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

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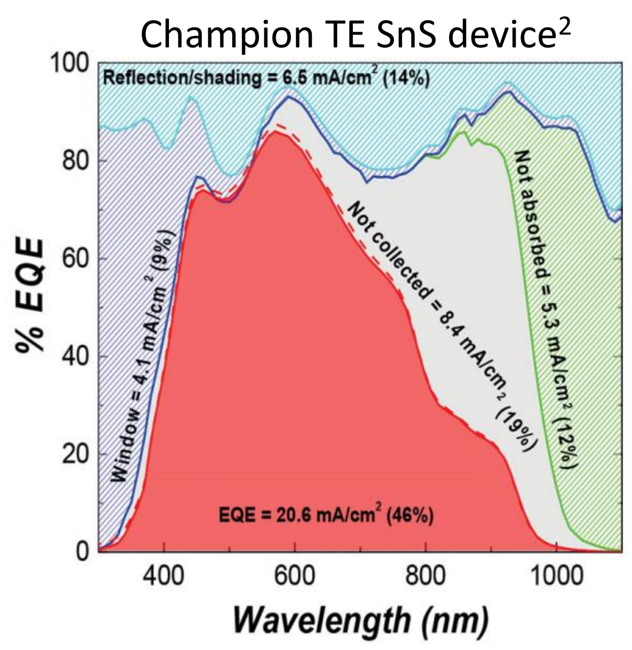
## SnS as a solar absorber

- 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)[1]

## SnS carrier collection deficit

- Recently achieved 3.88% conversion efficiency with TE SnS-based solar cell[2]
- Leading loss mechanism is recombination at long wavelengths
- Increasing SnS growth temperature $T_g$ may improve charge-carrier collection



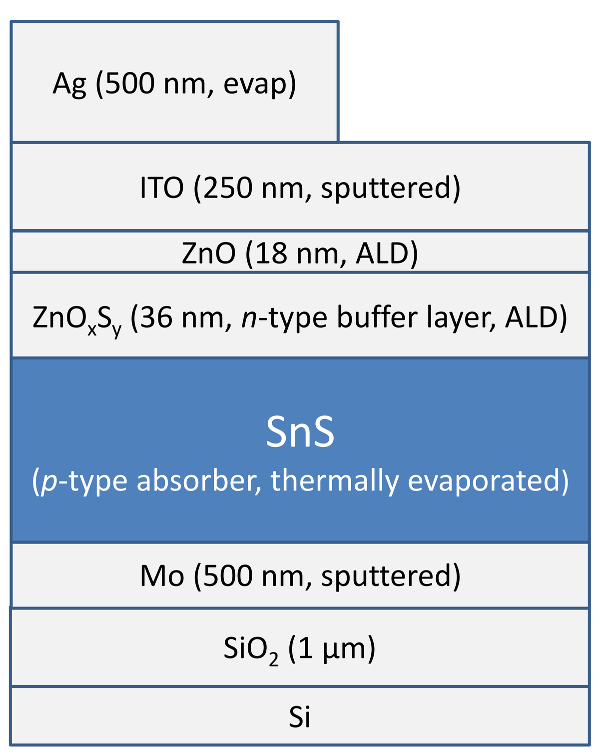

## Goal of this work

- 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

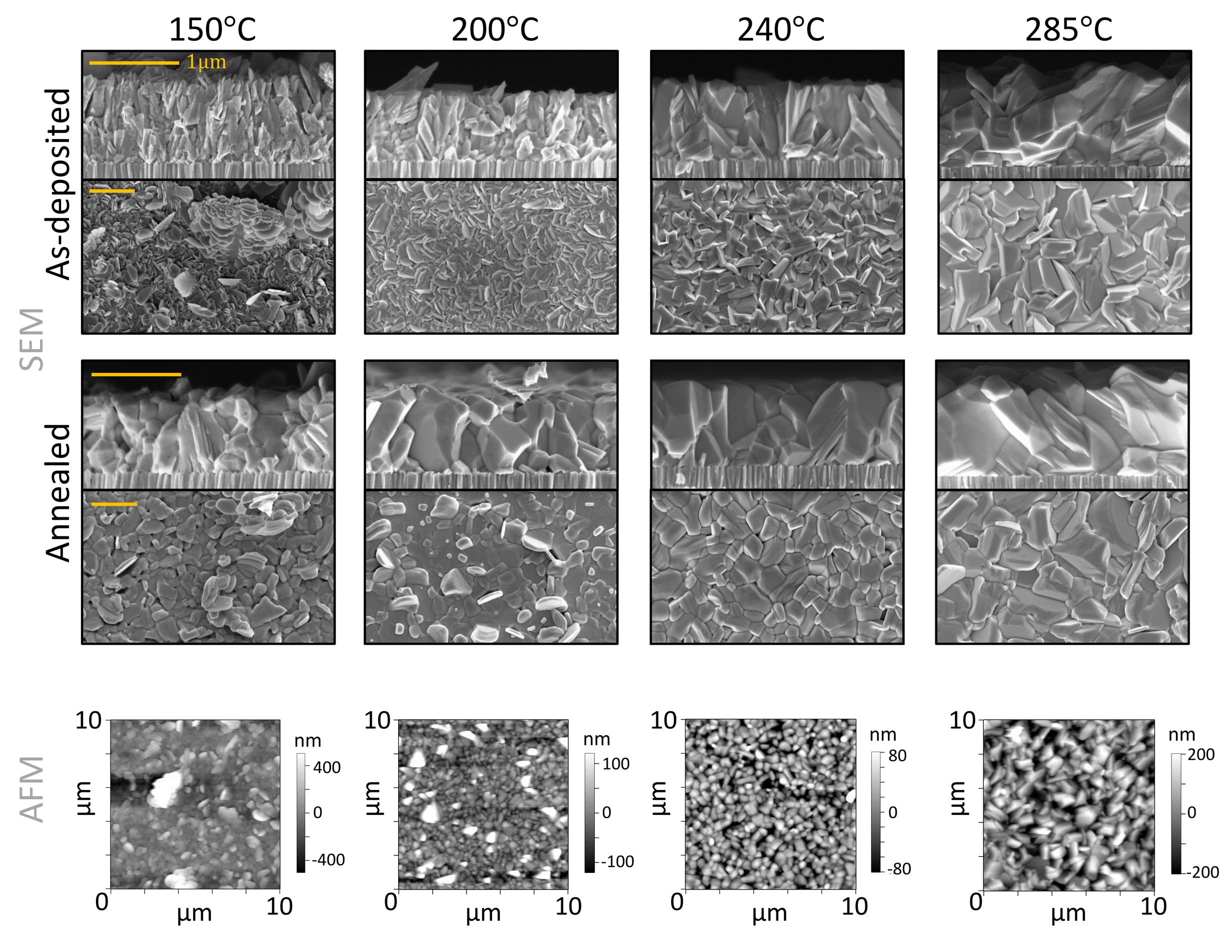
- Substrate temperature was varied while deposition rate and thickness were kept constant at 1 Å/s and 1 µm, respectively
- Used a previously reported device stack[2]

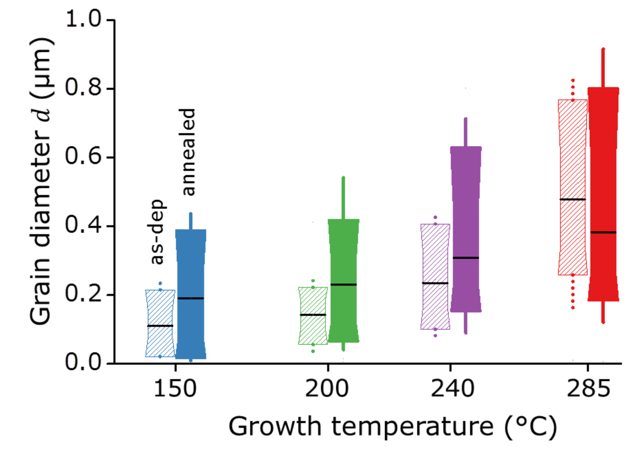
| | SnS growth temperature [°C] |
|---|---|
| A | 150 |
| B | 200 |
| C | 240 |
| D | 285 |

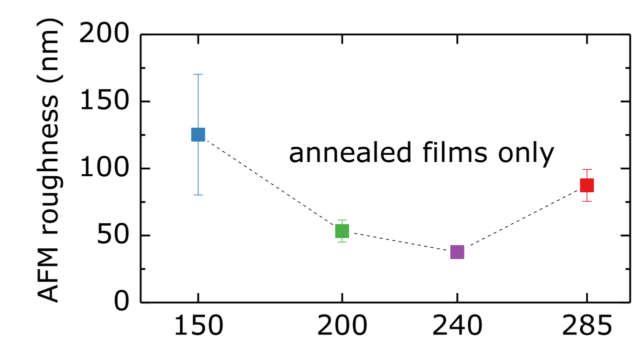



## SnS film characterization

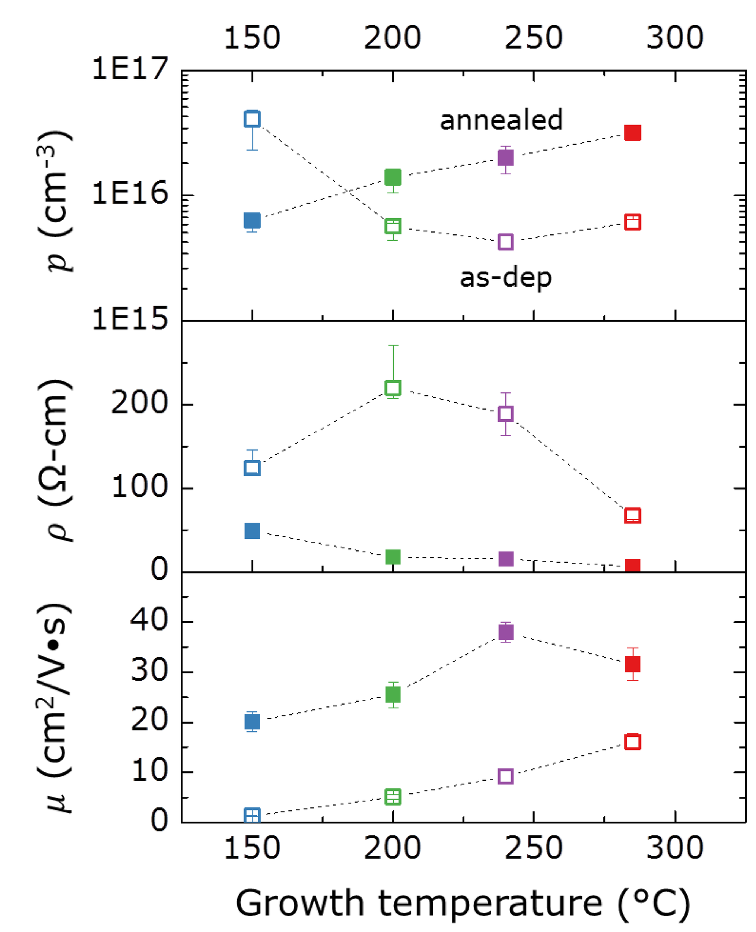
### Structural properties



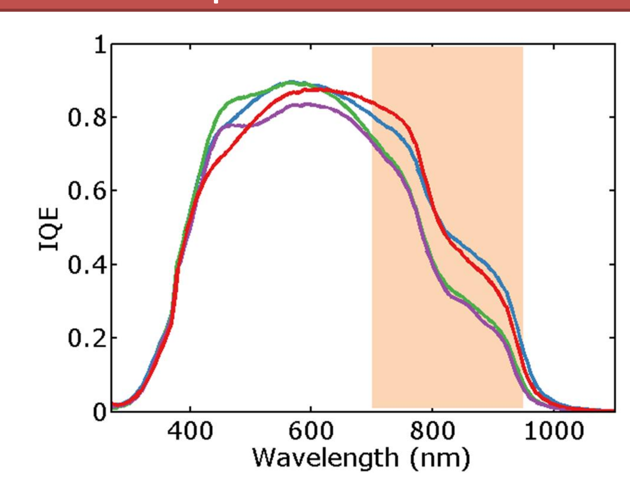




### Electronic properties




## SnS device performance and modeling

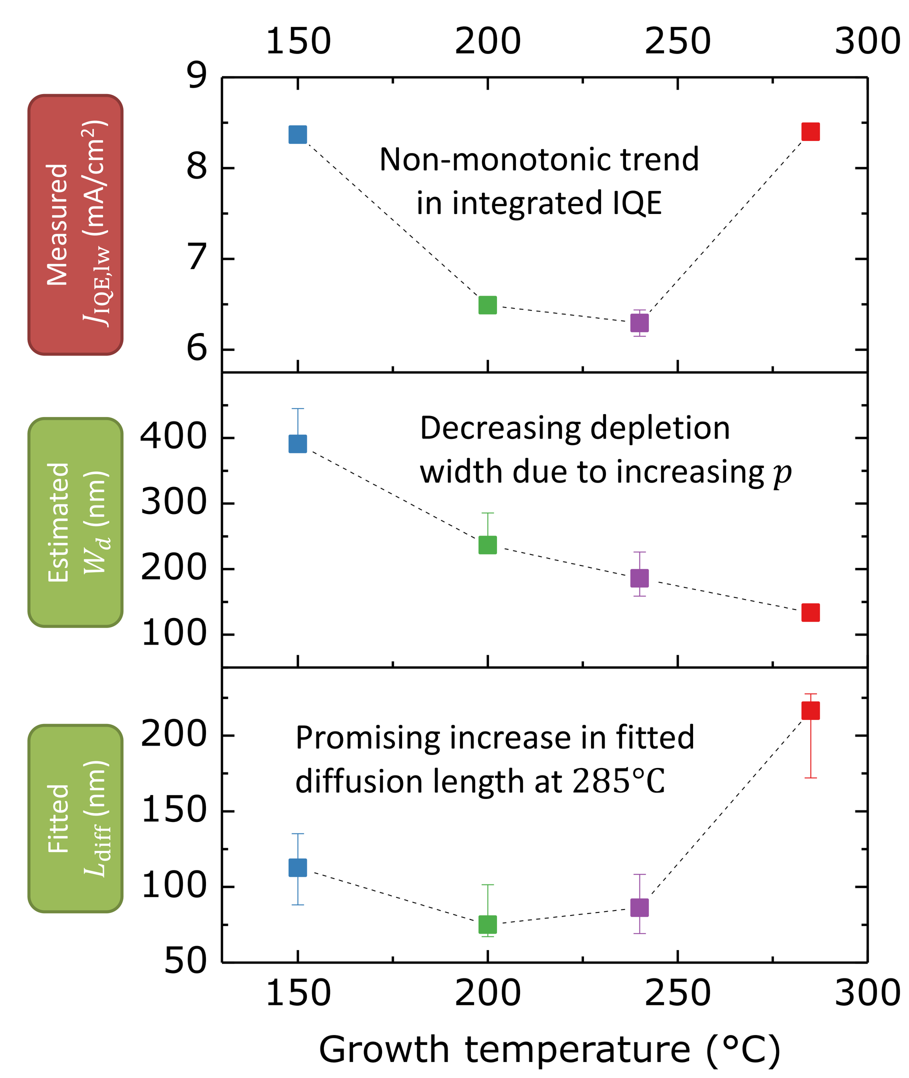
**Experimental IQE**



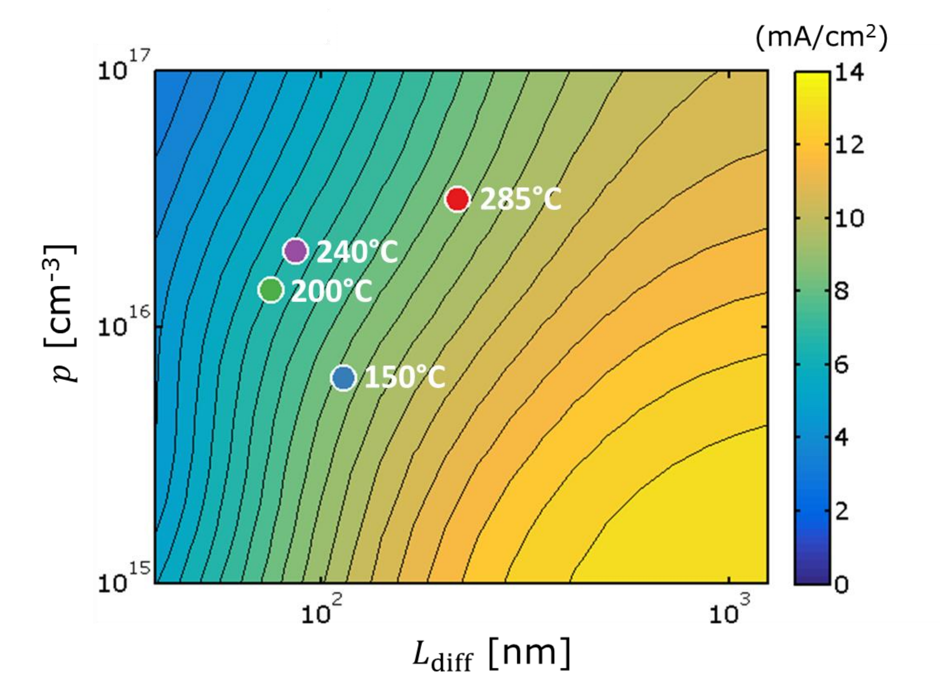

$$J_{\mathrm{IQE,lw}} = \int_{700\ \mathrm{nm}}^{950\ \mathrm{nm}} \mathrm{IQE}(\lambda)\ \phi_{AM1.5}(\lambda)\ \frac{\lambda}{hc}\ d\lambda$$

**SCAPS-1D Model**

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




**Simulated $J_{\mathrm{IQE,lw}}$ for range of $p$, $L_{\mathrm{diff}}$**



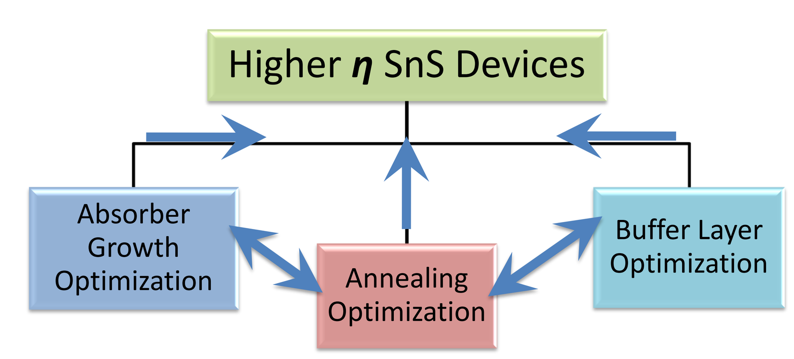

- Lower $p$ and higher $L_{\mathrm{diff}}$ necessary to achieve maximum $J_{\mathrm{IQE,lw}}$
- Decreasing $p$ has more limited improvement capacity than increasing $L_{\mathrm{diff}}$ in current parameter space

## Conclusions

- Grain size, $\mu$, 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

[1] H. Noguchi *et al.*, *Sol. Energy Mater. Sol. Cells,* **35**, 325 (1994).
[2] V. Steinmann *et al.*, *Adv. Mater.,* **26**, 7488 (2014).

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