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

Kannan Ramanathan, Rommel Noufi, David Young, Bobby To, Raghu Bhattacharya, Miguel Contreras, Ramesh Dhere, Glenn Teeter, Craig Perkins and Sally Asher

National Center for Photovoltaics, NREL

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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

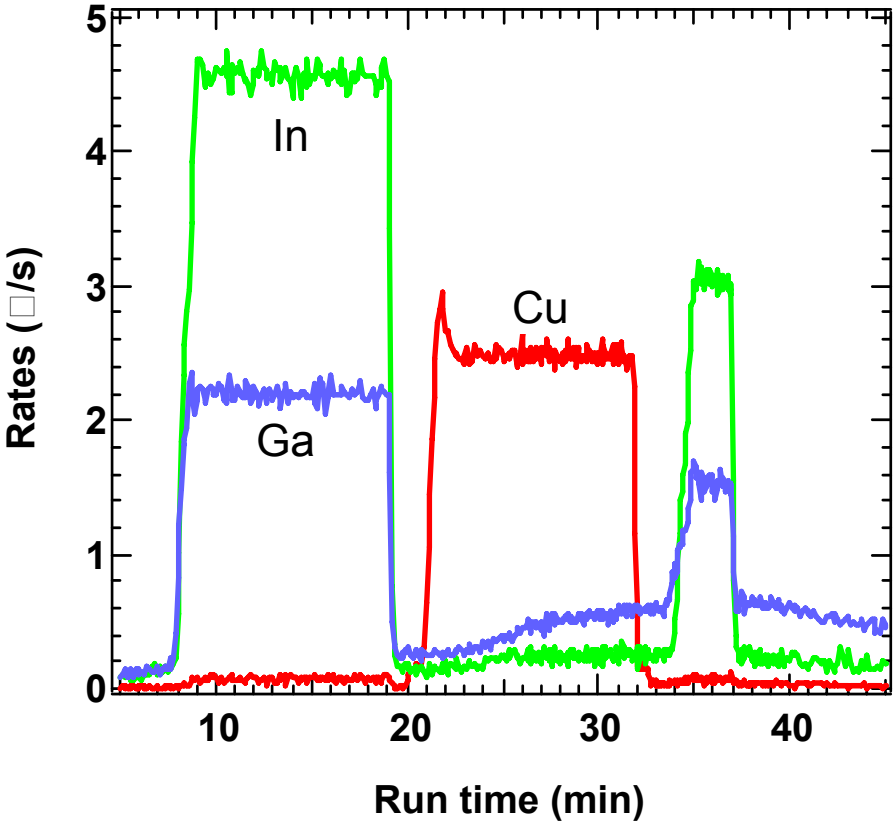
O. Lundberg, Prog. PV 11, 77 (2003)

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

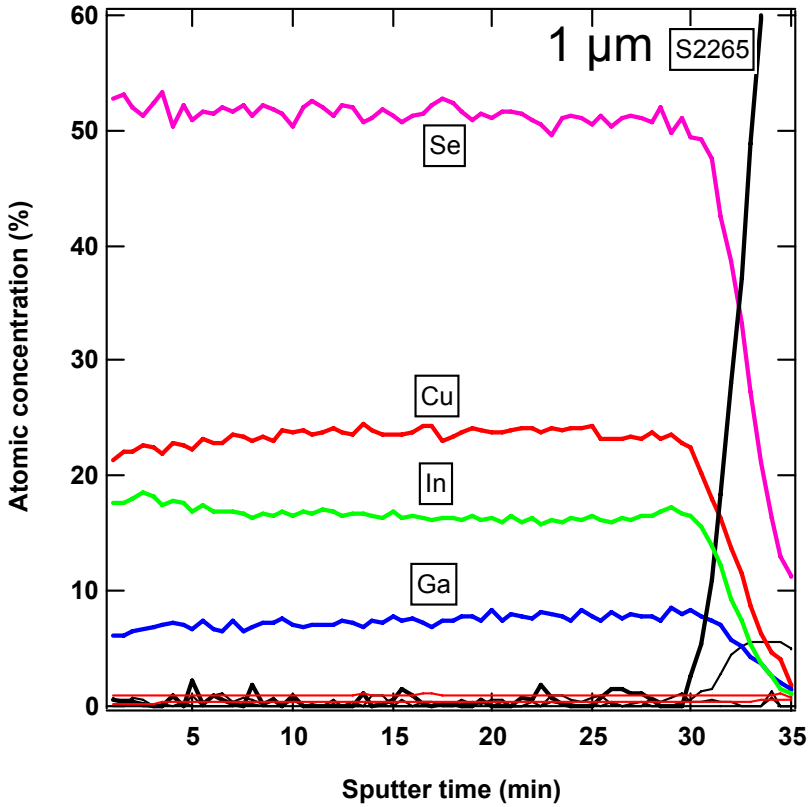
- M. Gloeckler and J. Sites, J. Appl. Phys. **98**, 103703 (2005)

3-stage process for thin absorbers

Elemental flux vs. time

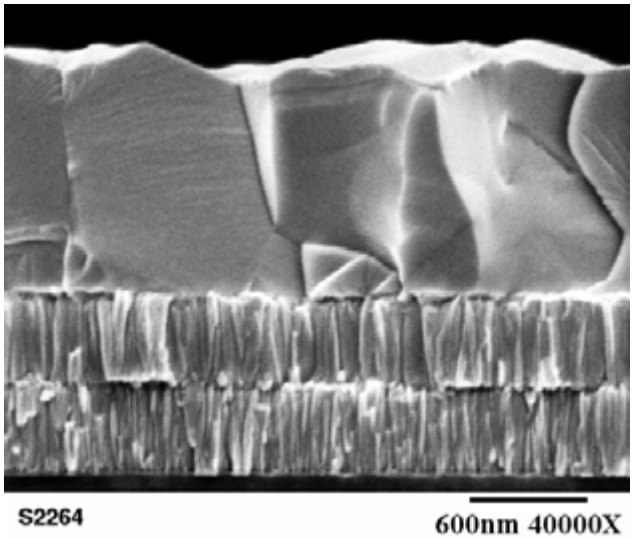


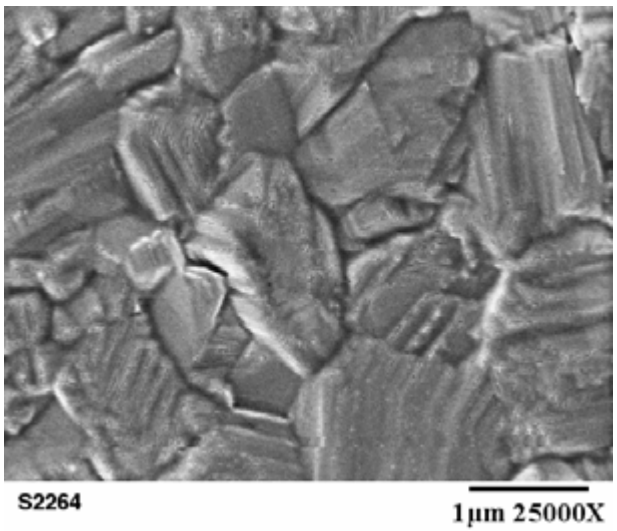
Auger depth profile



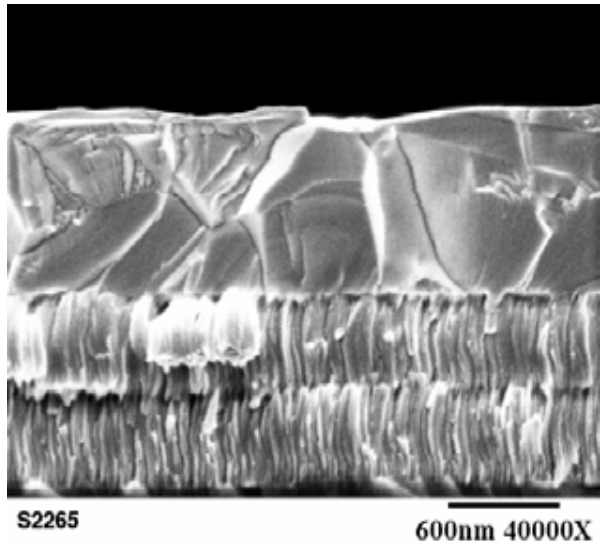
SEM Images- 3 stage

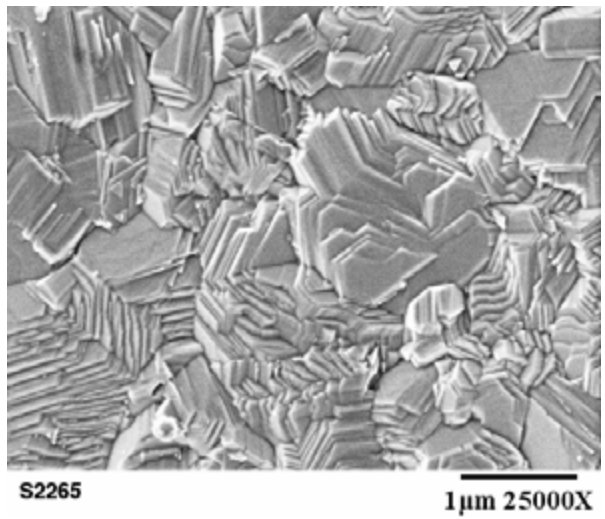
1.2 µ





1 µ





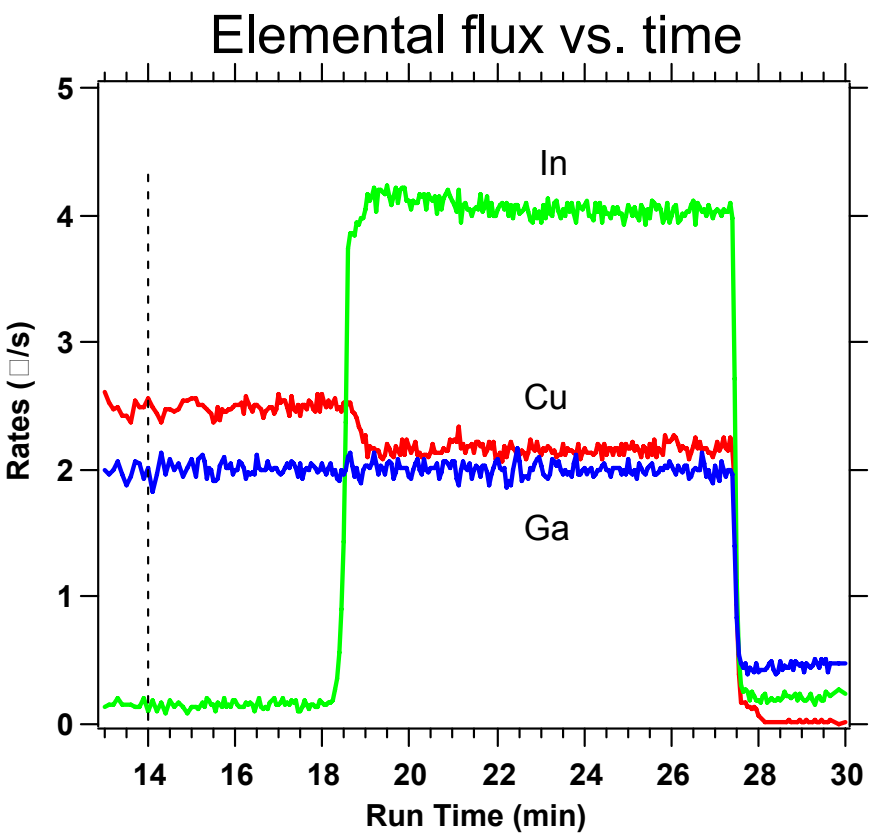
Cross section

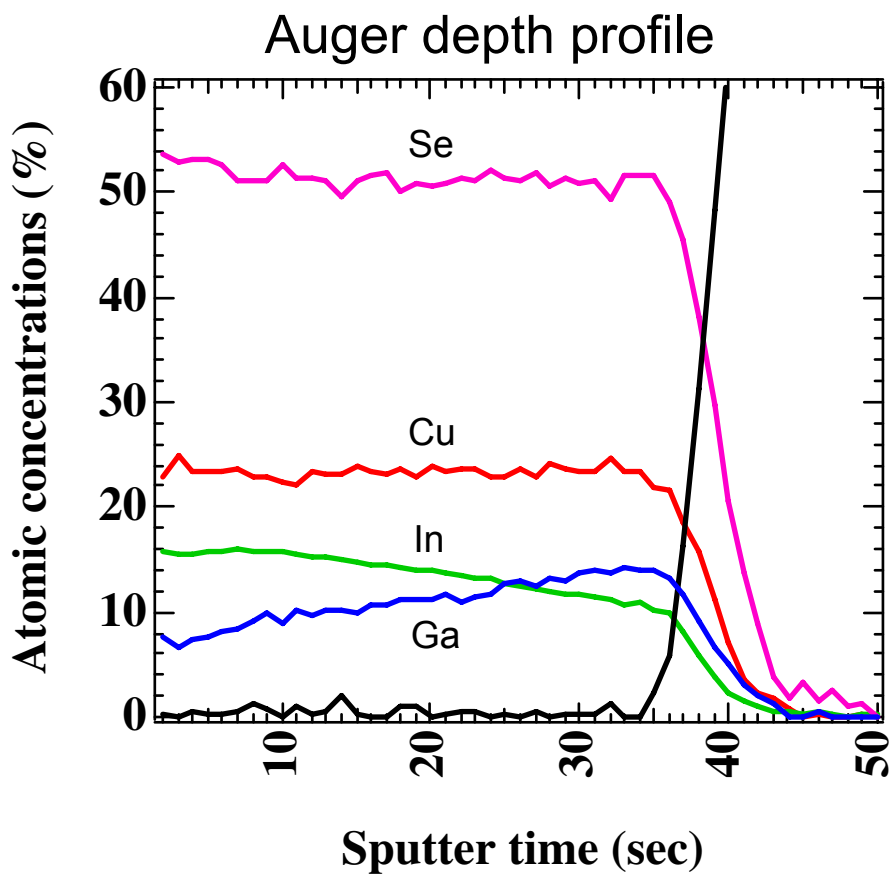
Plan view

Cu/(In+Ga)
= 0.89-0.91

Ga/(In+Ga)
= 0.27-0.28

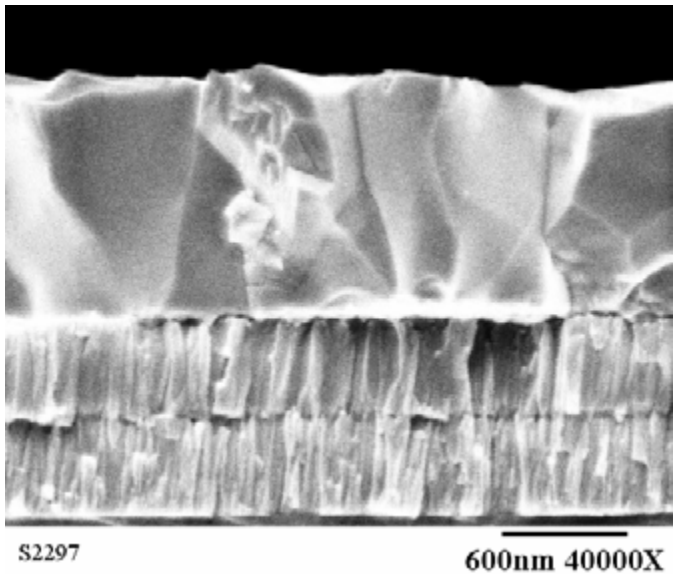
Co-deposition on CGS seed layer



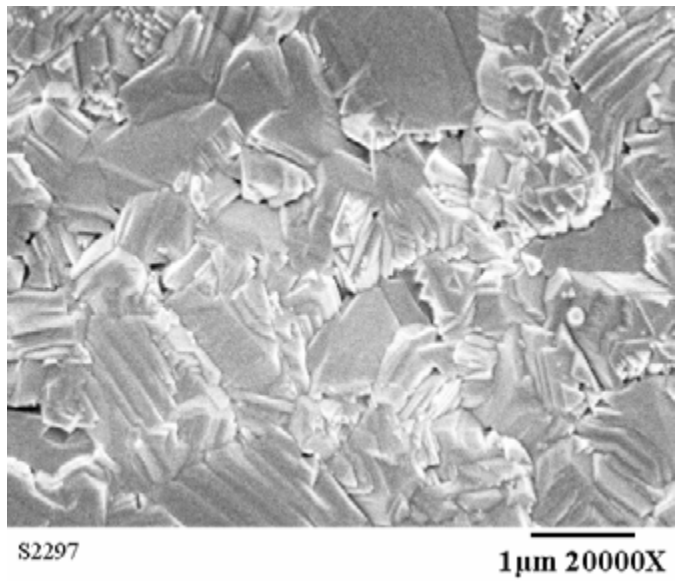


Co-deposition on CGS seed layer

Cross section

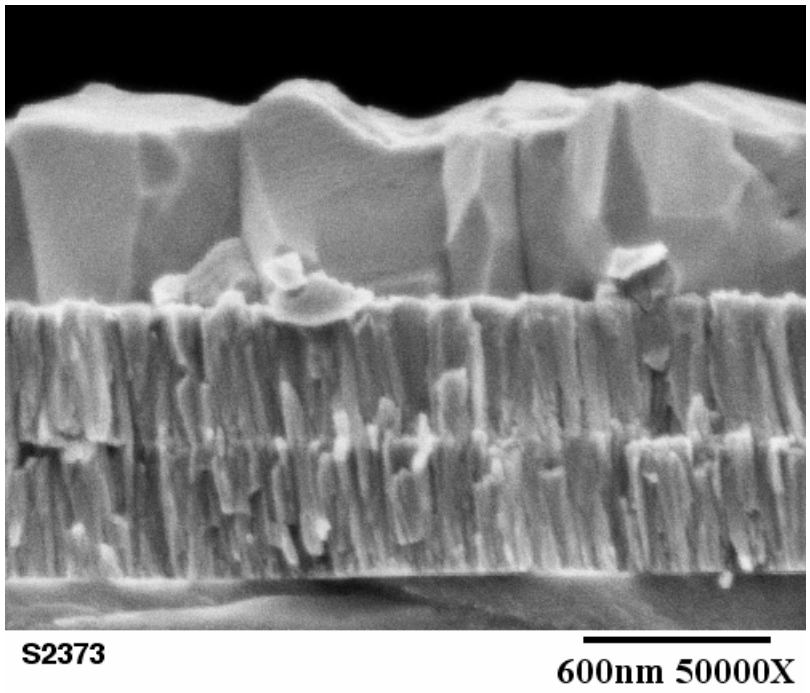


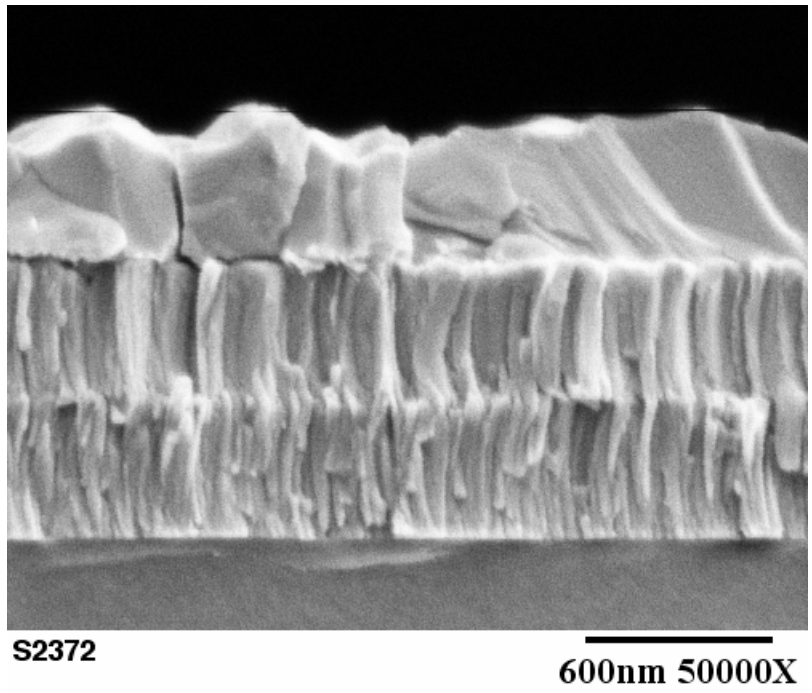
Plan view



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

Submicron layers





0.75 μm (12.5%)

0.4 μm (9.1%)

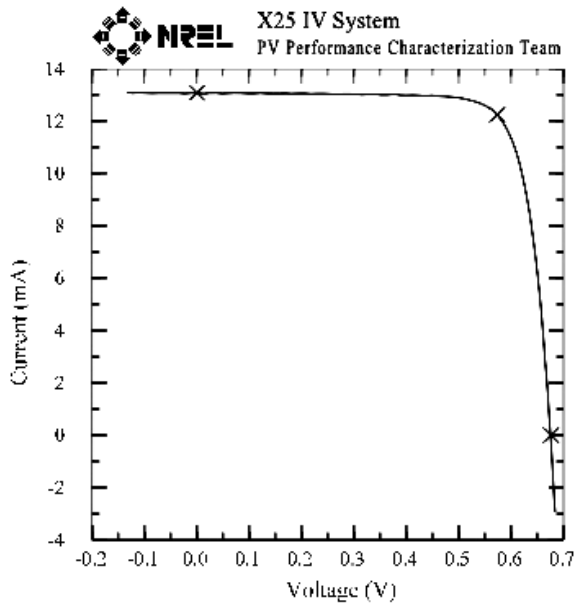
Best result for 1 μm (3- stage)

NREL

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



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 %

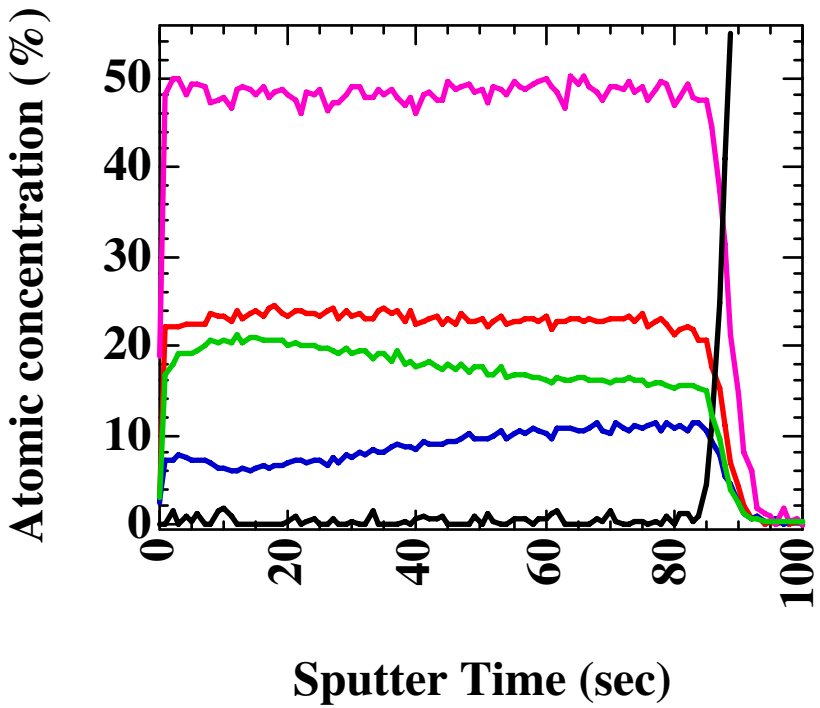
After 10 minute soak at P_{max}, 5 minute cool.

For 1 μm cell, $J_0 \sim 8 \times 10^{-11}$ A/cm^2, n = 1.33

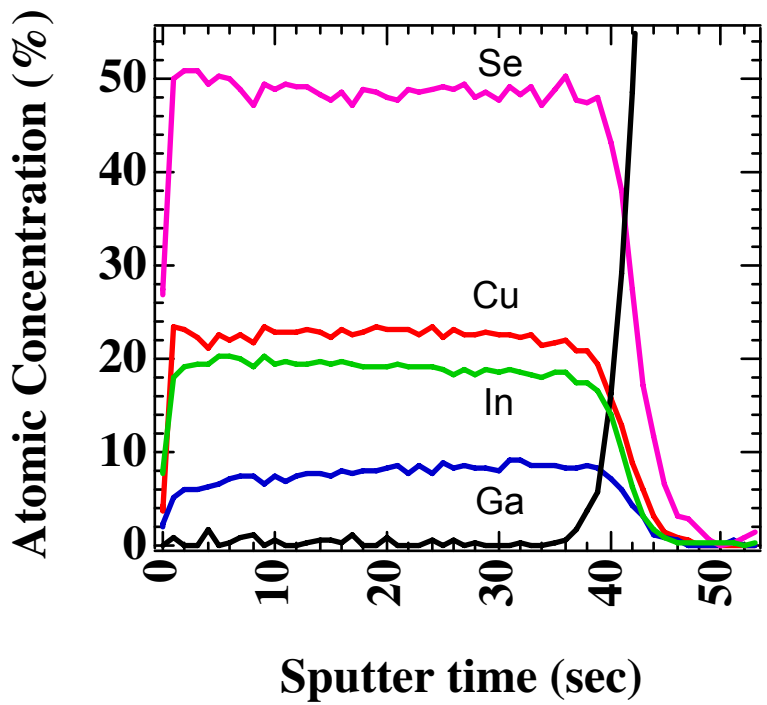
Values for 2.5 μm (19%) cells: n = 1.35, $J_0 \sim 4 \times 10^{-11}$ A/cm^2

Increase in J_0 partly accounts for the voltage shortfall.

Auger profile comparison

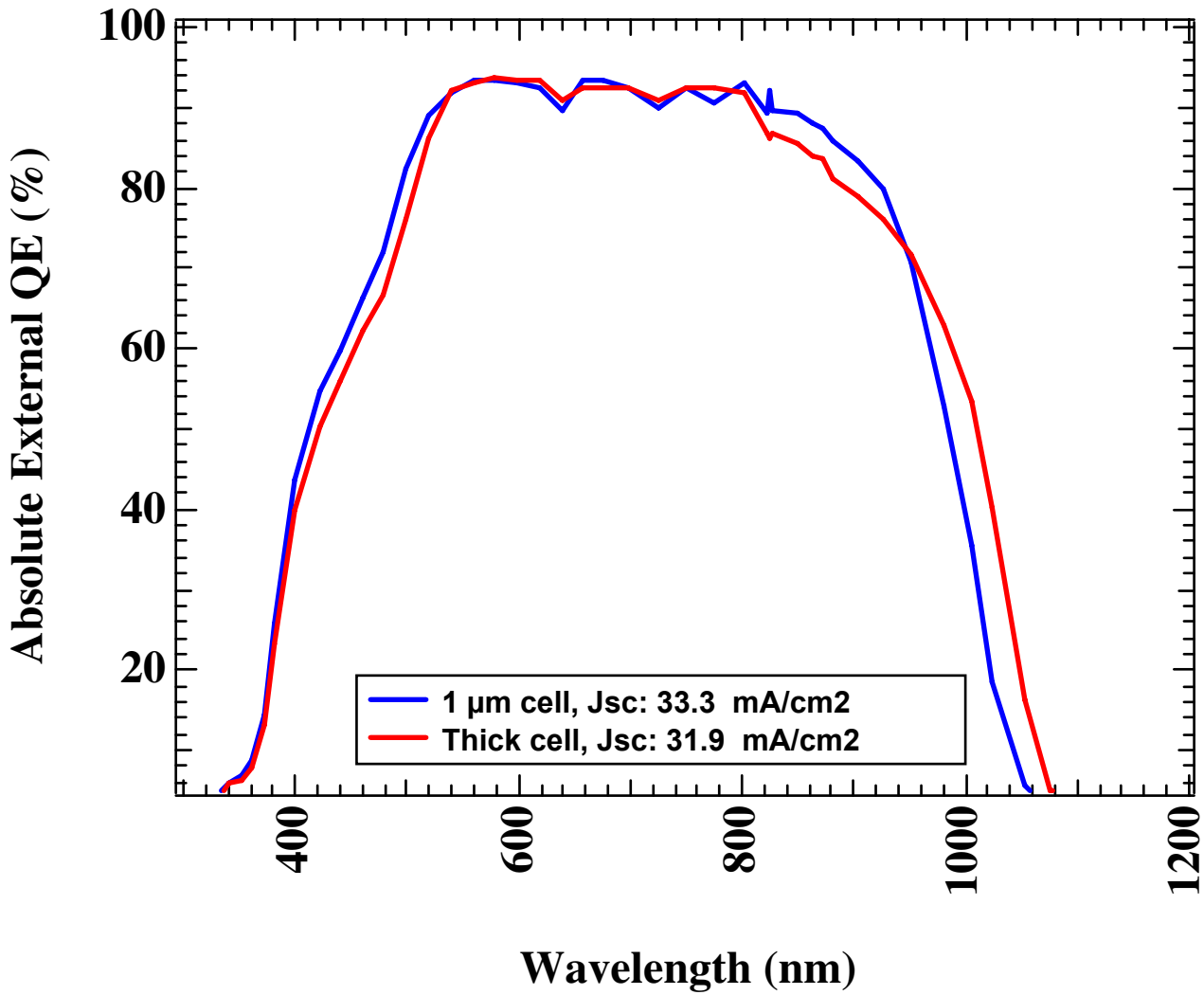


2.5-μm cell

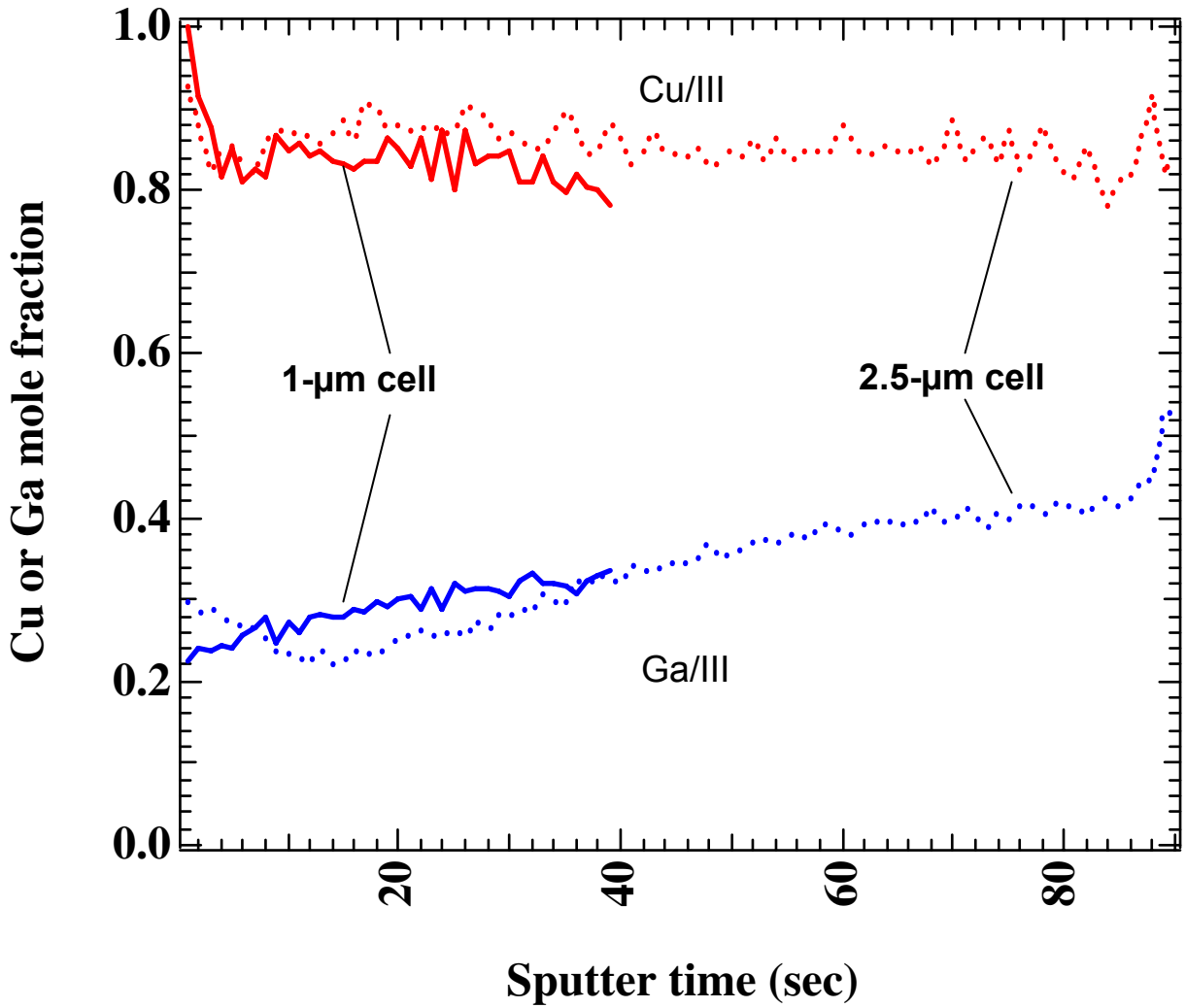


1-μm cell

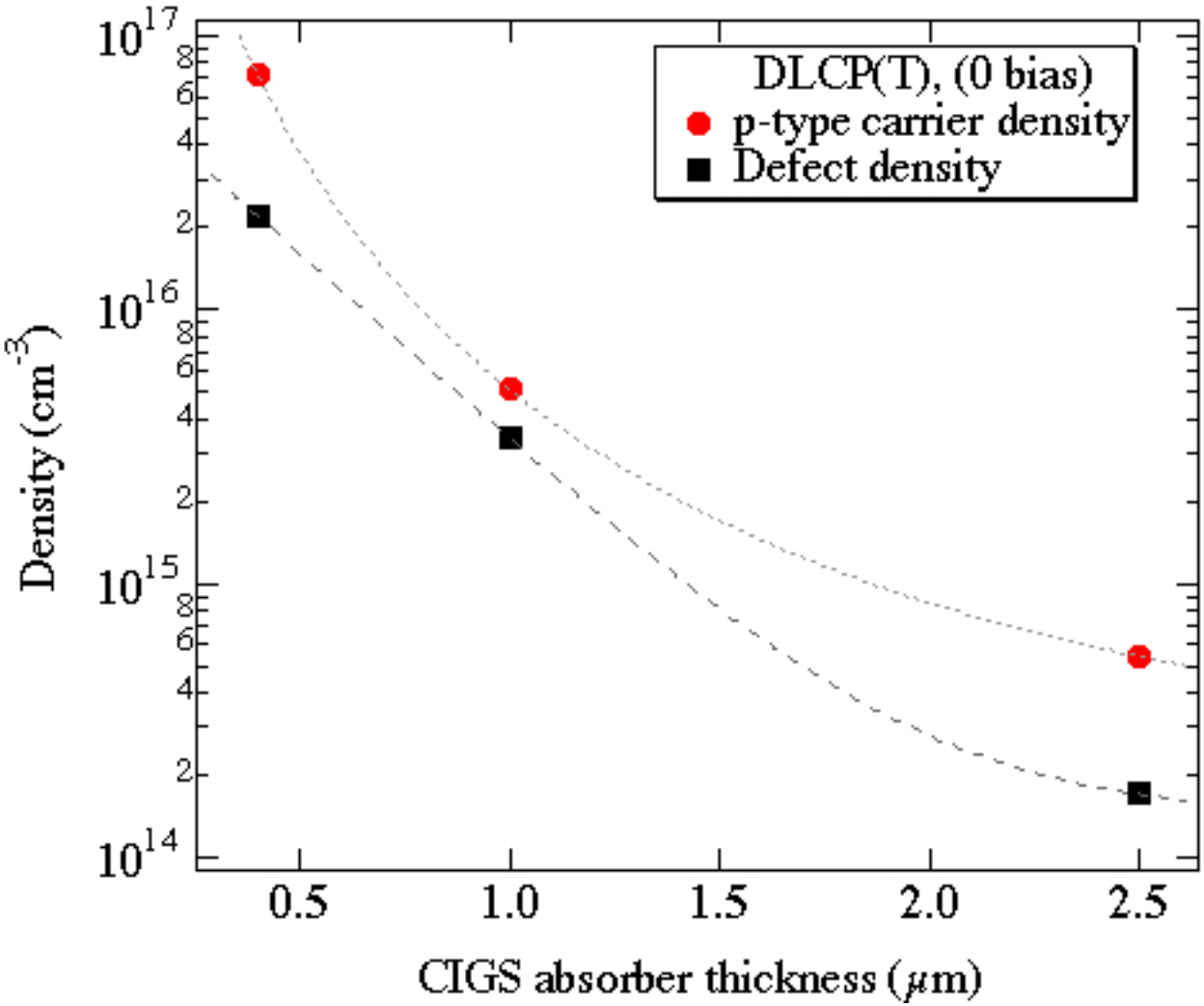
QE comparison



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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