Formation of ZnTe:Cu/Ti Contacts at High Temperature for CdS/CdTe Devices

T. A. Gessert, S. Asher, S. Johnston, A. Duda,
M.R. Young, and T. Moriarty

National Center for Photovoltaics
National Renewable Energy Laboratory

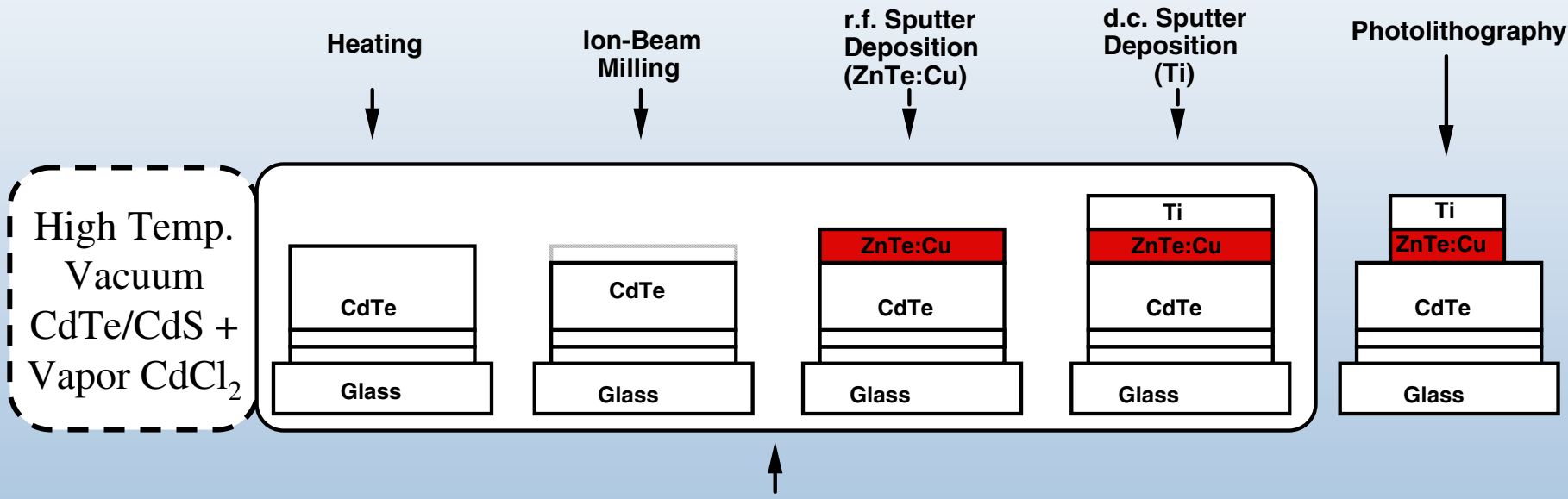
Acknowledgements
Alan Fahrenbruch (ALF)

Research supported by United States Department of Energy - Contract No. DE-AC36-99GO10337

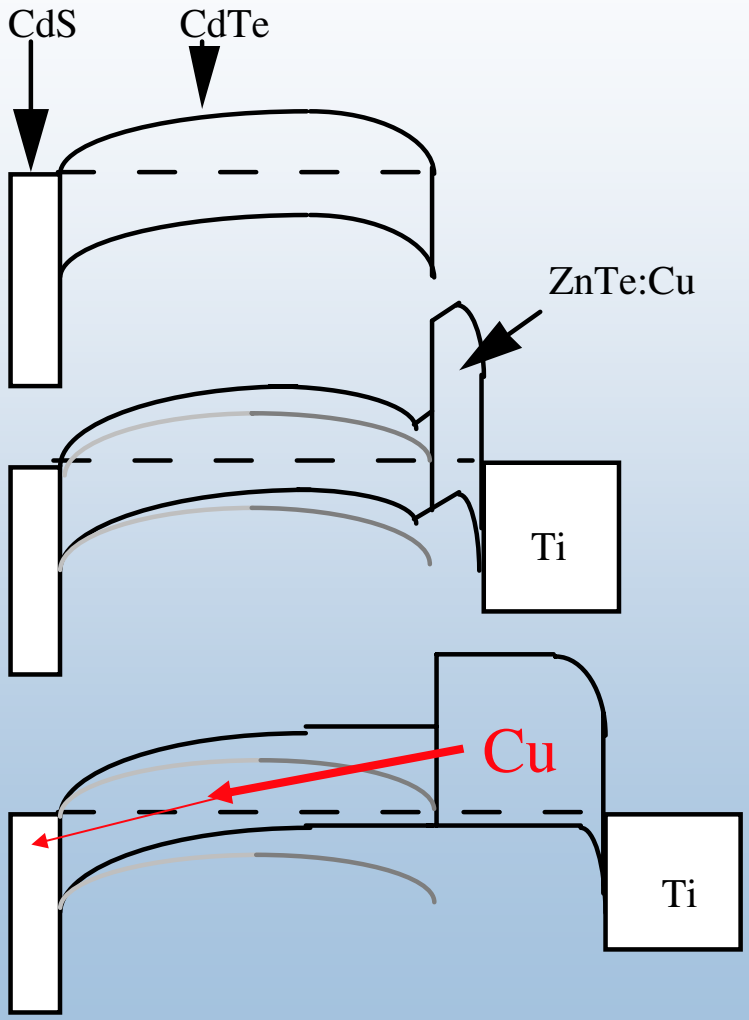
NREL/PR-520-39845
Presented at the 2006 IEEE 4th World Conference on Photovoltaic Energy Conversion (WCPEC-4) held May 7-12, 2006 in Waikoloa, Hawaii.

Disclaimer and Government License

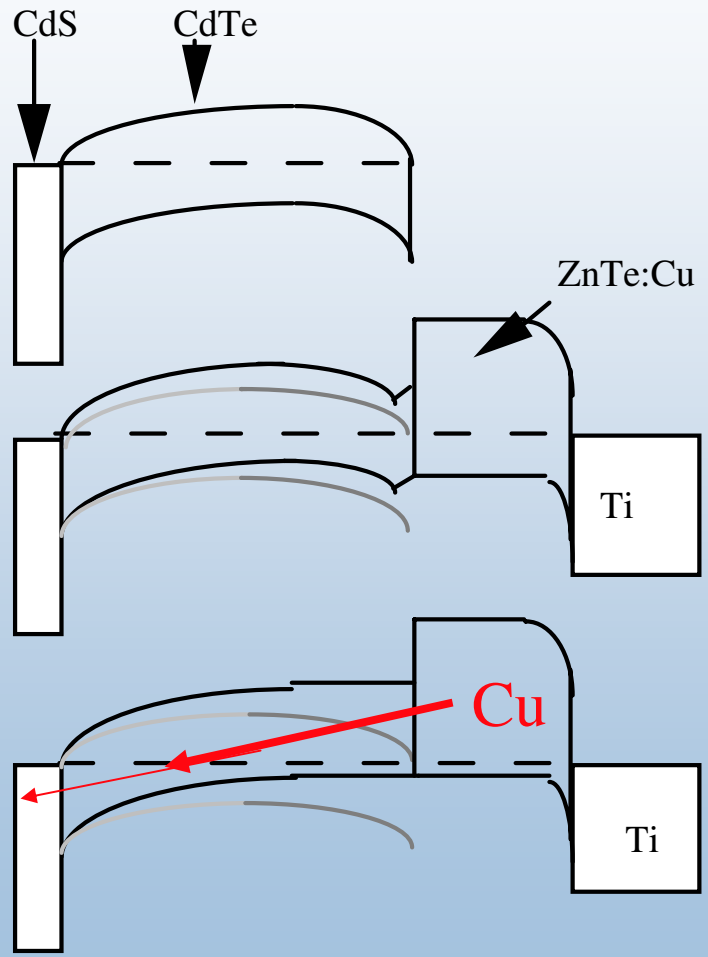
ZnTe:Cu/Ti Contact Process
(All-Dry, High-Temperature [300°C])



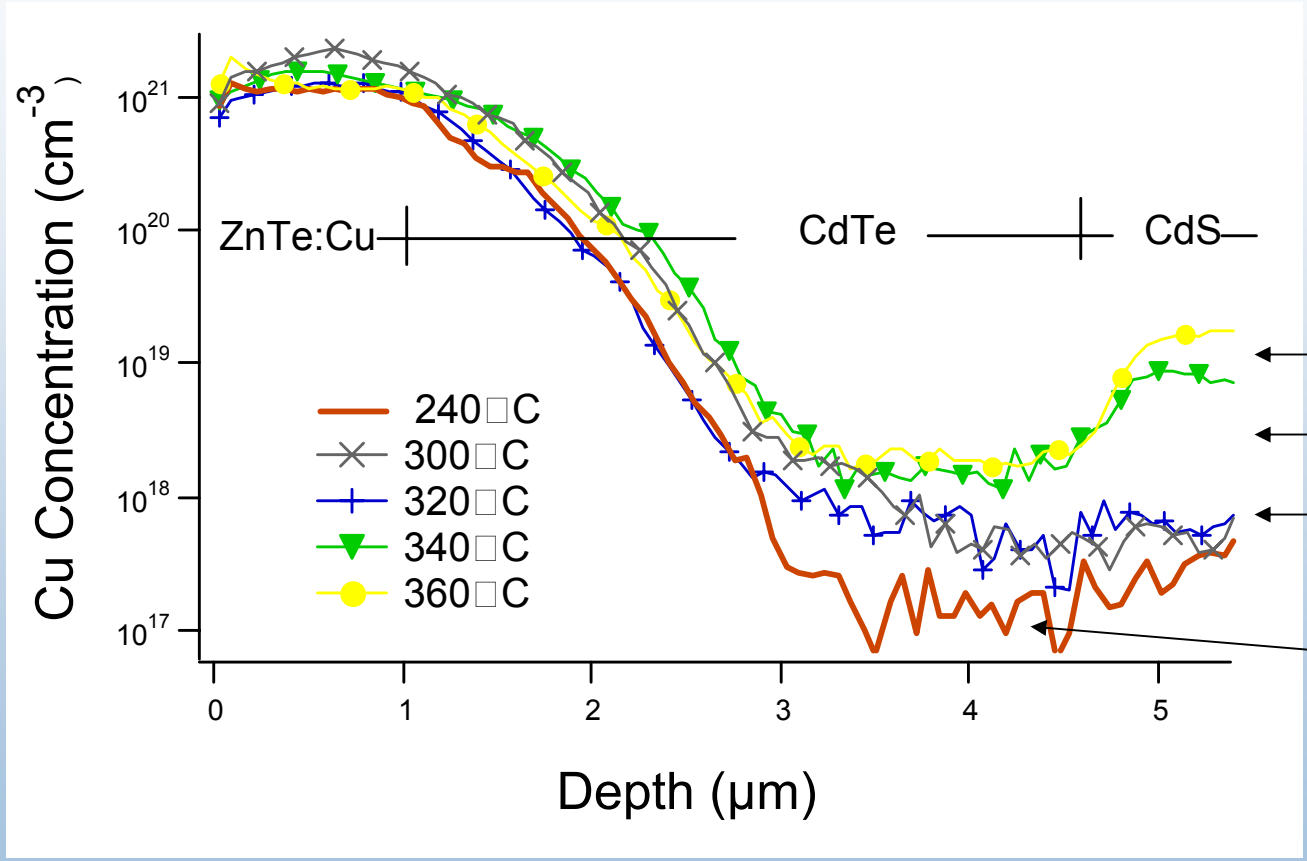
Constant Temperature ~300°C
Vary ZnTe:Cu Thickness



Constant Thickness ~0.5 µm
Vary ZnTe:Cu Temperature



SIMS Analysis of Temperature Dependence



Too Much Cu?

??

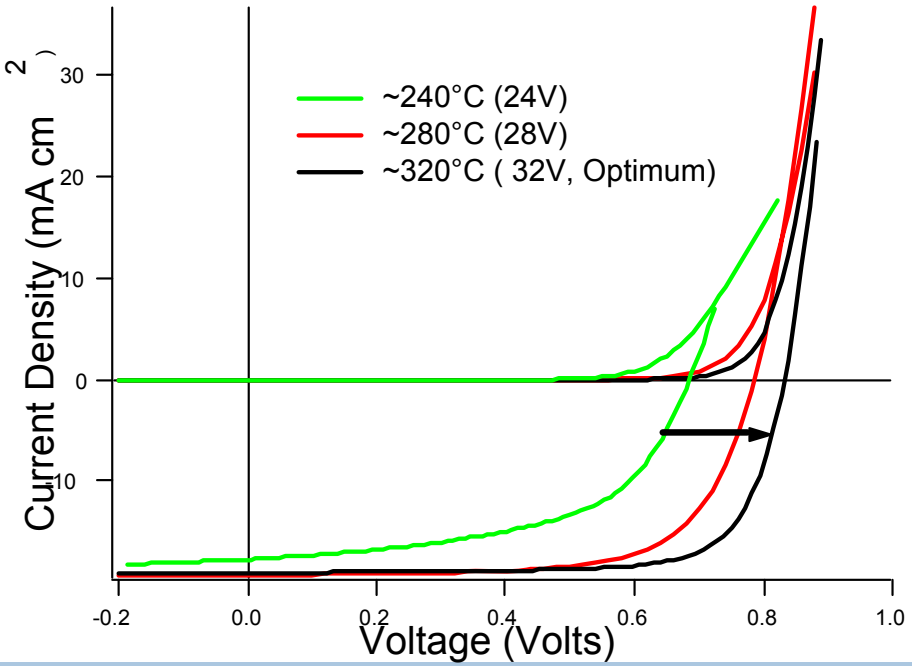
Just Right Cu?

Too Little Cu?

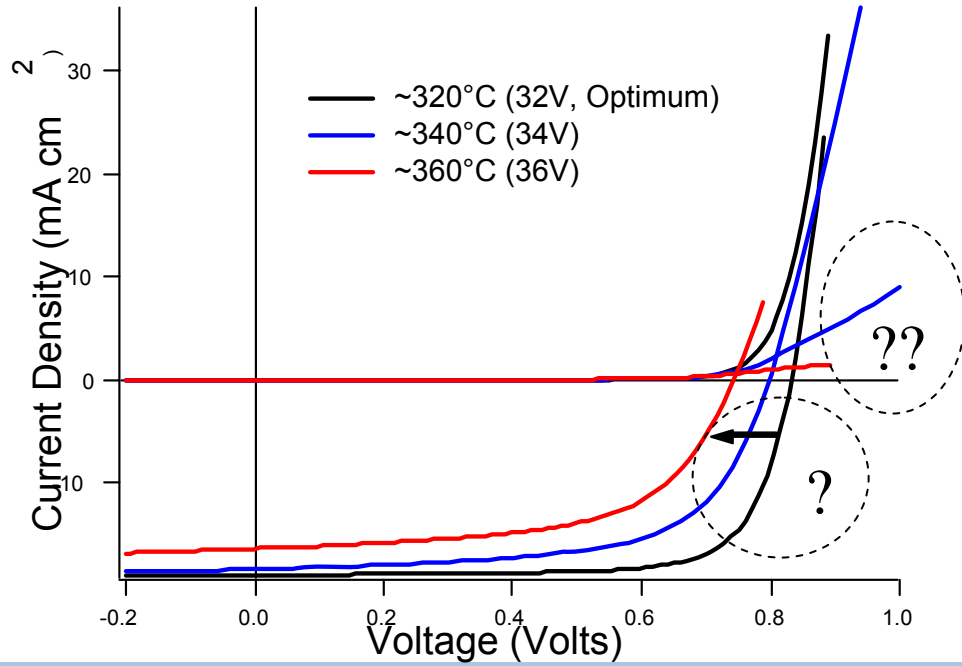
Insight from Temperature Dependent Studies

(ZnTe:Cu Contact Temperature)

Cu Diffusion Less Than Optimum

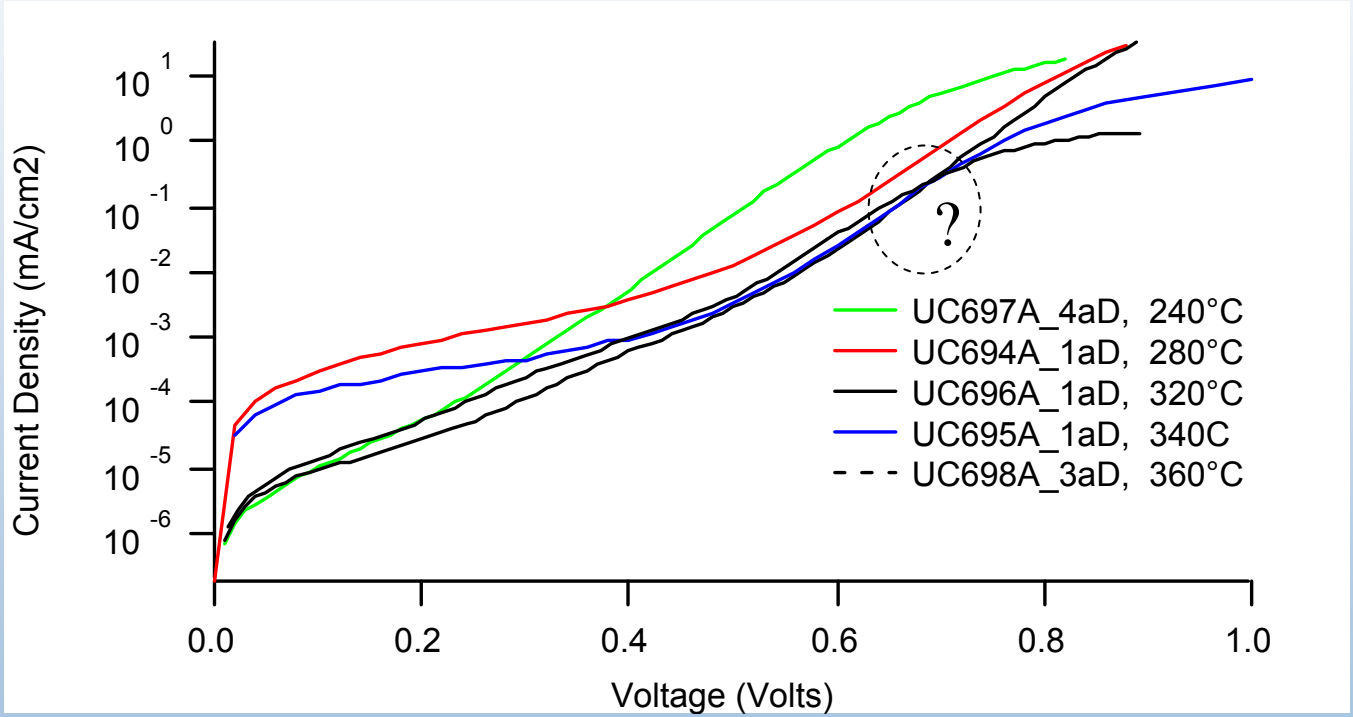


Cu Diffusion Greater Than Optimum

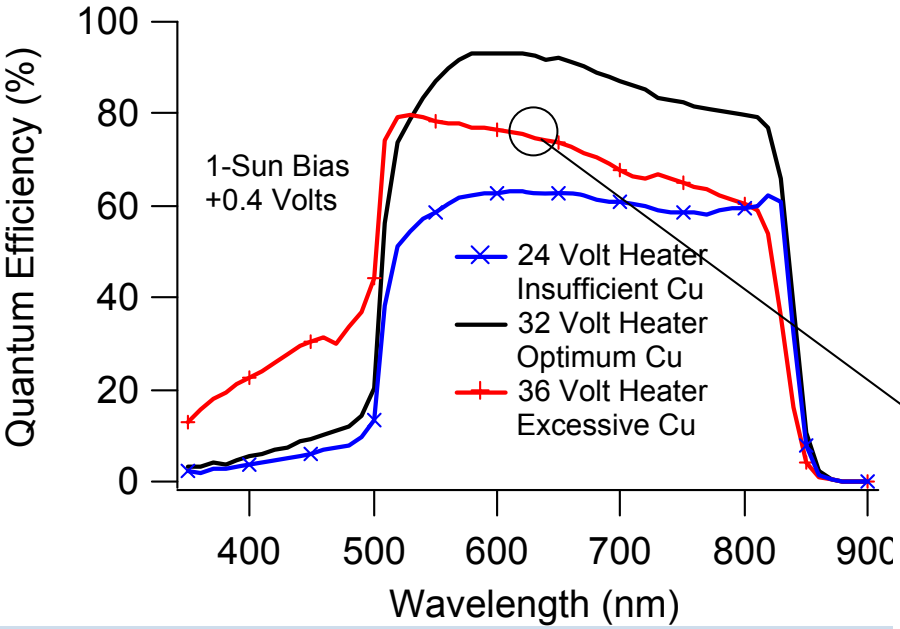


Some Insight from Past Studies

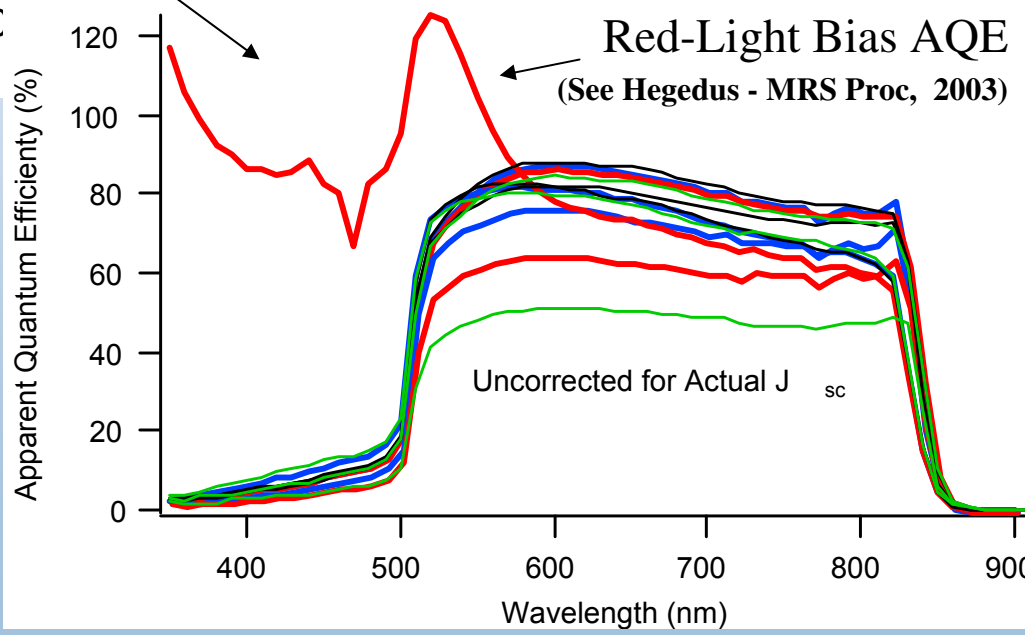
Dark IV Analysis of Temperature Dependence (Low J_o and Increase in R_s at Higher Contact Temperature)



Light and Voltage-Dependent Quantum Efficiency



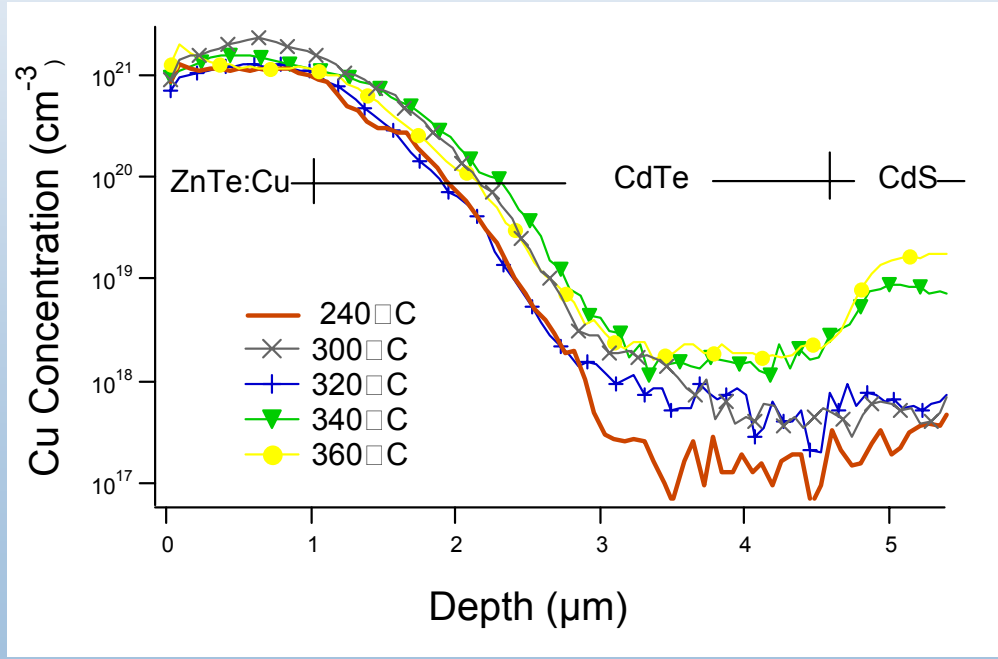
Red-Light Bias QE Confirms Photoconductive CdS For Excessive Cu Devices



QE Comparison Suggests Narrow Junction for Excessive Cu Devices

Some Resulting Questions

- Is Cu diffusion from the contact always "good" in CdTe and always "bad" in CdS?
- Is there a maximum Cu concentrations that can be tolerated?
- If Cu in the CdS can be minimized, does the V_{oc} increase?
- Can the Cu diffusion from contact be *controlled advantageously*



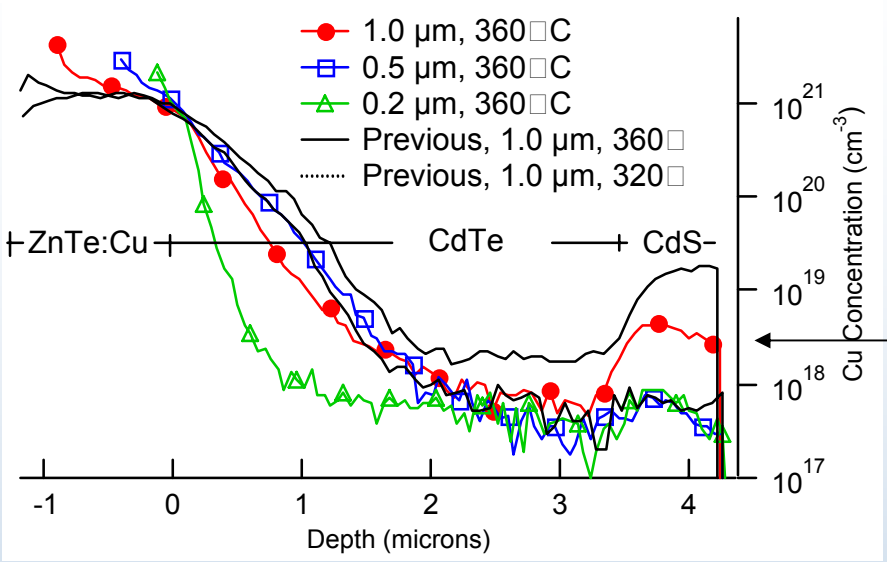
ZnTe:Cu Contact Parameters - This Study

•Ion Beam Mill Depth	1000 Å
•Cu Concentration in ZnTe	9 atomic percent
•ZnTe:Cu Thickness	(0.5 μm ~Optimum)
•Vary:	0.04-1.0 μm
•ZnTe:Cu Deposition Temperature	(300°C ~Optimum)
•Increase:	360°C (Too High!)
•Outer Metallization	Ti, 0.5 μm, 185°C

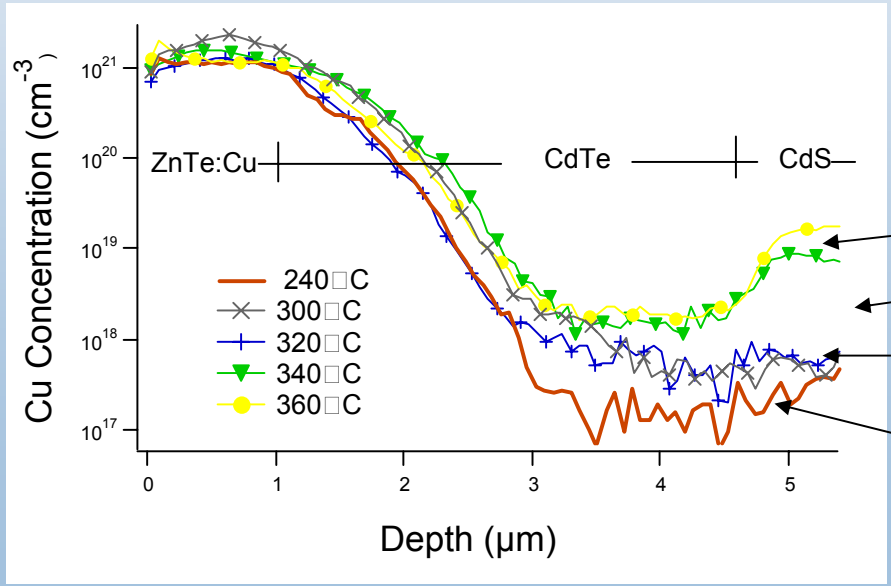
Device Performance (This Study, VTD Production Material)

•V_{oc}	~800 mV
•J_{sc}	~19 mA/cm^2
•FF	~71%
•Efficiency	~11%

Compositional Analysis



This Study
Maximum Cu
Midway Between
Past Studies

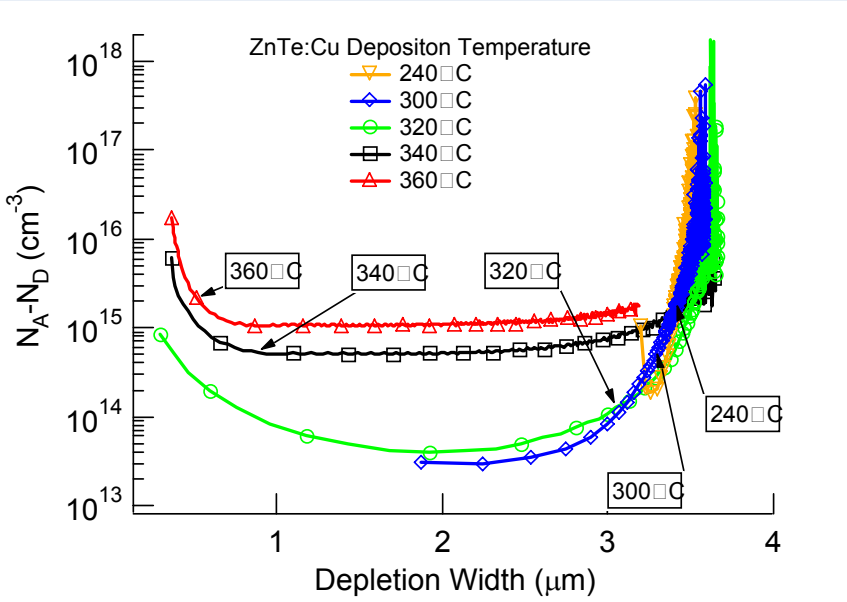


Previous Studies
Too Much Cu?
??
Just Right Cu?
Too Little Cu?

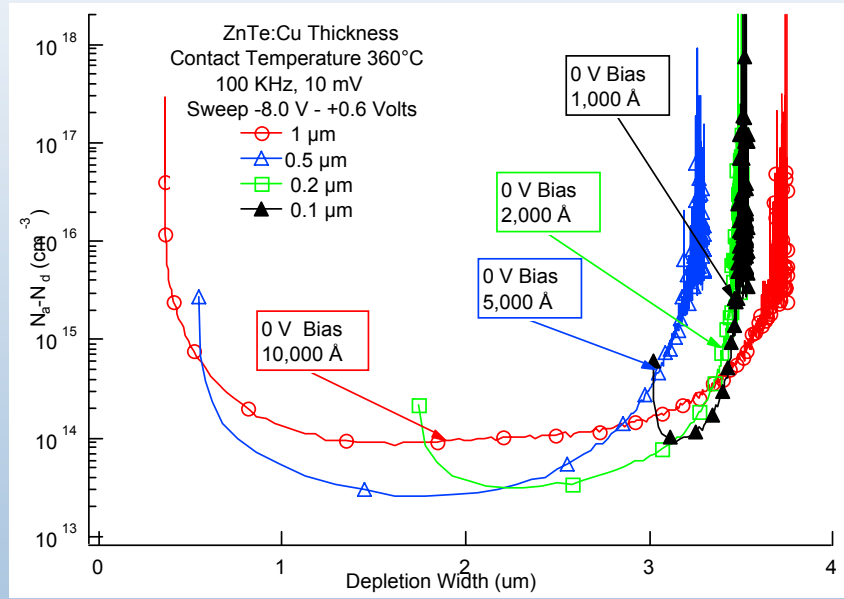
Key Result:
Extent of Cu Diffusion Limited by ZnTe:Cu Thickness at High Contact Temperature

Comparison of Previous and Present C-V Analysis

Previous Data - Contact Temperature

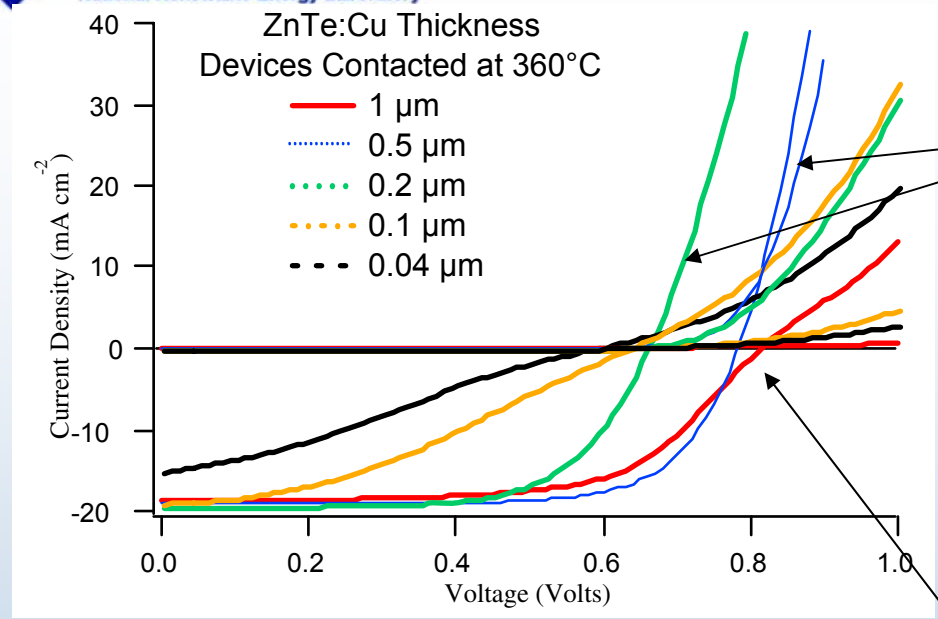


New Study - ZnTe:Cu Thickness



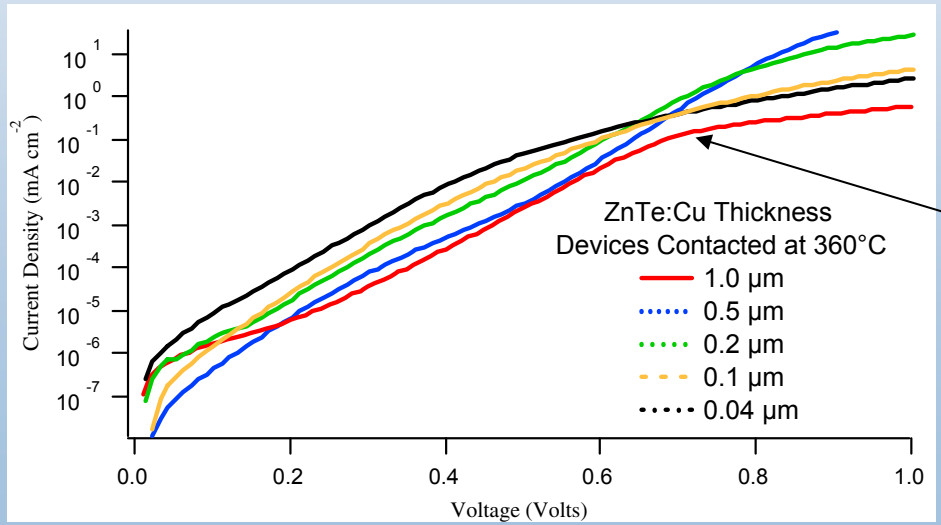
(100 kHz, 10 mV, -8.0 to +0.6 Sweep)

LIV/DIV Analysis



0.2 µm ZnTe:Cu Insufficient
- Even at 360°C

<u>Key Result:</u>
High Contact Temperature
Cannot Compensate for
Insufficient Cu from Contact

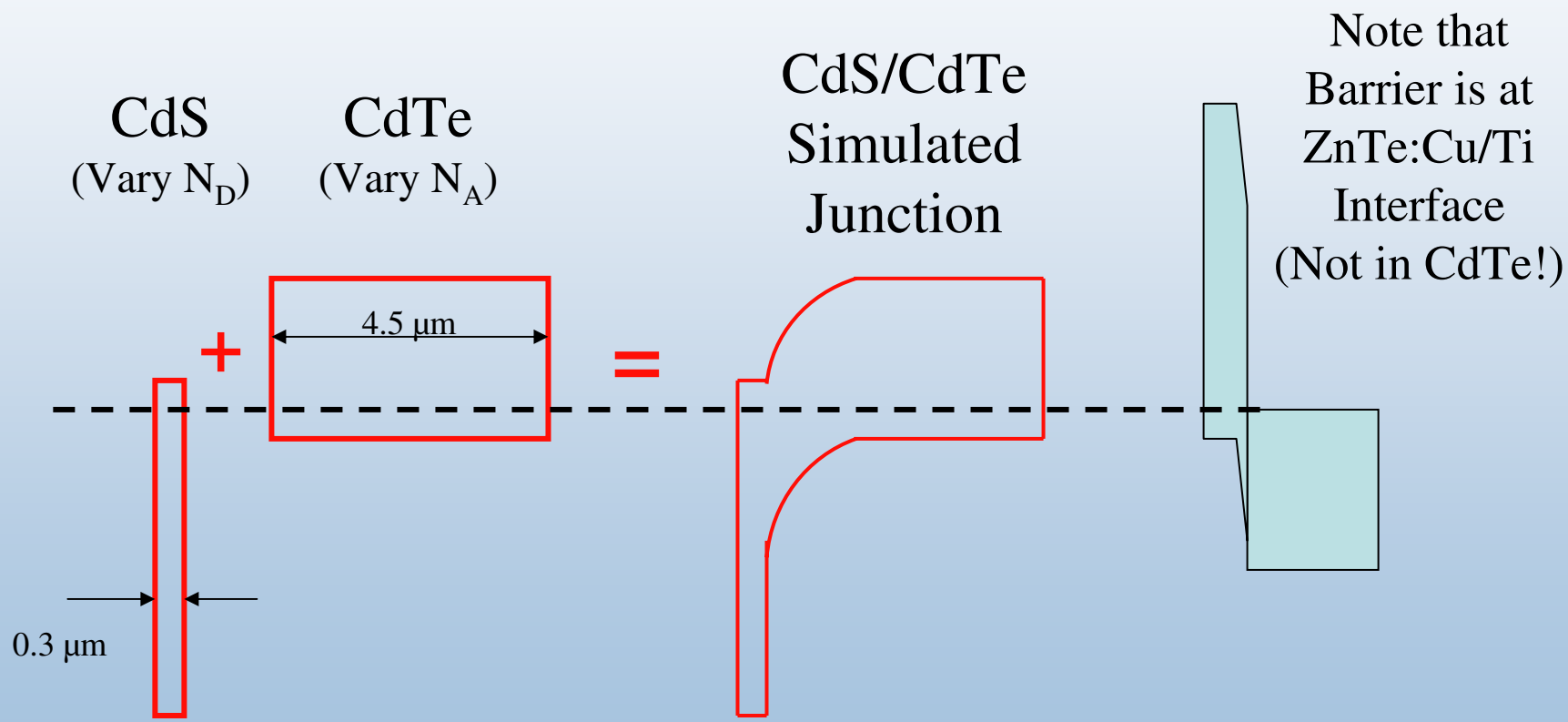


Unlike Previous Study
V_{oc} Increases to
1 µm ZnTe:Cu

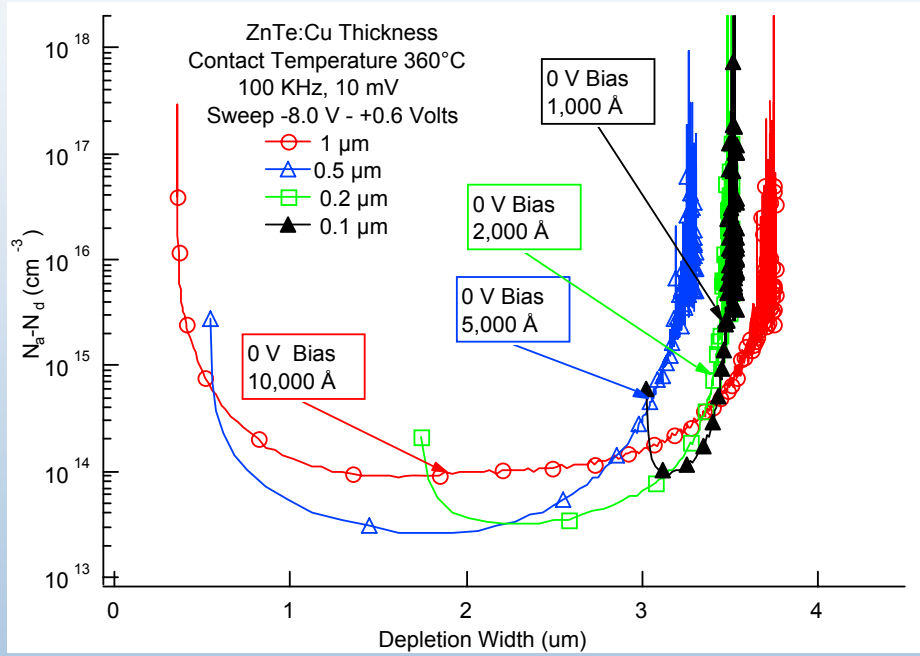
But still high apparent R_s

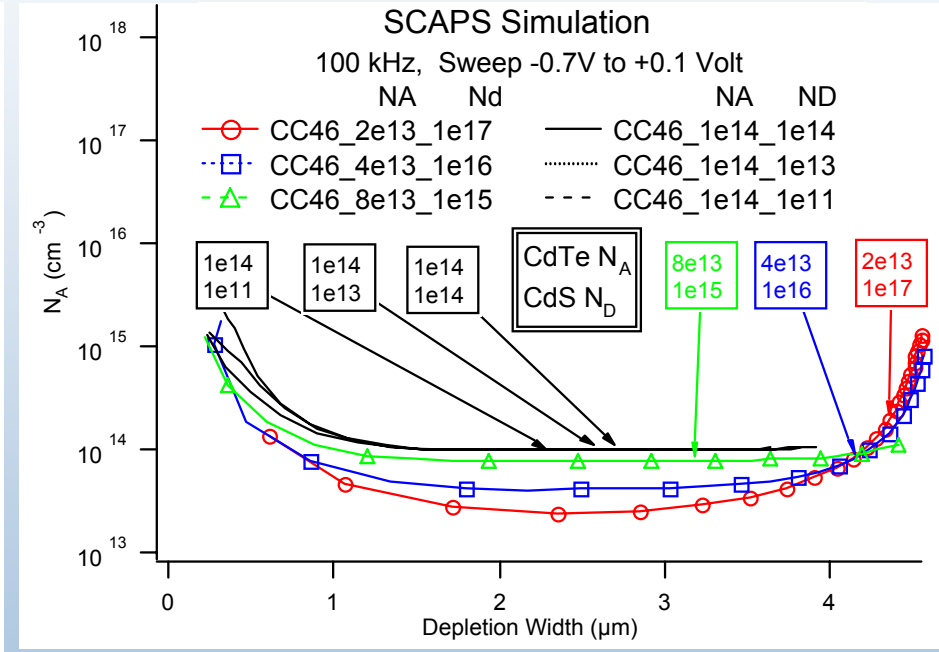
SCAPS-1D Simulation Model Device

(Vary Shallow CdS N_D and CdTe N_A Only - No Deep Defect Considered)

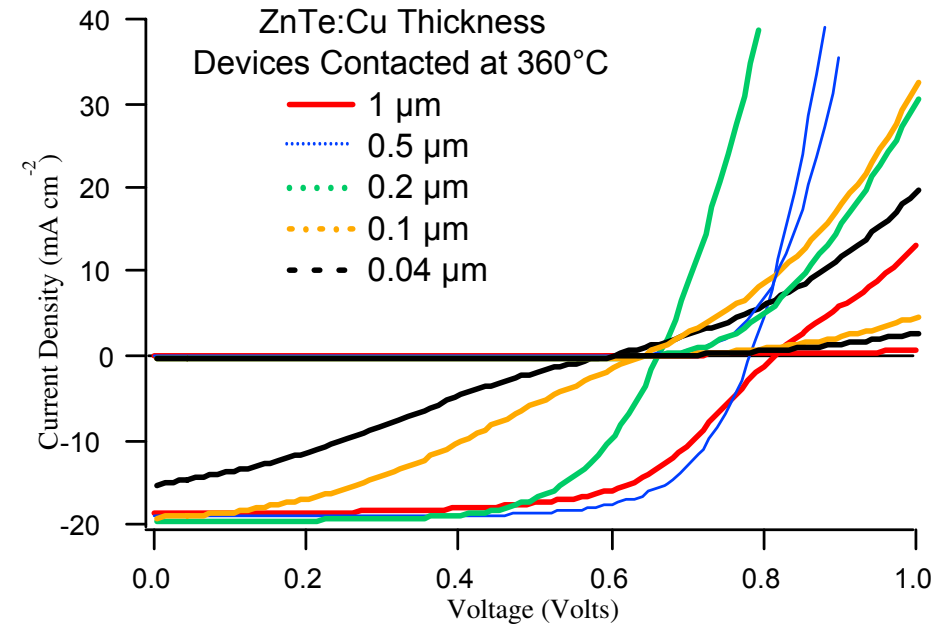


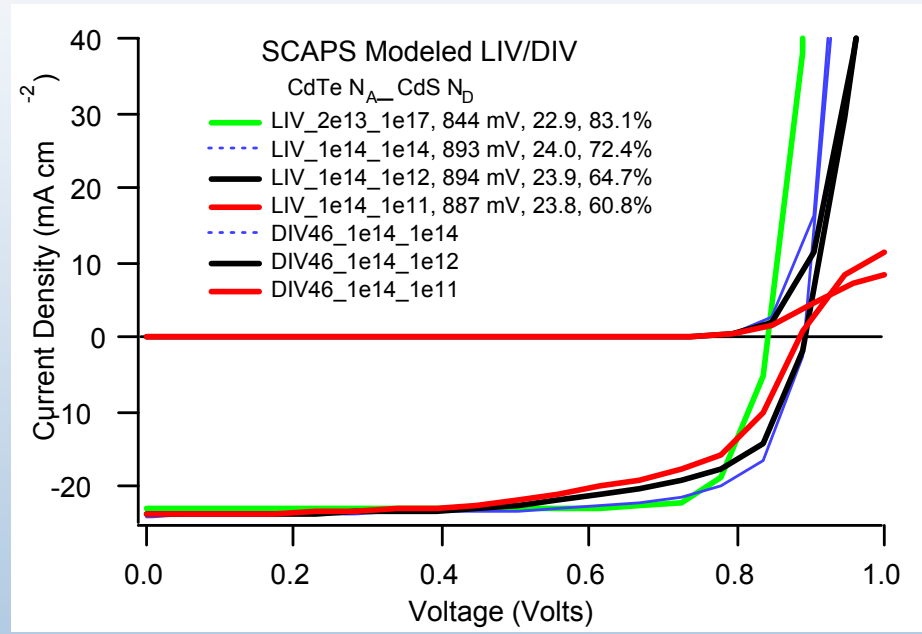
Comparison of C-V Measurement and SCAPS-1D C-V Simulation



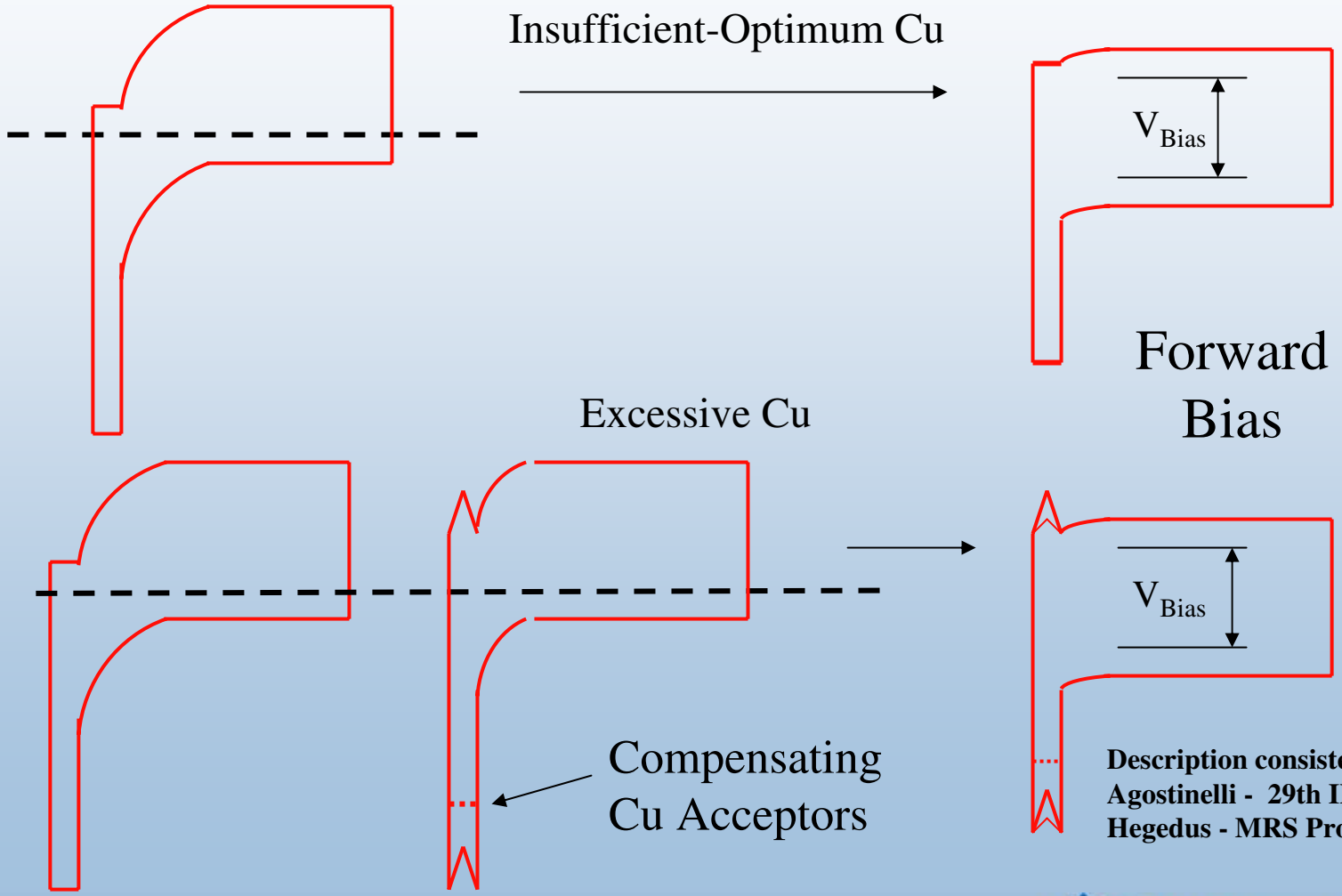


Comparison of LIV/DIV Measurement and SCAPS-1D Simulation





Probable Cause of Apparent Series Resistance For CdS/CdTe Devices with High Cu Concentration in CdS



Description consistent with -
Agostinelli - 29th IEEE PVSC, 2002
Hegedus - MRS Proc, 2003.

Conclusions

- Cu diffusion from a ZnTe:Cu contact causes good and bad things:
  - The Good (Cu in CdS < low 10^{18} cm^{-3})
    - Increase in CdTe N_A-N_D that leads to V_{oc} and FF improvement
  - The Bad (Cu in CdS > low 10^{18} cm^{-3})
    - Possibly decreased of shunt resistance (?)
    - Depletion width in CdTe can become too narrow for optimum current collection at J_{MPP}
    - Donor reduction in CdS (*Significant* FF loss in LIV)
    - Excessive Cu diffusion into CdS readily observed by red-light bias QE
- Next Question - Can we get the Good without the Bad?

  N_A-N_D?