

# Processing and Properties of Very Thin $\text{CuInGaSe}_2$ (CIGS) Solar Cells

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- Thin Absorber grown by 3-stage process
- Growth from Cu-rich CGS or CIGS layers
- Solar cell results
- Comparison of thin and thick cells
- Conclusions

# Need to study very thin CIGS

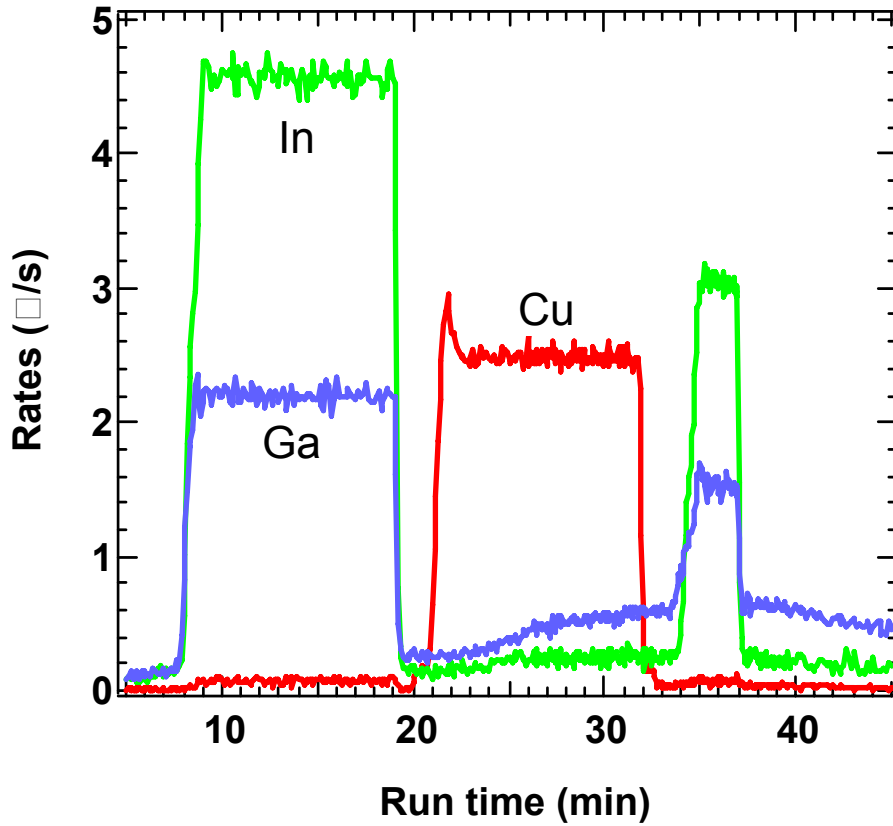
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- Cost of Indium is a concern in high-volume production.
- Thickness has an impact on cost, throughput
- It should be possible to make efficient solar cells with sub-micron absorbers.

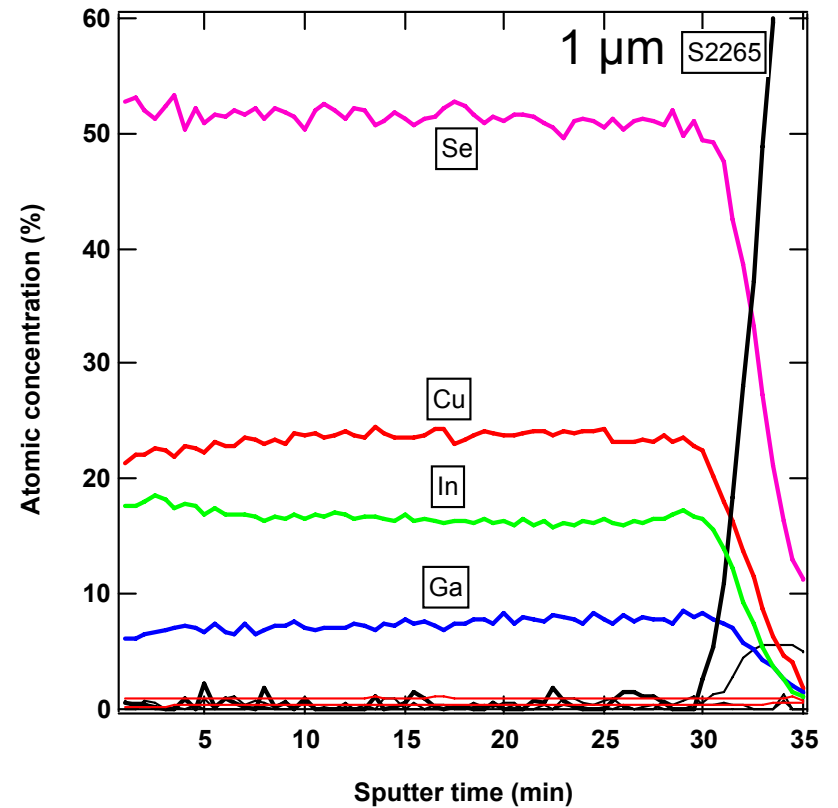
- IEC, Matsushita performed parametric study of absorber thickness
- Ångstrom Solar published comprehensive study  
*O. Lundberg, Prog. PV 11, 77 (2003)*  
*16% @ 1.8  $\mu\text{m}$ , 15% @ 0.8-1  $\mu\text{m}$ , 12% @ 0.6  $\mu\text{m}$*
- M. Gloeckler and J. Sites, J. Appl. Phys. **98**, 103703 (2005)

# 3-stage process for thin absorbers

## Elemental flux vs. time

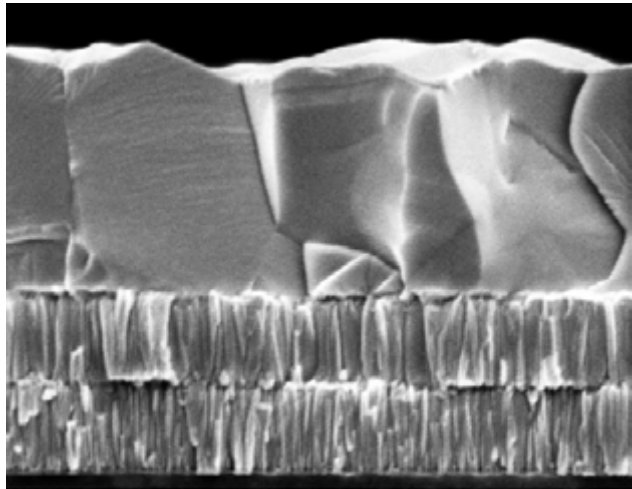


## Auger depth profile



# SEM Images- 3 stage

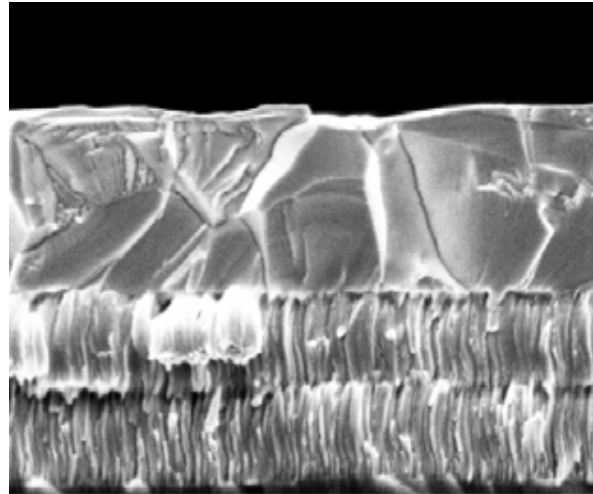
1.2  $\mu$



S2264

600nm 40000X

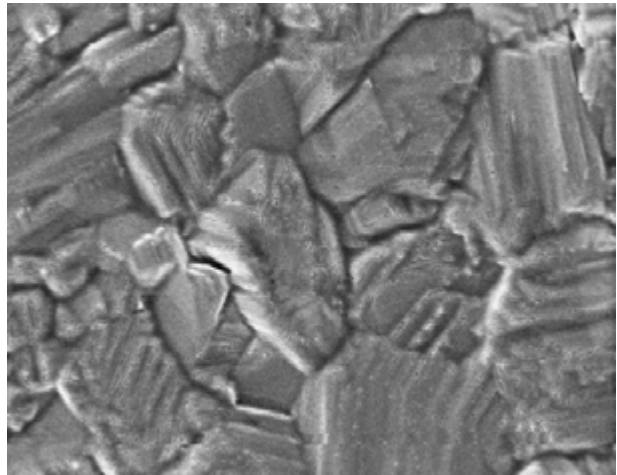
1  $\mu$



S2265

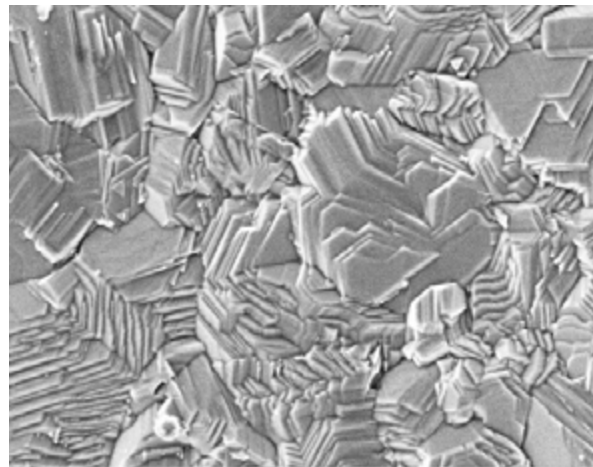
600nm 40000X

Cross section



S2264

1 $\mu$ m 25000X



S2265

1 $\mu$ m 25000X

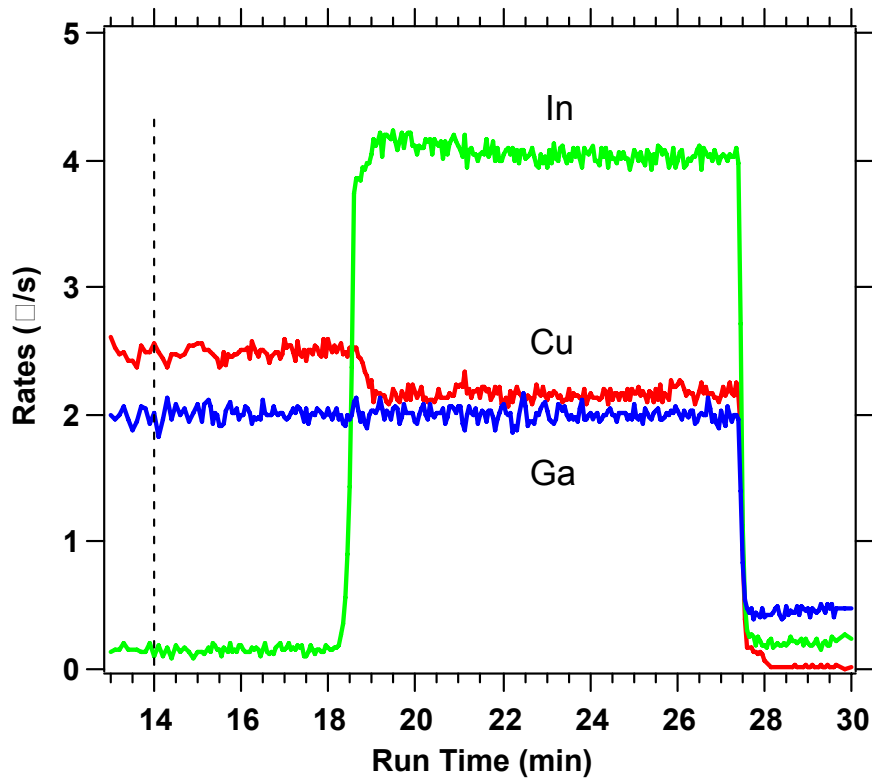
Plan view

$$\frac{\text{Cu}}{\text{In+Ga}} = 0.89-0.91$$

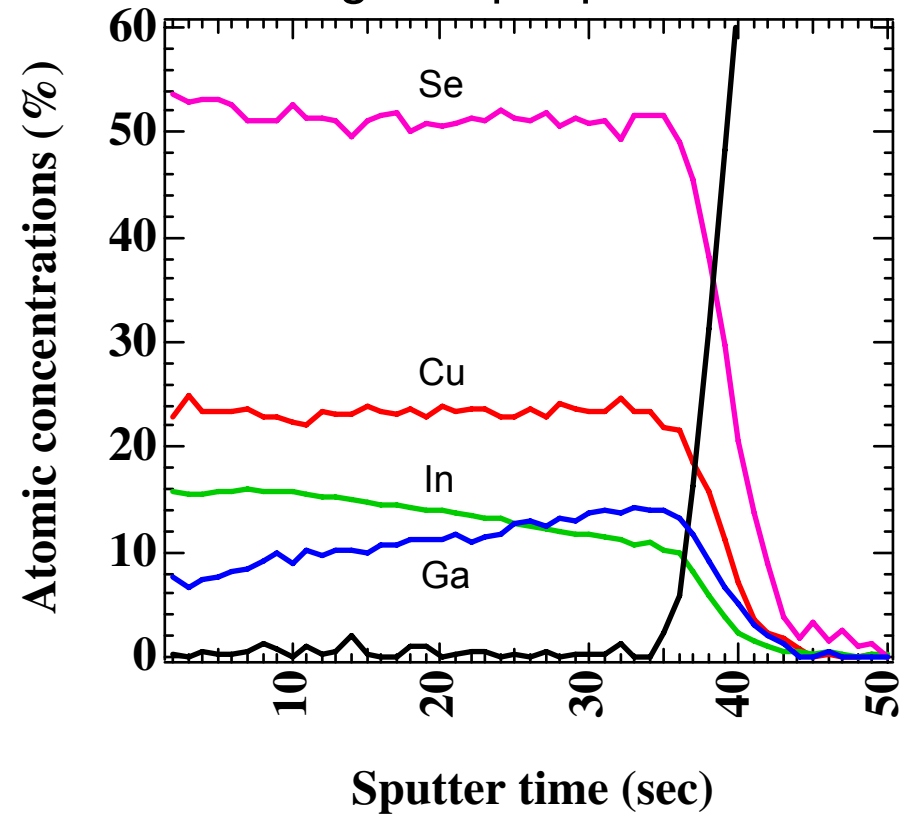
$$\frac{\text{Ga}}{\text{In+Ga}} = 0.27-0.28$$

# Co-deposition on CGS seed layer

## Elemental flux vs. time



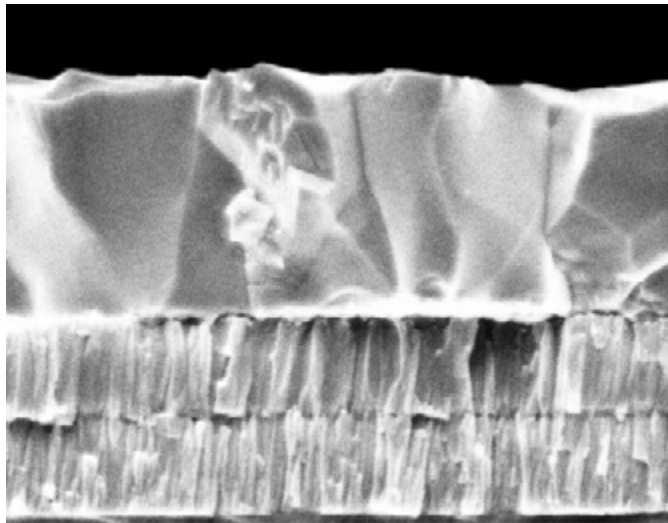
## Auger depth profile





# Co-deposition on CGS seed layer

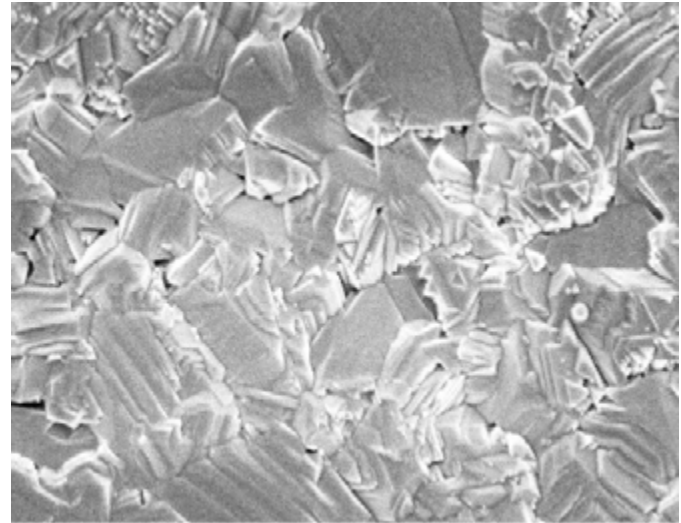
Cross section



S2297

600nm 40000X

Plan view



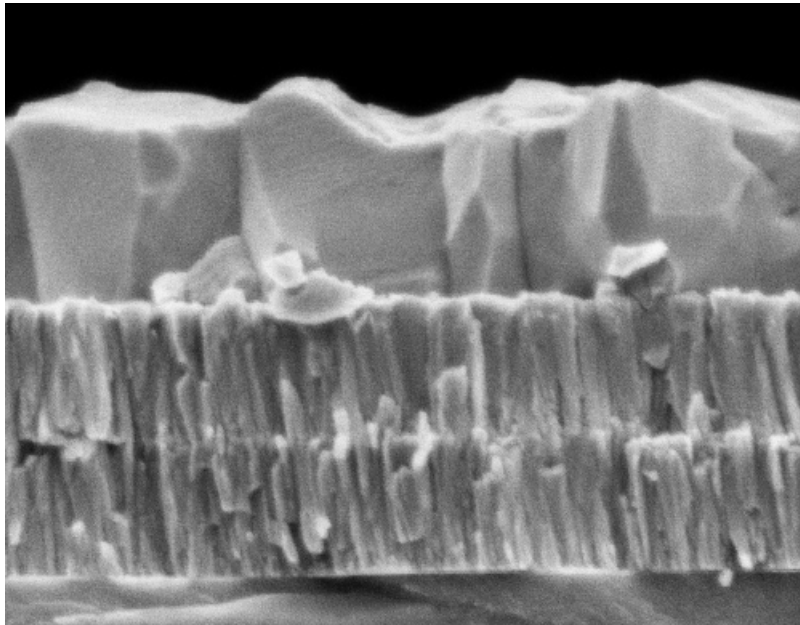
S2297

1µm 20000X

$$\text{Cu}/(\text{In}+\text{Ga}) = 0.91$$

$$\text{Ga}/(\text{In}+\text{Ga}) = 0.30$$

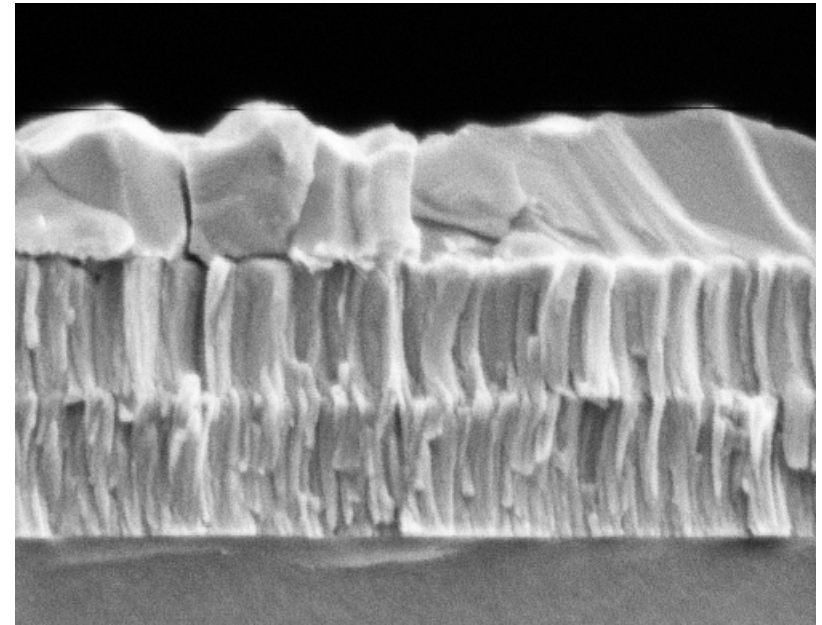
# Submicron layers



S2373

600nm 50000X

0.75  $\mu\text{m}$  (12.5%)



S2372

600nm 50000X

0.4  $\mu\text{m}$  (9.1%)

# Best result for 1 $\mu\text{m}$ (3- stage)

NREL

## CdS/Cu(In,Ga)Se<sub>2</sub> Cell

Device ID: S2438-B1 #3

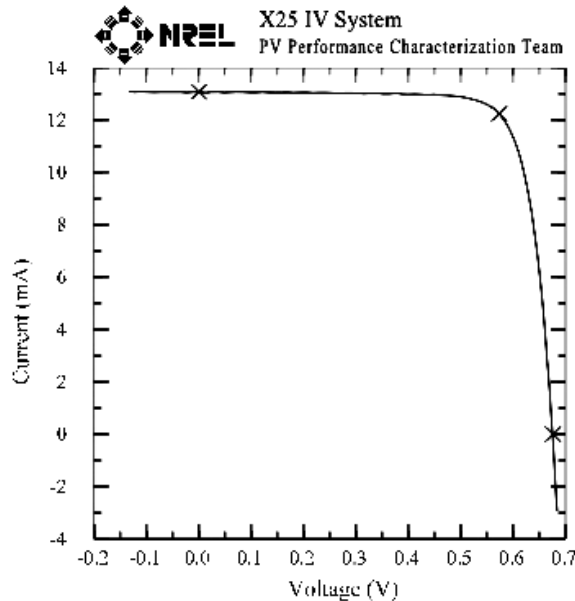
Device Temperature:  $25.0 \pm 1.0$  °C

Oct 31, 2005 13:29

Device Area:  $0.409$  cm<sup>2</sup>

Spectrum: AM1.5-G (IEC 60904)

Irradiance:  $1000.0$  W/m<sup>2</sup>



$V_{oc} = 0.6756$  V

$I_{max} = 12.243$  mA

$I_{sc} = 13.072$  mA

$V_{max} = 0.5732$  V

$J_{sc} = 31.961$  mA/cm<sup>2</sup>

$P_{max} = 7.0182$  mW

Fill Factor = 79.47 %

Efficiency = 17.16 %

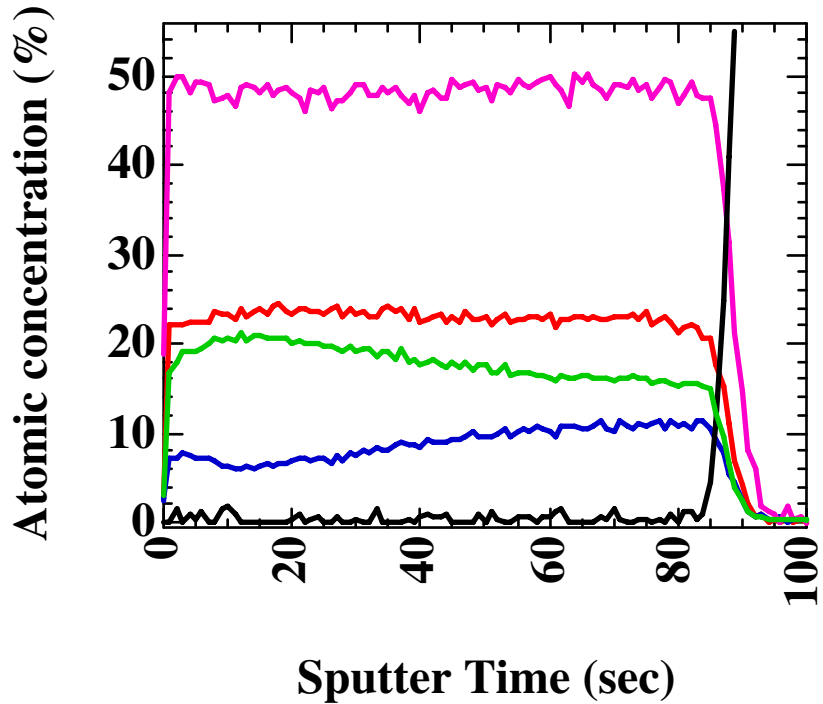
After 10 minute soak at  $P_{max}$ , 5 minute cool.

For 1  $\mu\text{m}$  cell,  $J_0 \sim 8 \times 10^{-11}$  A/cm<sup>2</sup>,  $n = 1.33$

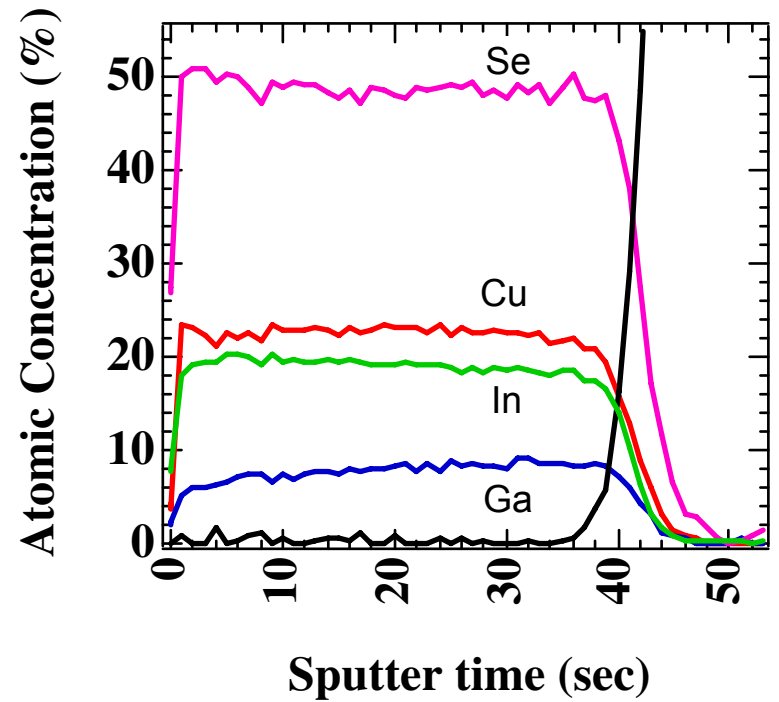
Values for 2.5  $\mu\text{m}$  (19%) cells:  $n = 1.35$ ,  $J_0 \sim 4 \times 10^{-11}$  A/cm<sup>2</sup>

Increase in  $J_0$  partly accounts for the voltage shortfall.

# Auger profile comparison

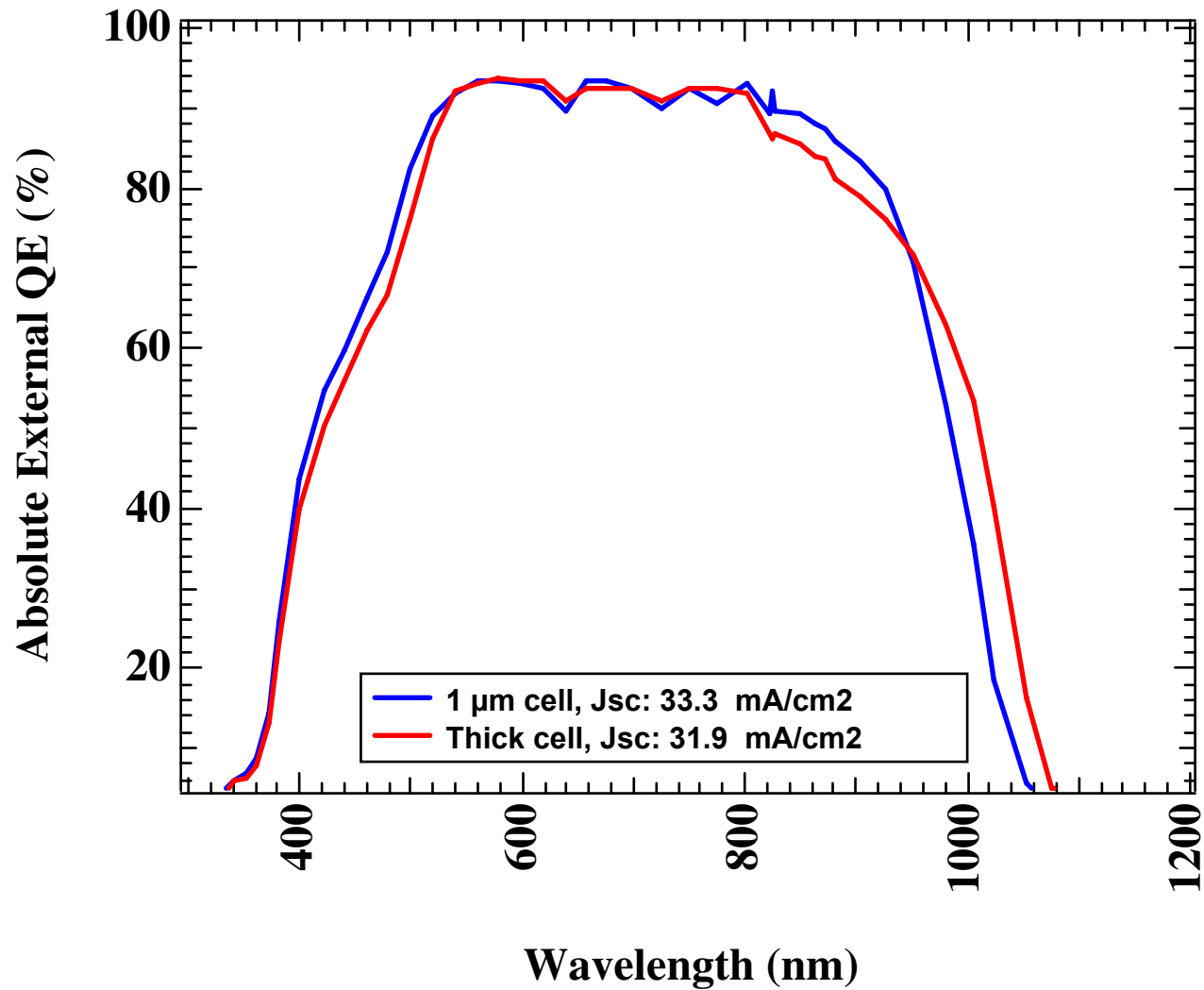


2.5- $\mu\text{m}$  cell

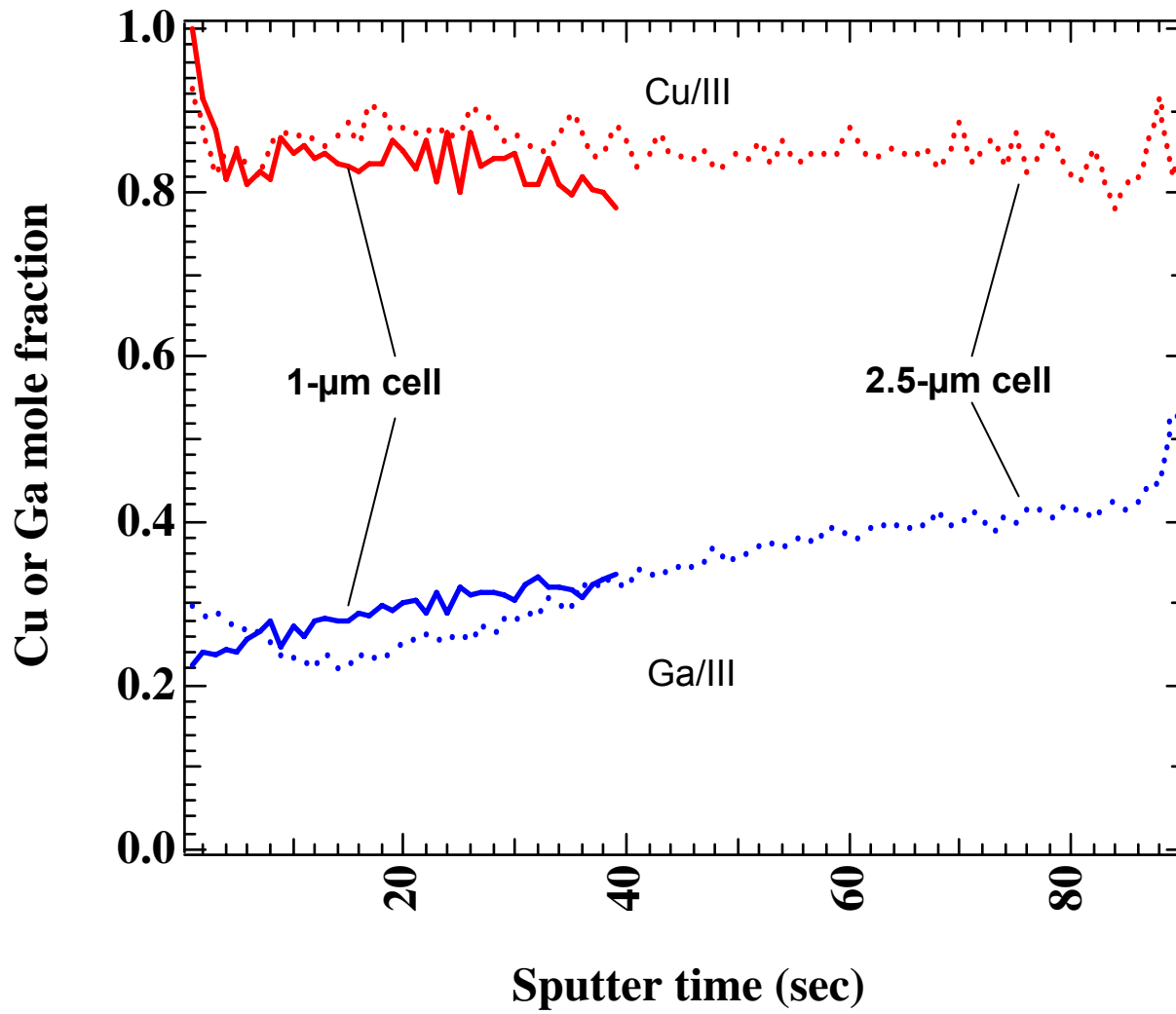


1- $\mu\text{m}$  cell

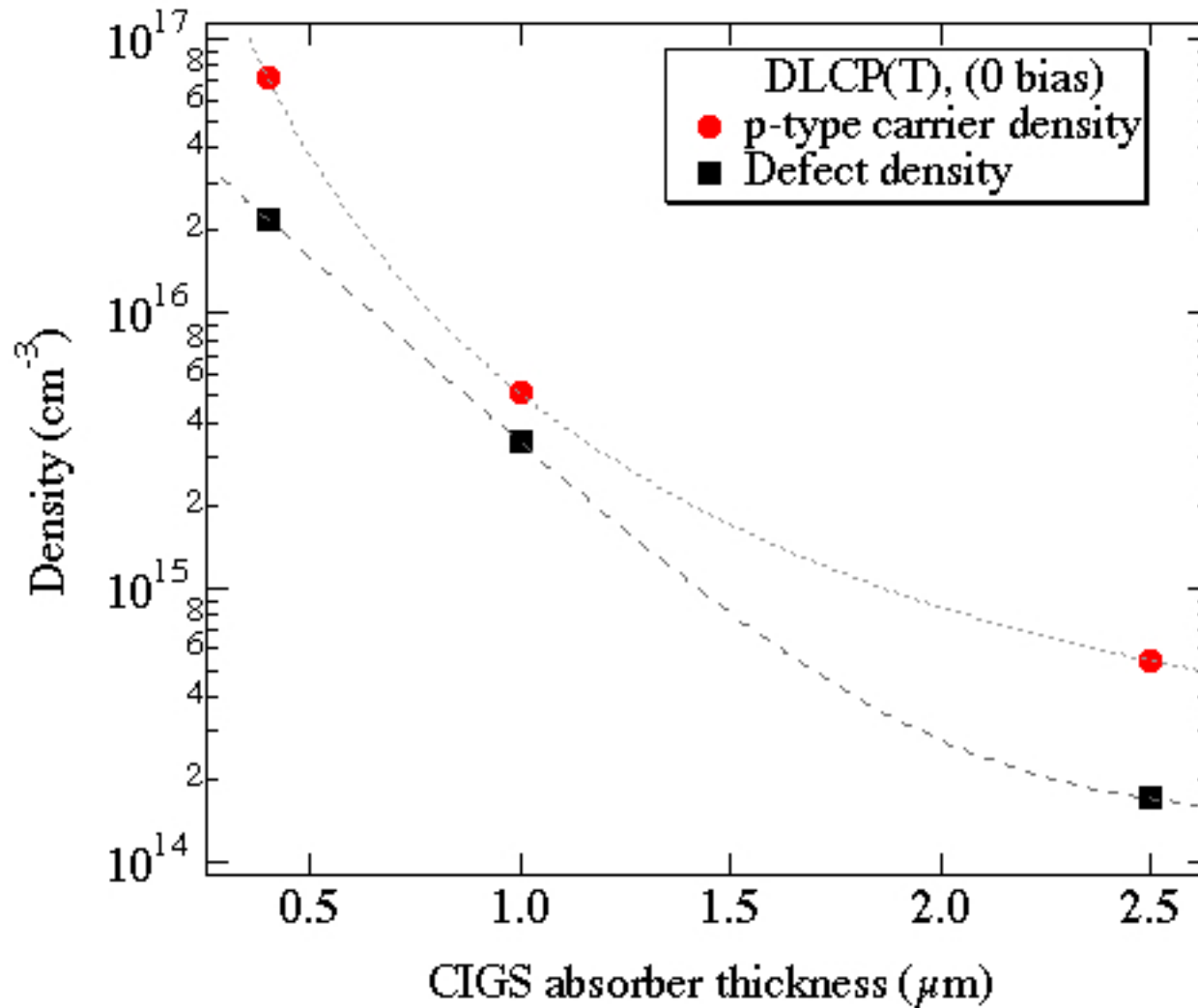
# QE comparison



# Cu and Ga ratios



# Carrier concentration & Defect density



## Summary of Best results

<b>t (<math>\mu\text{m}</math>)</b>	<b>V<sub>oc</sub> (V)</b>	<b>J<sub>sc</sub> (mA/cm<sup>2</sup>)</b>	<b>FF (%)</b>	<b>Eff (%)</b>
<b>1.0 (3 stg)</b>	<b>0.678</b>	<b>31.93</b>	<b>79.2</b>	<b>17.1</b>
<b>1.0 (codep)</b>	<b>0.699</b>	<b>30.6</b>	<b>75.4</b>	<b>16.0</b>
<b>0.60</b>	<b>0.658</b>	<b>26.1</b>	<b>73.1</b>	<b>12.6</b>
<b>0.40</b>	<b>0.565</b>	<b>21.3</b>	<b>75.7</b>	<b>9.1</b>
<b>Control</b>	<b>0.701</b>	<b>34.6</b>	<b>79.7</b>	<b>19.3</b>



# Conclusions

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- Three-stage process applied to micron thick CIGS layers. Best result of 17.1%. Most of the losses can be accounted for.  $V_{oc}$  reduction is the primary loss.
- Co-deposition and Boeing process were also used successfully to grow submicron films. Efficiency could be maintained down to 0.6  $\mu\text{m}$  (12.5%).
- Greater effort needed to understand crystal growth, diffusion, interfacial reactions and control of defects.
- Thin cells can benefit from light trapping and wide gap window layers. Efficiency can be increased.

# Acknowledgments

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