Supporting Information

High Performance PbS Quantum Dot/Graphene Hybrid Solar Cell with Efficient Charge Extraction

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Fig. S1 (a) X-ray diffraction patterns and HRTEM image (inset) of the PbS nanocrystal. (b) Representative SEM image of SG flakes (average lateral size of ~550 nm) homogeneously deposited on PbS QD film.

The crystallinity of the PbS QD film is examined by the XRD measurement as shown in Figure S1a. Well-defined diffraction peaks were assigned to the (111), (200), (220), and (311) planes, respectively. It clearly implies that the PbS in the solid state has a face-center-cubic (fcc) structure. The HRTEM lattice fringe image is taken from a 1.3 eV PbS QD and the diameter of the QD is approximately 2.5 nm (inset).

Fig. S2 UV-vis absorption of 1.3 eV PbS QDs capped with oleic acid in solution (peak
around 950 nm). A size distribution of the corresponding PbS QD is obtained with a mean diameter of ~ 2.5 nm.

**Fig. S3** 10 x 10 µm AFM images showing the surface morphologies of (a and b) PbS and (c and d) PbS/SG films. The root mean square (RMS) roughness are 13.204 and 11.641 nm, respectively. The image area is 10 x10 µm.

**Fig. S4** Schematic of devices of (a) TBAI-PbS, (b) TBAI-PbS/SG (5L), and (c) TBAI-PbS/SG (9L).
PbS/SG (9L). All devices are fabricated under the same conditions and consist of 12 layers of TBAI-PbS with 0, 5, and 9 layers of SG flake. For the hybrid cell fabrication, 5 and 9 layers of SG flake were symmetrically inserted in the TBAI-PbS layers as seen in Fig. S4 (b) and (c).

Fig. S5 Schematic of (a) TBAI-PbS/EDT-PbS and (b) TBAI-PbS/SG (9L)/EDT-PbS junction solar cells. They consist of 10 layers of TBAI-PbS and 2 layers of EDT-PbS on ZnO/ITO/glass substrates. For the hybrid cell fabrication, 9 layers of SG flake were inserted in TBAI-PbS CQD layers.

Table S1 Photovoltaic performance of TBAI-PbS/EDT-PbS and TBAI-PbS/SG (9L)/EDT-PbS junction structure. Average values of each device with standard deviations were collected from four devices.

|                      | $V_{oc}$ (V) | FF   | $J_{sc}$ (mA/cm$^2$) | $R_s$ (Ω) | PCE (%) |
|----------------------|--------------|------|----------------------|-----------|---------|
| TBAI-PbS/EDT-PbS     | 0.51±0.01    | 0.62±0.02 | 23.61±0.10          | 2.10±0.28 | 7.53±0.18 |
| TBAI-PbS/SG (9L)     | 0.48±0       | 0.61±0.03 | 29.81±0.66          | 1.47±0.78 | 8.82±0.55 |
| TBAI-PbS/SG (9L)     | 0.48         | 0.63    | 30.34                | 1.46      | 9.18     |

* Best performance of TBAI-PbS/SG (9L)/EDT-PbS junction device.

Table S2 Photoresponse characteristics of PbS and PbS/SG devices.
| off state (pA) | on state (nA) | on-off ratio | Rise time (τ, msec) |
|---------------|---------------|--------------|---------------------|
| PbS           | 310           | 8.91         | 28.74               | 3.3                 |
| PbS/SG        | 272           | 10.6         | 38.97               | 2.1                 |