NREL National Renewable Energy Laboratory

Processing and Properties of Very Thin $CuInGaSe_2$ (CIGS) Solar Cells

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Outline

- 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.

Prior Work

- IEC, Matsushita performed parametric study of absorber thickness

- Ångstrom Solar published comprehensive study

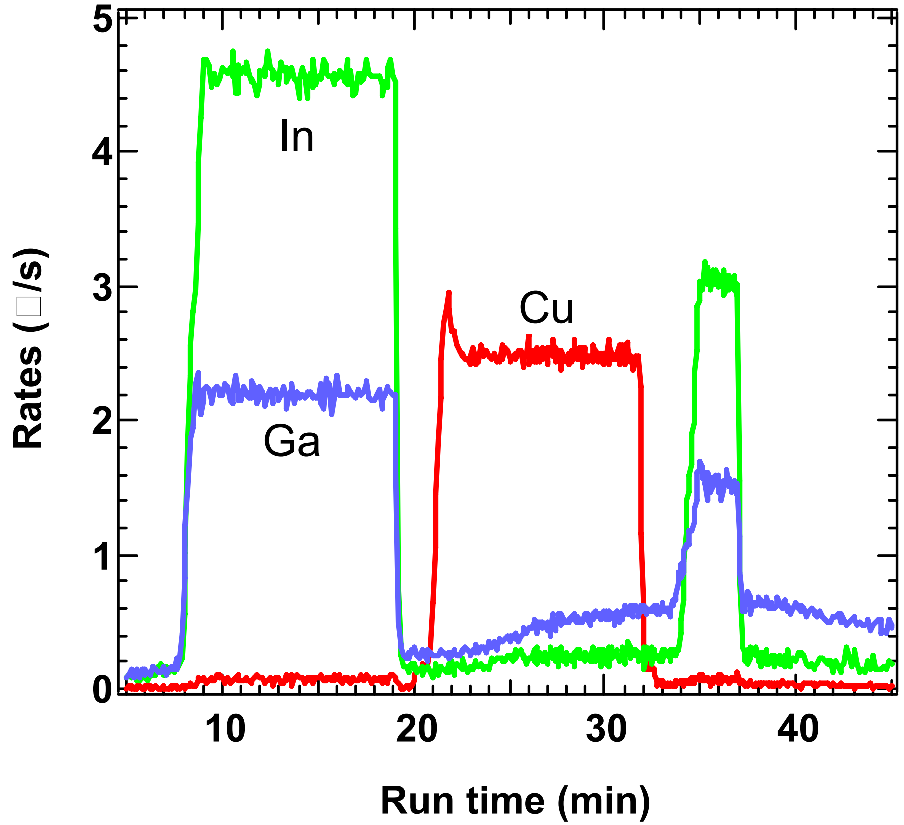
  O. Lundberg, Prog. PV 11, 77 (2003)

16% @ 1.8 µm, 15% @ 0.8-1 µm, 12% @ 0.6 µm

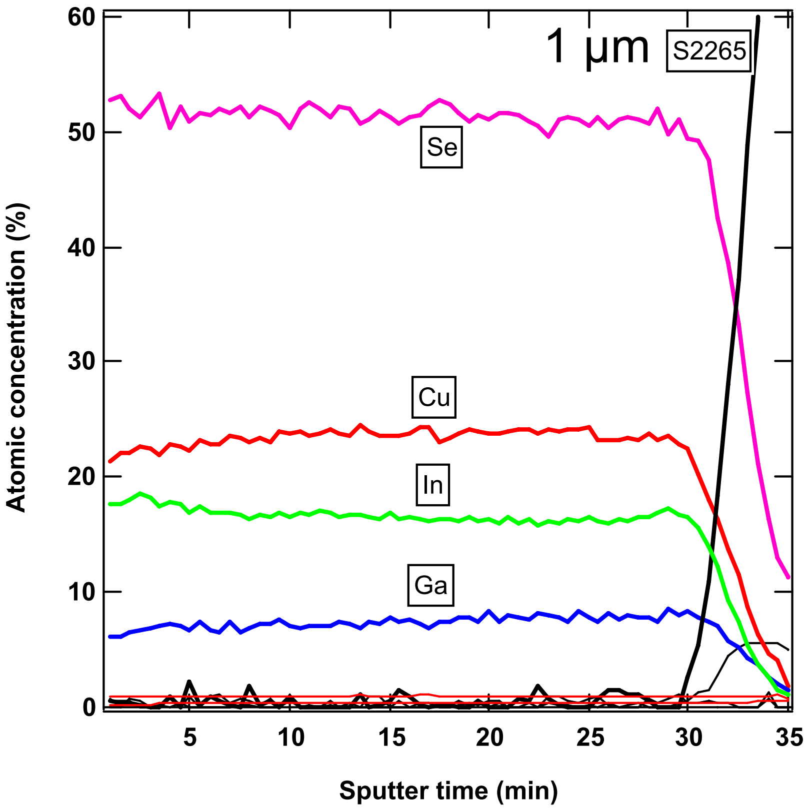
- M. Gloeckler and J. Sites, J. Appl. Phys. **98**, 103703 (2005)

3-stage process for thin absorbers

Elemental flux vs. time



Auger depth profile

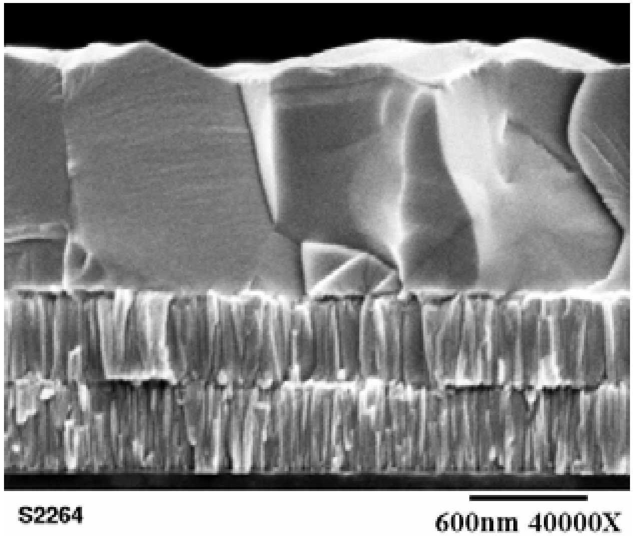


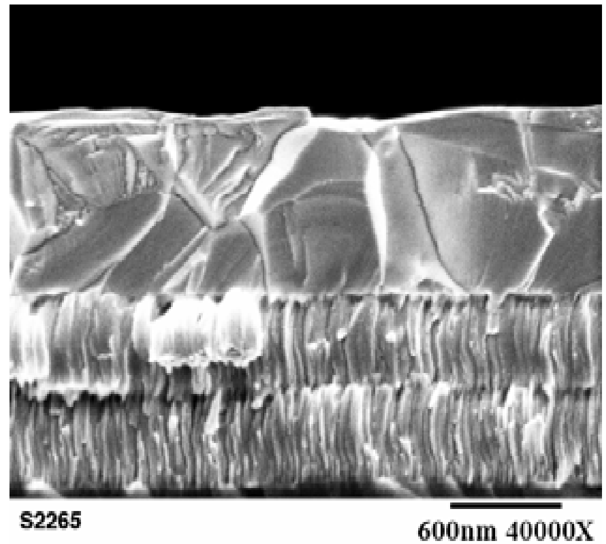
SEM Images- 3 stage

1.2 μ

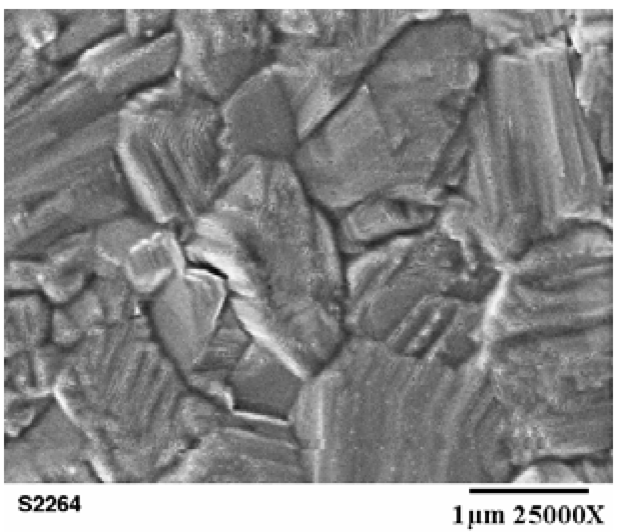
1 μ

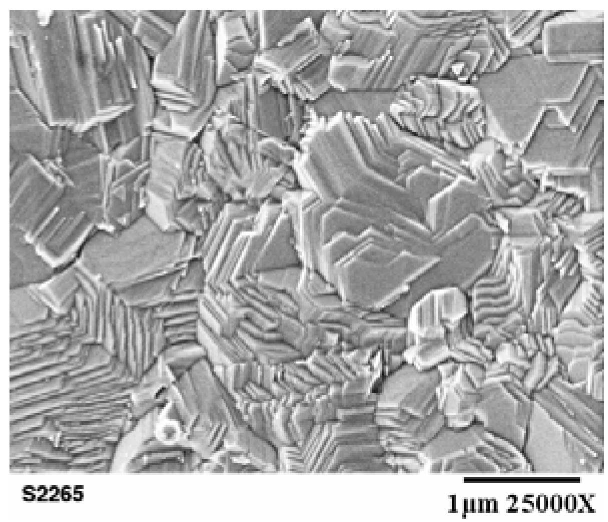
Cross section





Plan view



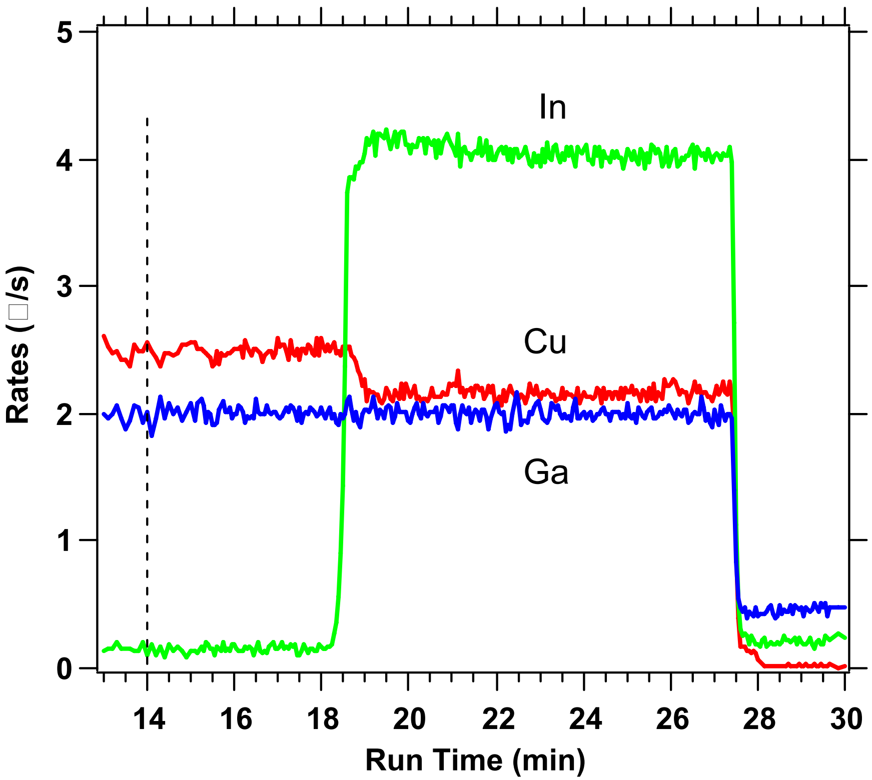


Cu/(In+Ga) = 0.89-0.91

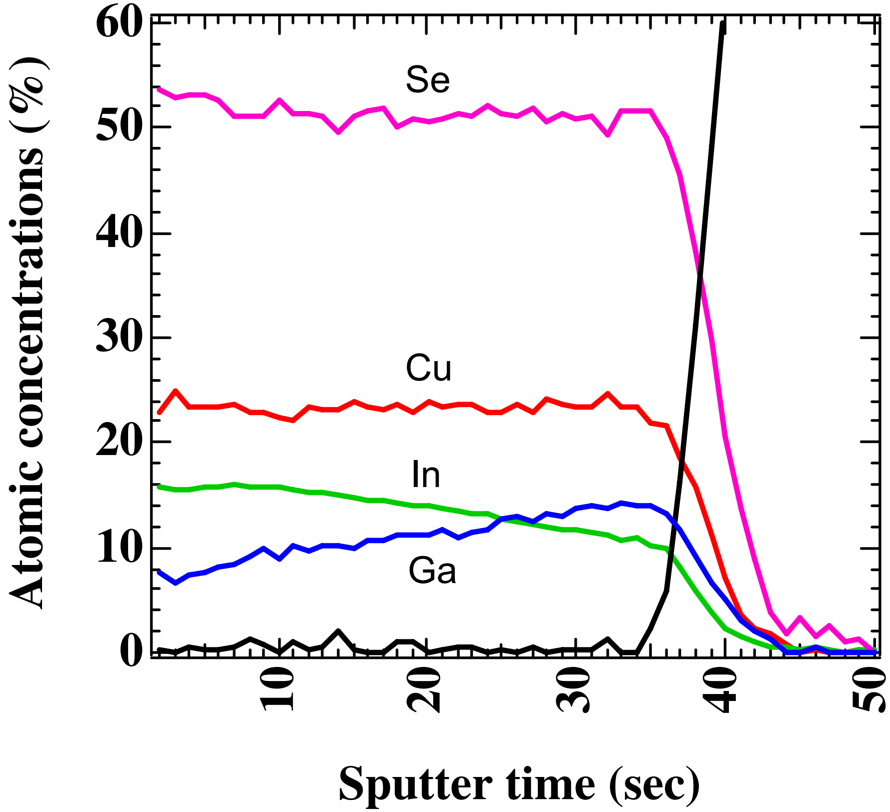
Ga/(In+Ga) = 0.27-0.28

Co-deposition on CGS seed layer

Elemental flux vs. time

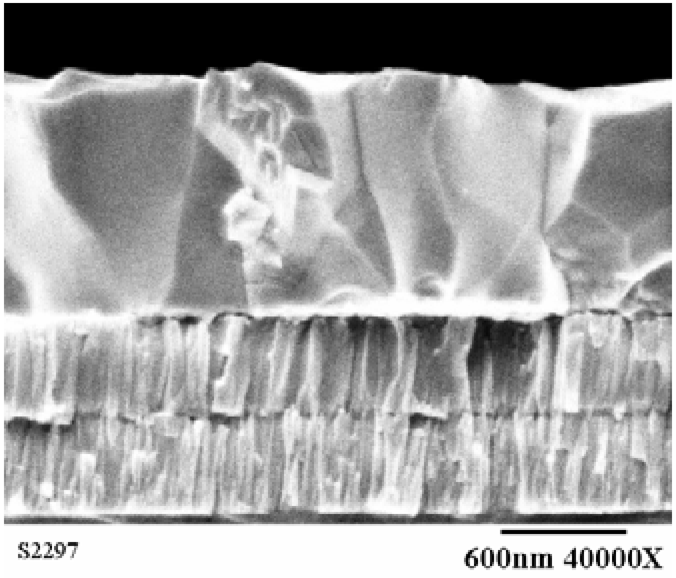


Auger depth profile

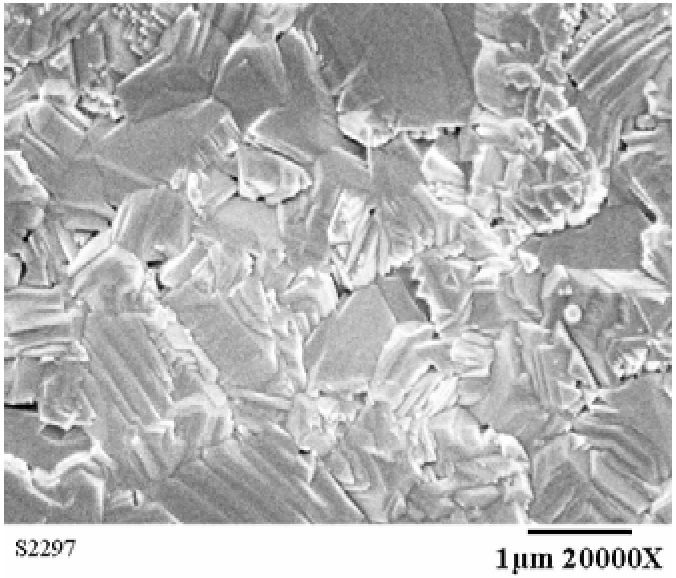


Co-deposition on CGS seed layer

Cross section

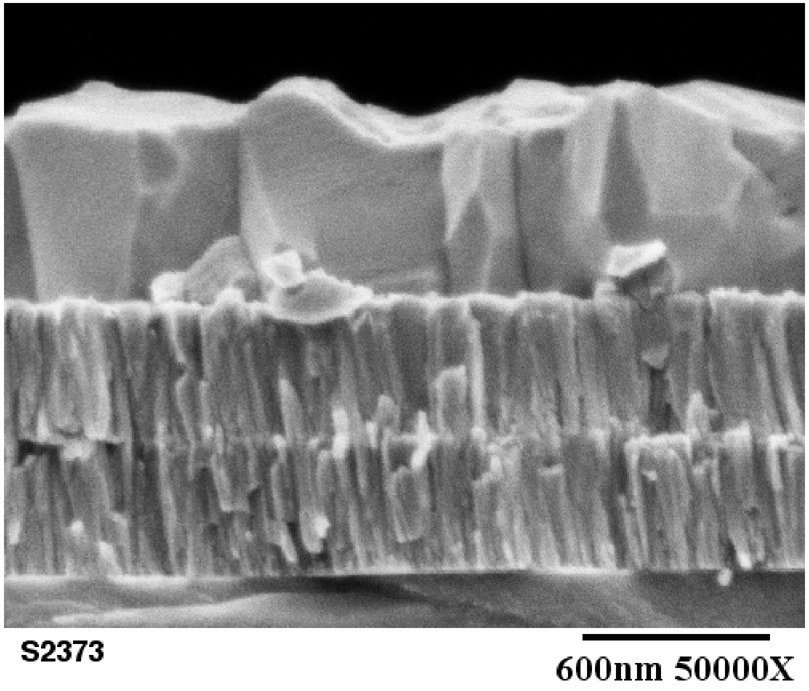


Plan view

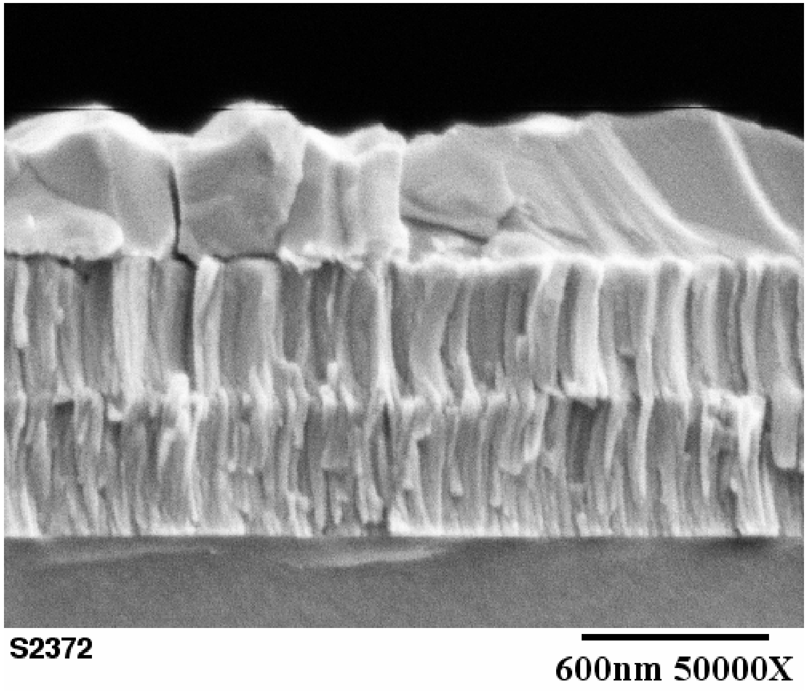


Cu/(In+Ga) = 0.91
Ga/(In+Ga) = 0.30

Submicron layers



0.75 µm (12.5%)



0.4 µm (9.1%)

Best result for 1 μm (3- stage)

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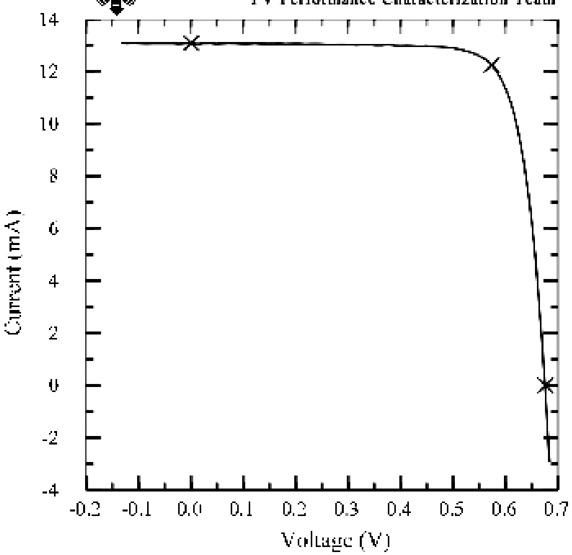
CdS/Cu(In,Ga)Se_2 Cell

Device ID: S2438-B1 #3
Oct 31, 2005 13:29
Spectrum: AM1.5-G (IEC 60904)

Device Temperature: 25.0 ± 1.0 °C
Device Area: 0.409 cm^2
Irradiance: 1000.0 W/m^2

NREL X25 IV System
PV Performance Characterization Team



V_{oc} = 0.6756 V
I_{sc} = 13.072 mA
J_{sc} = 31.961 mA/cm^2
Fill Factor = 79.47 %

I_{max} = 12.243 mA
V_{max} = 0.5732 V
P_{max} = 7.0182 mW
Efficiency = 17.16 %

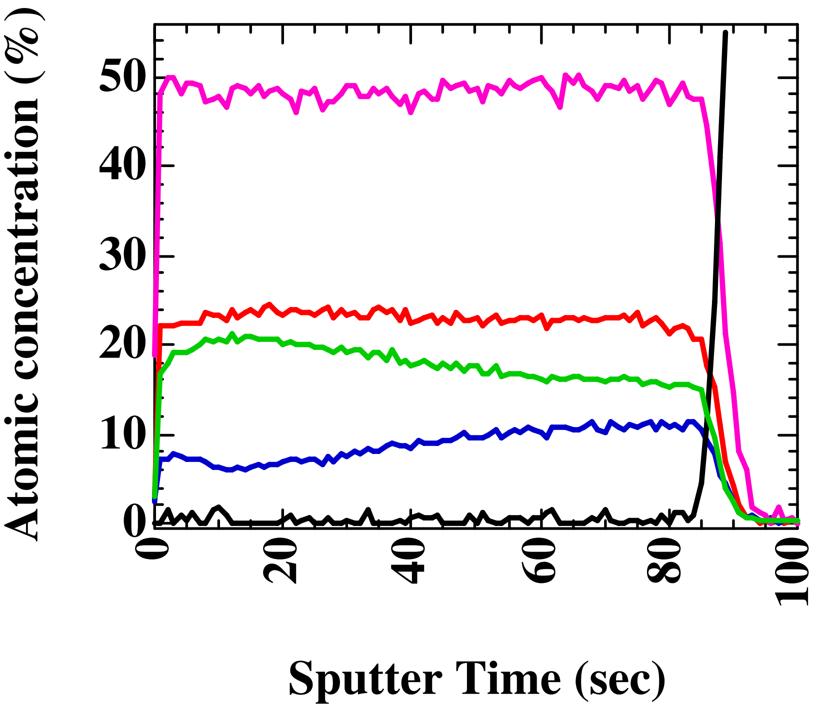
After 10 minute soak at P_{max}, 5 minute cool.

For 1 μm cell, J_0 ~ 8x10^{-11} A/cm^2, n = 1.33

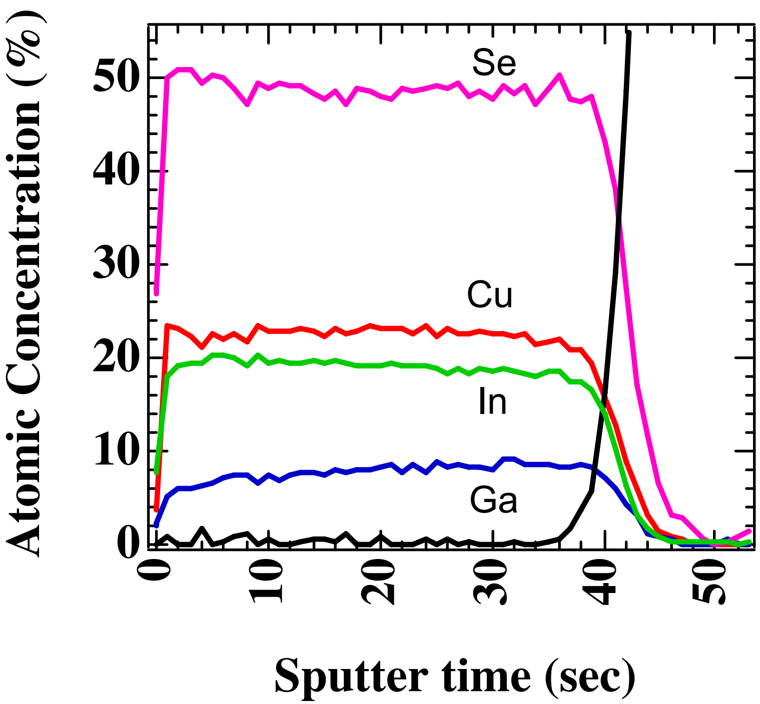
Values for 2.5 μm (19%) cells: n = 1.35, J_0 ~ 4x10^{-11} A/cm^2

Increase in J_0 partly accounts for the voltage shortfall.

Auger profile comparison

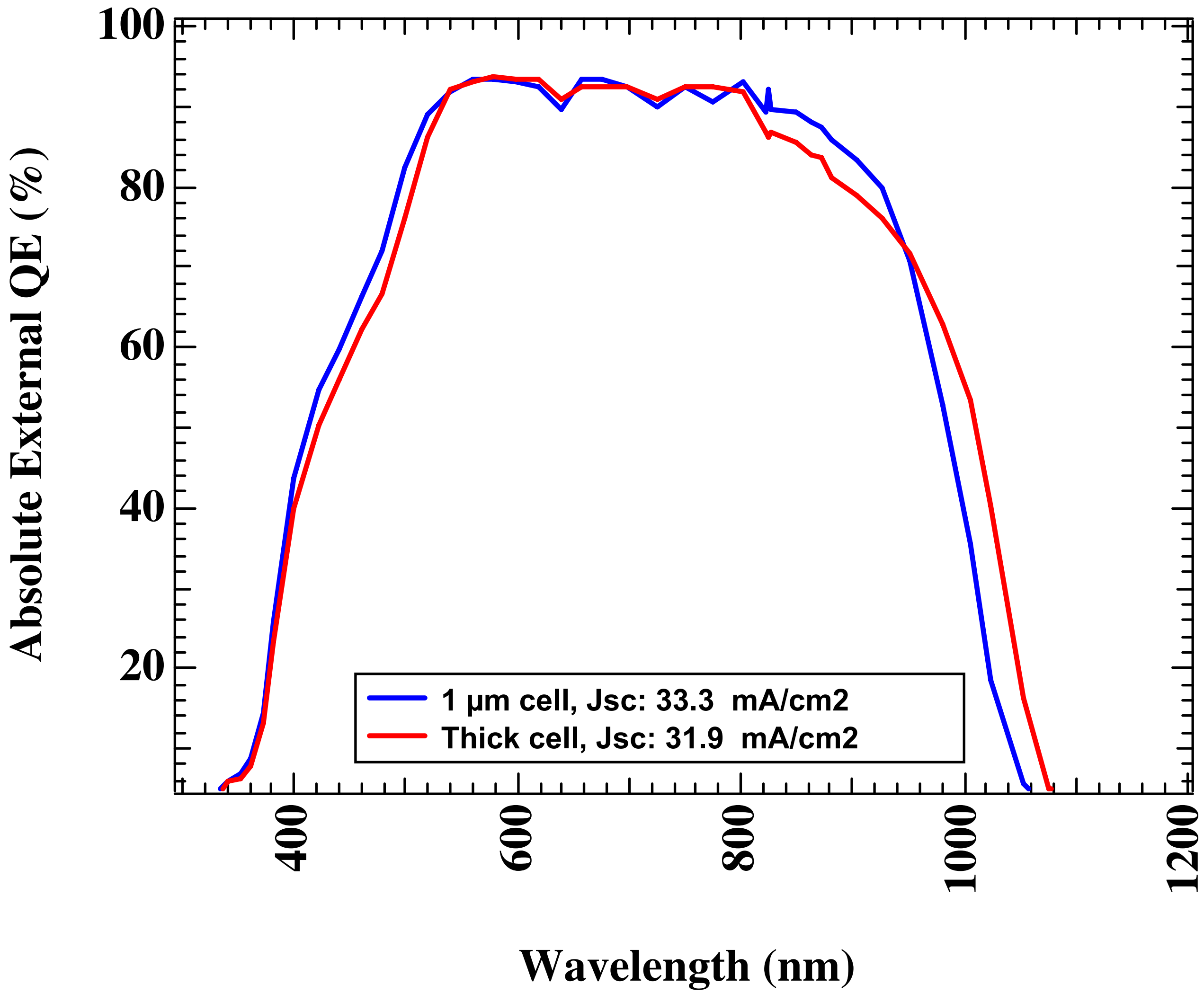


2.5-μm cell

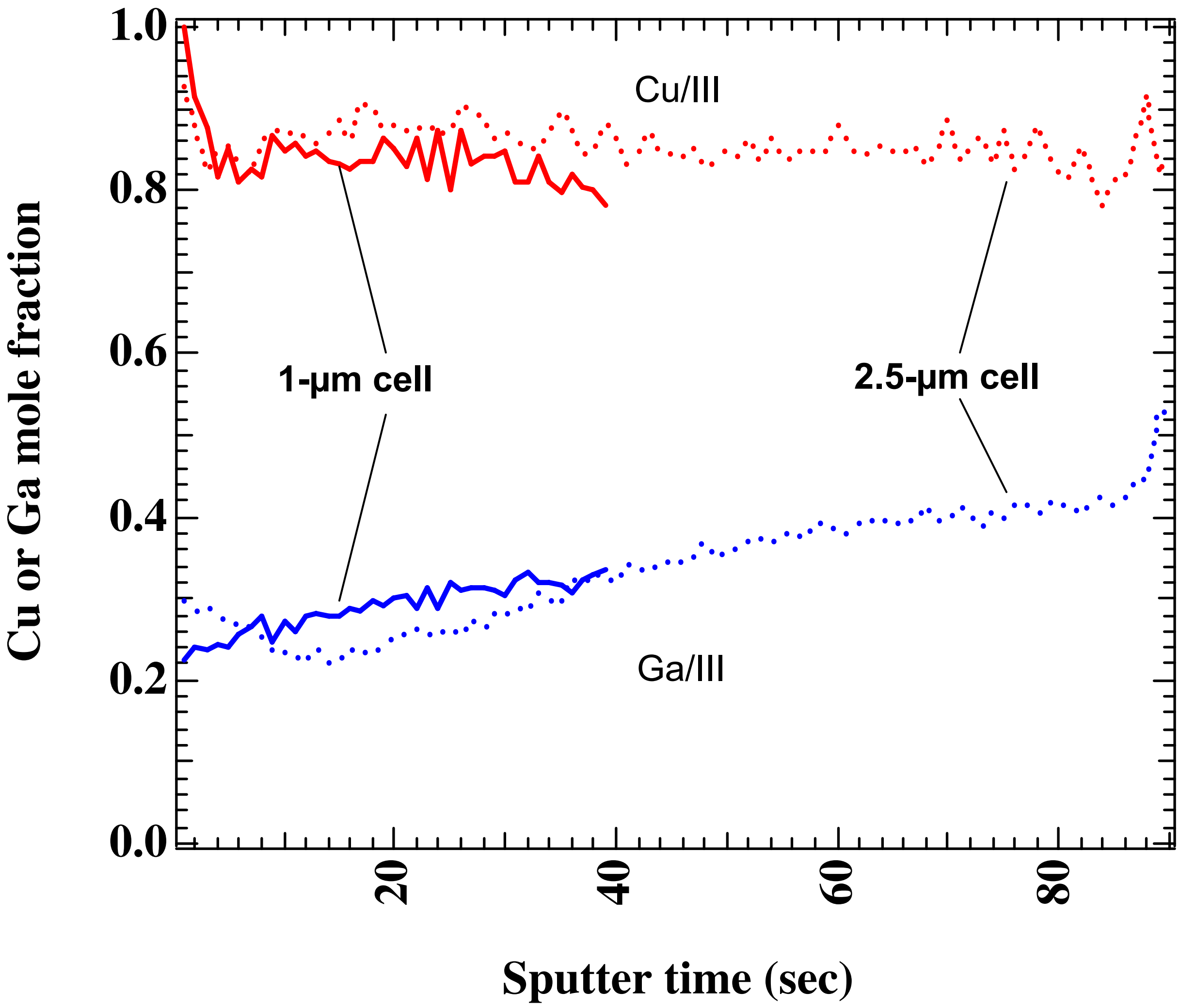


1-μm cell

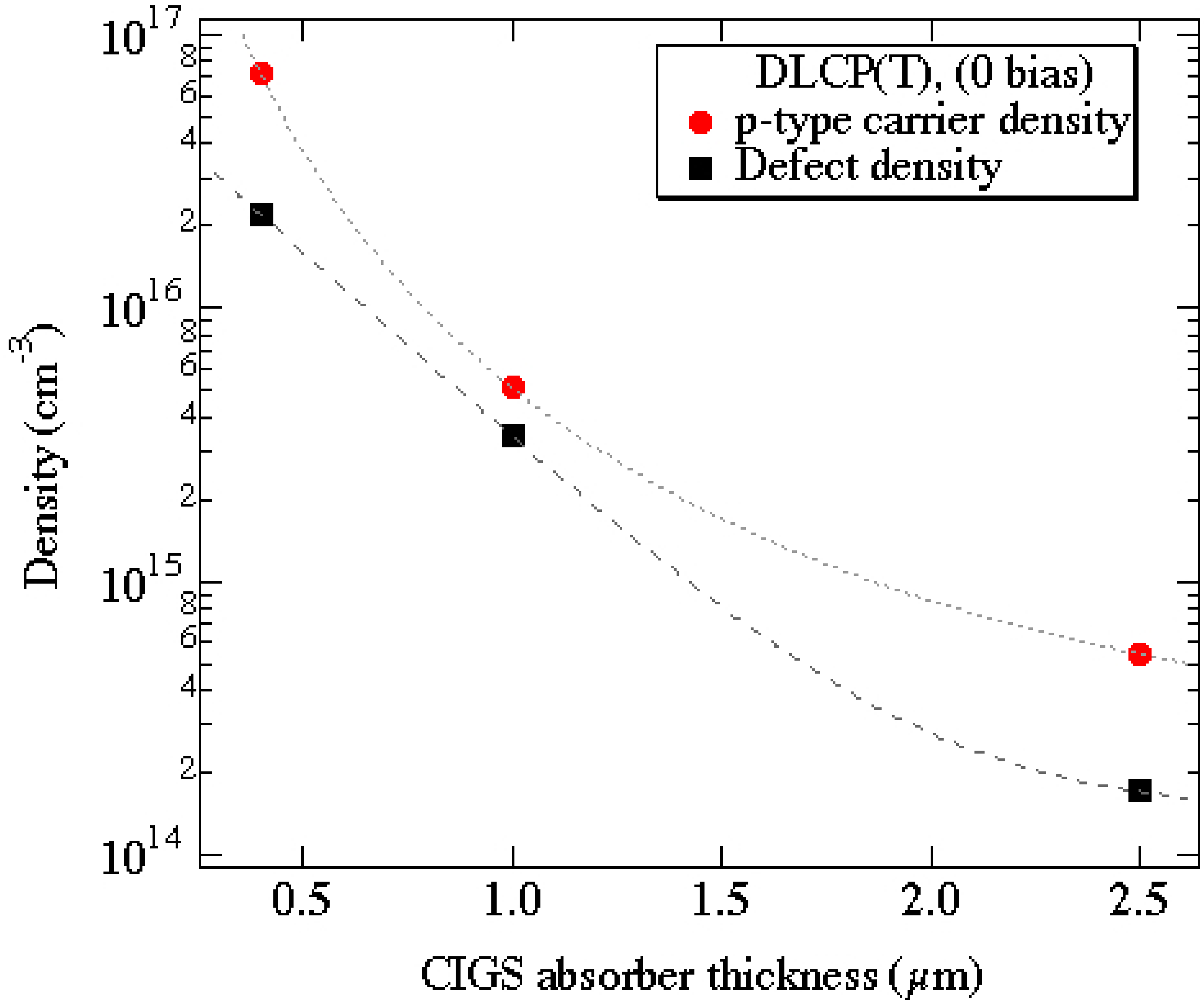
QE comparison



Cu and Ga ratios



Carrier concentration & Defect density



Summary of Best results

t (μm)	V_{oc} (V)	J_{sc} (mA/cm^2)	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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