

Processing and Properties of Very Thin 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

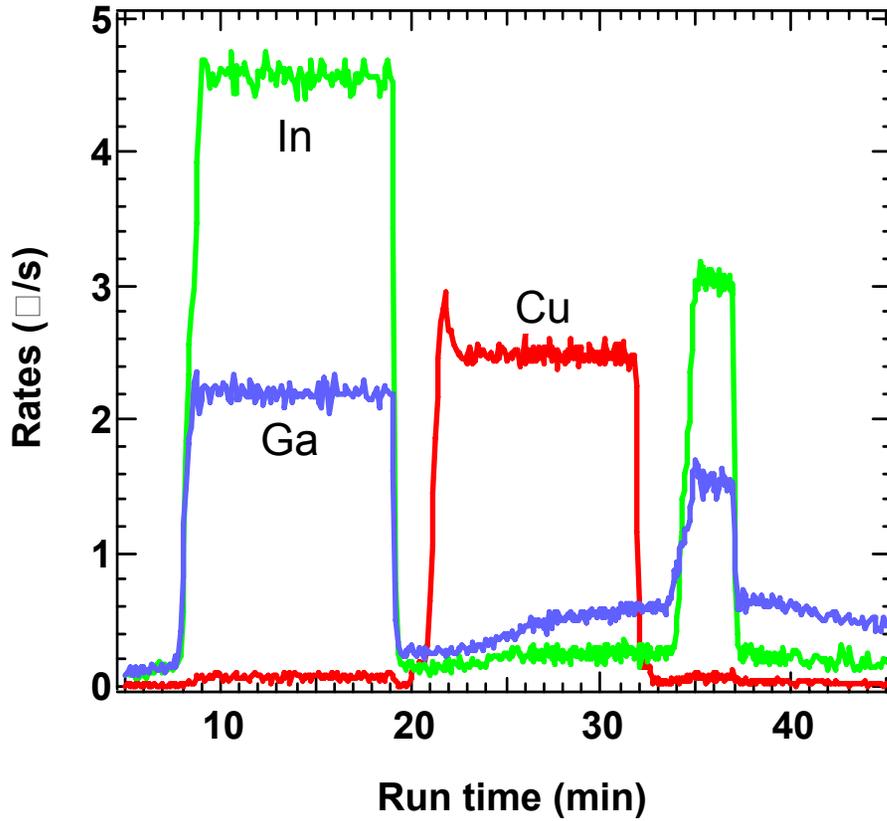
Need to study very thin CIGS

- 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.

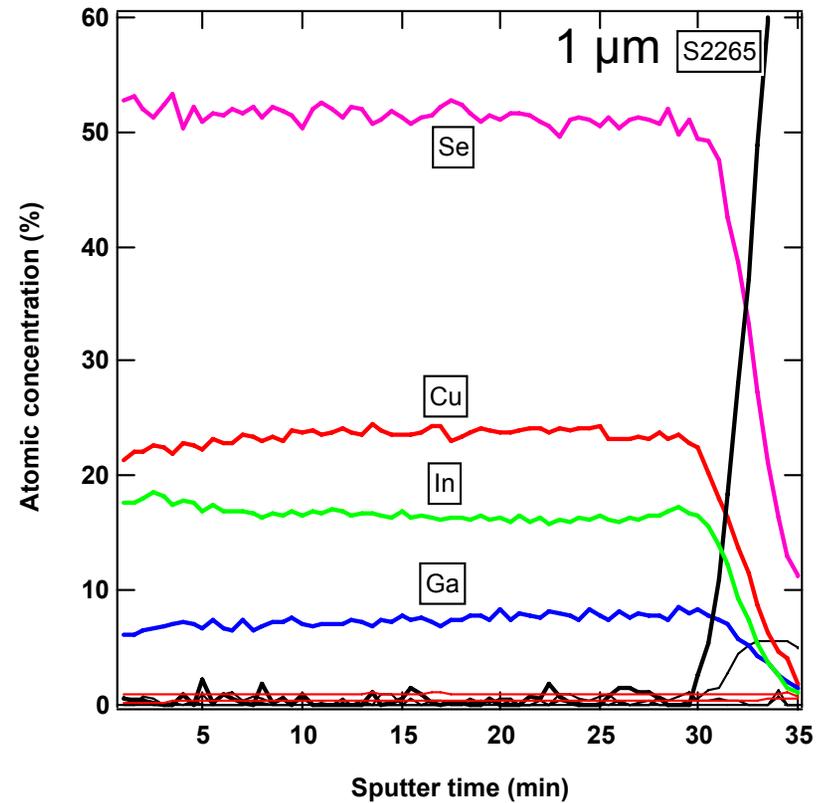
- IEC, Matsushita performed parametric study of absorber thickness
- Ångstrom Solar published comprehensive study
O. Lundberg, Prog. PV 11, 77 (2003)
16% @ 1.8 μm , 15% @ 0.8-1 μm , 12% @ 0.6 μm
- M. Gloeckler and J. Sites, J. Appl. Phys. **98**, 103703 (2005)

3-stage process for thin absorbers

Elemental flux vs. time

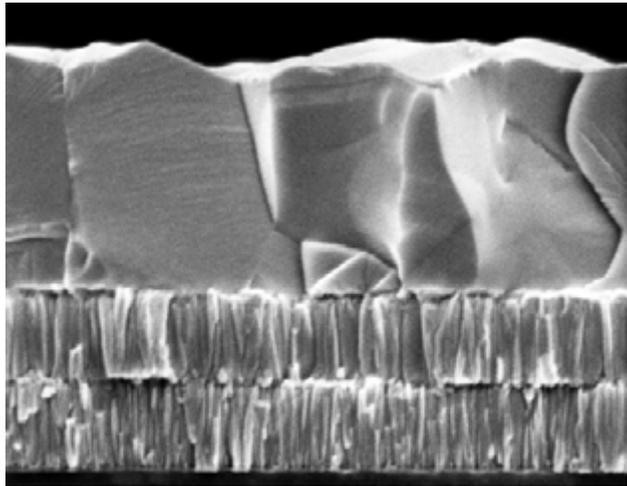


Auger depth profile



SEM Images- 3 stage

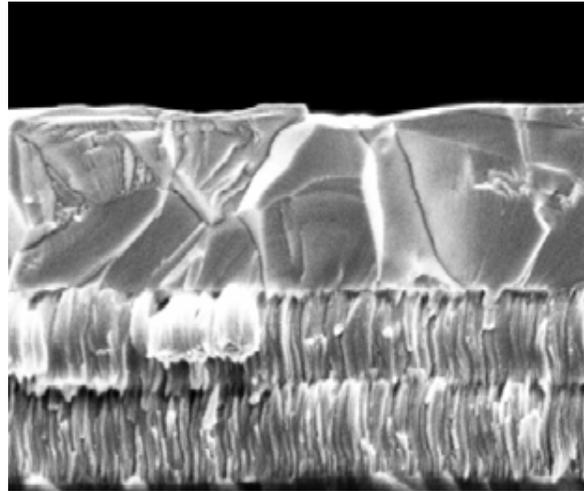
1.2 μ



S2264

600nm 40000X

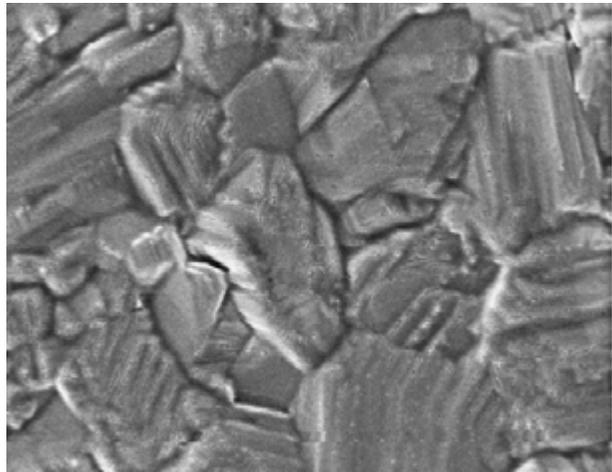
1 μ



S2265

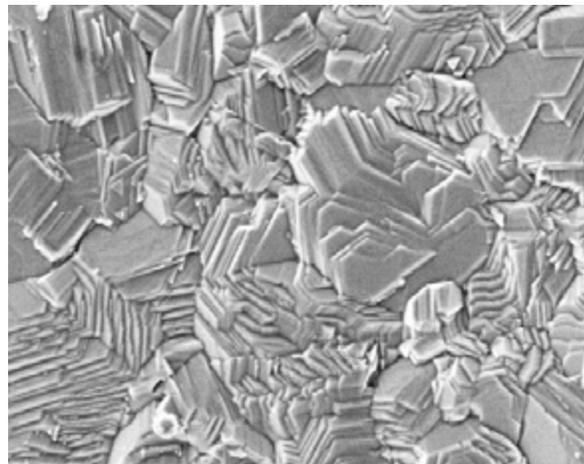
600nm 40000X

Cross section



S2264

1 μ m 25000X



S2265

1 μ m 25000X

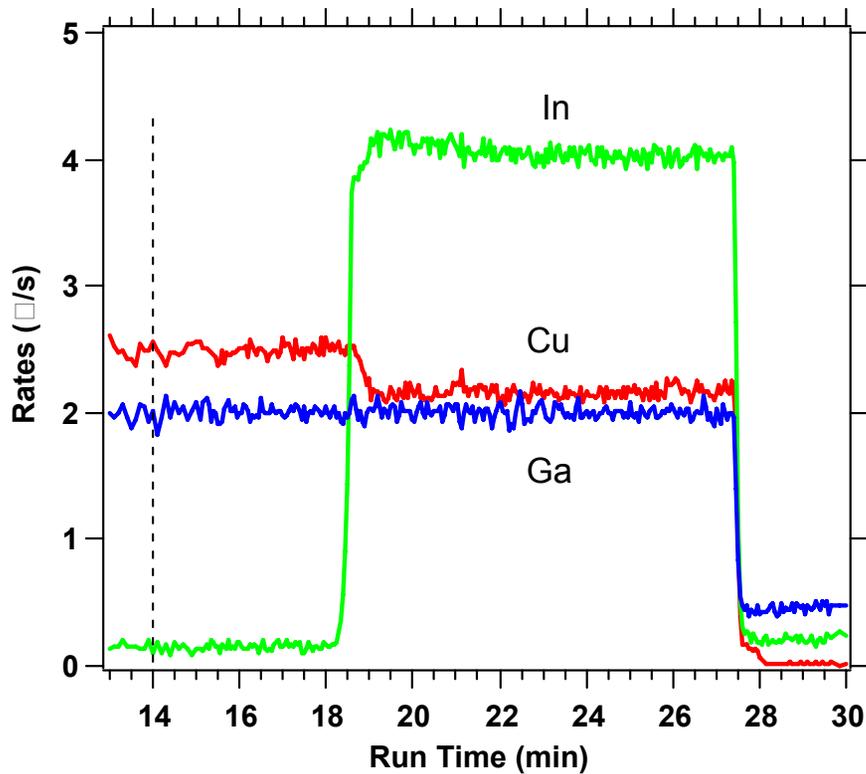
Plan view

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

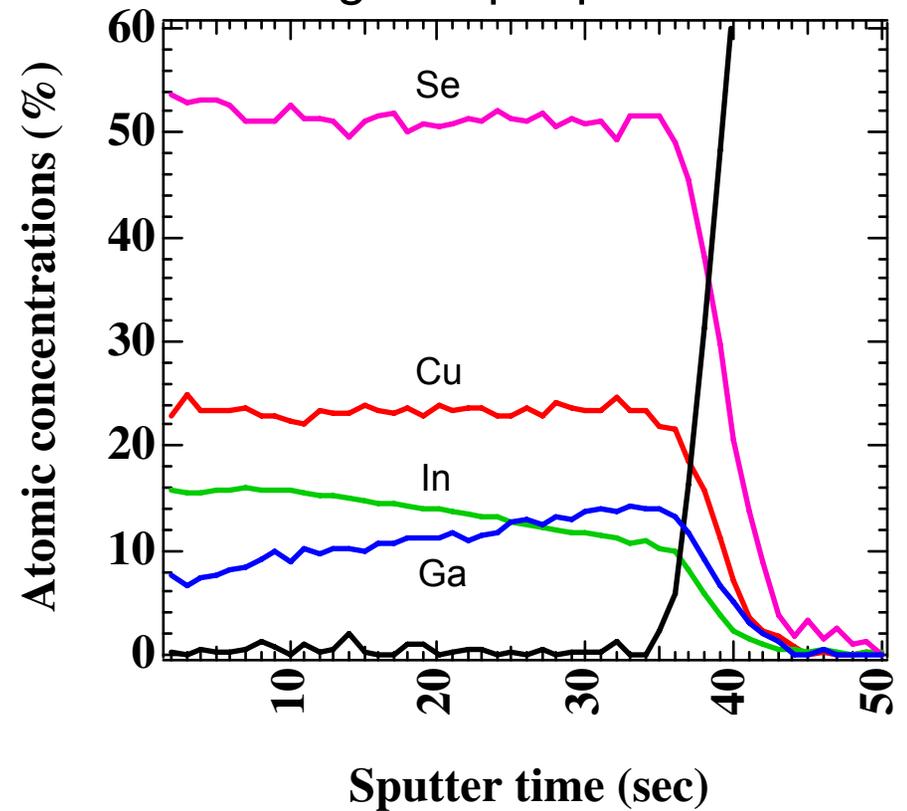
$$\frac{\text{Ga}}{\text{In+Ga}} = 0.27-0.28$$

Co-deposition on CGS seed layer

Elemental flux vs. time

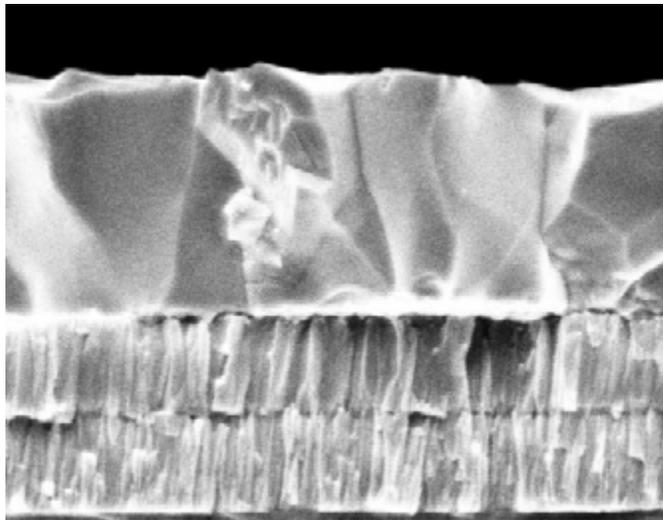


Auger depth profile



Co-deposition on CGS seed layer

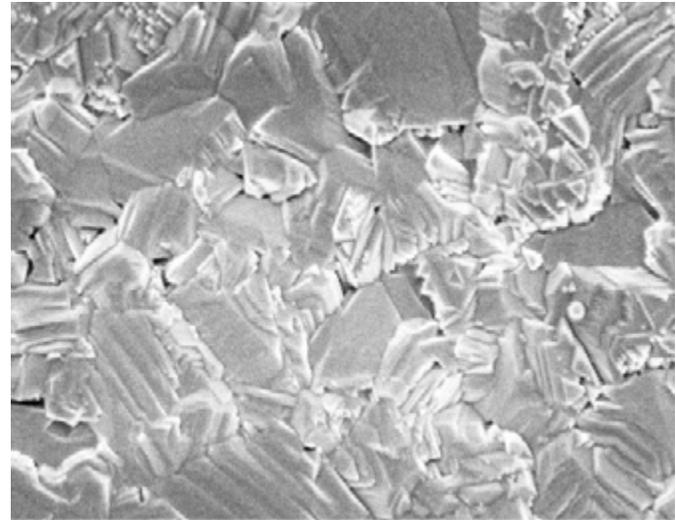
Cross section



S2297

600nm 40000X

Plan view



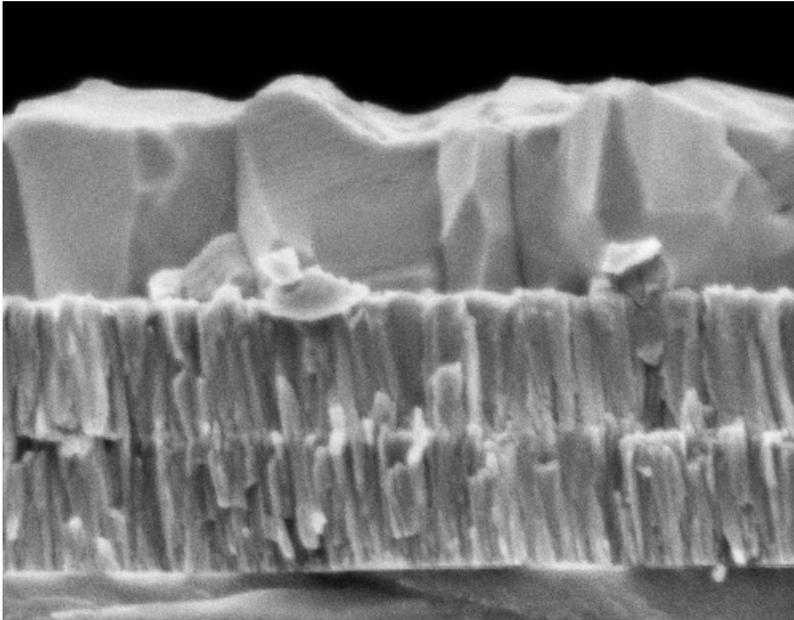
S2297

1µm 20000X

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

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

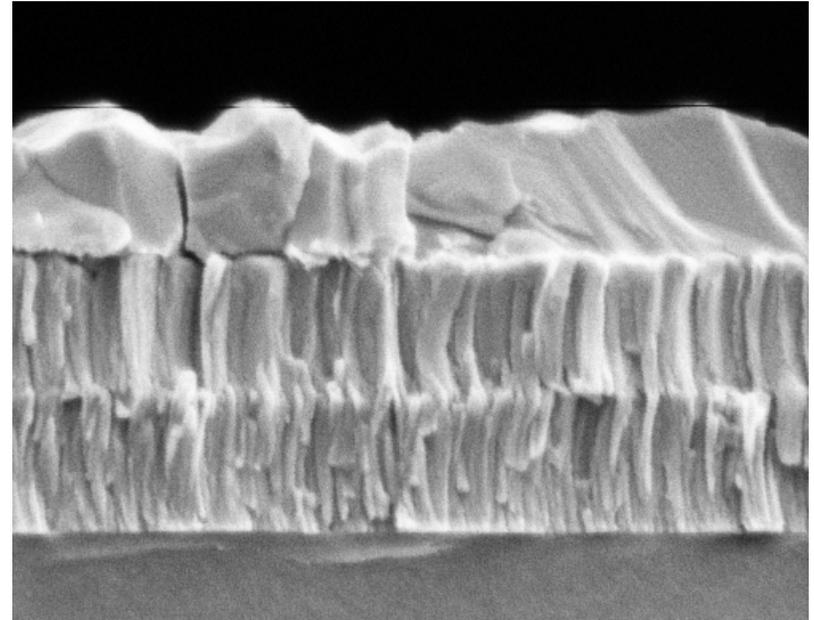
Submicron layers



S2373

600nm 50000X

0.75 μm (12.5%)



S2372

600nm 50000X

0.4 μm (9.1%)

Best result for 1 μm (3- stage)

NREL

CdS/Cu(In,Ga)Se₂ Cell

Device ID: S2438-B1 #3

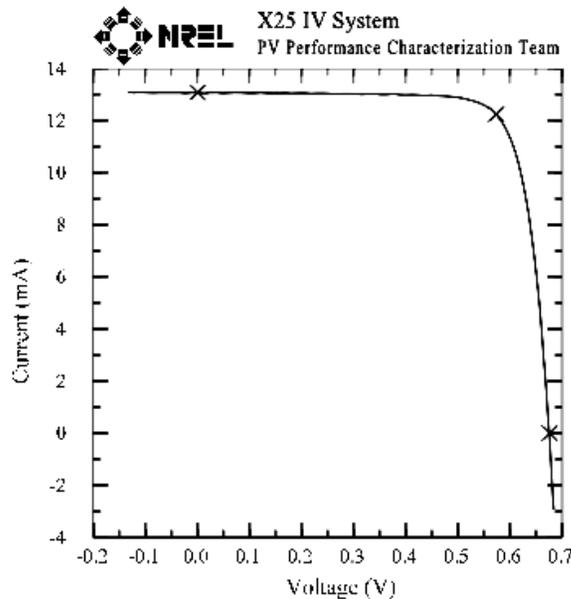
Device Temperature: 25.0 ± 1.0 °C

Oct 31, 2005 13:29

Device Area: 0.409 cm²

Spectrum: AM1.5-G (IEC 60904)

Irradiance: 1000.0 W/m²



$V_{oc} = 0.6756$ V

$I_{max} = 12.243$ mA

$I_{sc} = 13.072$ mA

$V_{max} = 0.5732$ V

$J_{sc} = 31.961$ mA/cm²

$P_{max} = 7.0182$ mW

Fill Factor = 79.47 %

Efficiency = 17.16 %

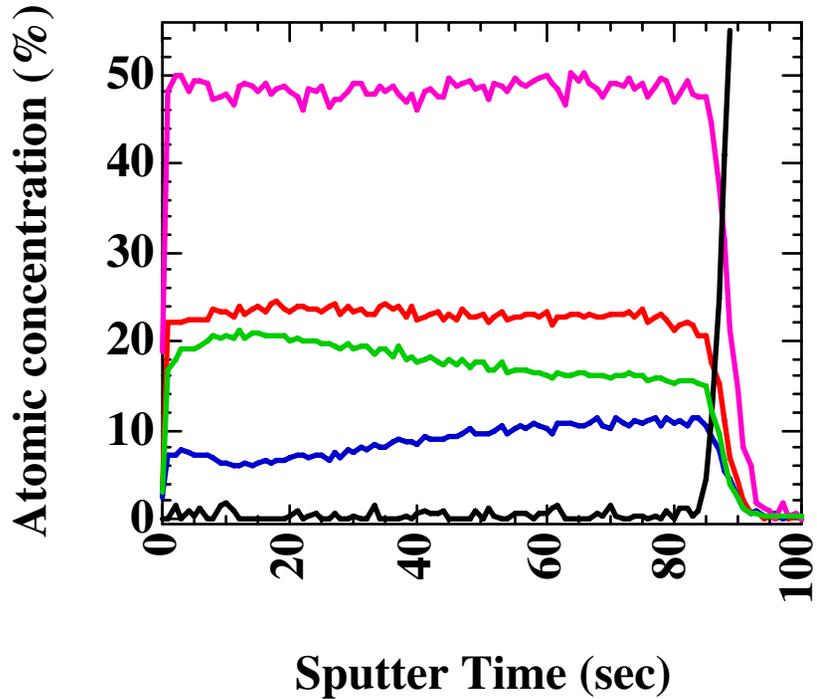
After 10 minute soak at P_{max} , 5 minute cool.

For 1 μm cell, $J_0 \sim 8 \times 10^{-11}$ A/cm², $n = 1.33$

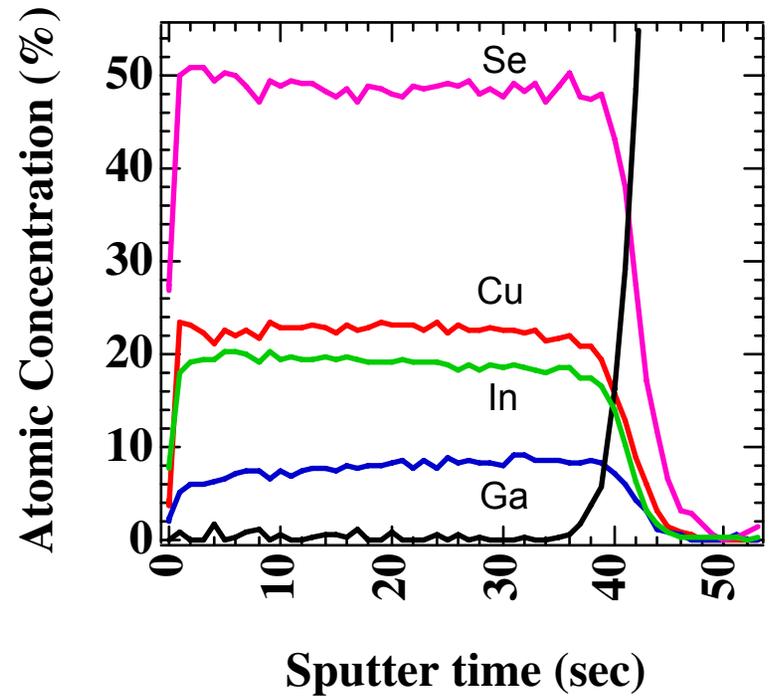
Values for 2.5 μm (19%) cells: $n = 1.35$, $J_0 \sim 4 \times 10^{-11}$ A/cm²

Increase in J_0 partly accounts for the voltage shortfall.

Auger profile comparison

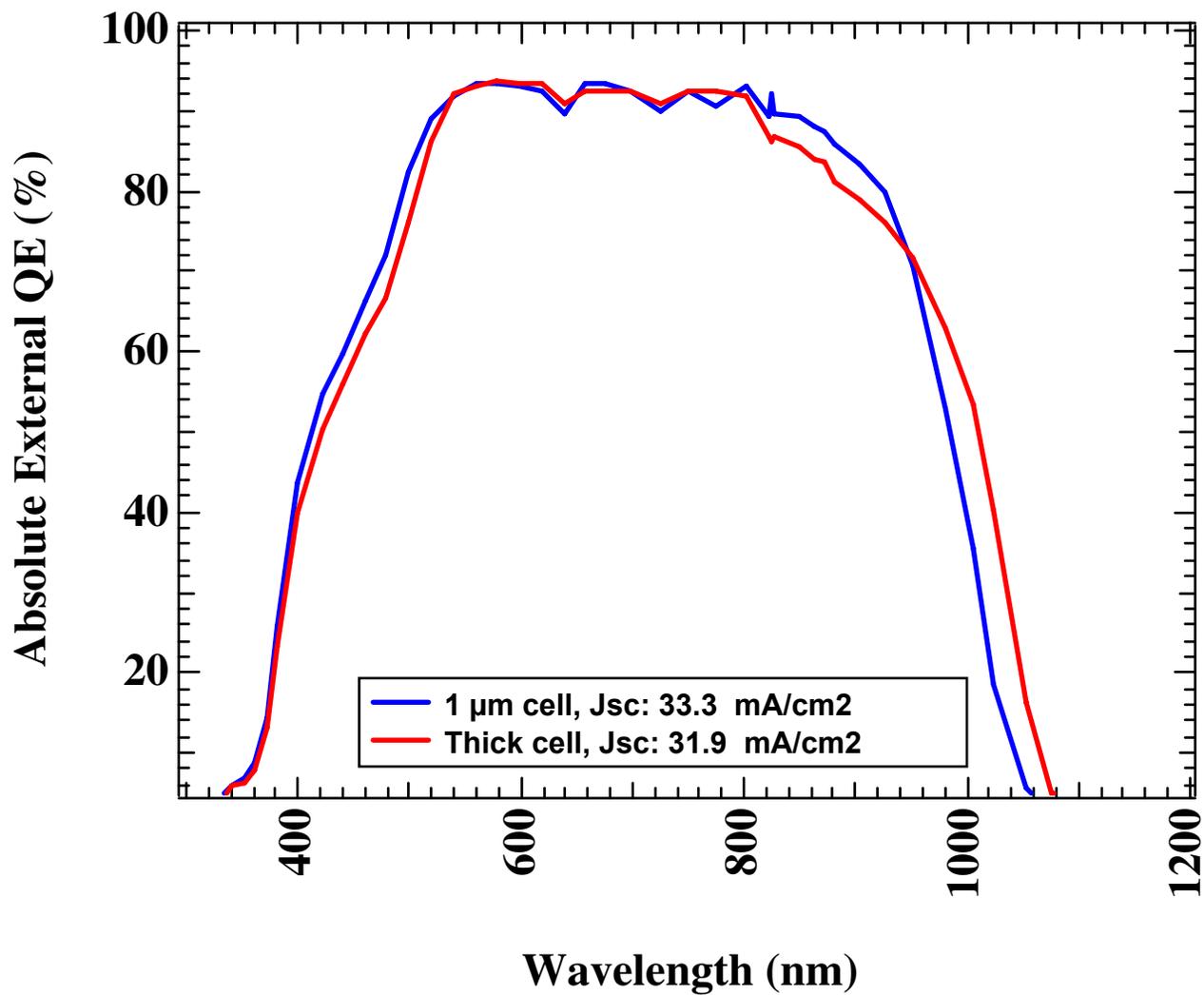


2.5- μm cell

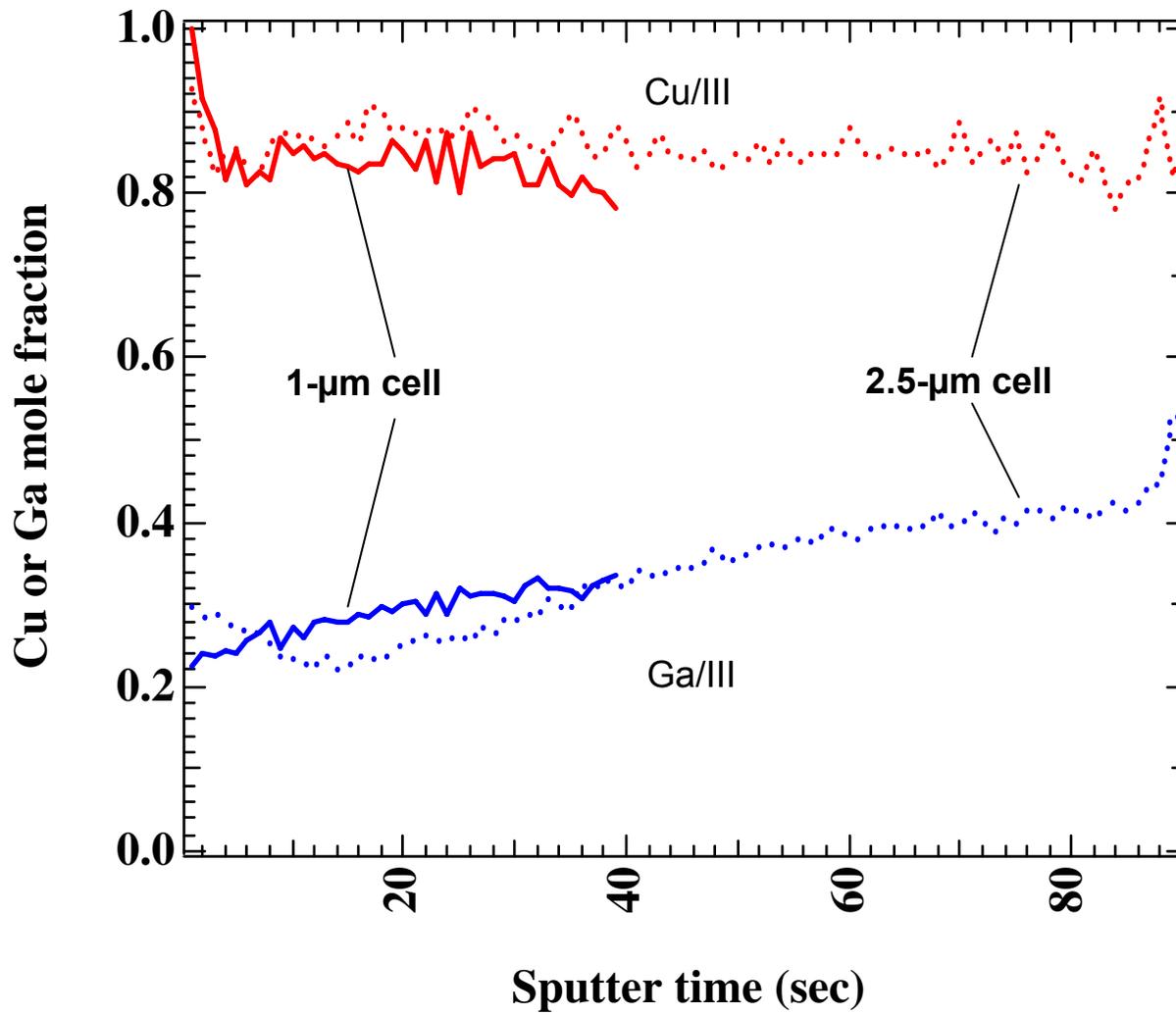


1- μm cell

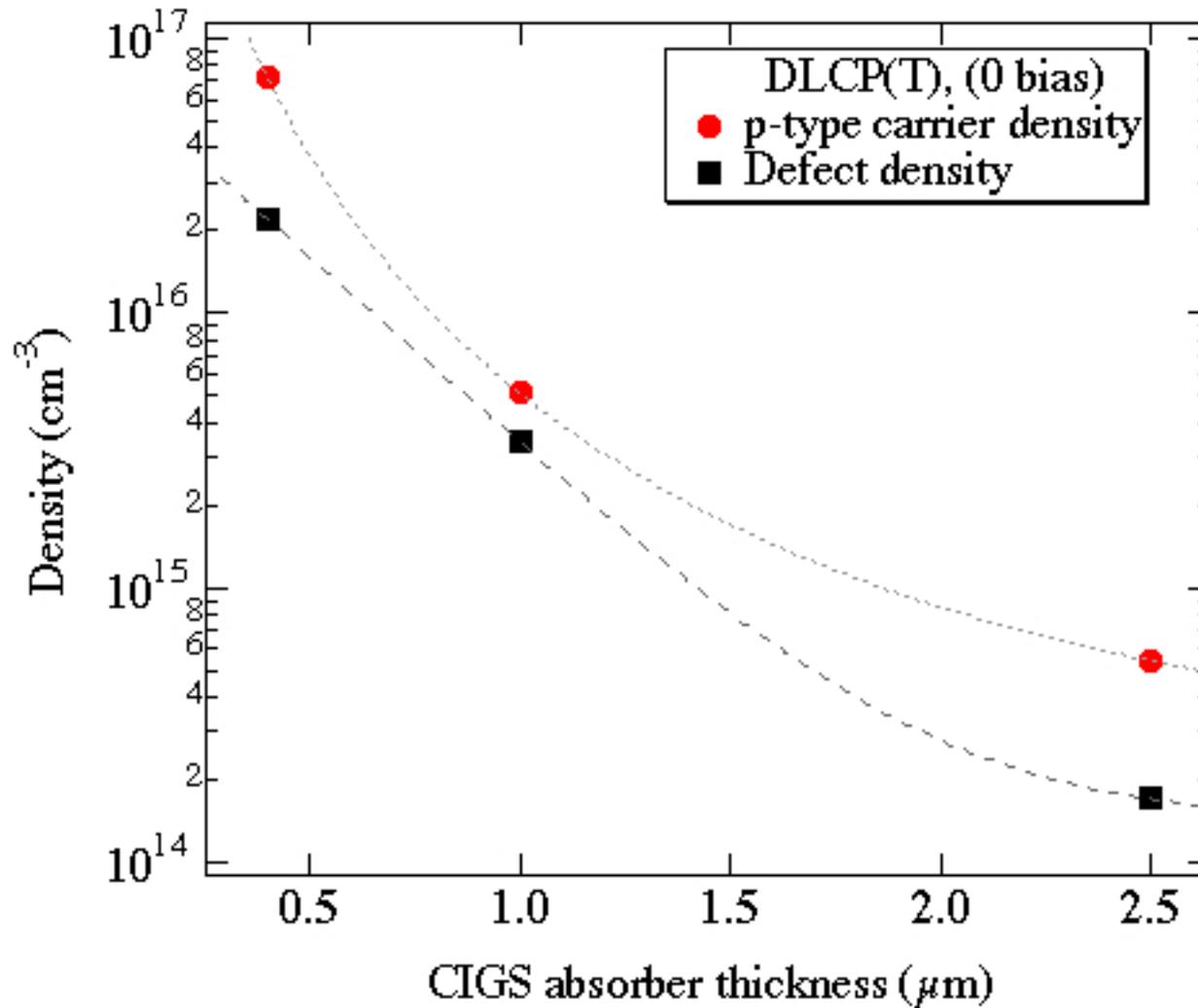
QE comparison



Cu and Ga ratios



Carrier concentration & Defect density



Summary of Best results

t (μm)	V_{oc} (V)	J_{sc} (mA/cm²)	FF (%)	Eff (%)
1.0 (3 stg)	0.678	31.93	79.2	17.1
1.0 (codep)	0.699	30.6	75.4	16.0
0.60	0.658	26.1	73.1	12.6
0.40	0.565	21.3	75.7	9.1
Control	0.701	34.6	79.7	19.3

Conclusions

- 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 μm (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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