Junction Evolution During Fabrication of CdS/CdTe Thin–film PV Solar Cells

Timothy A. Gessert

Principal Scientist, Group Manager

CdTe Thin Film PV Materials and Devices Research

National Center for Photovoltaics, NREL

tim_gessert@nrel.gov, 303-384-6451

Presented at the China New Energy International Forum and Fair 2010

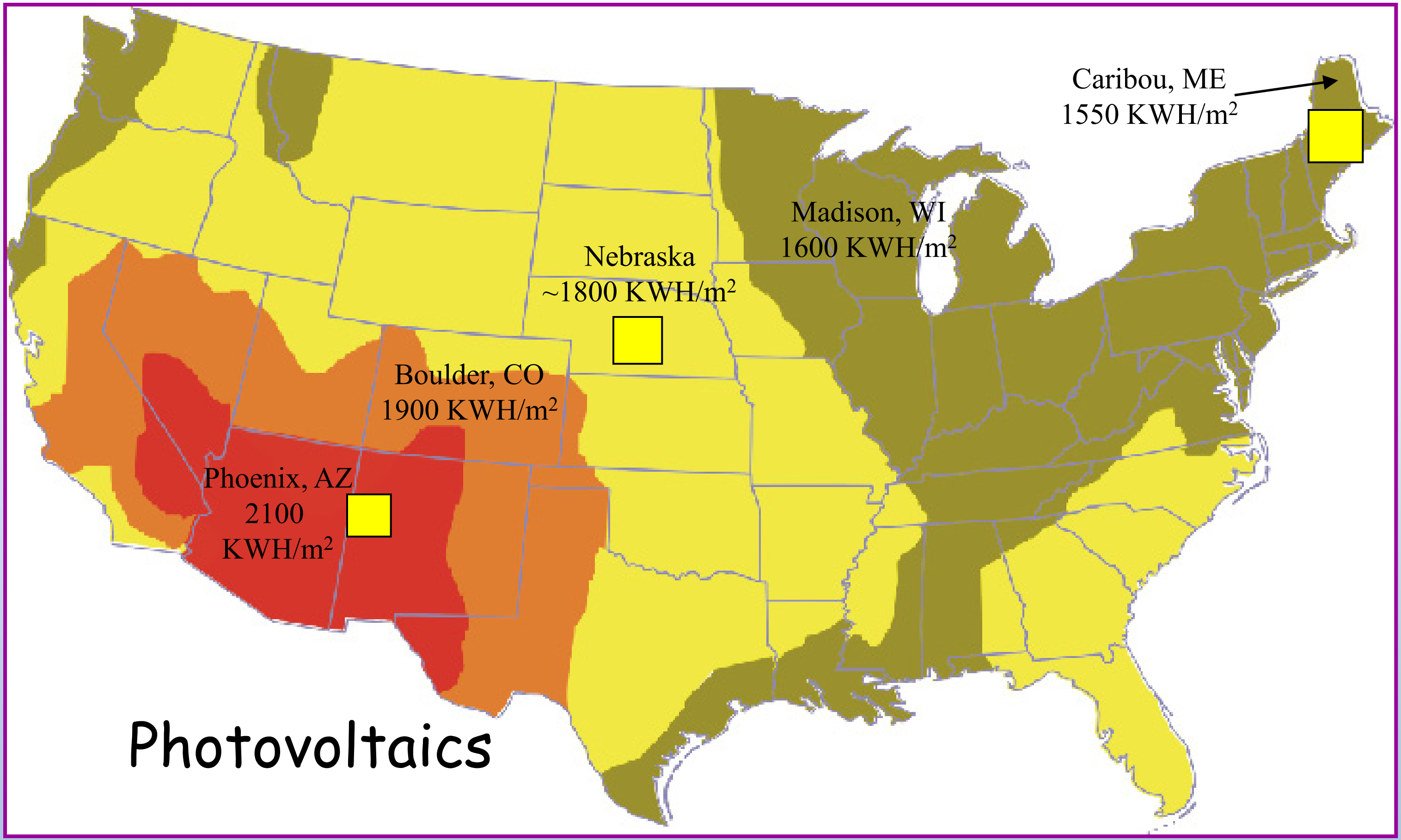
28-30 September 2010, Chengdu, China

This work was supported by the U.S. Department of Energy under Contract No. DE-AC36-08GO28308 with the National Renewable Energy Laboratory.

NREL/PR-520-49387

Disclaimer and Government License

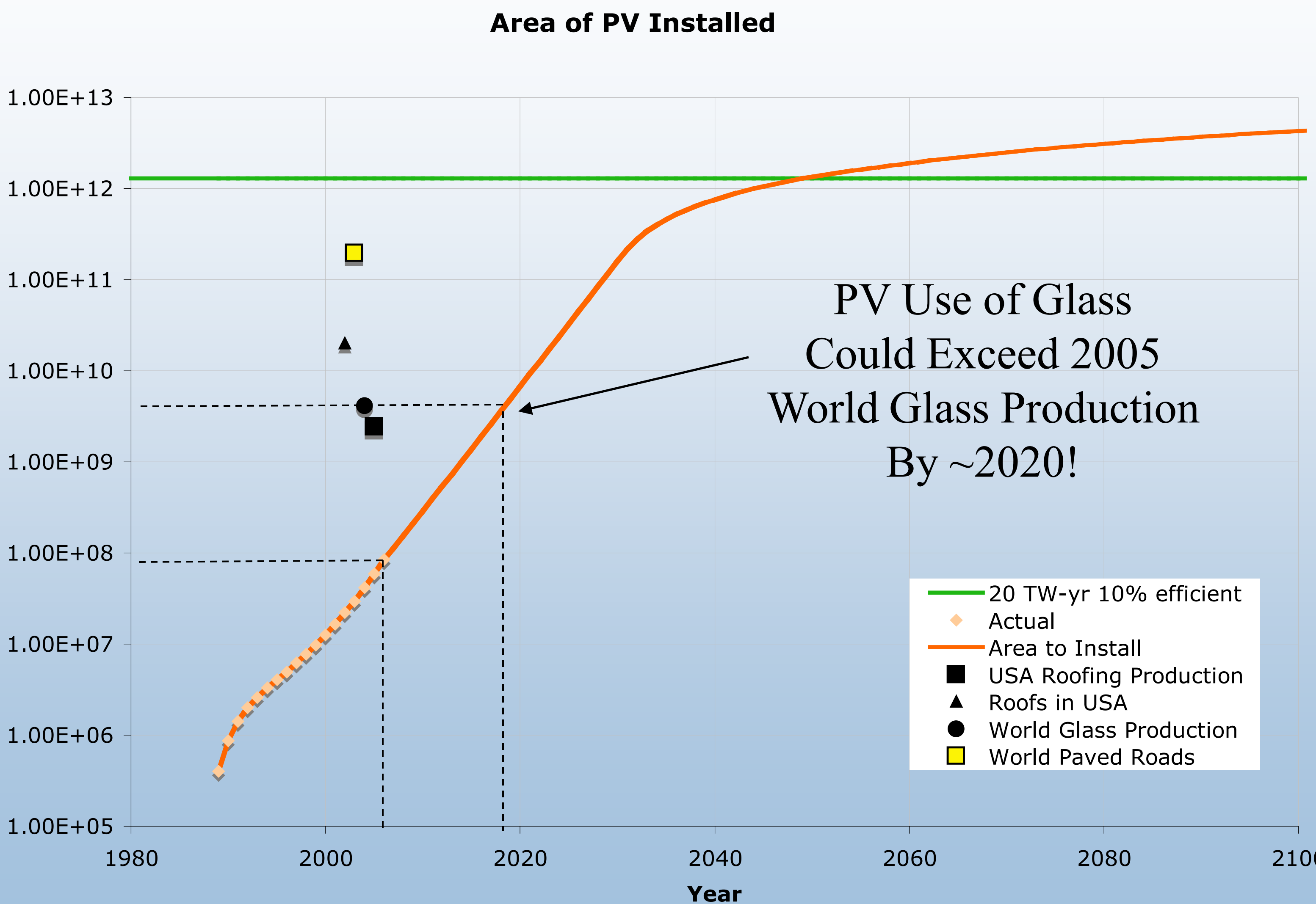
Solar Land Area Requirements For 2004 US Electricity Requirements



Note:
Munich, Germany
~1100 KWH/m²

Sources: K. Zweibel, "PV Past the Tipping Point" (www.nrel.gov/ncpv/thin_film)
PVWATTS Calculator, Version 1 (http://rredc.nrel.gov/solar/codes_algs/PVWATTS/)

Example - Size of PV Market for Commercial Glass



Source: Brent Nelson, NREL

Some CIGS-alloy, CdTe, & a-Si Laboratory Cell NREL-Confirmed Record Efficiencies

	Area (cm^2)	V_{OC} (V)	J_{SC} (mA/cm^2)	FF (%)	Efficiency (%)	Comments
CIGSe	0.410	0.697	35.1	79.52	20.0	CIGSe/CdS/Cell NREL, 3-stage process
CIGSe	0.402	0.67	35.1	78.78	18.5	CIGSe/ZnS (O,OH) NREL, Nakada et al
CIGS	0.409	0.83	20.9	69.13	12.0	Cu(In,Ga)S_2/CdS Dhere, FSEC
CIAS	–	0.621	36.0	75.50	16.9	Cu(In,Al)Se_2/CdS IEC, Eg = 1.15eV
CdTe	1.03	0.845	25.9	75.51	16.7	CTO/ZTO/CdS/CdTe NREL, CSS
CdTe	–	0.814	23.56	73.25	14.0	ZnO/CdS/CdTe/Metal U. of Toledo, sputtered
a-Si	-	-	-	73.25	12.1	United Solar, Stabilized Efficiency

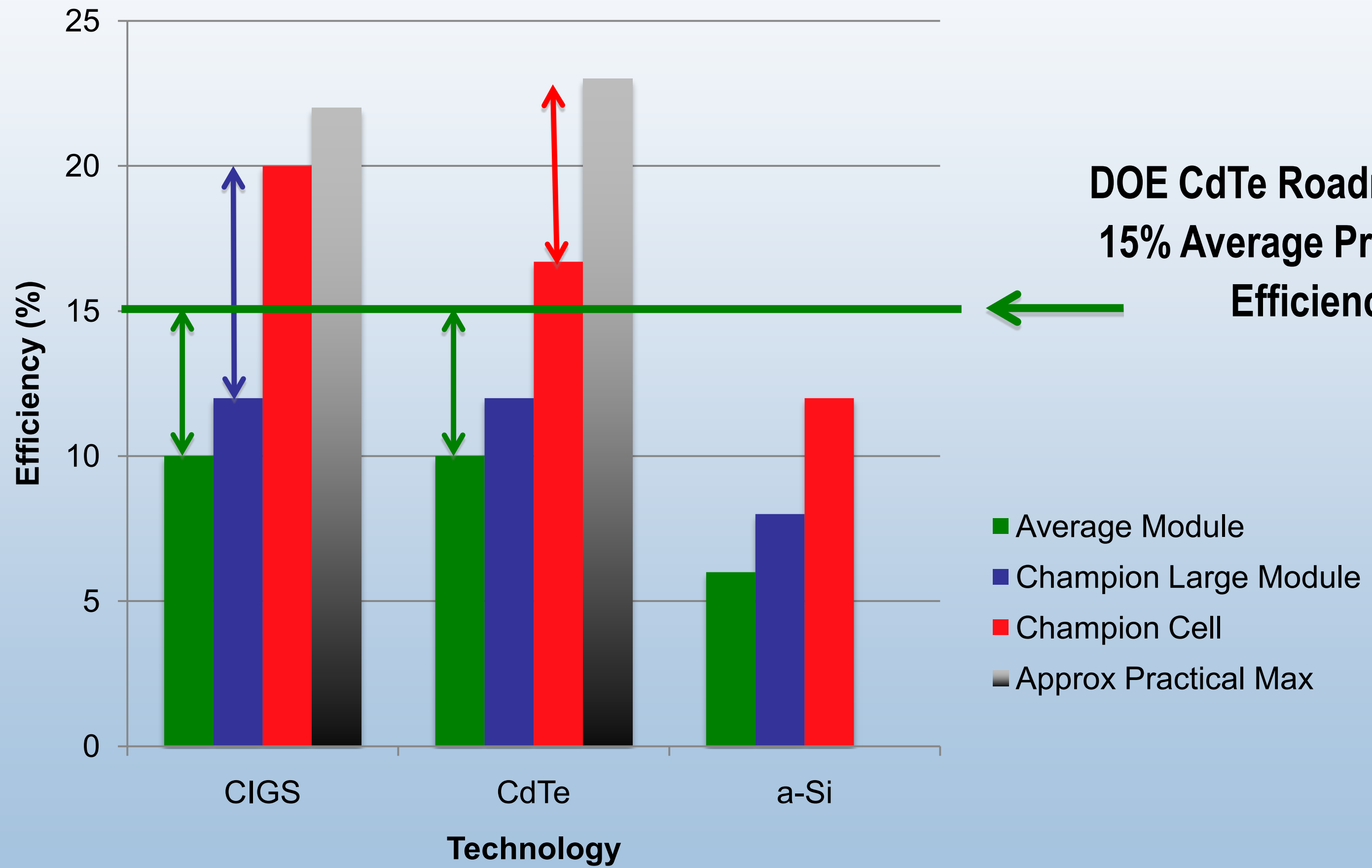
Sources: Updated from R. Noufi and K. Zweibel, Proc. 4th WCPEC, Waikola, Hawaii, 5/2006, Photon International, October 2004

Polycrystalline Thin Film PV Modules (Standard conditions, Aperture-area, *NREL Confirmed) Ranked by Power

Company	Device	Aperture (cm^2)	Efficiency*(%)	Power (W)	Date
Miasole	CIGS	9762	13.6-13.8	-	4/10
Global Solar	CIGS	8390	10.2*	88.9	8/02
First Solar	CdTe	6623	12.6*	84.4	8/08
Wurth Solar	CIGS	6500	13.0	84.6	6/04
United Solar	a-Si	4519	7.9*	35.7	6/97
Shell Solar	CIGSS	3626	12.8*	46.5	3/03
Showa Shell	CIGS	3459	13.5	-	8/02

Sources: Updated From R. Noufi and K. Zweibel, Proc. 4th WCPEC, Waikola, Hawaii, 5/2006, Photon International October 2004,

Goal
Increase Average Production Module Efficiency



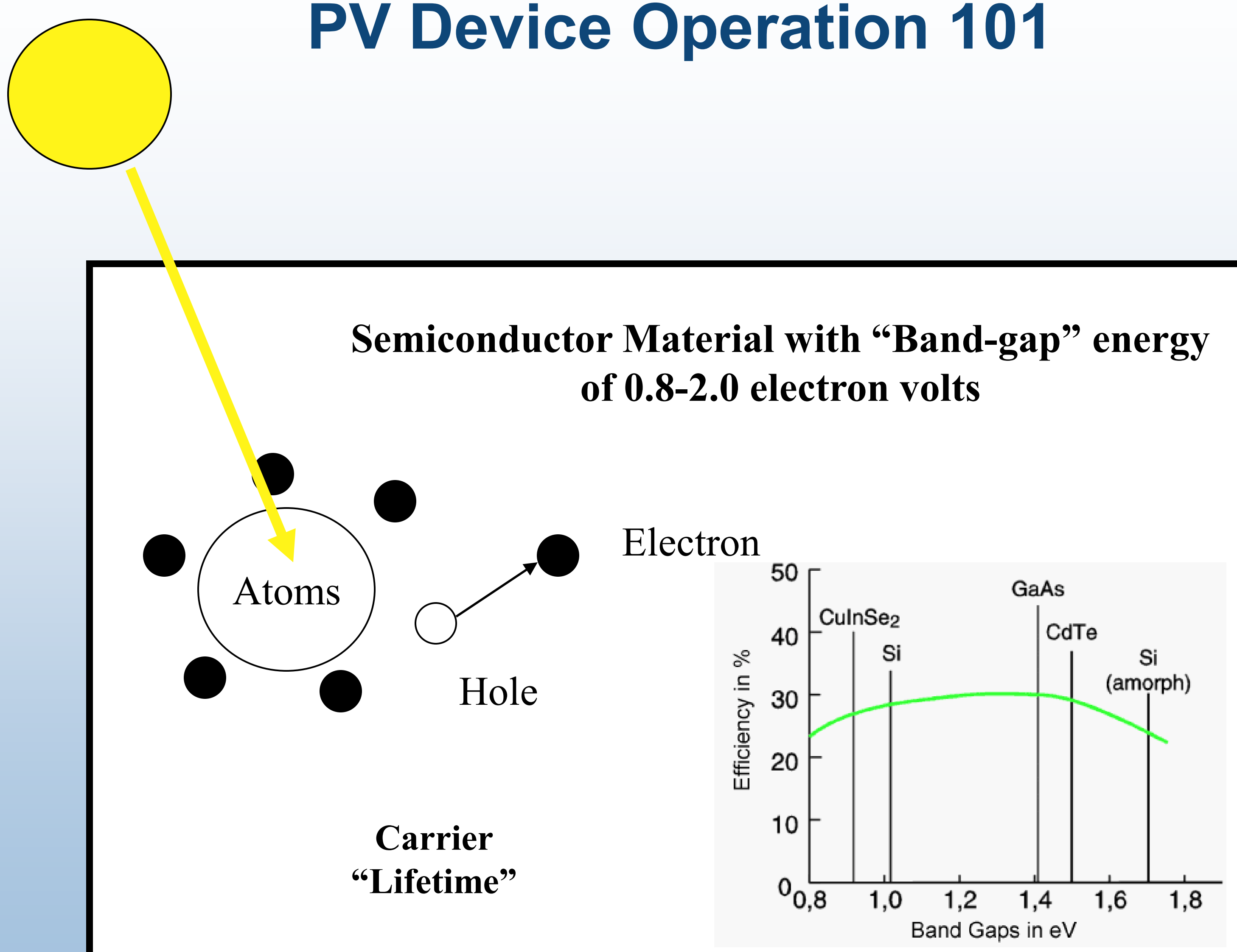
DOE CdTe Roadmap Goal
15% Average Production Efficiency

Present Strengths of Each Thin-film PV Technology

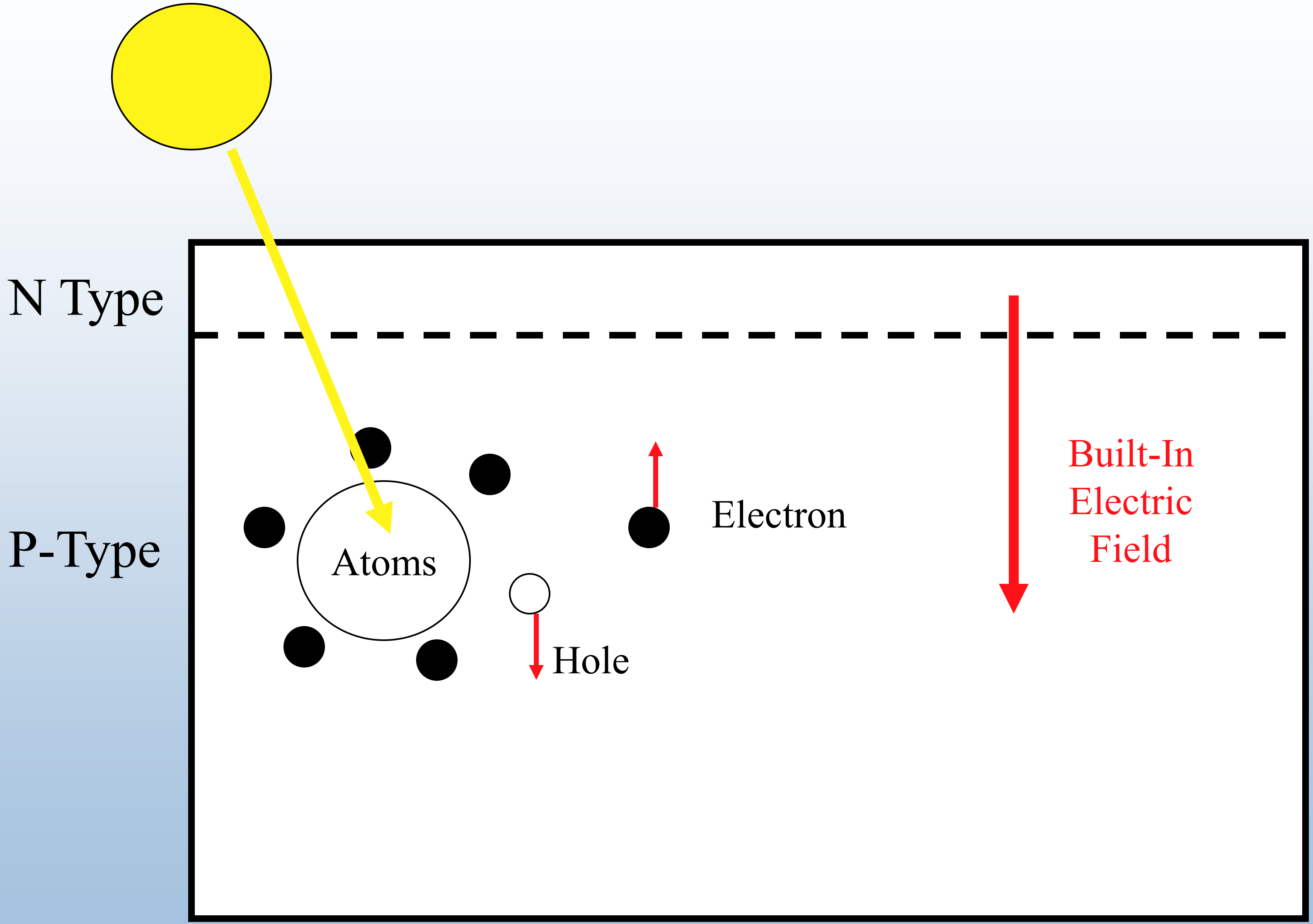
	Demonstrated Efficiency	Perceived Production Advantage	Perceived Materials Abundance/ Low Toxicity
a-Si			Strength
CdTe		Strength	
CIS	Strength		

Thoughts:
Each technology has different advantages
Its not clear which (if any) advantage will yield a long-term product advantage
This situation could remain true for many years!

How Do These Things Work?
PV Device Operation 101

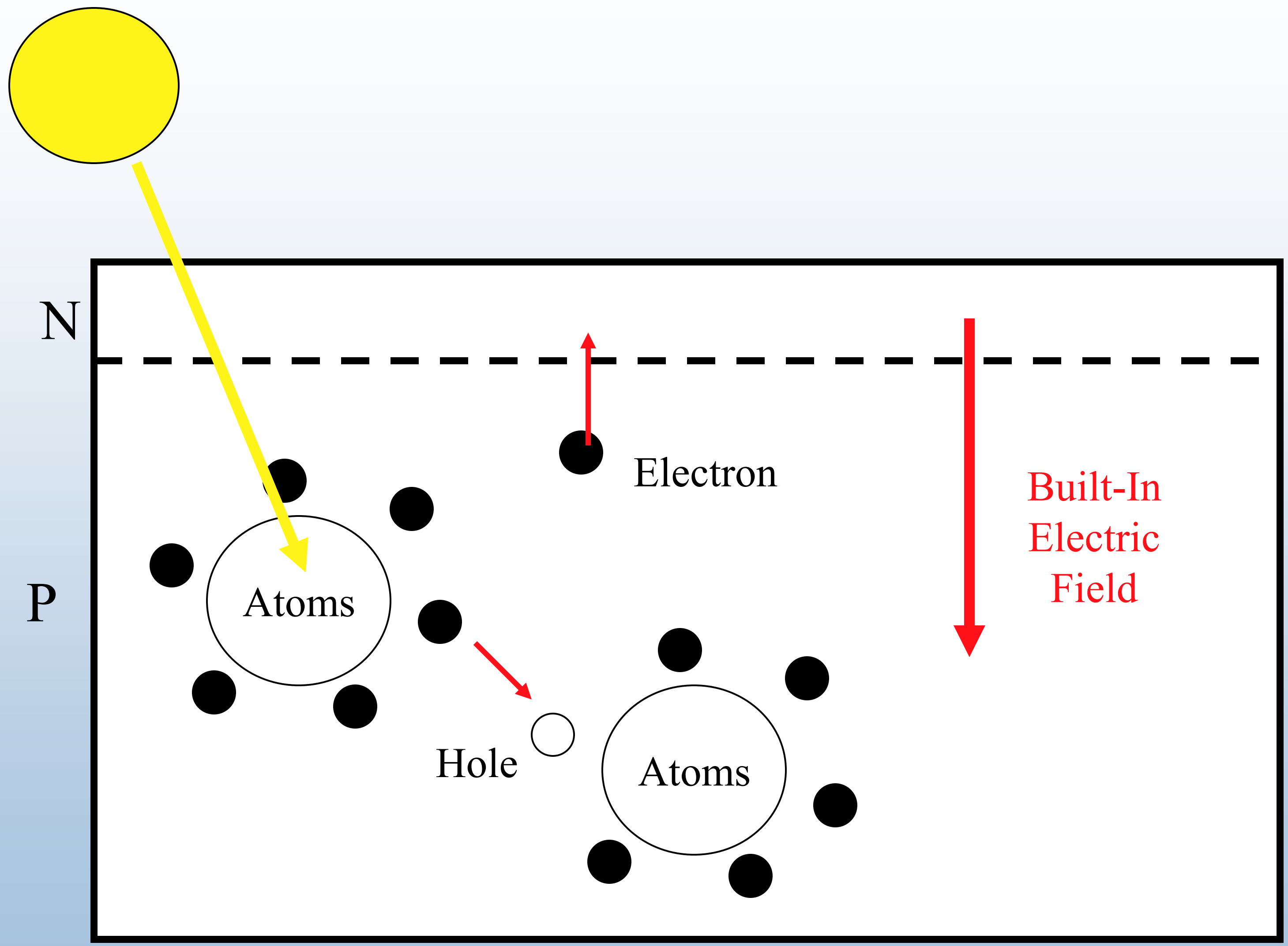


PV Device Operation 101

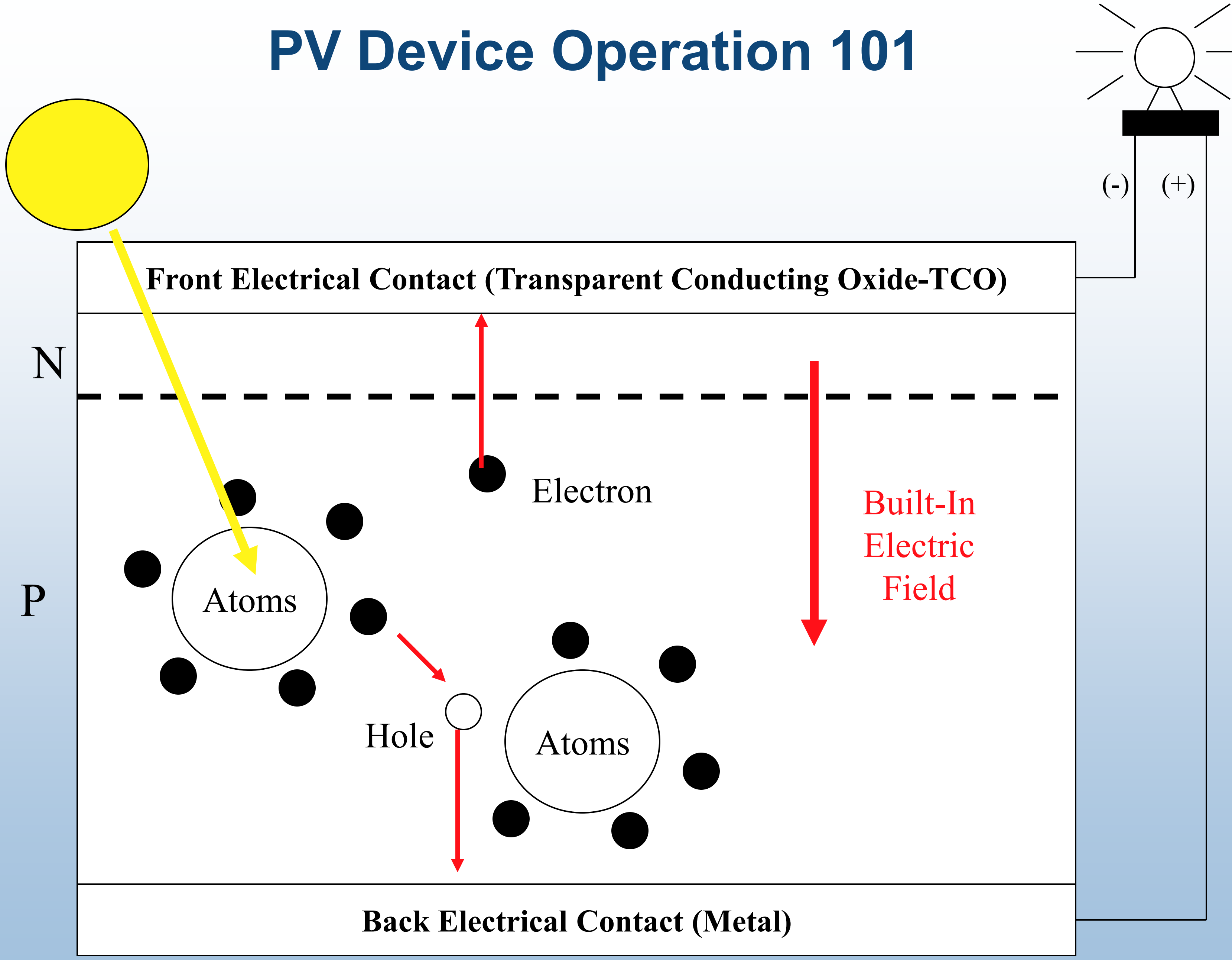


Tim Gessert

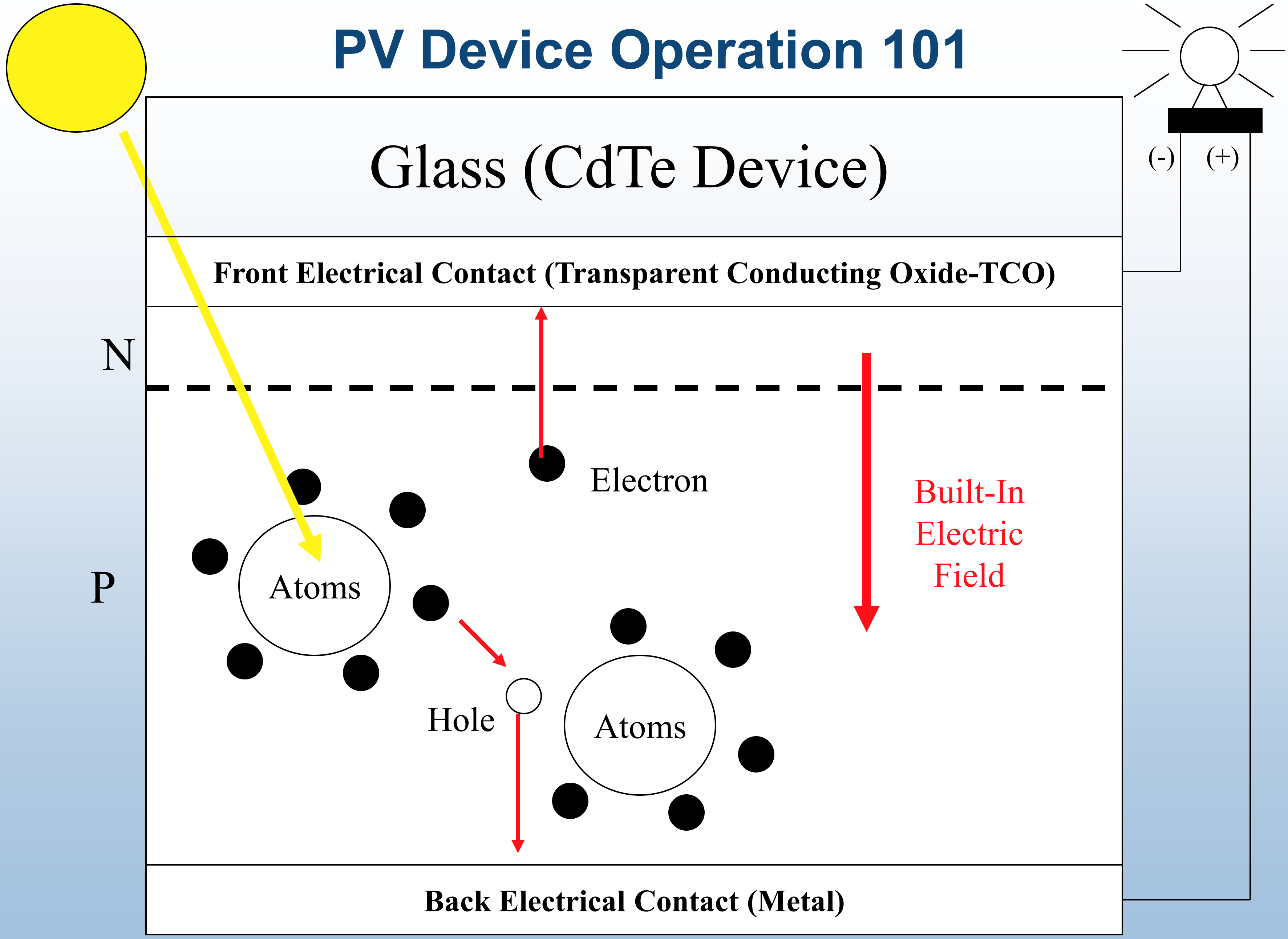
PV Device Operation 101



PV Device Operation 101

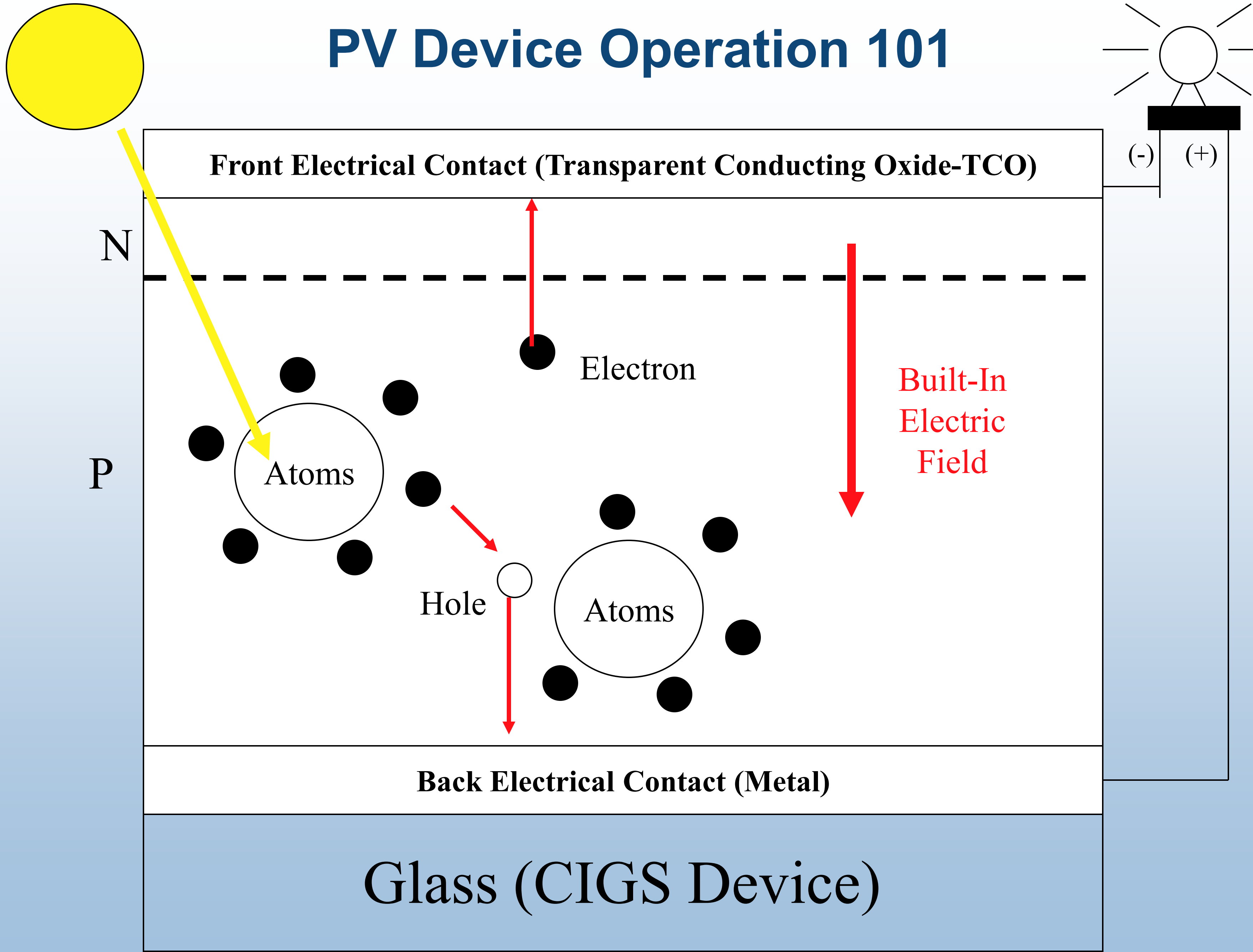


PV Device Operation 101

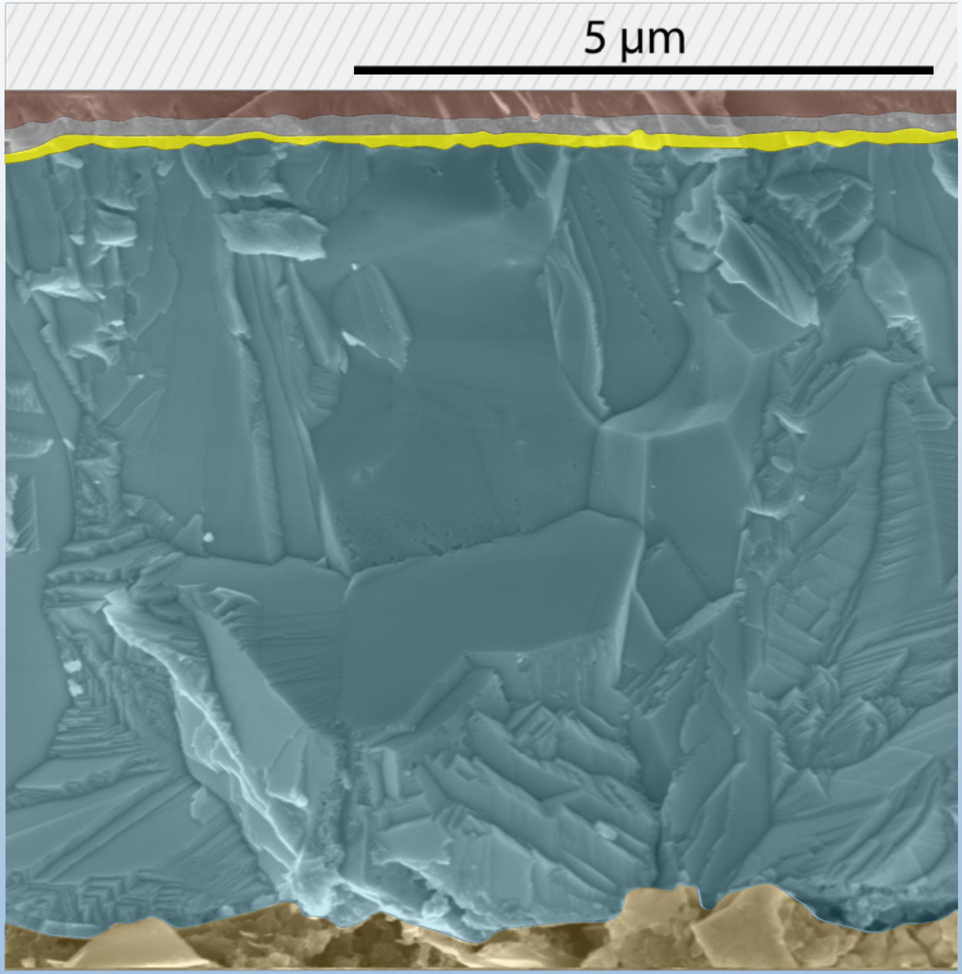


Tim Gessert

PV Device Operation 101



Thin Film CdTe Solar Cells



Glass

TCO

CdS (600-2000 Å)

CdTe

2-8 µm

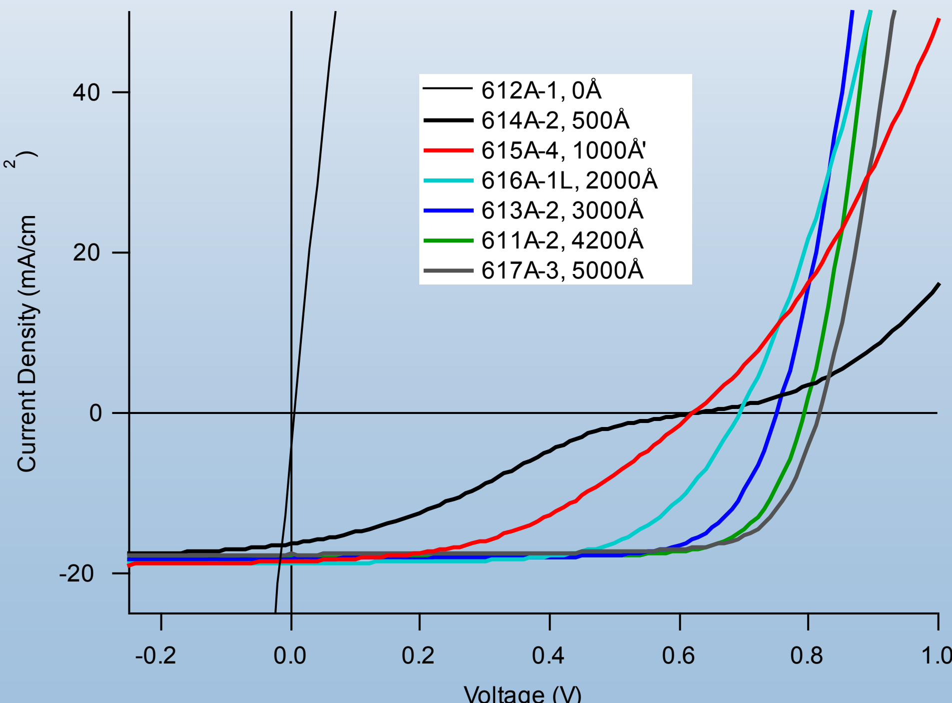
Cu-Containing Interface (Paste, Pretreatments, ZnTe:Cu) + Metals

η = 16.7% (NREL)

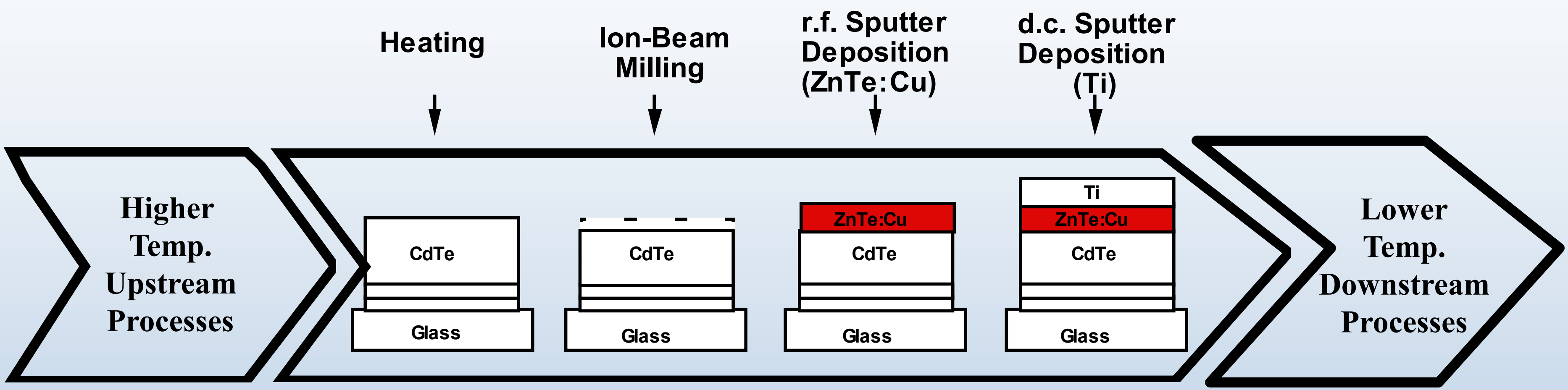
How do CdTe Thin-Film PV Junctions Form??

What this really means:

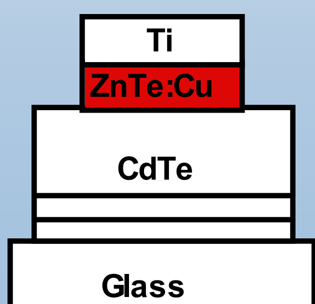
How do we get the electric field to form in the device at the correct location and strength -- without destroying the minority-carrier lifetime?



The ZnTe:Cu/Ti Contact Process
(All-Dry, High-Temperature [~300°C])



Photolithography



<u>Some Research Advantages</u>

Precise control of junction performance

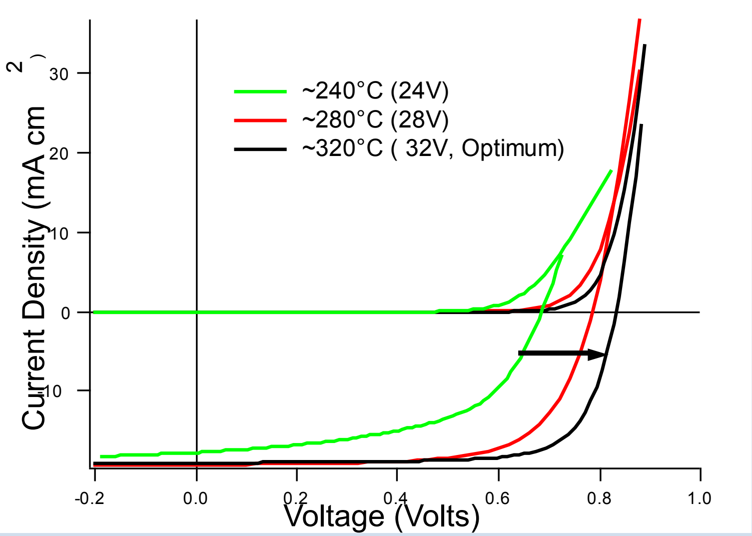
High device stability

Can achieve very low Cu incorporation

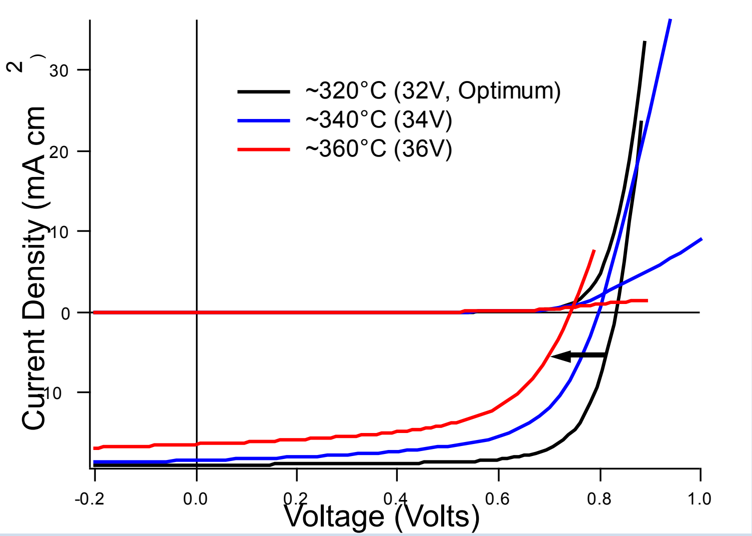
Easy to make large, identical sample sets

Some Insight from Past Studies

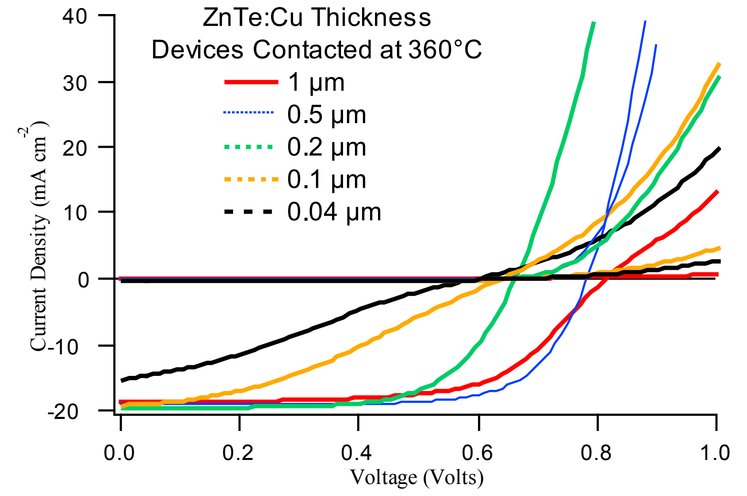
Cu Diffusion Less Than Optimum



Cu Diffusion Greater Than Optimum



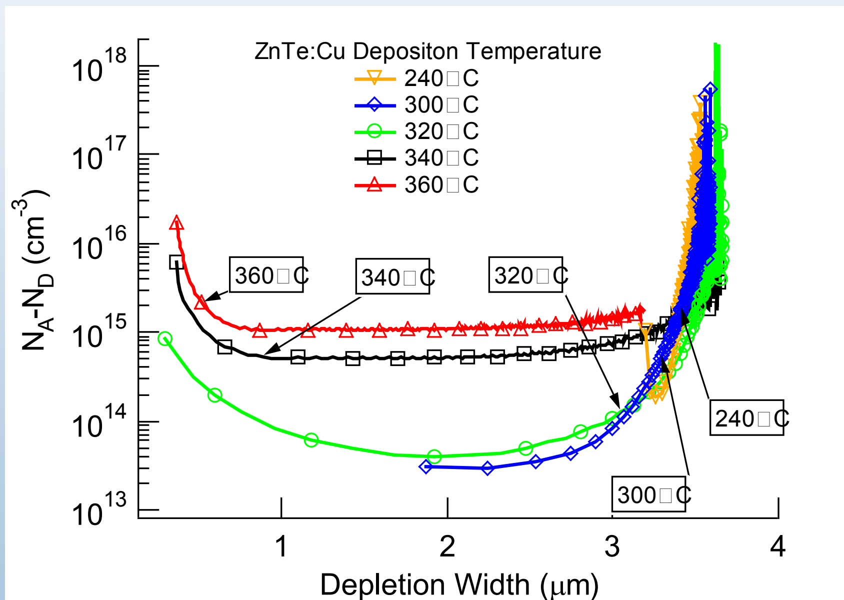
Effect of Contacting Temperature



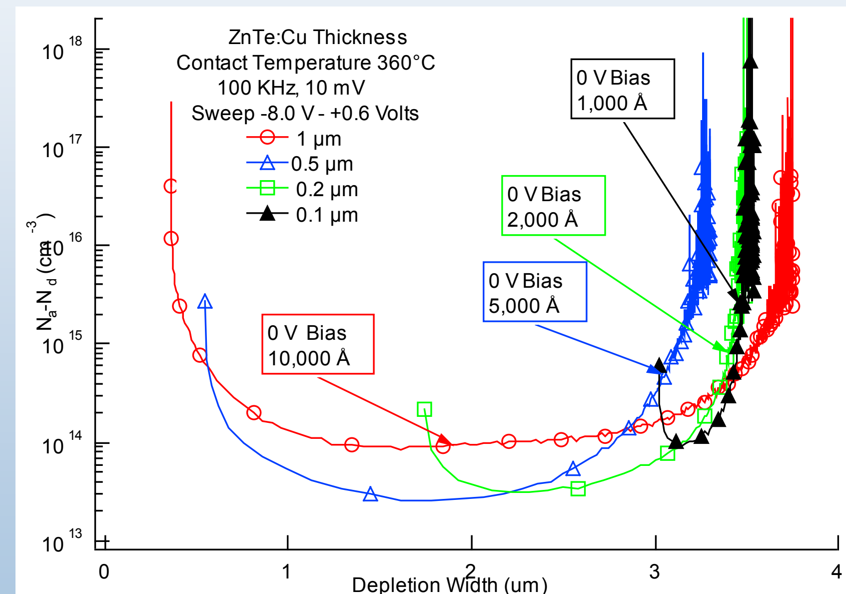
Effect of ZnTe:Cu Thickness

Comparison of Profiling C-V Analysis

Vary Contact Temperature



Vary ZnTe:Cu Thickness



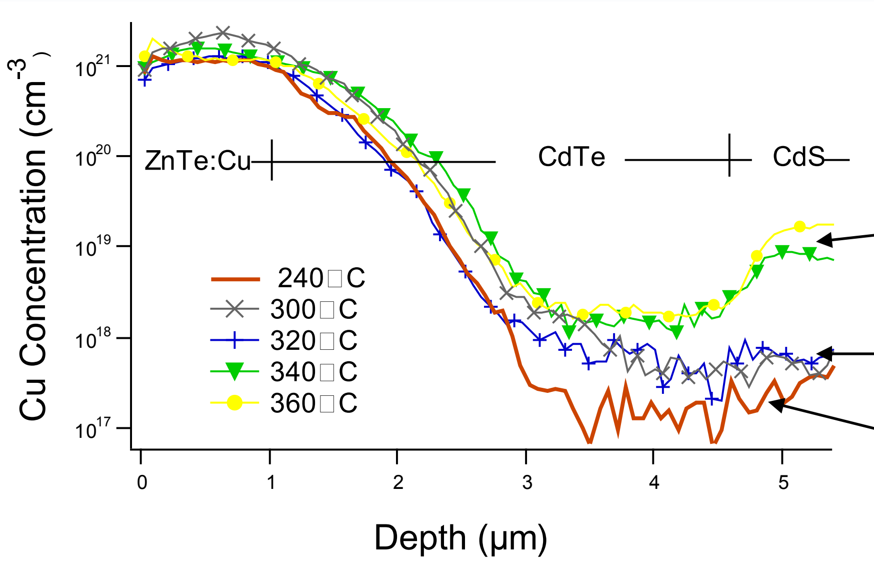
(100 kHz, 10 mV, -8.0 to +0.6 Sweep)

T.A. Gessert, S. Smith, T. Moriatry, M. Young, S. Asher, S. Johnston, A. Duda, C. DeHart
Proc. 31st. IEEE Photovoltaics Specialists Conf. (IEEE, Piscataway, NJ, 2005), pp. 291-294

T.A. Gessert, S. Asher, S. Johnston, A. Duda, M.R. Young, T. Moriarty,
Proc. 4th World Conf. on PV Energy Convr. (IEEE, Piscataway, NJ, 2006) pp. 432-435

NREL
NATIONAL RENEWABLE ENERGY LABORATORY

Some Insight from Past Studies



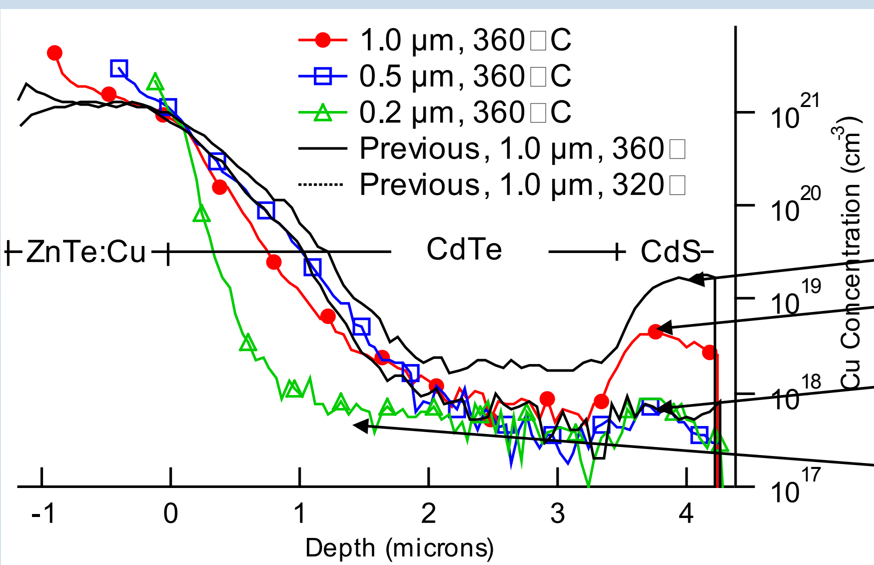
<u>Vary Contact Temperature</u>

Excessive Cu

Optimum Cu

Insufficient Cu

High-Resolution Compositional Depth-Profiling Secondary Ion Mass Spectrometry Analysis (SIMS)



<u>Vary Contact Thickness</u>

Excessive Cu

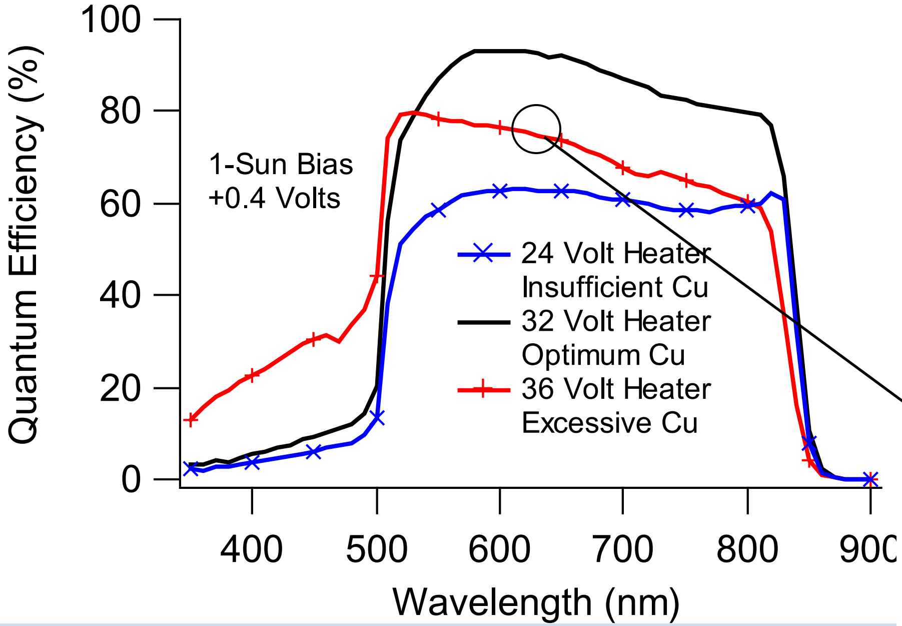
??

Optimum Cu

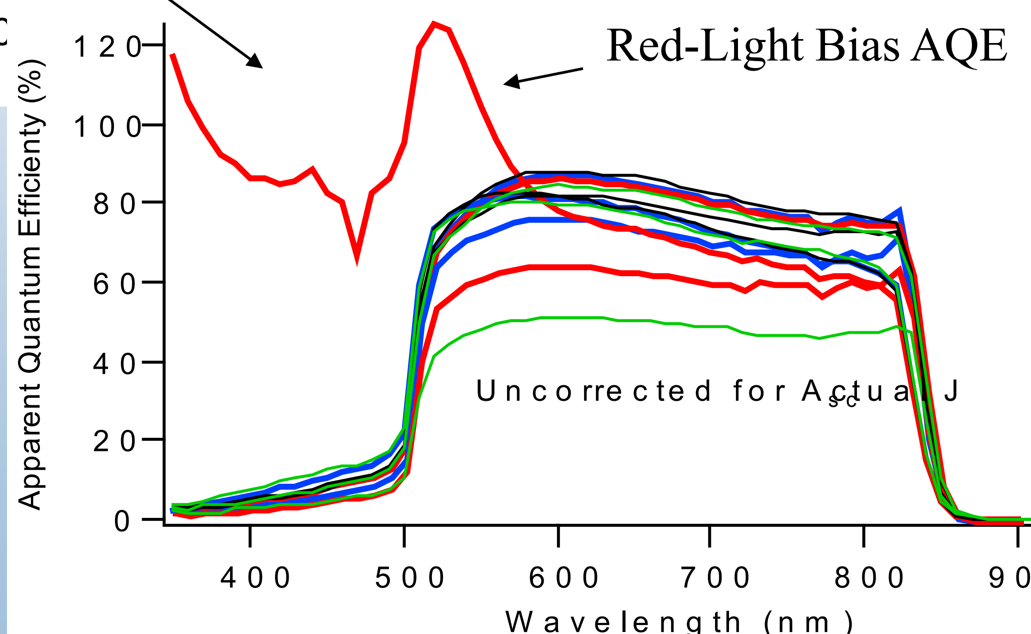
Insufficient Cu

T.A. Gessert, W.K. Metzger, P. Dippo, S.E. Asher, R.G. Dhere, M.R. Young, Thin Solid Films, 517, 2370-2373 (2009)

Light and Voltage-Dependent Quantum Efficiency



Red-Light Bias QE Confirms
Photoconductive CdS
Only For "Excessive" Cu Devices

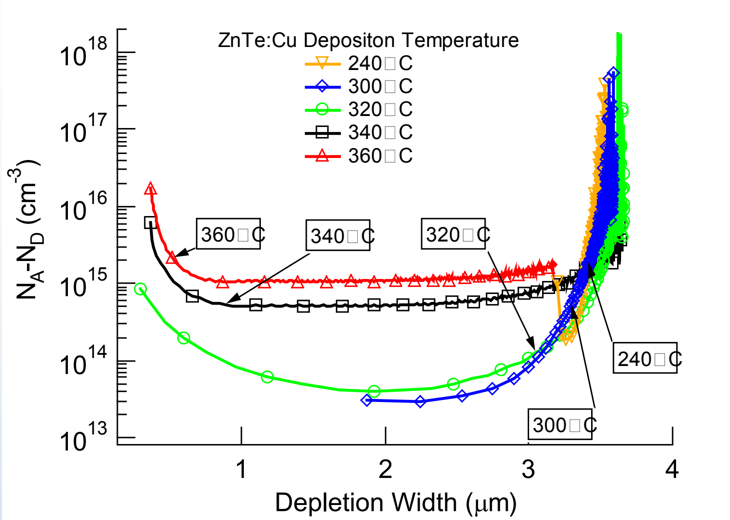


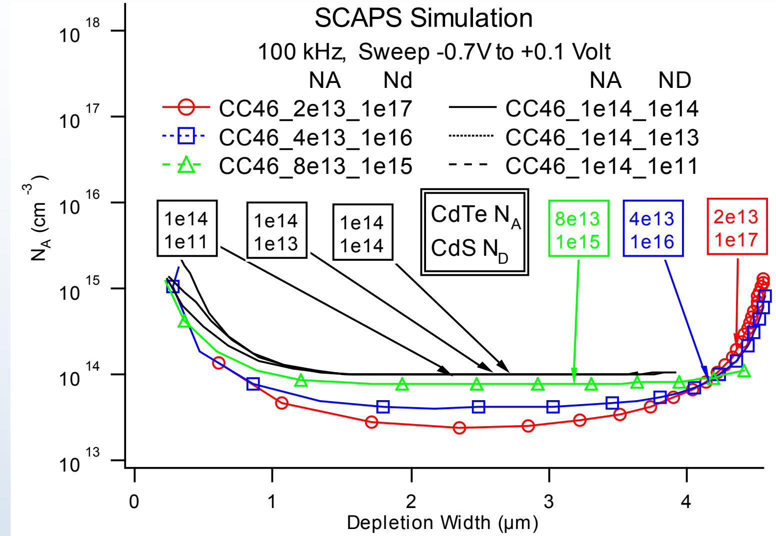
QE Comparison Suggests
Narrowing Junction
for Excessive Cu Devices

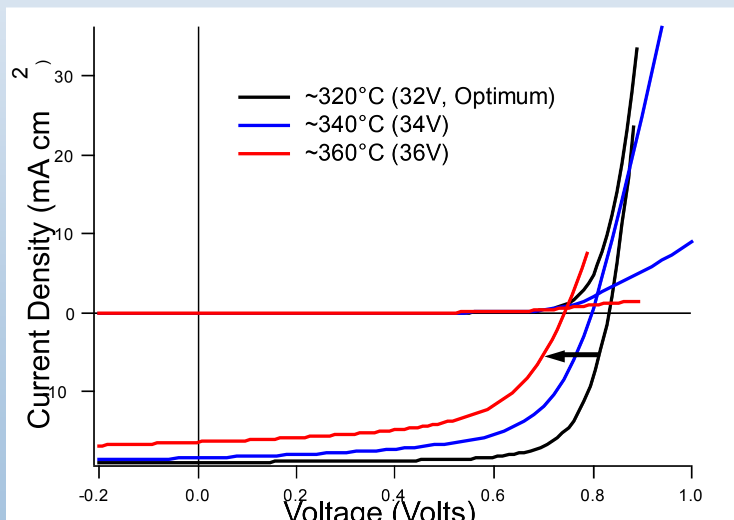
Tim Gessert
General PV Energy Talk, Date

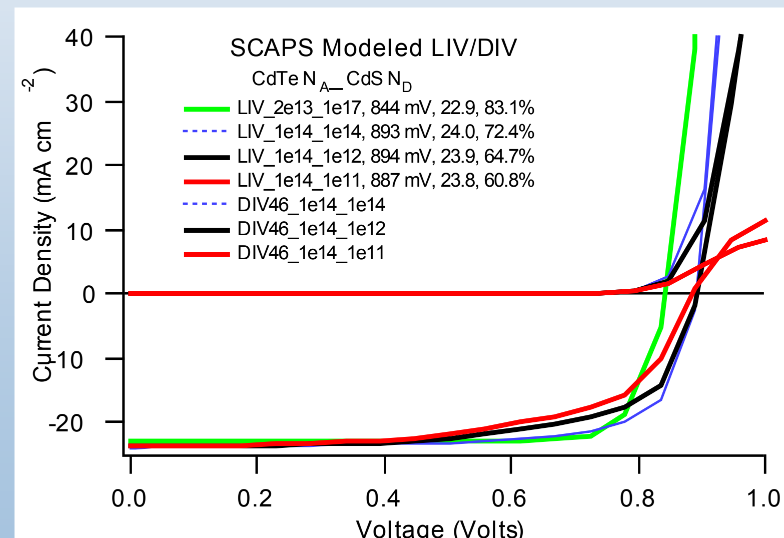
T.A. Gessert, W.K. Metzger, S.E. Asher, M.R. Young, S. Johnston, R. Dhere, T. Moriarty, A. Duda
Proc. 33rd Photovoltaics Specialists Conf. (IEEE, Piscataway, NJ, 2008) Manuscript No. 14.

SCAPS1D Simulation





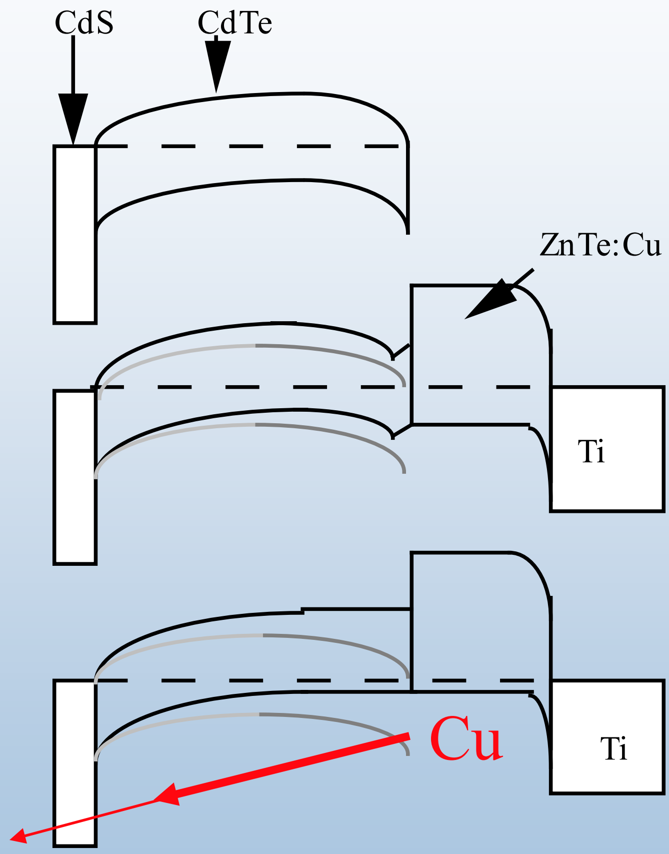




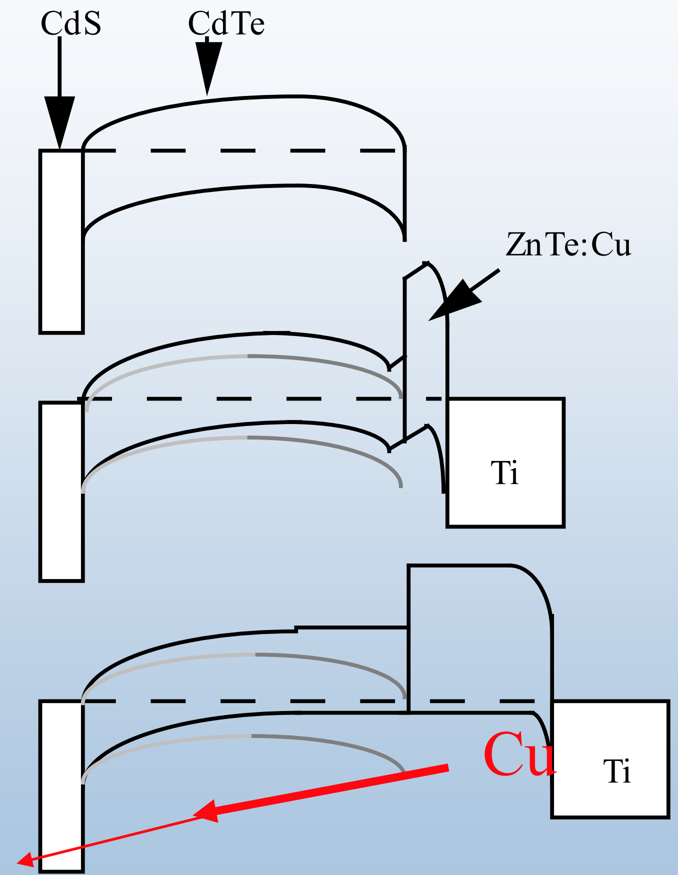
T.A. Gessert, S. Asher, S. Johnston, A. Duda, M.R. Young, T. Moriarty,
Proc. 4th World Conf. on PV Energy Convr. (IEEE, Piscataway, NJ, 2006) pp. 432-435

Some Insight from Past Studies

Constant Thickness ~0.5 µm
Vary ZnTe:Cu Temperature



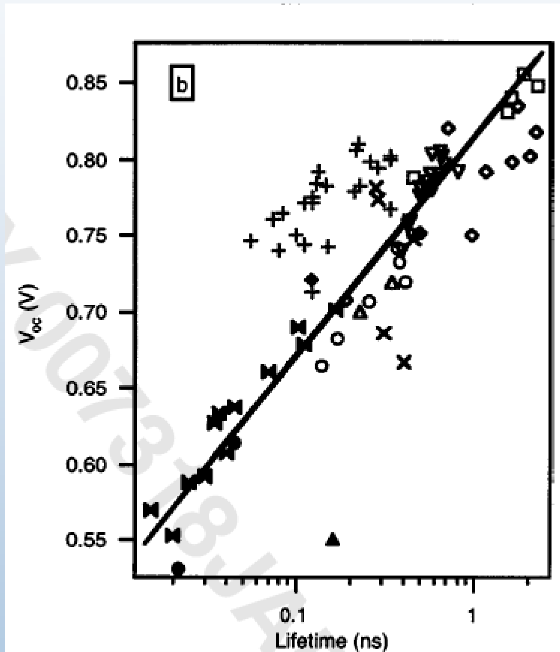
Constant Temperature ~300°C
Vary ZnTe:Cu Thickness

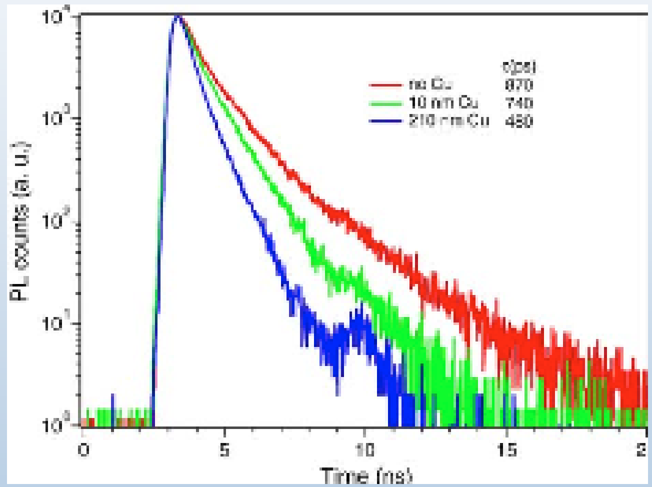


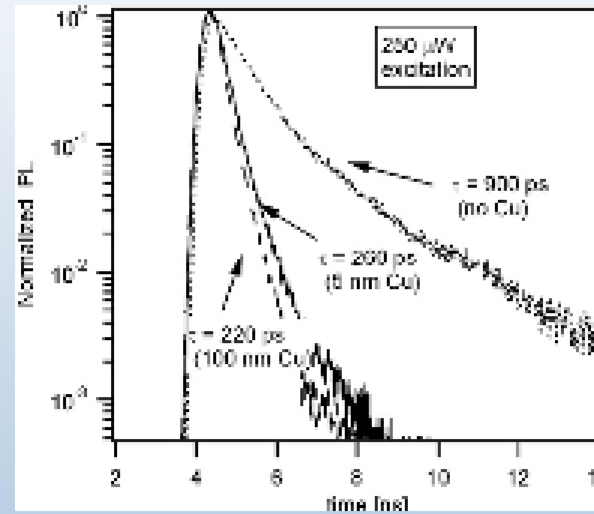
But…Assumes Minority Carrier Lifetime Does Not Change

T.A. Gessert, M.J. Romero, S. Johnston, B. Keys, and P. Dippo
Proc. 29th IEEE Photovoltaics Specialists Conf. (Piscataway, NJ, 2002) pp. 535-538

Previous TRPL studies indicate minority carrier lifetime decreases with Cu







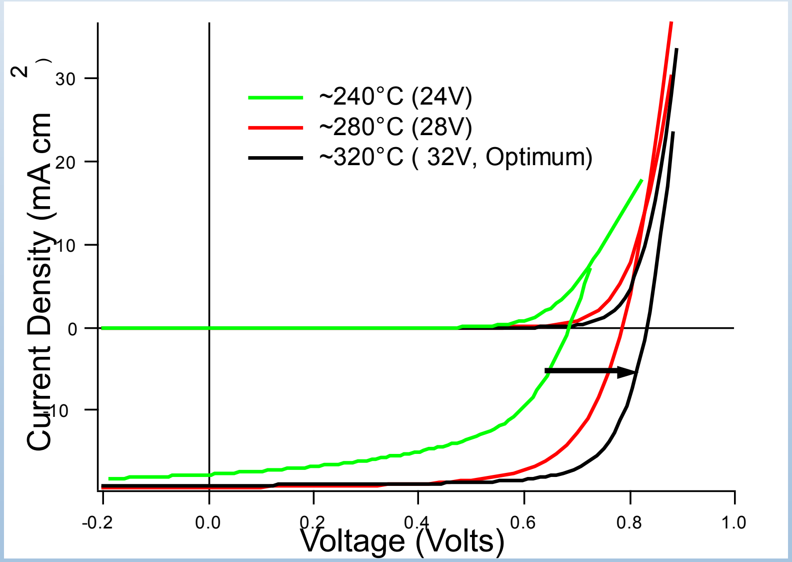
Metzger, Albin, Levi, Sheldon, Li, Keyes, Ahrenkeil, JAP 94(6) (2003)

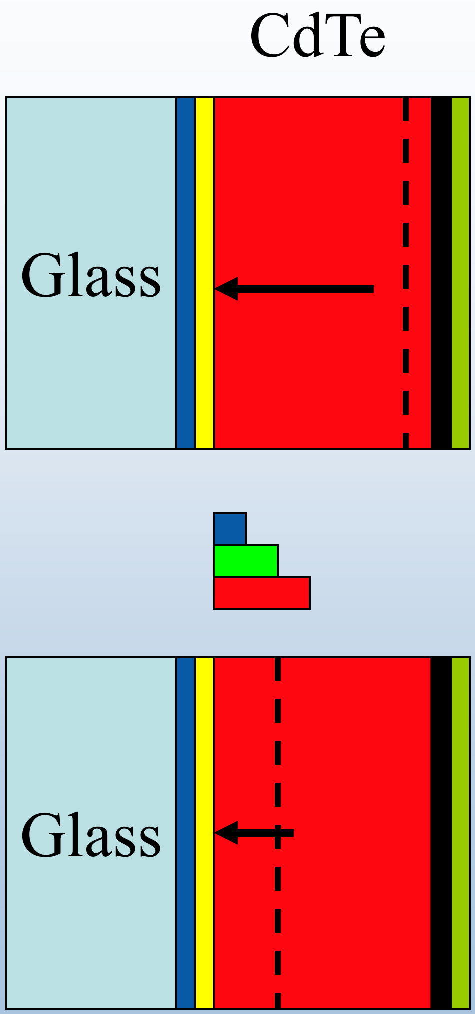
Wu, Zhou, Duda, Yan, Teeter, Asher, Metzger, Demtsu, Wei, Noufi, TSF, 515, 5798 (2007)

Demtsu, Albin, Sites, Metzger, Duda, TSF, 516 p. 2251 (2008)

Question

If both carrier lifetime and space charge width decreases with Cu incorporation, why does voltage-dependant collection decrease?

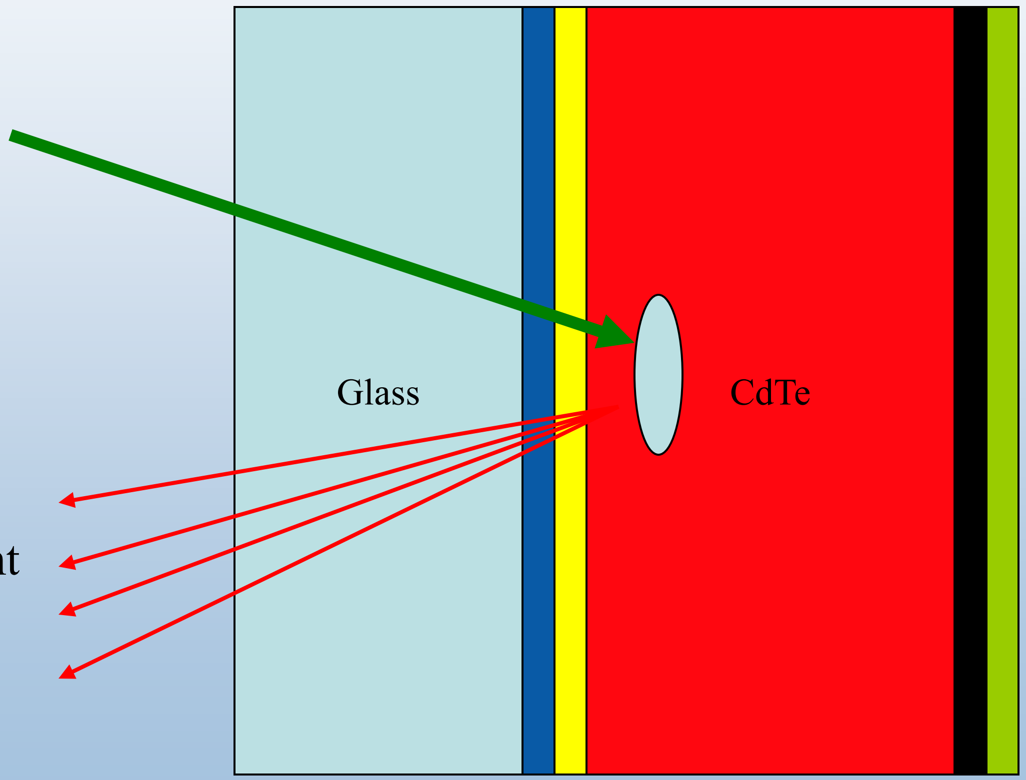




Time Resolved Photoluinescence (TRPL)

650 nm Excitation

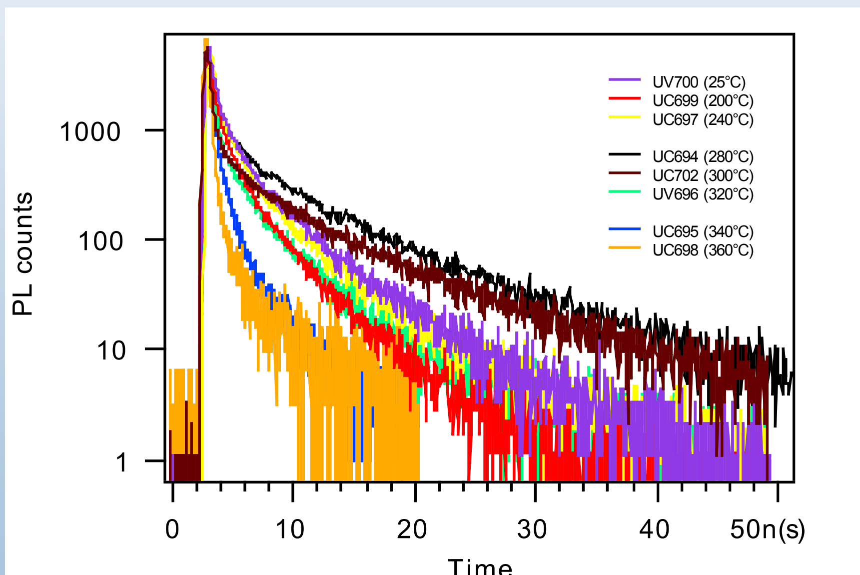
Two Power Levels
250 μW and 2500 μW



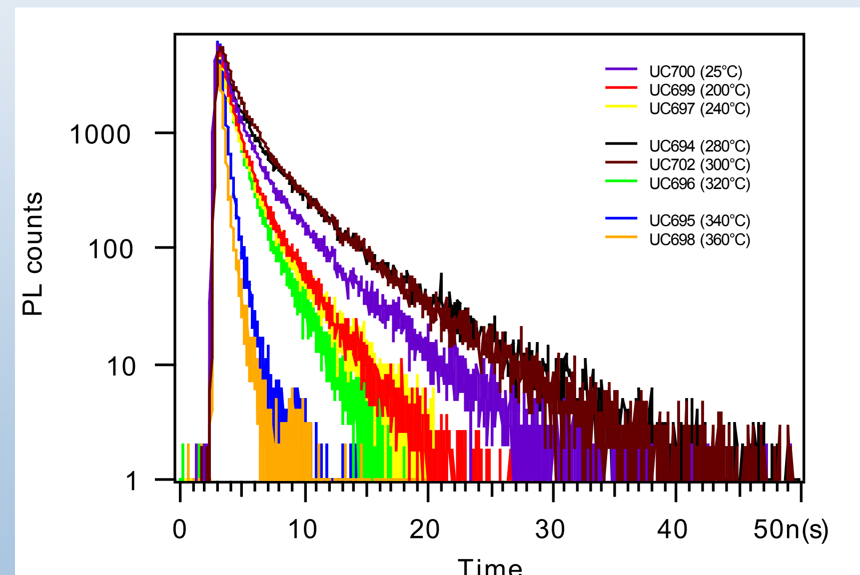
820 nm PL Measurement
Room Temperature

TRPL Study of Cu Diffusion and Contact Temperature

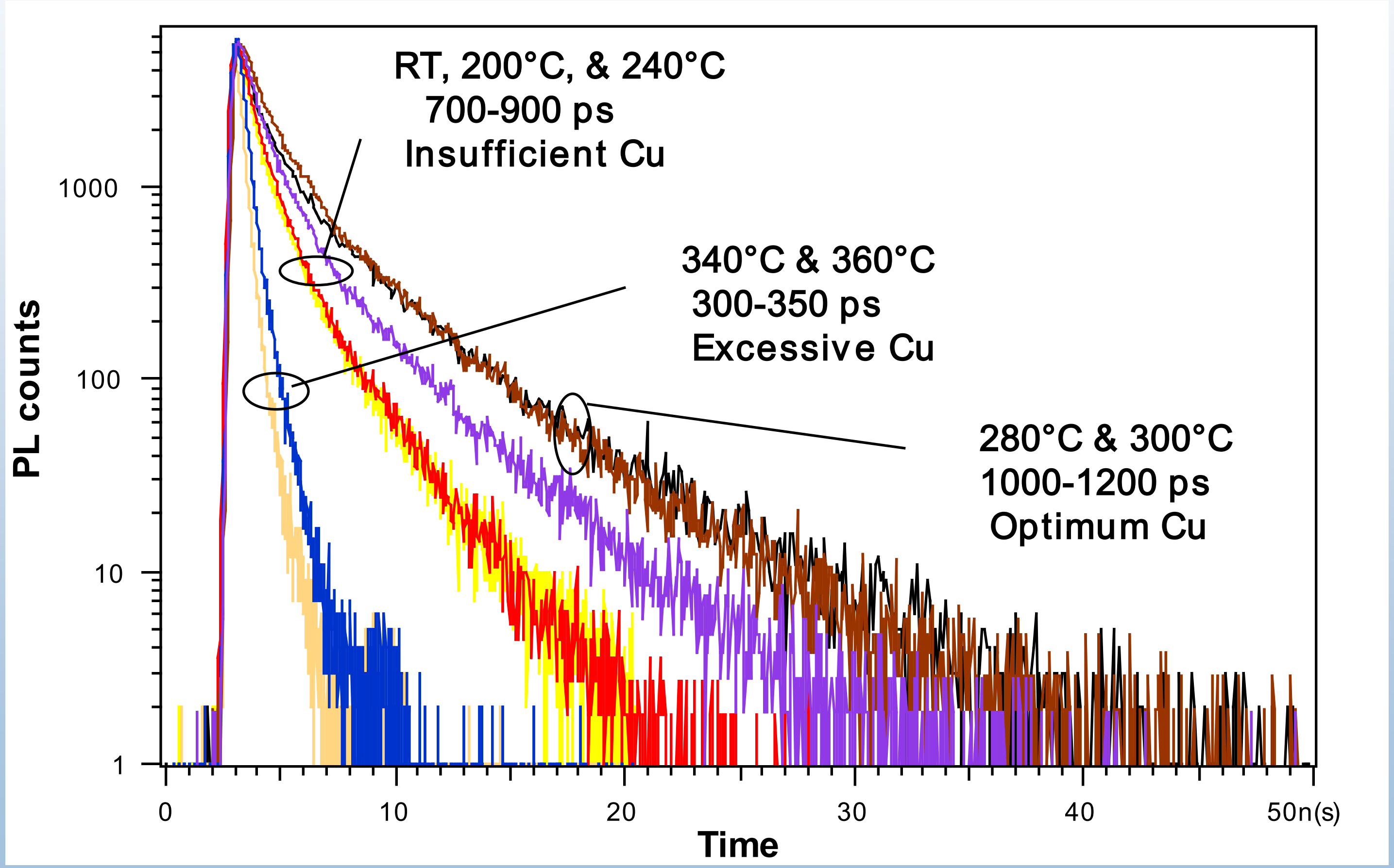
250 μW Power



2500 μW Power

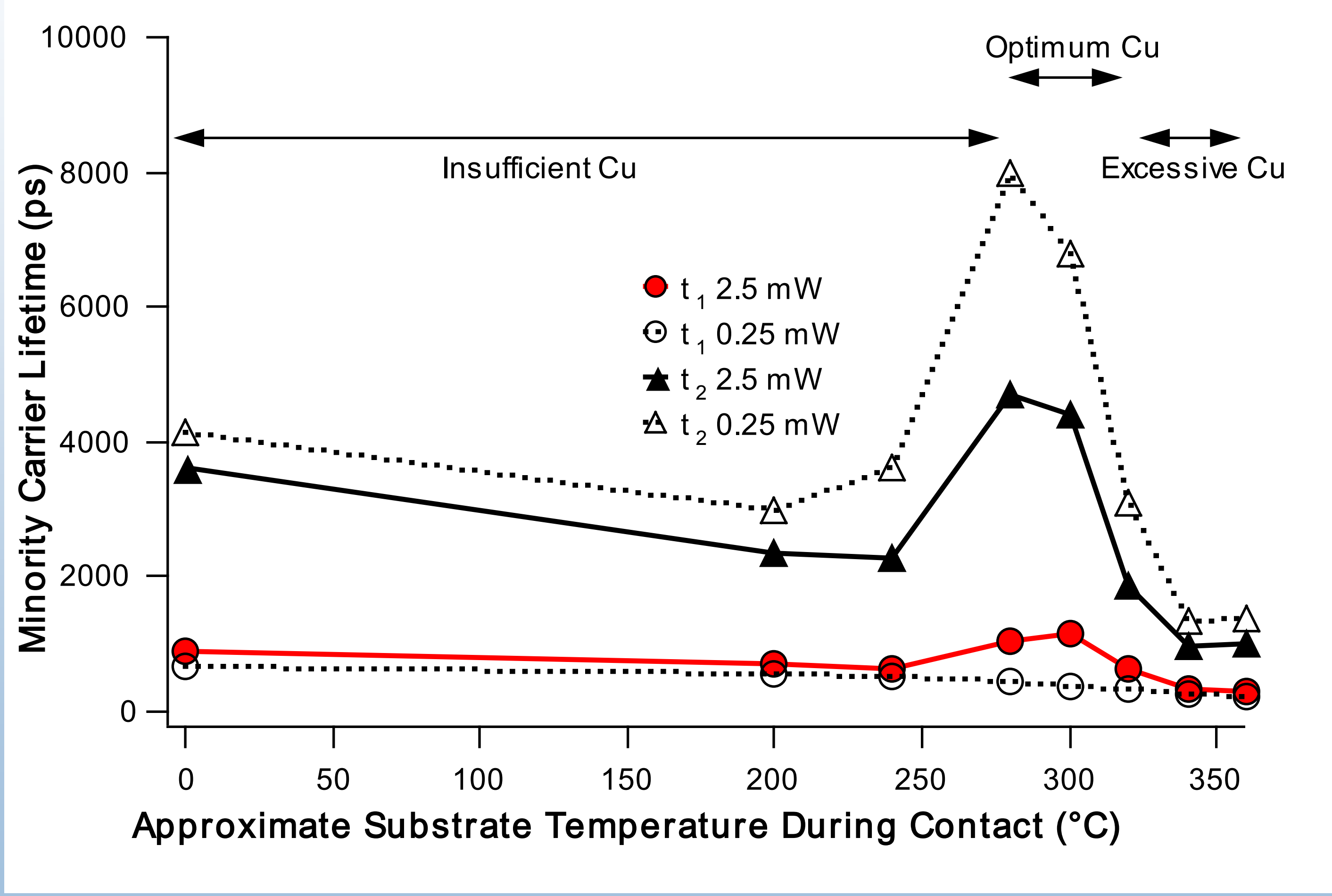


TRPL Study of Cu Diffusion and Contact Temperature (2500 µW Power)



T.A. Gessert, W.K. Metzger, P. Dippo, S.E. Asher, R.G. Dhere, M.R. Young, Thin Solid Films, 517, 2370-2373 (2009)

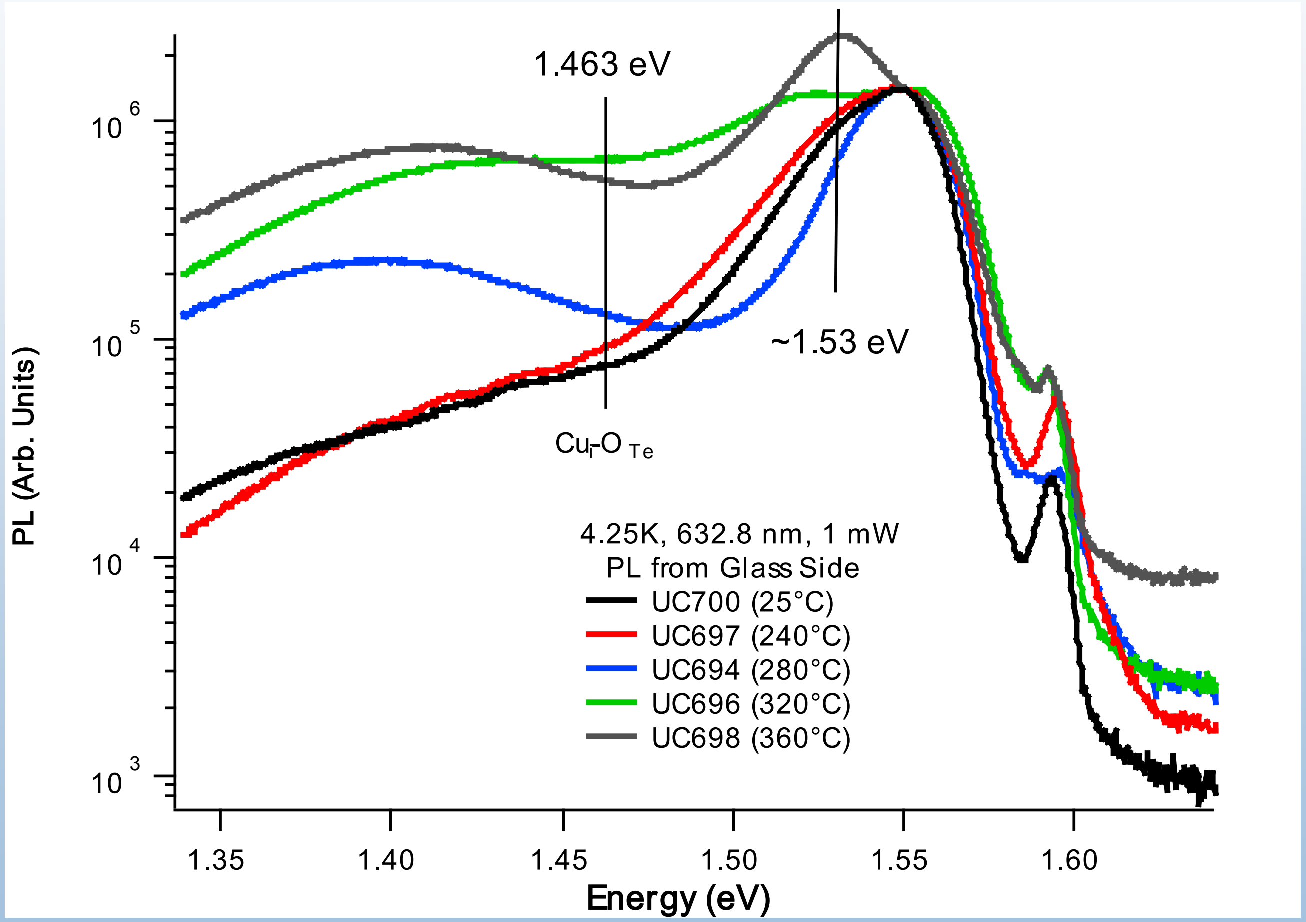
Time Resolved Photoluinescence (TRPL)



T.A. Gessert, W.K. Metzger, P. Dippo, S.E. Asher, R.G. Dhere, M.R. Young, Thin Solid Films, 517, 2370-2373 (2009)

Low-Temperature Photoluinescence (LTPL)

Increasing Contact Temperature produces peak that that has been associated with a defect complex Cu_i-O_{Te} , and an unidentified peak at ~1.53 eV

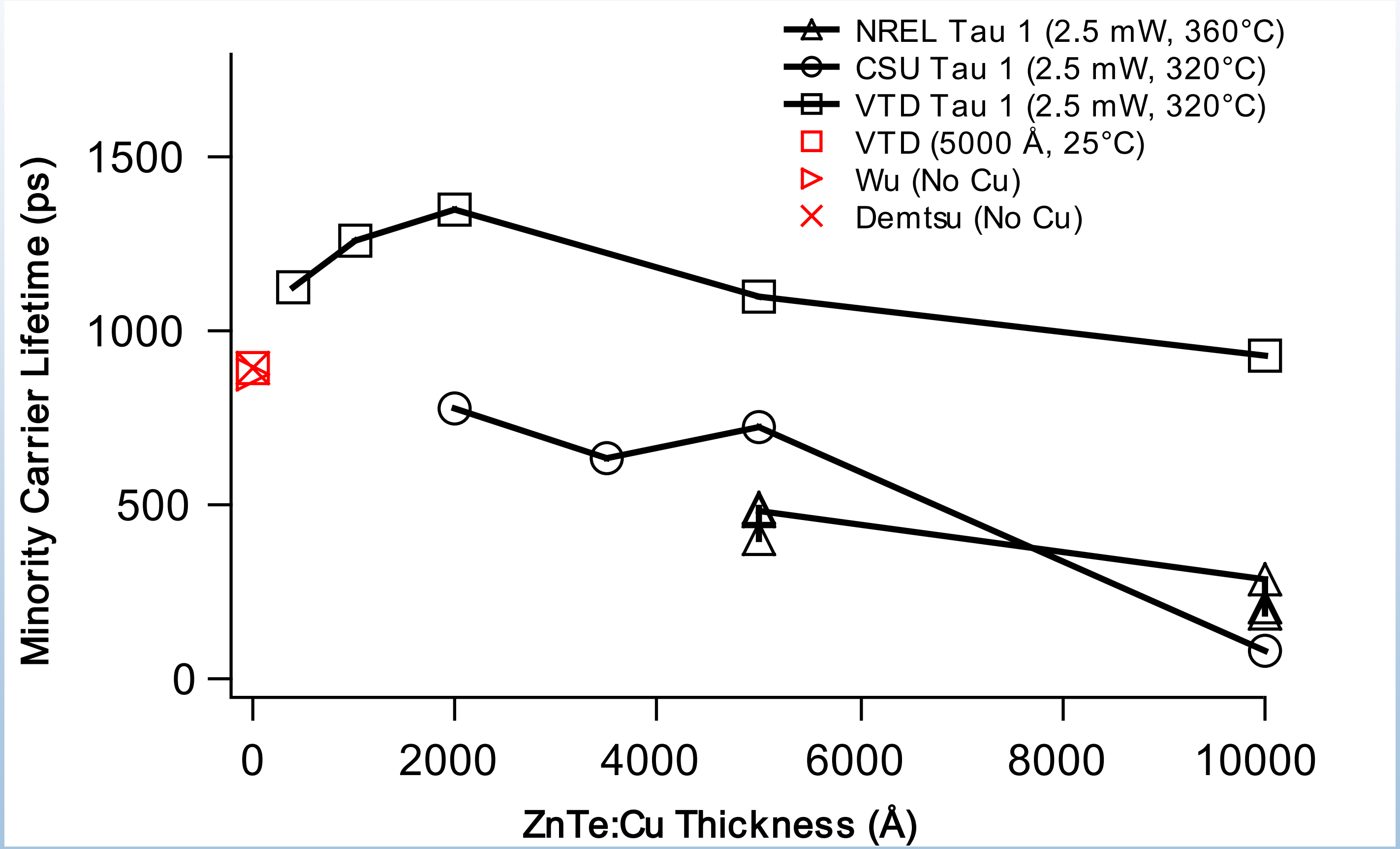


Reference for Cu_i-O_{Te}

Corwine, Sites, Gessert, Metzger, and Duda, Appl. Phys Lett. 86 (1) 221909 (2005)

T.A. Gessert, W.K. Metzger, P. Dippo, S.E. Asher, R.G. Dhere, M.R. Young, Thin Solid Films, 517, 2370-2373 (2009)

Time Resolved Photoluinescence (TRPL)

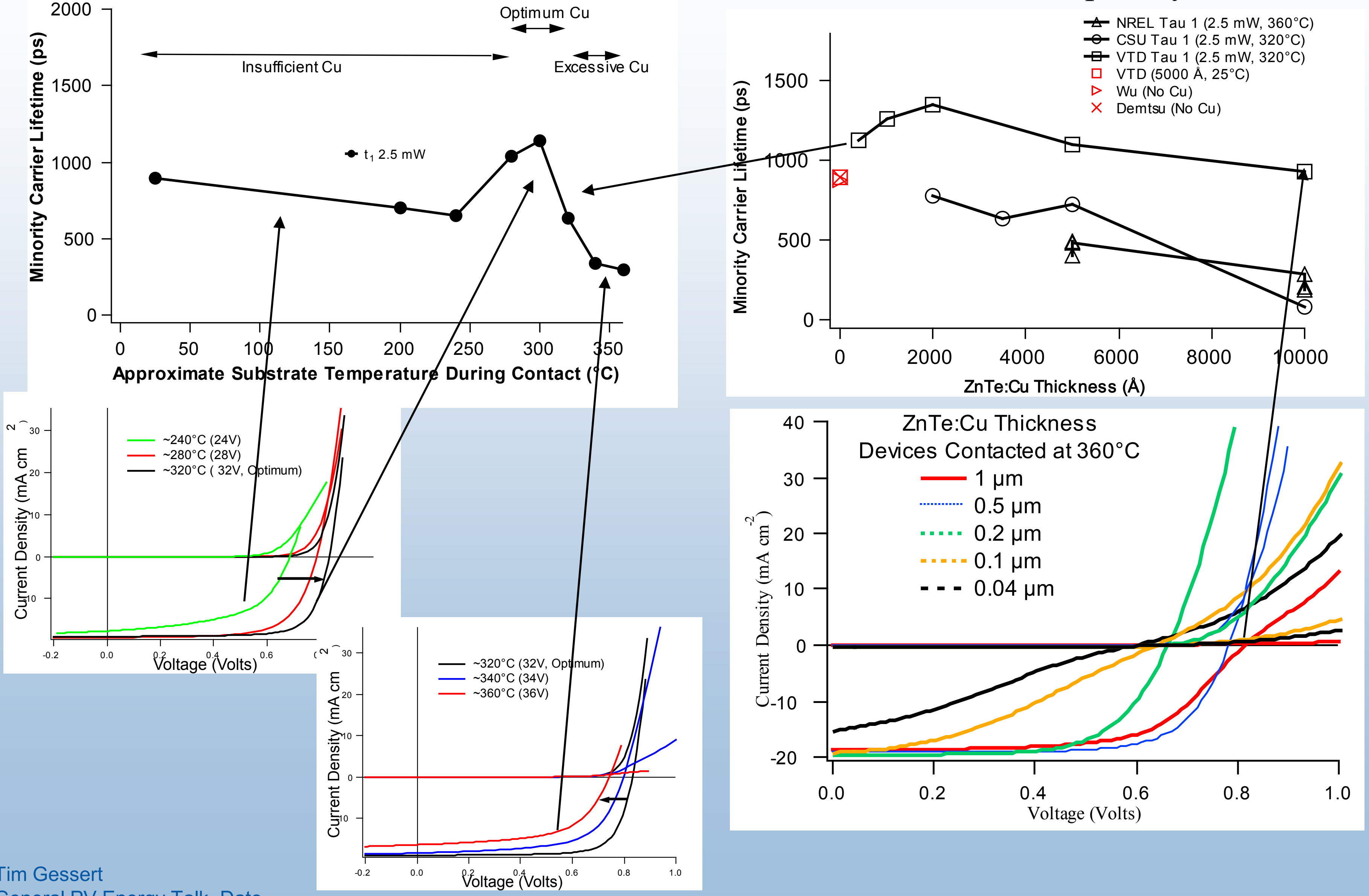


T.A. Gessert, W.K. Metzger, P. Dippo, S.E. Asher, R.G. Dhere, M.R. Young,
Thin Solid Films, 517, 2370-2373 (2009)

What Does it all Mean??

Constant Cu, Vary Temp

Constant Temp, Vary Cu



CdTe PV Devices Conclusions

- Net acceptor level increases during contacting, control produces optimum $W_{depletion}$
- Minority carrier lifetime can decrease and/or increase during contacting
    - Primarily depends on temperature during Cu diffusion
    - Also depends on amount of Cu diffused
    - Reason(s) remain uncertain
- For the ZnTe:Cu/Ti contact, the longest lifetimes occur at contact temperature of ~280-320°C
    - This may explain various contact-process functionalities!
- Strategy for optimization of Cu-containing contacts:
    - Understand effect of temperature on lifetime
    - Adjust Cu to optimize depletion width and V_{oc} (and limit Cu diffusion into CdS)
    - **Future work – maintain lifetime in quazi-neutral region during contacting!**

Thank You!