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Nanoscale electrical properties enhancement through antimony incorporation to pave the development of $Cu_2ZnSn(S,Se)_4$ solar cells towards low temperature

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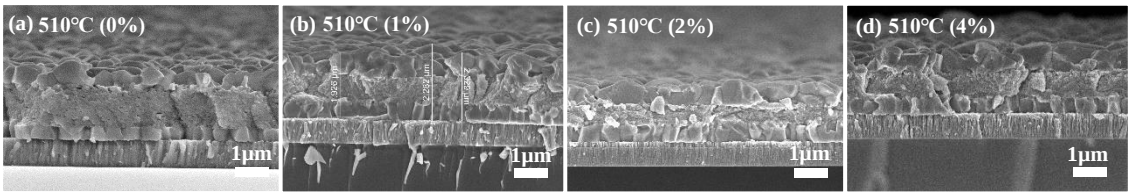

Fig. S1 Cross-section SEM images of the 510 °C selenized CZTSSe films with antimony incorporation content of 0 mol %, 1 mol %, 2 mol % and 4 mol %.

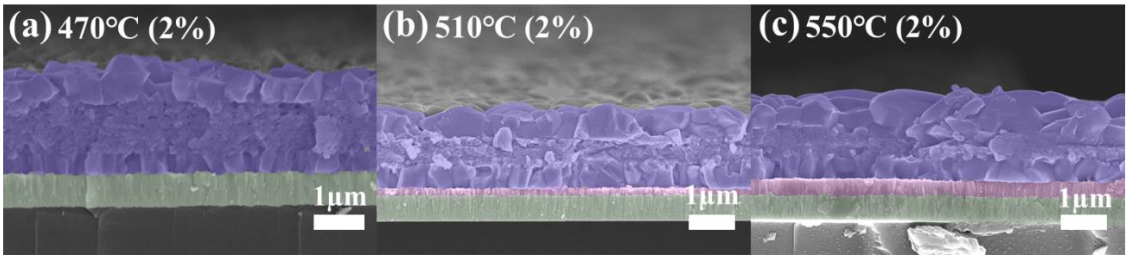

Figure S2. SEM cross-section images of (a) 470 °C, (b) 510 °C and (c) 550 °C selenized CZTSSe films with 2 mol% Sb incorporation content. The absorber layer, Mo substrate and $MoSe_2$ layer are highlighted by blue, light green and pink colors, respectively.

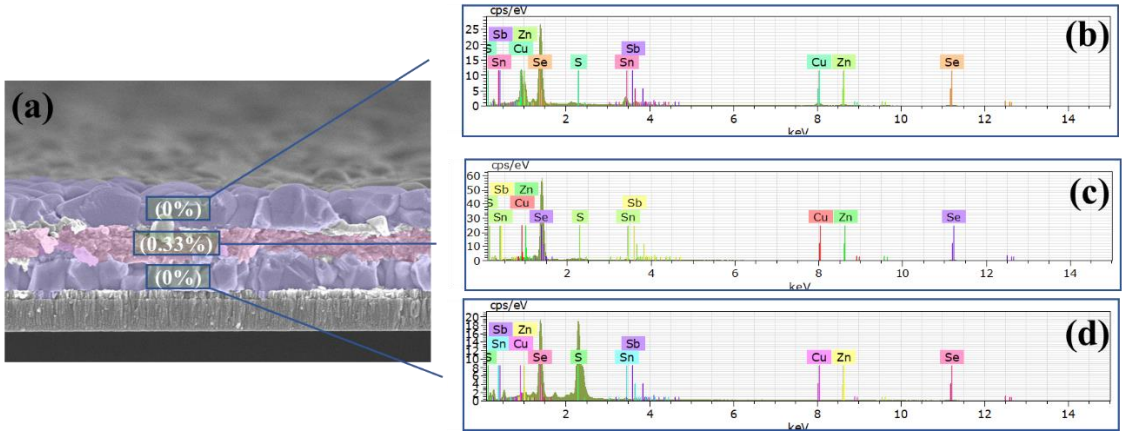

Figure S3. (a) SEM cross-section image of 510 °C selenized CZTSSe films with 2 mol% Sb incorporation content. The EDS characterized residual Sb content within the top large-grain layer, middle fine-grain layer and bottom large-grain layer are (b) 0%, (c) 0.33%, and (d) 0%, respectively.

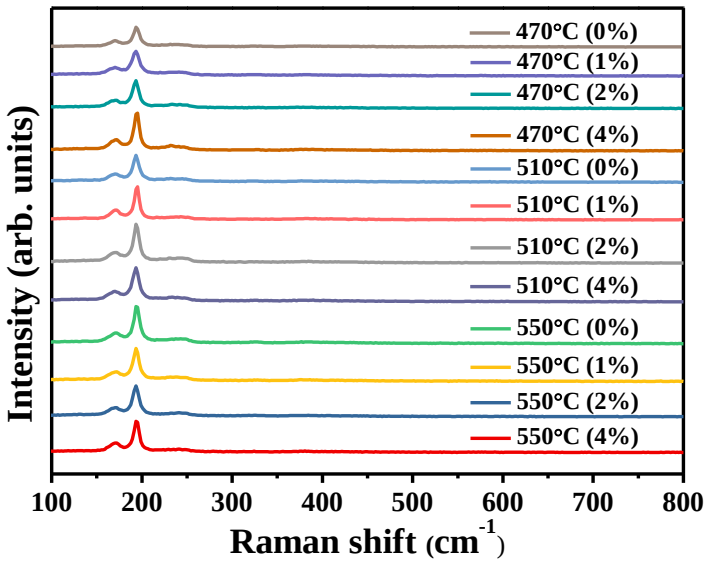

Figure S4. Raman spectra of different temperature selenized CZTSSe films with different Sb incorporation content.

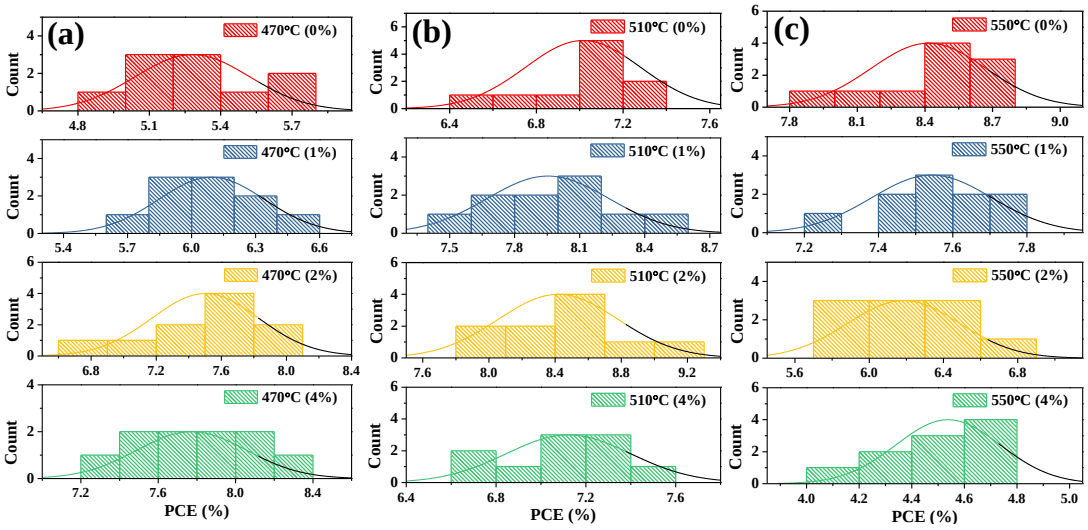

Figure S5. The statistical distributions of cell efficiencies derived from 10 devices for each type with different Sb incorporation contents and selenization temperatures. (a) 470 °C, (a) 510 °C and (c) 550 °C.