Effect of growth temperature on carrier collection in SnS-based solar cells

The Harvard community has made this article openly available. Please share how this access benefits you. Your story matters

Citation

Citable link http://nrs.harvard.edu/urn-3:HUL.InstRepos:32186291

Terms of Use
This article was downloaded from Harvard University’s DASH repository, and is made available under the terms and conditions applicable to Open Access Policy Articles, as set forth at http://nrs.harvard.edu/urn-3:HUL.InstRepos:dash.current.terms-of-use#OAP
Effect of growth temperature on carrier collection in SnS-based solar cells

Rupak Chakraborty, Vera Steinmann, Jeremy R. Poindexter, Rafael Jaramillo, Katy Hartman, Alex Polizzotti, Riley E. Brandt, Niall Mangan, Chuanxi Yang, Roy G. Gordon, Tonio Buonassisi

1Massachusetts Institute of Technology, Cambridge, MA (USA), 2Harvard University, Cambridge, MA (USA)

SnS as a solar absorber

- Tin (Sn) and sulfur (S) are non-toxic and abundant in nature
- SnS is conducive to thermal evaporation (TE), which has potential for high-throughput manufacturing
- Strong optical absorption (> 10^4 cm^-1 above 1.4 eV)

SnS carrier collection deficit

- Recently achieved 3.88% conversion efficiency with TE SnS-based solar cell
- Leading loss mechanism is recombination at long wavelengths
- Increasing SnS growth temperature T_g may improve charge-carrier collection

Goal of this work

- Determine the effect of T_g on structural and electrical properties of SnS films, and on long-wavelength internal quantum efficiency (IQE) of devices
- Explain the variation in long-wavelength IQE as a function of T_g through optoelectronic modeling
- Determine a path toward higher-current SnS devices

SnS growth conditions & device stack

- Substrate temperature was varied while deposition rate and thickness were kept constant at 1 Å/s and 1 μm, respectively
- Used a previously reported device stack

<table>
<thead>
<tr>
<th>SnS growth temperature (°C)</th>
<th>Ag (500 nm, evap)</th>
<th>ITO (250 nm, sputtered)</th>
<th>ZnO (18 nm, ALD)</th>
<th>ZnO_xS_y (36 nm, n-type buffer layer, ALD)</th>
<th>SnS (n-type absorber, thermally evaporated)</th>
<th>Mo (500 nm, sputtered)</th>
<th>SiO_2 (1 μm, sputtered)</th>
<th>Si</th>
</tr>
</thead>
<tbody>
<tr>
<td>A</td>
<td>150</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>B</td>
<td>200</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>C</td>
<td>240</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>D</td>
<td>285</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

SnS film characterization

Structural properties

Electronic properties

SnS device performance and modeling

Experimental IQE

\[ J_{\text{IQE}} = \int_{0}^{\lambda_{\text{cut}}} \lambda\Phi_{\text{abs}}(\lambda) \frac{J}{h\nu} d\lambda \]

- Device simulation with p, μ values from measurements; other material parameter values from literature
- Fit IQE in 700-950 nm range, with L_{diff} as free parameter

SCAPS-1D Model

- Promising increase in fitted diffusion length at 285°C

Conclusions

- Grain size, μ, and p increase with T_g
- Increasing p leads to decreasing drift-assisted collection
- At the highest T_g of 285°C, carrier collection recovers due to an increase in diffusive minority-carrier transport
- Higher carrier collection may be achievable by simultaneously decreasing carrier concentration while increasing diffusion length

Future directions

- Higher T_g with optimized deposition geometry (CSS-like)
- Co-optimization of growth conditions with post-deposition annealing

References


Acknowledgements

The authors are thankful to Maria Lizet Castillo for helping with substrate preparation. The authors also thank Luka Barrera and Kelsey Dodds for helping with the grain size analysis and anisotropic calculations, respectively. This work is supported by the U.S. Department of Energy through the SunShot Initiative under contract DE-EE0005129, and by Robert Bosch LLC through the Bosch Energy Research Network under grant 02.20.ANC1. V. Steinmann, R. Jaramillo, K. Hartman, and R.E. Brandt acknowledge the support of the Alexander von Humboldt Foundation, a DOE EERE Postdoctoral Research Award, an Intel PhD Fellowship, and an NSF GRFP Fellowship respectively. This work made use of the MRSEC Shared Experimental Facilities at MIT that is supported by the National Science Foundation (NSF) under award DMR-08-1762, and the Center for Nanoscale Systems that is supported by the NSF under award ECS-0335765.