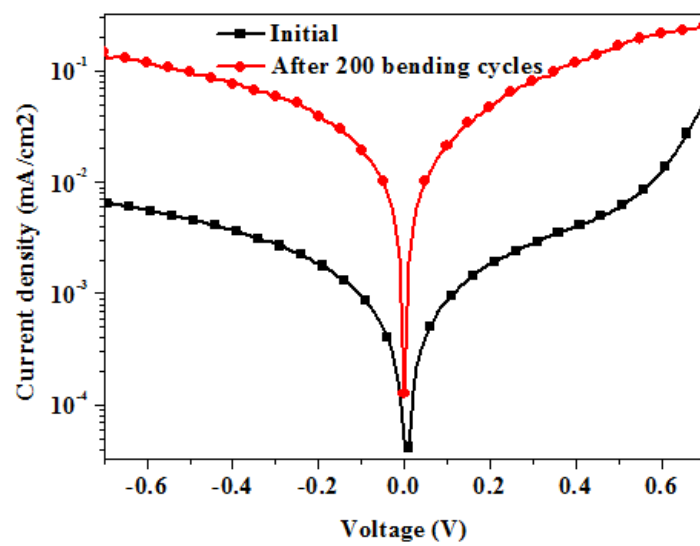


Fig. S6 Dark current curves of bendable solar cell before and after mechanical bending test with a diameter of 40 mm.

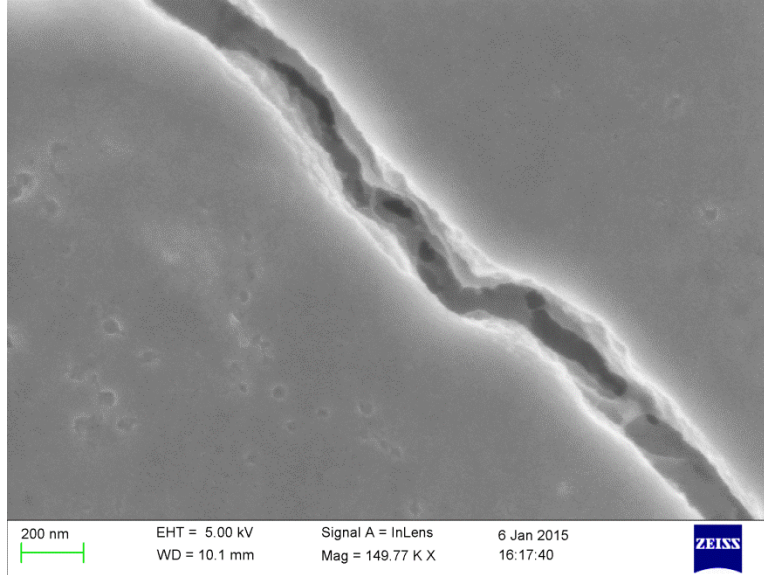


Fig. S7 Top surface SEM image of QD film after mechanical bending test. The sample is similar with the solar cell except without the hole transport materials and top contact electrode.

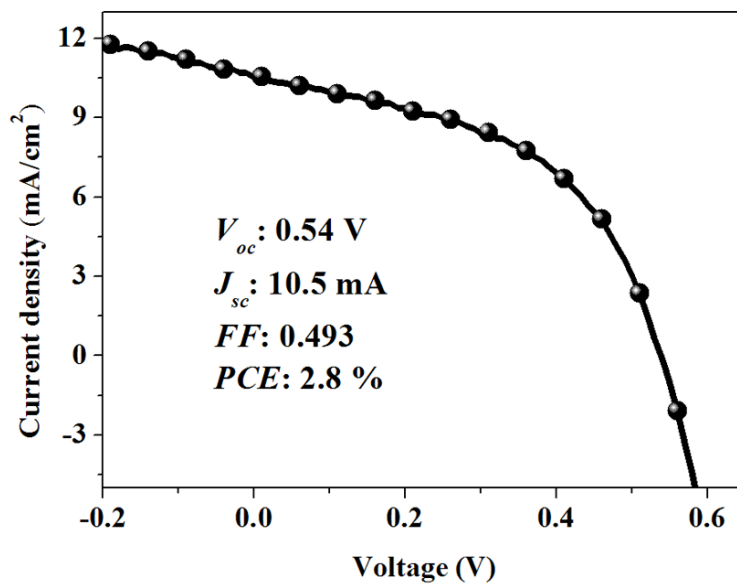


Fig. S8 J - V characteristics curve of the bendable QD solar cell bending with a diameter of 40 mm.

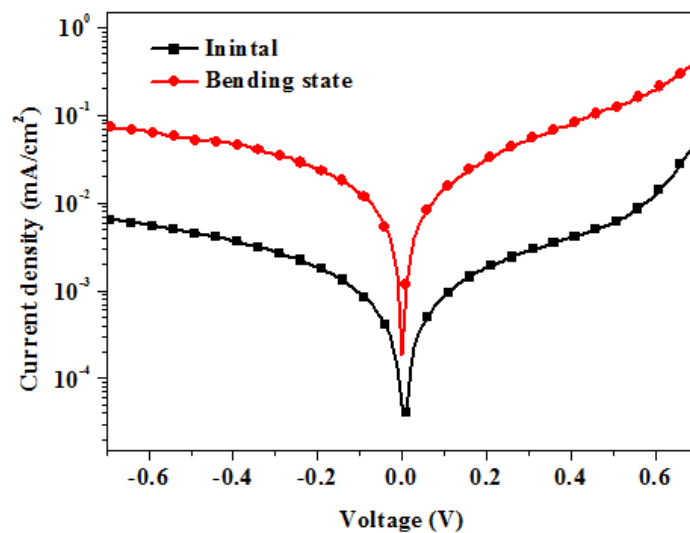


Fig. S9 Dark current curves of the bendable solar cell under flat state (initial state) and bent state with a diameter of 40 mm.

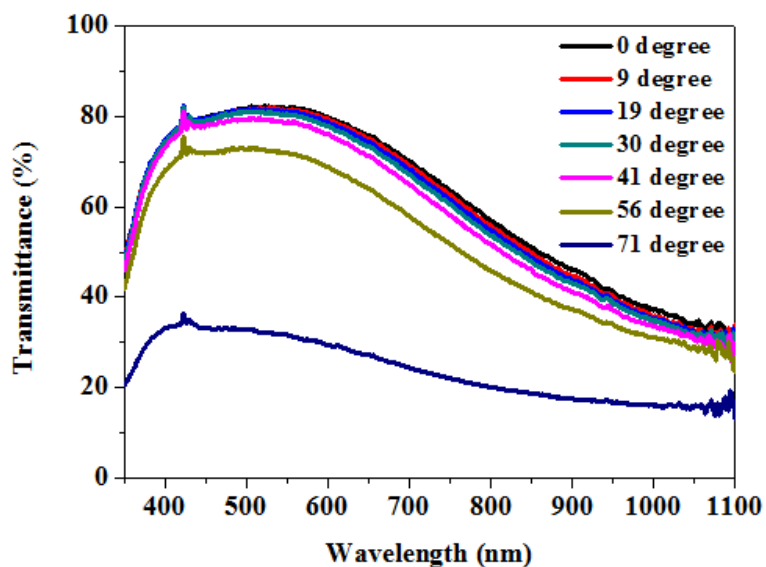


Fig. S10 Light transmission spectra of PET substrate with different light incident angle (versus the normal to the substrate).

References

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