Electronic Supplementary Material (ESI) for Physical Chemistry Chemical Physics.

Supporting Information

Hole transport free carbon-based high thermal stability $CsPbI_{1.2}Br_{1.8}$ solar cells with amorphous $InGaZnO_4$ electron transport layer

Cong Zhang, Xingtian Yin*, Yuxiao Guo, Haixia Xie, Dan Liu, Wenxiu Que*

Electronic Materials Research Laboratory, Key Laboratory of the Ministry of Education & International Center for Dielectric Research, Shaanxi Engineering Research Center of Advanced Energy Materials and Devices, School of Electronic Science and Engineering, Xi'an Jiaotong University, Xi'an 710049, Shaanxi, P. R. China

*Corresponding authors: xt_yin@mail.xjtu.edu.cn (XT Yin), wxque@mail.xjtu.edu.cn (WX Que)

Table S1 Summary of major performance of devices with or without hole transport layer

Cell configuration	PCE (%)	J_{SC} (mA/cm^2)	V_{OC} (V)	FF
ITO/a-IGZO/$CsPbI_{1.2}Br_{1.8}$/C	9.07	13.60	1.23	0.54
ITO/a-IGZO/$CsPbI_{1.2}Br_{1.8}$/Spiro-OMeTAD/Au	9.29	12.41	1.25	0.60

Table S2 Summary of major performance of carbon-based devices in recent years

	Cell configuration	PCE (%)	J_{SC} (mA/cm^2)	V_{OC} (V)	FF	Ref.
1	ITO/a-IGZO/$CsPbI_{1.2}Br_{1.8}$/C	9.07	13.6	1.23	0.54	This work
2	FTO/c-TiO_2/$CsPbIBr_2$/C	8.10	10.99	1.27	0.58	[1]
3	FTO/c-TiO_2/$CsPbIBr_2$/C	6.55	9.11	1.14	0.63	[2]
4	FTO/c-TiO_2/$CsPbIBr_2$/C	7.46	10.7	1.26	0.55	[3]
5	FTO/c-TiO_2/$CsPbIBr_2$/C	8.60	11.17	1.28	0.60	[4]
6	FTO/c-TiO_2/m-TiO_2/$CsPbIBr_2$/C	8.25	-	-	-	[5]
7	FTO/c-TiO_2/m-TiO_2/$CsPbIBr_2$/C	6.14	-	-	-	[6]
8	FTO/c-TiO_2/$CsPbIBr_2$/CuPc/C	8.76	10.4	1.29	0.65	[7]
9	FTO/c-TiO_2/$CsPbIBr_2$/CuPc/C	7.41	9.32	1.15	0.69	[8]
10	FTO/c-TiO_2(CsBr)/$CsPbIBr_2$/C	10.71	11.8	1.26	0.72	[9]
11	FTO/SnO_2/$CsPbIBr_2$/C	4.36	8.56	0.99	0.54	[10]
12	ITO/SnO_2/$CsPbIBr_2$/C	4.73	7.55	1.07	0.58	[11]
13	ITO/SnO_2($SnCl_2$)/$CsPbIBr_2$/C	7.00	8.50	1.23	0.67	[11]

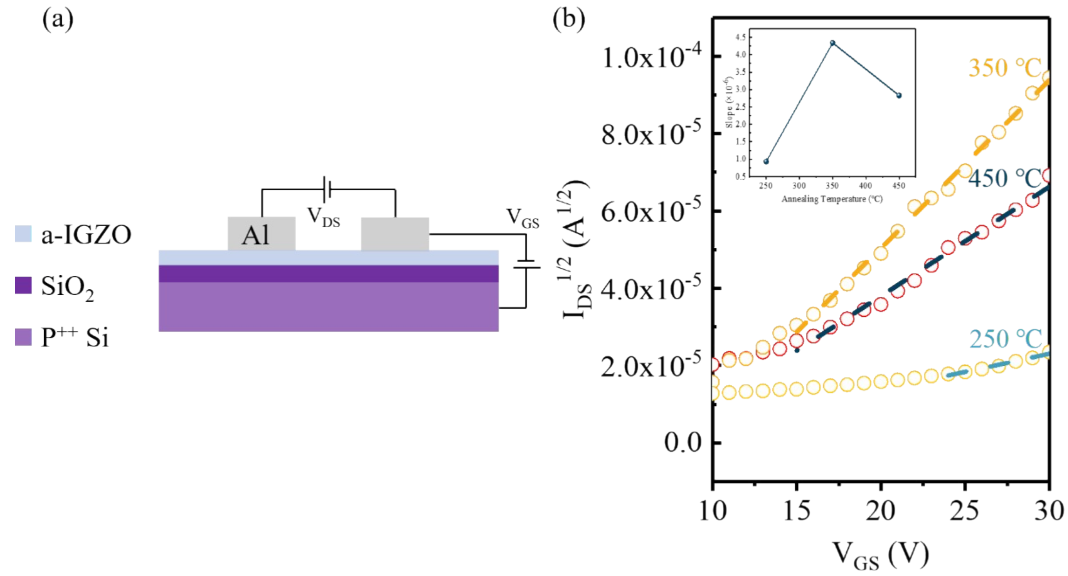

Figure S1. (a) A-IGZO thin film field effect transistor device structure diagram. (b) $I_{DS}^{1/2}$-V_{GS} curve of a-IGZO thin films with different annealing temperature. The illustration shows the value of the slope of the fitting curve.

A-IGZO thin films with different annealing temperatures can be used as active layers of thin film field effect transistors and the relative field effect carrier mobility of a-IGZO thin films can be characterized by drawing $I_{DS}^{1/2}$-V_{GS} diagrams. The device structure diagram is shown in Figure S1(a), according to formula 1, the field effect mobility of the film is proportional to the square of the slope of the $I_{DS}^{1/2}$-V_{GS} curve.

$$I_{DS} = \mu_{FE}\frac{W}{2L}C_i(V_{GS} - V_{TH})^2$$

$$\mu_{FE} = \frac{2L \times Slope^2}{WC_i} \# formula\ 1$$

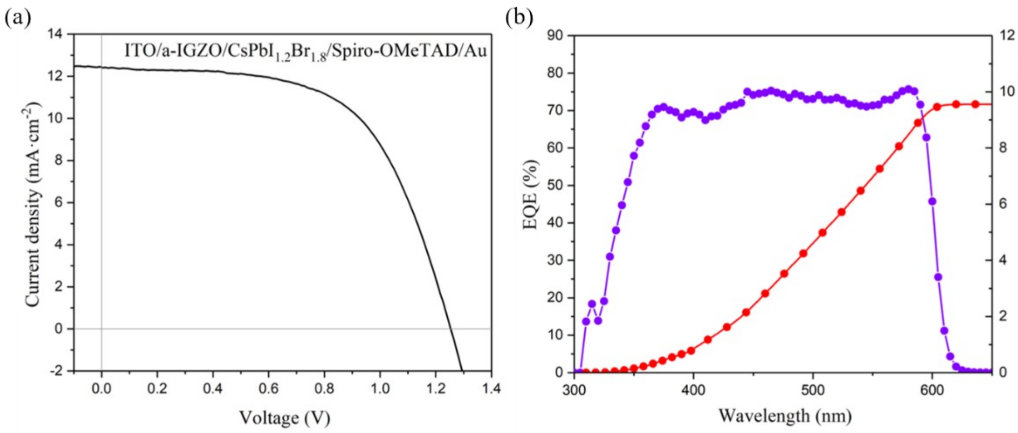

Figure S2. J-V curve (a) and EQE spectra and the corresponding integrated current densities (b) of the device with structure of ITO/a-IGZO (350 °C)/$CsPbI_{1.2}Br_{1.8}$/Spiro-OMeTAD/Au

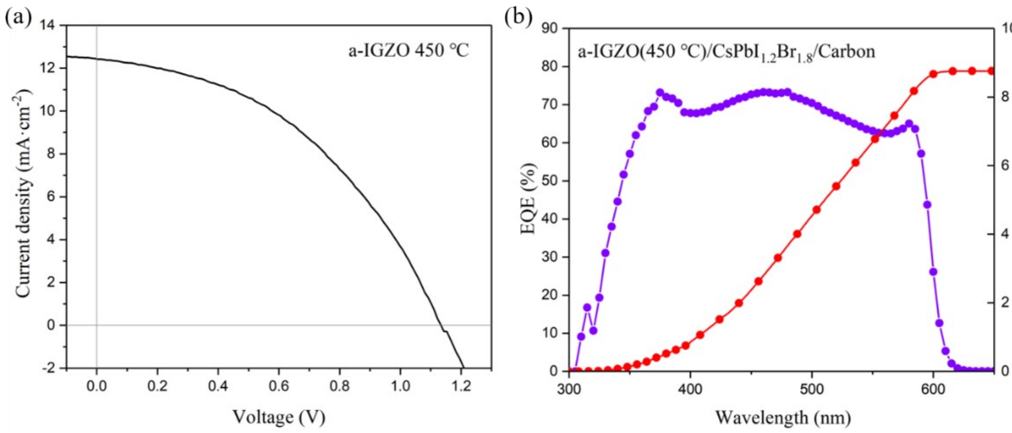

Figure S3. J-V curve (a) and EQE spectra and the corresponding integrated current densities (b) of the device with structure of ITO/a-IGZO (450 °C)/$CsPbI_{1.2}Br_{1.8}$/Carbon

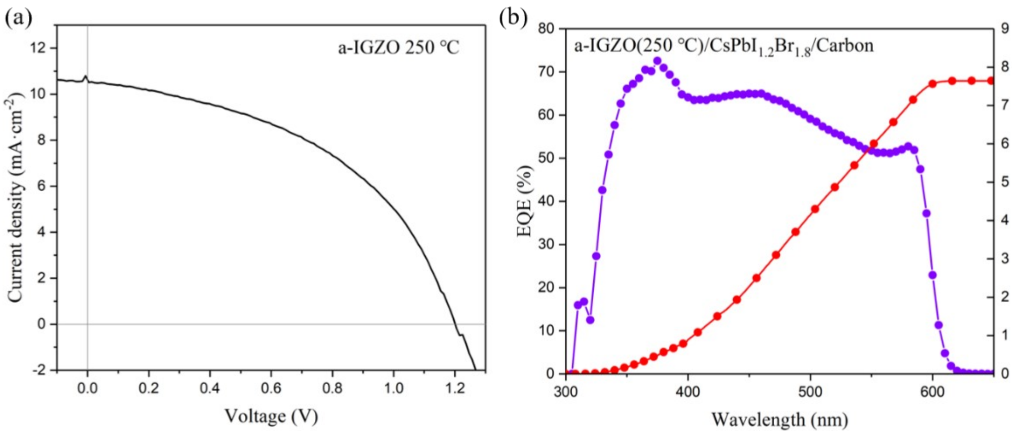

Figure S4. J-V curve (a) and EQE spectra and the corresponding integrated current densities (b) of the device with structure of ITO/a-IGZO (250 °C)/$CsPbI_{1.2}Br_{1.8}$/Carbon

Notes and references

1. Wang, G.; Liu, J.; Lei, M.; Zhang, W.; Zhu, G., Optimizing the substrate pre-heating and post-annealing temperatures for fabricating high-performance carbon-based CsPbIBr2 inorganic perovskite solar cells. *Electrochim. Acta* **2020,** *349*.

2. Zhu, W.; Zhang, Q.; Zhang, C.; Zhang, Z.; Chen, D.; Lin, Z.; Chang, J.; Zhang, J.; Hao, Y., Aged Precursor Solution toward Low-Temperature Fabrication of Efficient Carbon-Based All-Inorganic Planar CsPbIBr2 Perovskite Solar Cells. *ACS Appl. Energy Mater.* **2018,** *1* (9), 4991-4997.

3. Chen, D.; Tian, B.; Fan, G.; Wang, Y.; Zhu, W.; Ren, Z.; Xi, H.; Su, K.; Zhang, J.; Zhang, C.; Zhang, J.; Hao, Y., Simple and Convenient Interface Modification by Nanosized Diamond for Carbon Based All-Inorganic CsPbIBr2 Solar Cells. *ACS Appl. Energy Mater.* **2021,** *4* (6), 5661-5667.

4. Zhang, Q.; Zhu, W.; Chen, D.; Zhang, Z.; Lin, Z.; Chang, J.; Zhang, J.; Zhang, C.; Hao, Y., Light Processing Enables Efficient Carbon-Based, All-Inorganic Planar CsPbIBr2 Solar Cells with High Photovoltages. *ACS Appl. Mater. Inter.* **2019,** *11* (3), 2997-3005.

5. Liang, J.; Zhao, P.; Wang, C.; Wang, Y.; Hu, Y.; Zhu, G.; Ma, L.; Liu, J.; Jin, Z., CsPb0.9Sn0.1IBr2 Based All-Inorganic Perovskite Solar Cells with Exceptional Efficiency and Stability. *J. Am. Chem. Soc.* **2017,** *139* (40), 14009-14012.

6. Liang, J.; Liu, Z.; Qiu, L.; Hawash, Z.; Meng, L.; Wu, Z.; Jiang, Y.; Ono, L. K.; Qi, Y., Enhancing Optical, Electronic, Crystalline, and Morphological Properties of Cesium Lead Halide by Mn Substitution for High-Stability All-Inorganic Perovskite Solar Cells with Carbon Electrodes. *Adv. Energy Mater.* **2018,** *8* (20).

7. Liu, X.; Li, J.; Liu, Z.; Tan, X.; Sun, B.; Xi, S.; Shi, T.; Tang, Z.; Liao, G., Vapor-assisted deposition of CsPbIBr2 films for highly efficient and stable carbon-based planar perovskite solar cells with superior V-oc. *Electrochim. Acta* **2020,** *330*.

8. Tan, X.; Liu, X.; Liu, Z.; Sun, B.; Li, J.; Xi, S.; Shi, T.; Tang, Z.; Liao, G., Enhancing the optical, morphological and electronic properties of the solution-processed CsPbIBr2 films by Li doping for efficient carbon-based perovskite solar cells. *Appl. Surf. Sci.* **2020,** *499*.

9. Zhu, W.; Zhang, Z.; Chai, W.; Zhang, Q.; Chen, D.; Lin, Z.; Chang, J.; Zhang, J.; Zhang, C.; Hao, Y., Band Alignment Engineering Towards High Efficiency Carbon-Based Inorganic Planar CsPbIBr2 Perovskite Solar Cells. *Chemsuschem* **2019,** *12* (10), 2318-2325.

10. Wang, R.; Zhang, H.; Han, S.; Wu, Y.; Hu, Z.; Zhang, G.; Liu, H.; He, Q.; Zhang, X., Cadmium doping for improving the efficiency and stability of carbon-based CsPbIBr2 all-inorganic perovskite solar cells. *New J. Chem.* **2021,** *45* (20), 9243-9250.

11. Guo, Z.; Teo, S.; Xu, Z.; Zhang, C.; Kamata, Y.; Hayase, S.; Ma, T., Achievable high V-oc of carbon based all-inorganic CsPbIBr2 perovskite solar cells through interface engineering. *J. Mater. Chem. A* **2019,** *7* (3), 1227-1232.