Supplementary Materials for

A bulk Schottky junction for high-sensitivity portable radiation detectors

Yihan Zhang, Zongming Huang, Ning Gao, Xie George Xu, Yaping Li, Cheng Zheng, Yidong Yang, Jingjing Zhao, Zhengguo Xiao*

Correspondence to: zhengguo@ustc.edu.cn

Section 1: Calculation of the barrier width and built-in electric field of the Schottky barrier

It has been reported that the conduction band minimum (E_c) and valence band maximum (E_v) of $MAPbI_3$ are -3.9 eV and -5.4 eV, respectively, and the work function of carbon is -5.0 eV[1]. From the KPFM result, we know that the Fermi level of $MAPbI_3$ (E_F) is approximately -4.85 eV. Thus, the built-in potential difference (V_D) is 0.15 V.

The width x_d of the Schottky barrier can be calculated by the following equation:

$$x_d = \left(\frac{2\varepsilon_r \varepsilon_0 V_D}{qN_A}\right)^{\frac{1}{2}}$$

where ε_0 is the vacuum permittivity, ε_r is the dielectric constant, q is the electron charge, and N_A is the acceptor concentration. N_A can be derived as:

$$N_A = N_v \times \exp\left(\frac{E_v - E_F}{k_0 T}\right)$$

N_v is the effective density of states in the valance bands, k_0 is the Boltzmann constant, and T is the temperature. N_v can be calculated by the following equation:

$$N_v = 2\left(\frac{m_h kT}{2\pi\hbar^2}\right)^{\frac{3}{2}}$$

m_h is the relative mass of holes, and $\hbar$ is the reduced Planck constant. For $MAPbI_3$, m_h is 0.29 m_0, and m_0 is the electronic inertial mass. Thus, N_v is approximately 3.9×10^{24} cm^{-3}.

According to the above equations, the barrier width x_d of the Schottky barrier is calculated to be 0.73 μm, which is comparable to the pore size of the microporous carbon membrane. The built-in electric field of the Schottky barrier is estimated to be approximately 0.2 V/μm based on the equation $E=V_D/x_d$.

Section 2: Calculation of the theoretical maximum sensitivity of the X-ray detector

The following equation is used to calculate the theoretical S_m value[2]:

$$S_m = \frac{\frac{\phi}{X}\bar{E}\beta}{W_{\pm}} e\eta$$

where ϕ is the photon fluence (photons/mm^2), X is the dose per unit of exposure, $\overline{E}$ is the mean energy of the X-ray photons, β is the X-ray absorption efficiency, e is the elemental electron charge, η is the carrier collection efficiency of the detector, and $W_{\pm}$ is the ionization energy. In our experiment, the $\overline{E}$ value is ~16 keV. It has been reported that the ϕ/X value reaches 3.78×10^{11} photons cm^{-2} Gy_{air}^{-1} for X-rays with a mean energy of 16 keV[3]. The β is calculated to be approximately 87% for the microporous carbon/perovskite membranes according to the energy spectrum of our X-ray source and the absorption coefficient of $MAPbI_3$. The η value at -1 V is estimated to be approximately 93% by comparing the sensitivity under -1 V and maximum sensitivity. The $W_{\pm}$ value is 4.43 eV according to the empirical equation: $W_{\pm} = 2E_g + 1.43$ eV. Therefore, the theoretical S_m value of the BSJ detectors at -1 V can be obtained, which is 176 μC Gy_{air}^{-1} cm^{-2}.

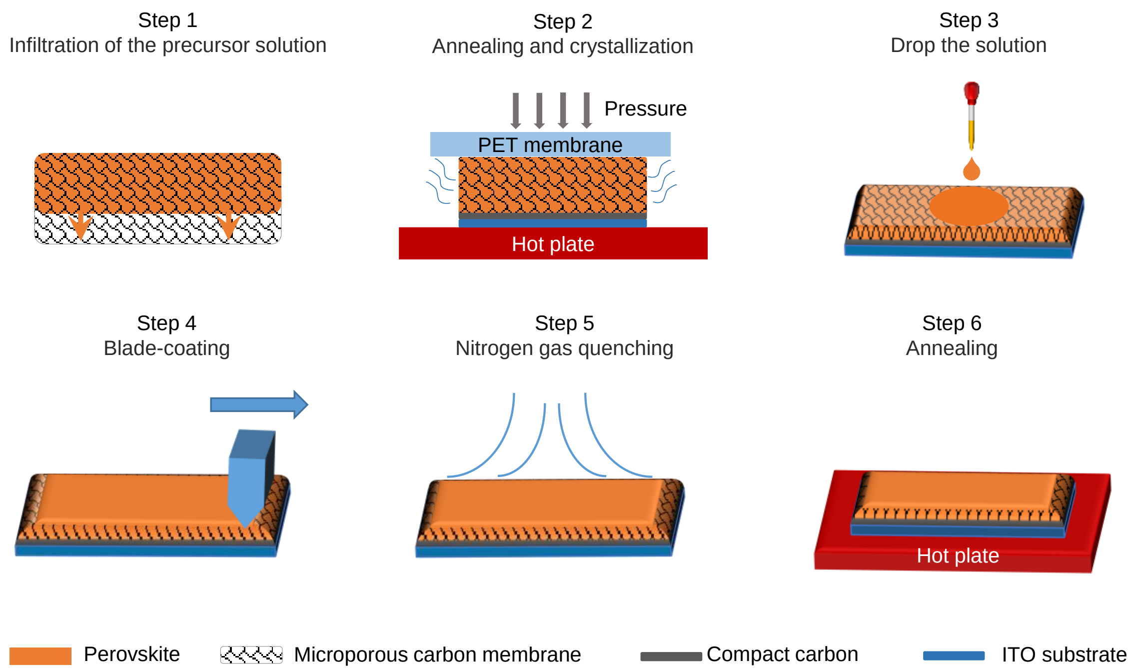

Figure S1. Schematics of microporous-carbon-perovskite membrane fabrication process.

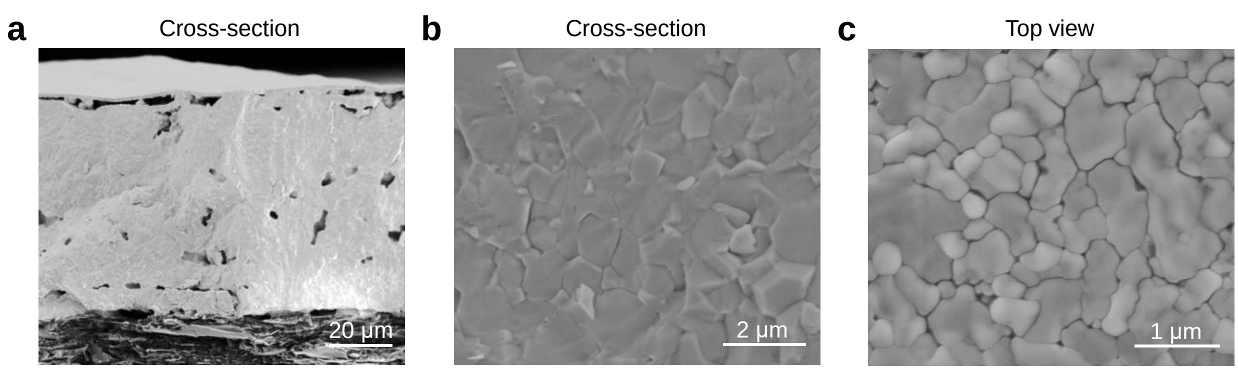

Figure S2. Cross-sectional (a and b) and top view (c) SEM images of thick perovskite film.

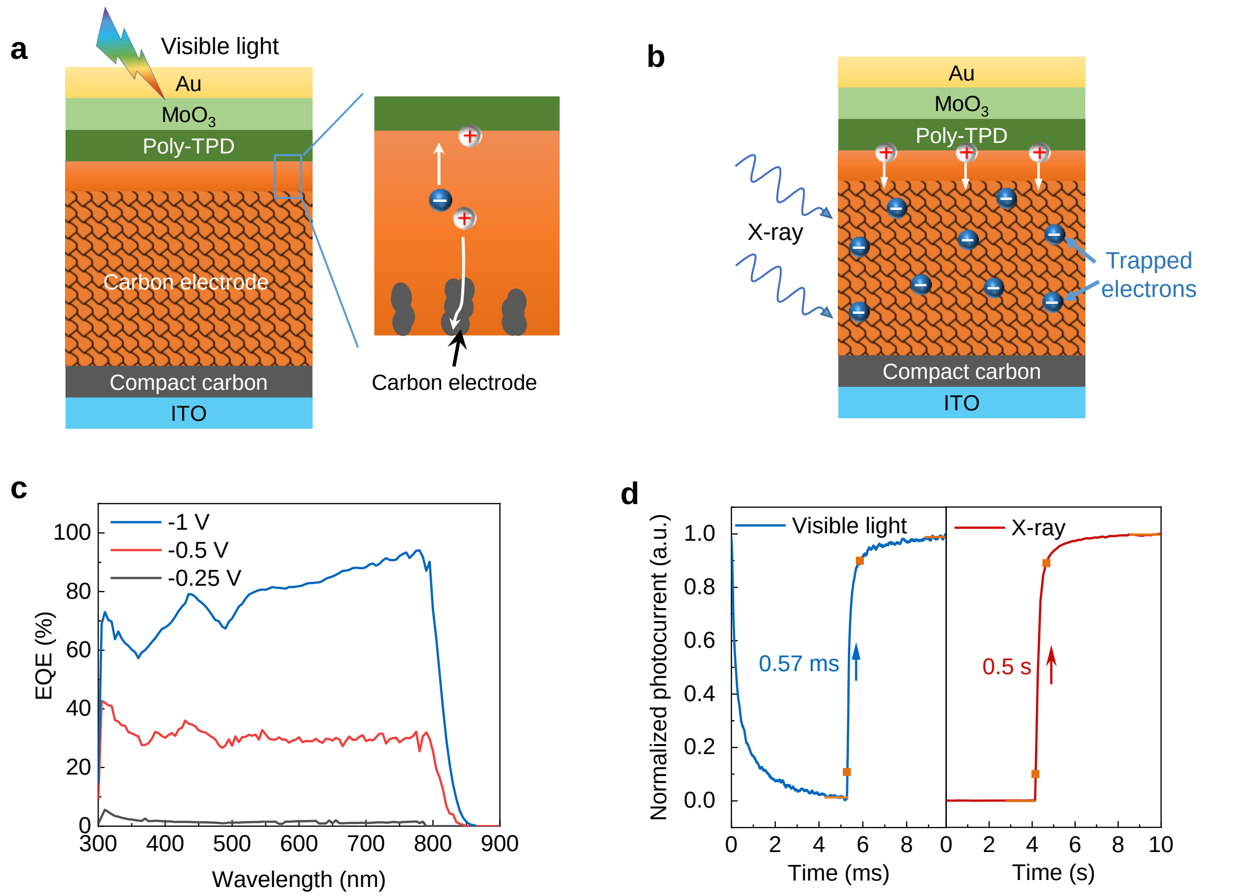

Figure S3. a, b, Schematic of the BSJ detector under visible light (a) and under X-ray (b). **c,** EQE of the BSJ detector under different voltages. **d,** Response time of the BSJ detector under visible light and X-ray.

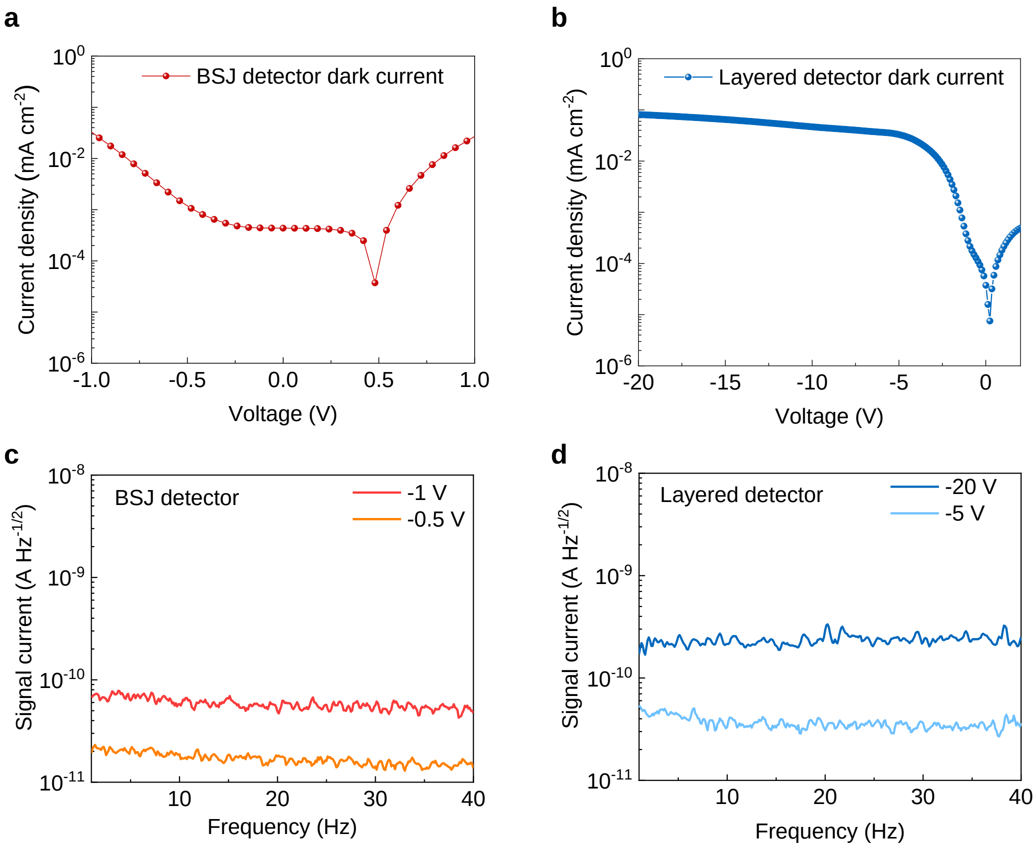

Figure S4. Dark current density of the BSJ detector (a) and conventional layered detector (b) under working conditions. Noise current of microporous structure detectors (c) and layered structure detectors (d) under working conditions.

References

1 Chen, H. & Yang, S. Carbon-Based Perovskite Solar Cells without Hole Transport Materials: The Front Runner to the Market? *Adv. Mater.* **29**, 1603994 (2017).

2 Liu, Y. *et al.* Triple-Cation and Mixed-Halide Perovskite Single Crystal for High-Performance X-ray Imaging. *Adv. Mater.* **33**, 2006010 (2021).

3 Pan, W. *et al.* $Cs_2AgBiBr_6$ single-crystal X-ray detectors with a low detection limit. *Nat. Photon.* **11**, 726-732 (2017).