

## Supporting Information

### **High-Efficiency (12.5%) Kesterite Solar Cell Realized by Crystallization**

### **Growth Kinetics Control over Aqueous Solution Based $\text{Cu}_2\text{ZnSn}(\text{S}, \text{Se})_4$**

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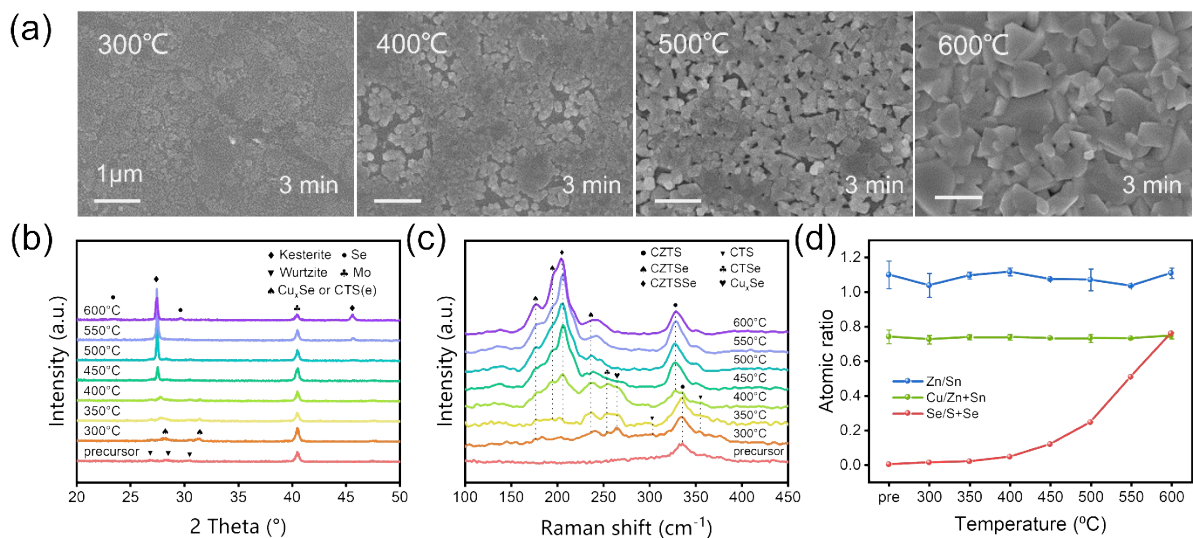
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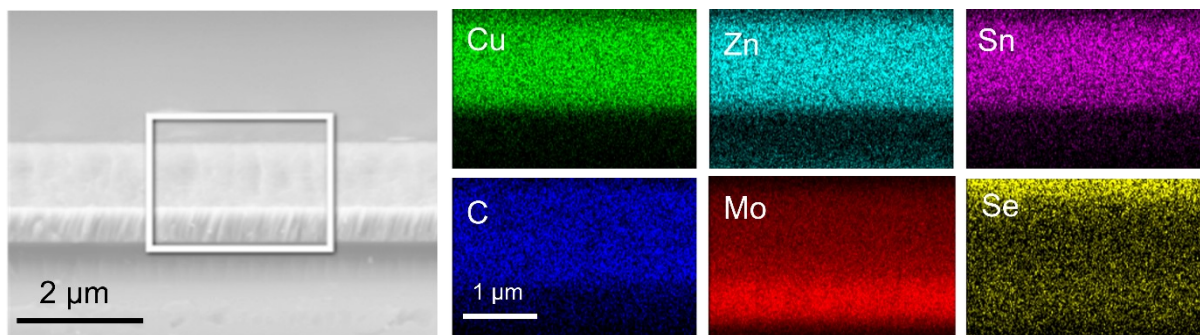
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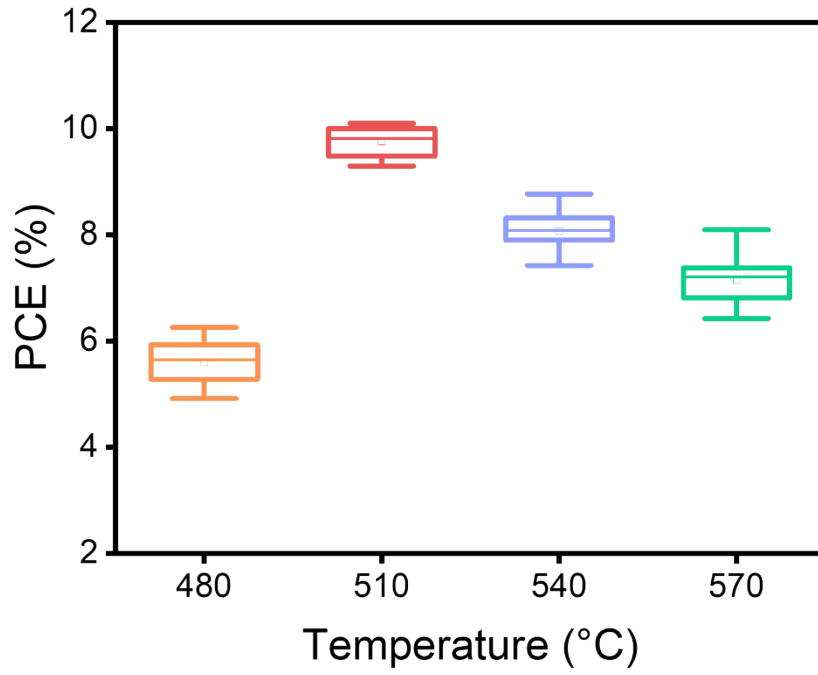
*E-mail: shijj@iphy.ac.cn E-mail: yhluo@iphy.ac.cn E-mail: qbmeng@iphy.ac.cn*



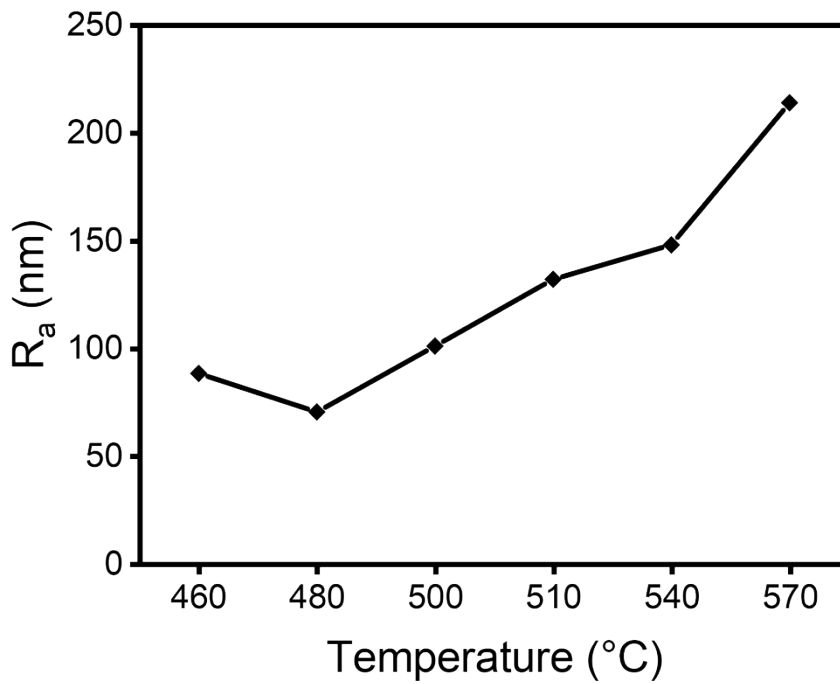
**Fig. S1.** (a) Top-view SEM images of the CZTSSe films fabricated at different selenization temperatures for 3 min. (b) XRD patterns, (c) Raman spectra and (d) XRF results of the CZTS precursor and those CZTSSe films selenized at different temperatures.



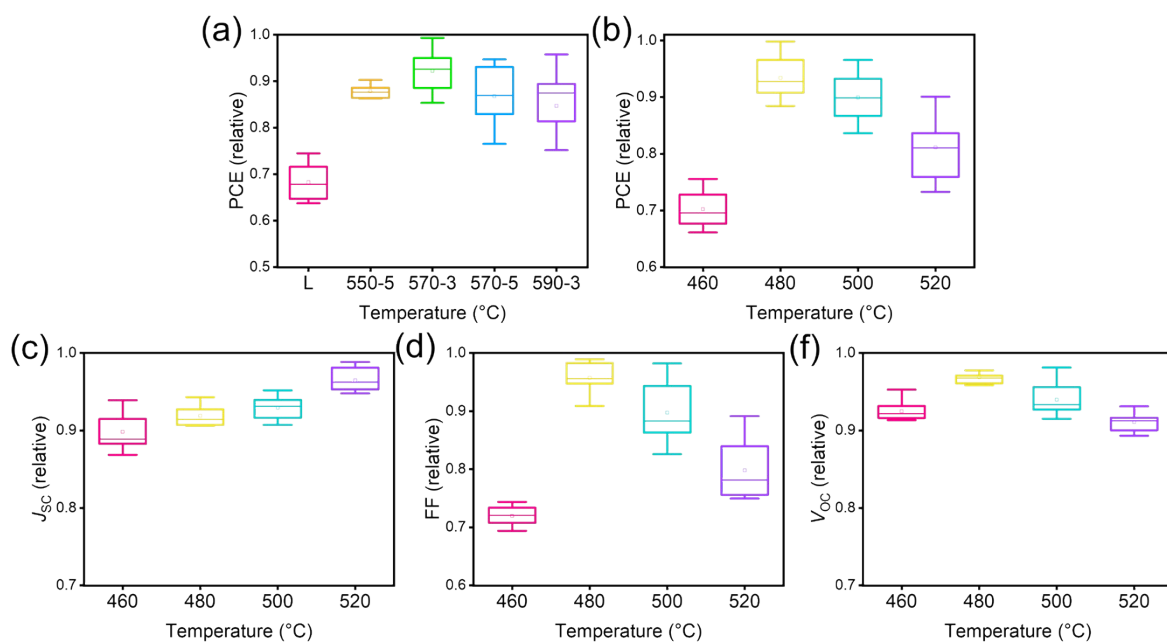
**Fig. S2.** Cross-sectional SEM and EDX element mapping images of the CZTSSe film selenized at 510 °C for 1 min. The element distribution in the CZTSSe film is measured by SEM EDX mapping. It can be seen that the fine grain layer has uniformly distributed concentration of metal elements (i.e. Cu, Zn and Sn) and carbon while Se is observed on the film surface.



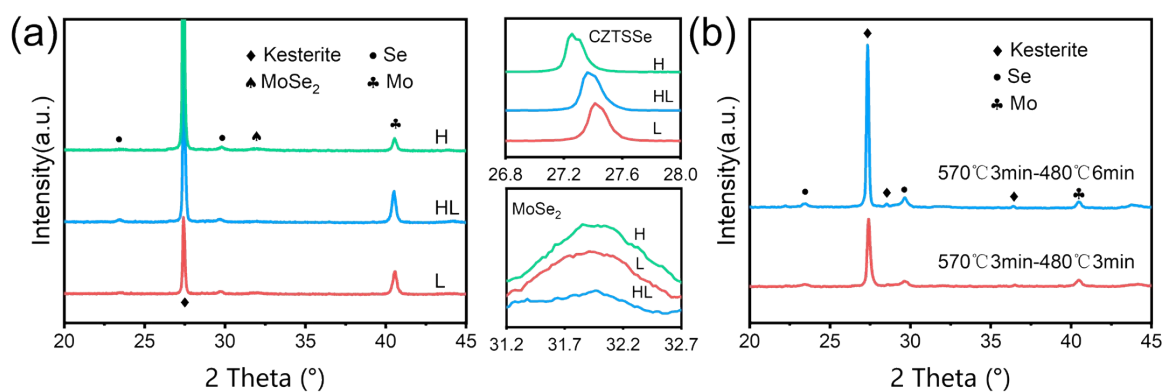
**Fig. S3.** Statistical PCE of the solar cells with CZTSSe films prepared at different selenization temperatures.



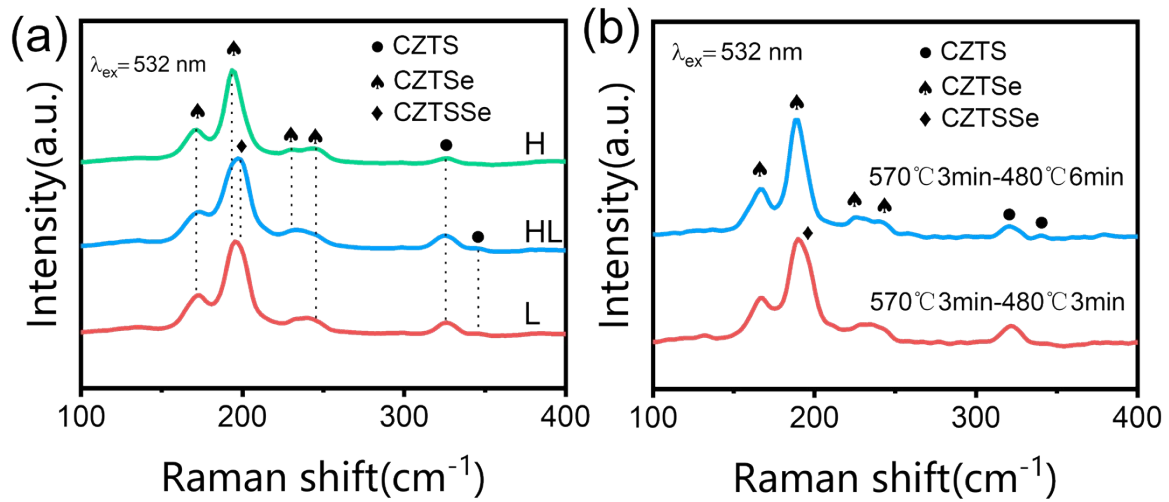
**Fig. S4.** Surface roughness of the CZTSSe films selenized at different temperatures measured by AFM.



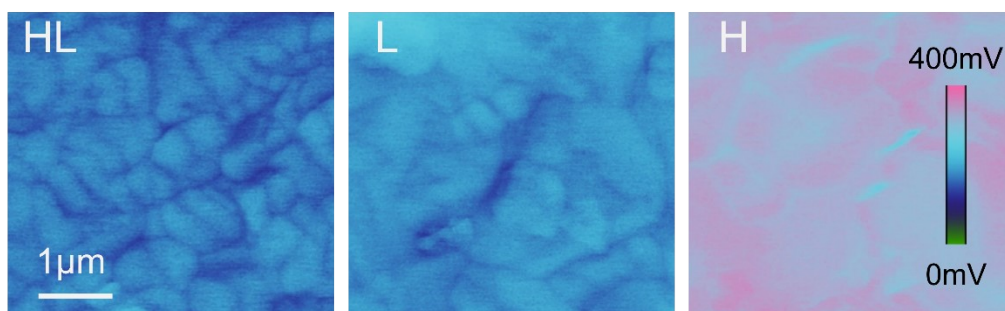
**Fig. S5.** (a) Statistical PCE of cells with CZTSSe films annealing at different temperatures and time during the first stage of HL process (550 °C for 5 min, 570 °C for 3 min, 570 °C for 5 min, 590 °C for 3 min and the second stage temperatures of these cells are all 480 °C for 10 min) comparing to L process. (b-f) Statistical parameters of cells with CZTSSe films annealing at different temperatures during the second stage of HL process (570 °C for 3 min and then 460 °C, 480 °C, 500 °C, 520 °C for 10 min) comparing to L process. All parameters of cells are normalized by each maximum value.



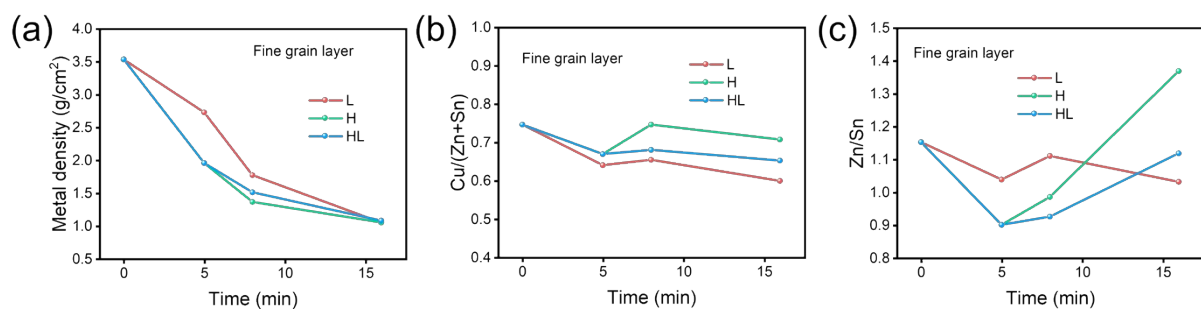
**Fig. S6.** (a) XRD patterns of the CZTSSe films prepared with different selenization strategies and (b) CZTSSe films crafted after 570 °C 3 min – 480 °C 3 min and 570 °C 3 min – 480 °C 6 min.



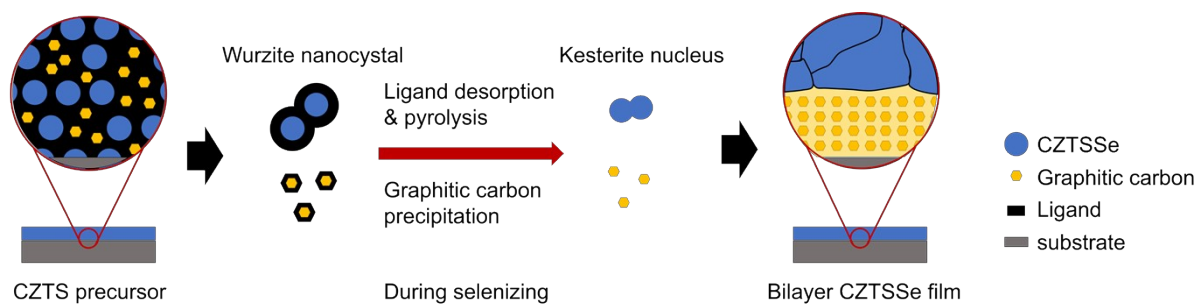
**Fig. S7.** (a) Raman spectra measured under 532 nm excitation of the CZTSSe films prepared with different selenization strategies and (b) CZTSSe films crafted after 570 °C 3 min – 480 °C 3 min and 570 °C 3 min – 480 °C 6 min.



**Fig. S8.** Surface potential measured by KPFM of the CZTSSe films prepared with different selenization strategies.



**Fig. S9.** (a) Metal density (b) Cu/(Zn+Sn) and (c) Zn/Sn variations in the fine grain layer at different selenizing time measured by XRF.



**Fig. S10.** Schematic diagram for the formation of the graphitic carbon layer.