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

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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>SnS (as-dep), thermally evaporated</th>
</tr>
</thead>
<tbody>
<tr>
<td>A</td>
<td>150</td>
</tr>
<tr>
<td>B</td>
<td>200</td>
</tr>
<tr>
<td>C</td>
<td>240</td>
</tr>
<tr>
<td>D</td>
<td>285</td>
</tr>
<tr>
<td>Ag (500 nm, evap)</td>
<td></td>
</tr>
<tr>
<td>ITO (250 nm, sputtered)</td>
<td></td>
</tr>
<tr>
<td>ZnO (18 nm, ALD)</td>
<td></td>
</tr>
<tr>
<td>ZnO:SnS (36 nm, n-type buffer layer, ALD)</td>
<td></td>
</tr>
</tbody>
</table>

SnS device performance and modeling
- 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

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

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