Comparison of Novel 3D Nanoarchitectures for Solar Cells

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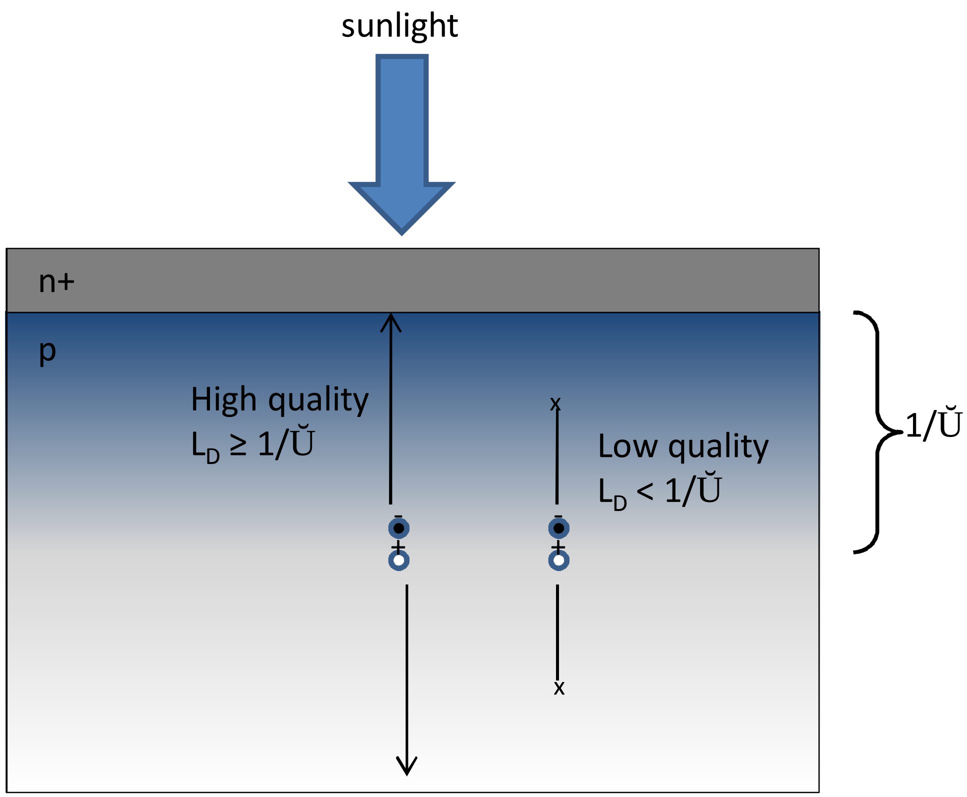
Artit Wangperawong, Carl Hagglund and Stacey F. Bent

Stanford University

Bent Research Group

bentgroup.stanford.edu

Carrier collection in planar devices

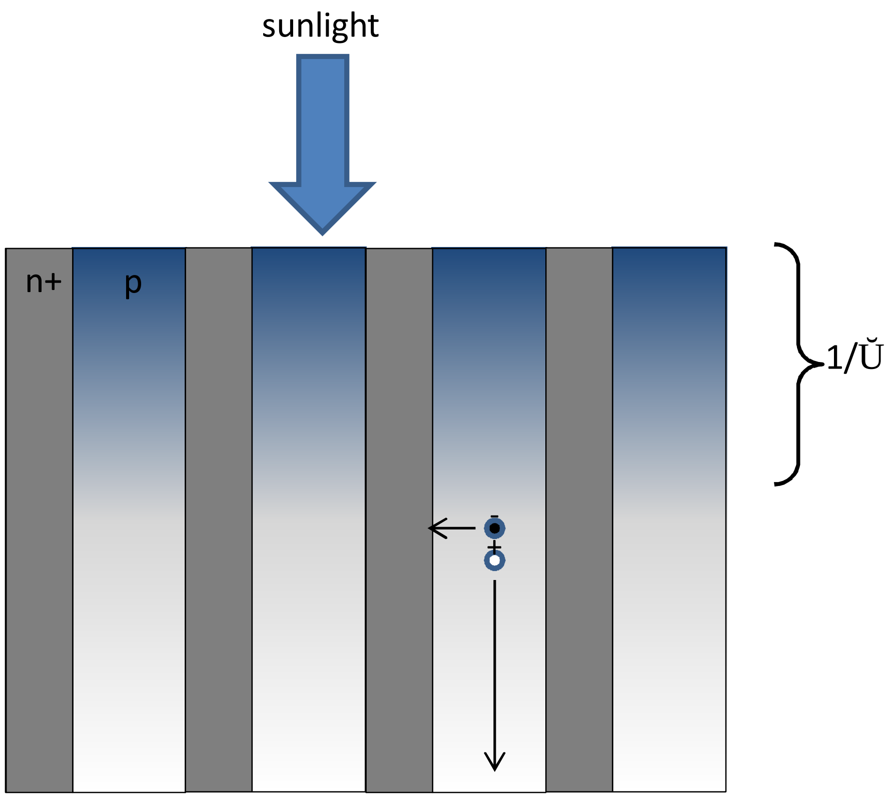


Diffusion length of minority carriers needs to be longer than the absorption depth for efficient carrier collection.

Problem: High quality materials are expensive. As for cheaper low quality materials, L_D is nanoscale.

Solution: Consider vertical nanojunctions to decouple absorption from collection.

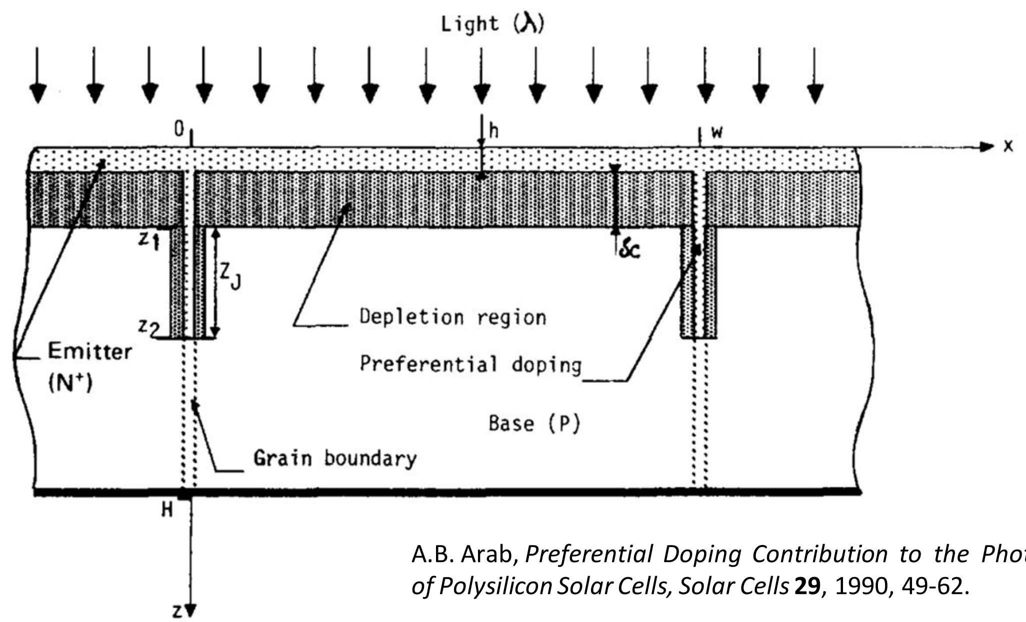
Carrier collection in vertical junctions



- Diffusion length of minority carriers no longer needs to be greater than the absorption depth for efficient carrier collection.
- Low-quality materials can be made more efficient.
- Since L_D is nanoscale, junction spacing should be nanoscale.
- To maximize benefit, we need to consider 3-D interdigitated nanojunctions.
- 4 designs will be presented here.

Not a new idea - Vertical Nanojunctions from 1980s

1. Preferential doping along grain boundaries



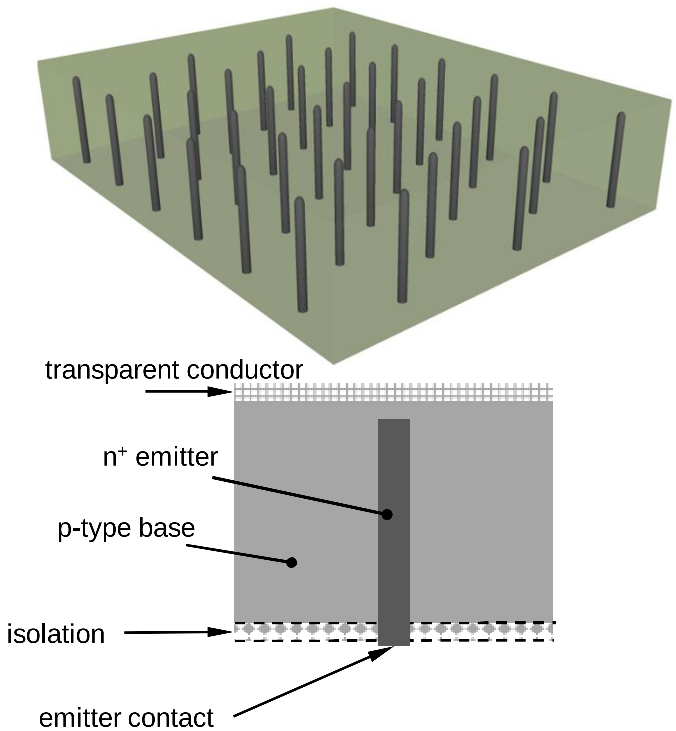
A.B. Arab, *Preferential Doping Contribution to the Photoresponse of Polysilicon Solar Cells, Solar Cells* **29**, 1990, 49-62.

This effect has also been reported for CIGS and CdTe

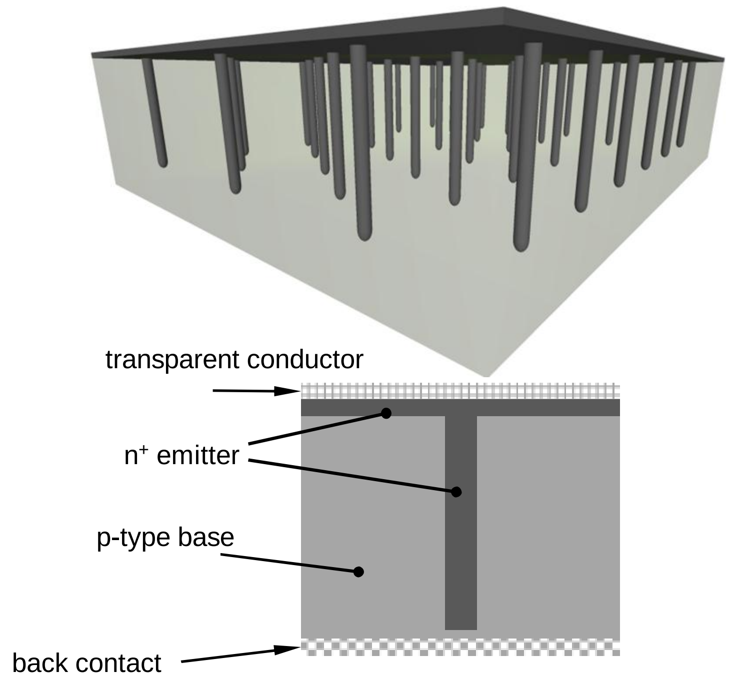
New 3D interdigitated designs reported

Note that electronic communication between junctions

2. Point-contact nanojunctions



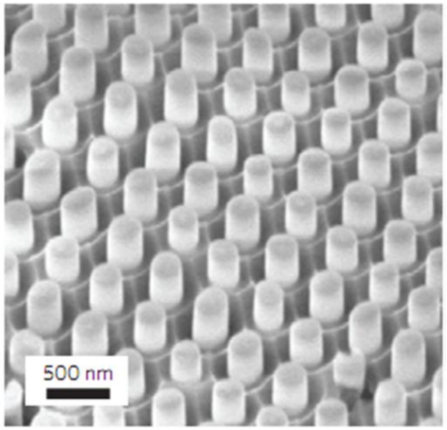
3. Extended nanojunctions

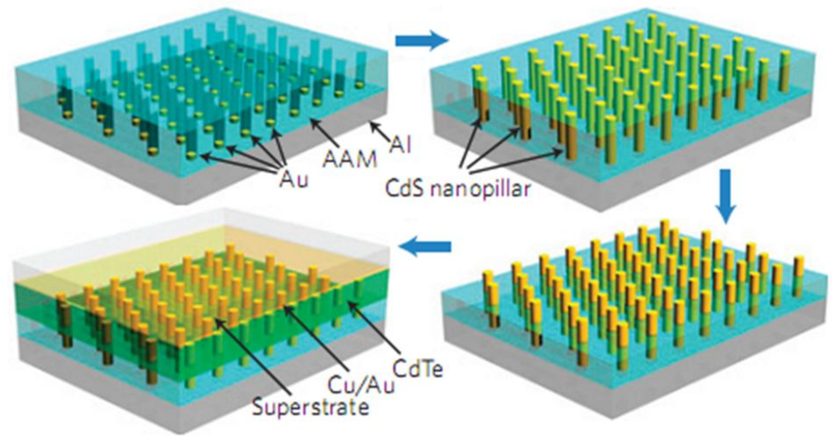


A. Wangperawong, S.F. Bent, *Appl. Phys. Lett.* **98**, 233106 (2011).

Experimental interdigitated devices

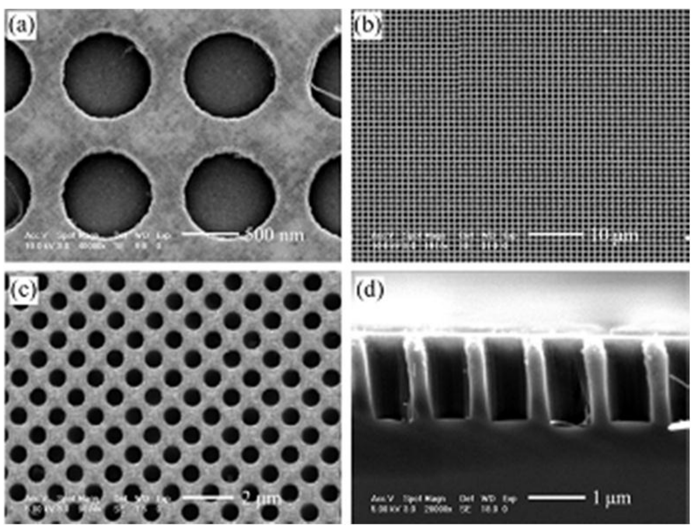
2. Point-contact nanojunctions

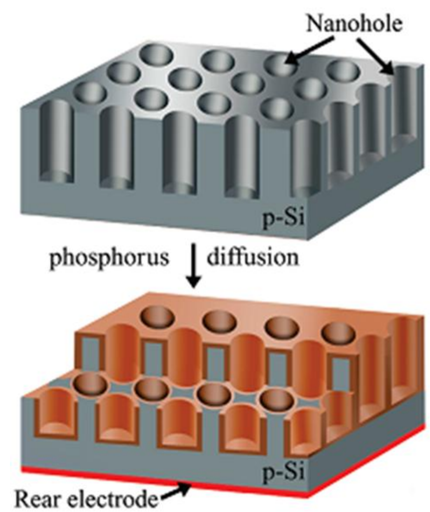




Fan, *et al.*, *Nature Mater.* 8, 648 (2009).

3. Extended nanojunctions

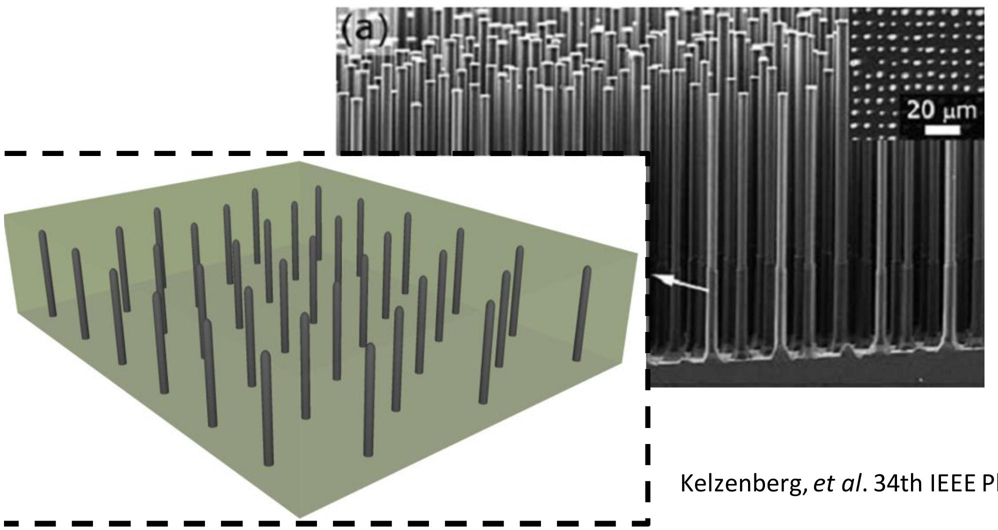


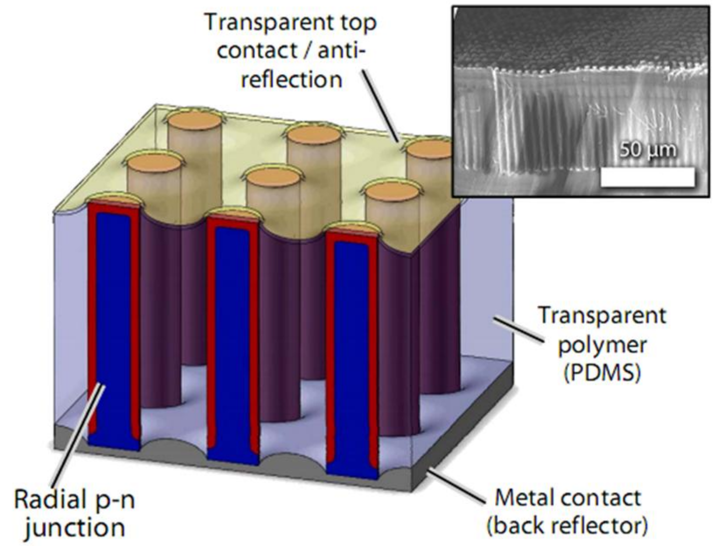


Peng, *et al.*, *J. Am. Chem. Soc.*, 132 (20), 6872 (2010).

Modeling beyond isolated nanojunctions

4. Isolated radial nanojunctions





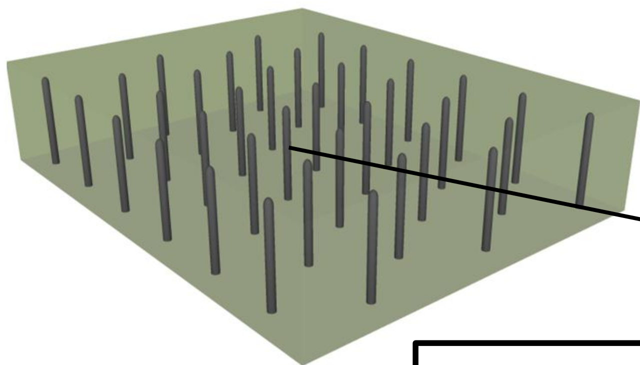
Kelzenberg, *et al*. 34th IEEE Photovoltaic Specialists Conference. IEEE , New York, pp. 391 (2010).

Limited 3D modeling work reported thus far

- Only on isolated radial junctions, i.e. nanowires.
  - <u>Interdigitated design ≠ isolated radial junctions.</u>
- Should consider 3D carrier collection – computationally expensive if numerical
- Is nano better than planar? Which nano is the best?
  - Depletion region lifetime greater than bulk lifetime + operate in full depletion
  - Not likely, not generally applicable

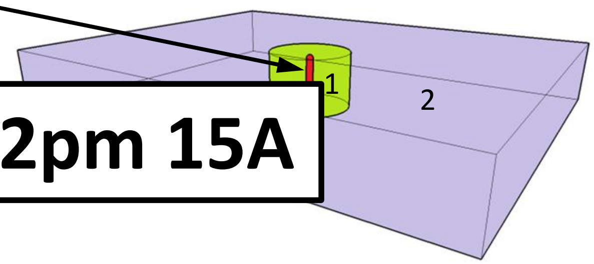
Modeling Approach

1. Point-contact nanojunctions



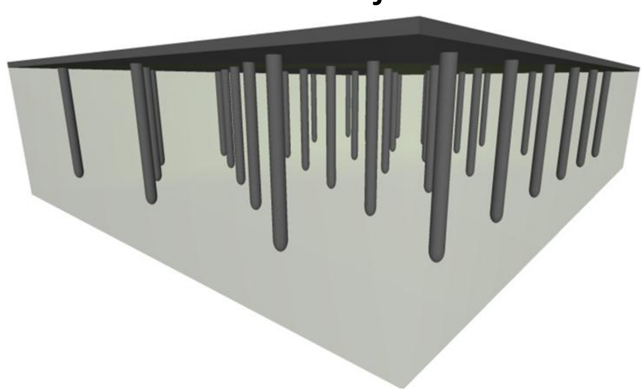
Analytical approach using effective medium approximation to solve diffusion-collection problem in 3-D:

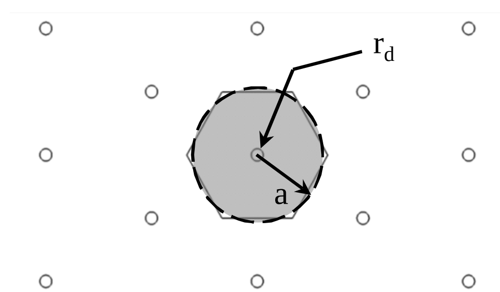
$$\frac{1}{r}\frac{\partial}{\partial r}\left(r\frac{\partial \varphi_m}{\partial r}\right)+\frac{\partial^2 \varphi_m}{\partial z^2}-\frac{1}{L_m^{\ 2}}\varphi_m=0 \qquad m=1,2$$



More details 2pm 15A

2. Extended nanojunctions





Boundary conditions due to continuity:

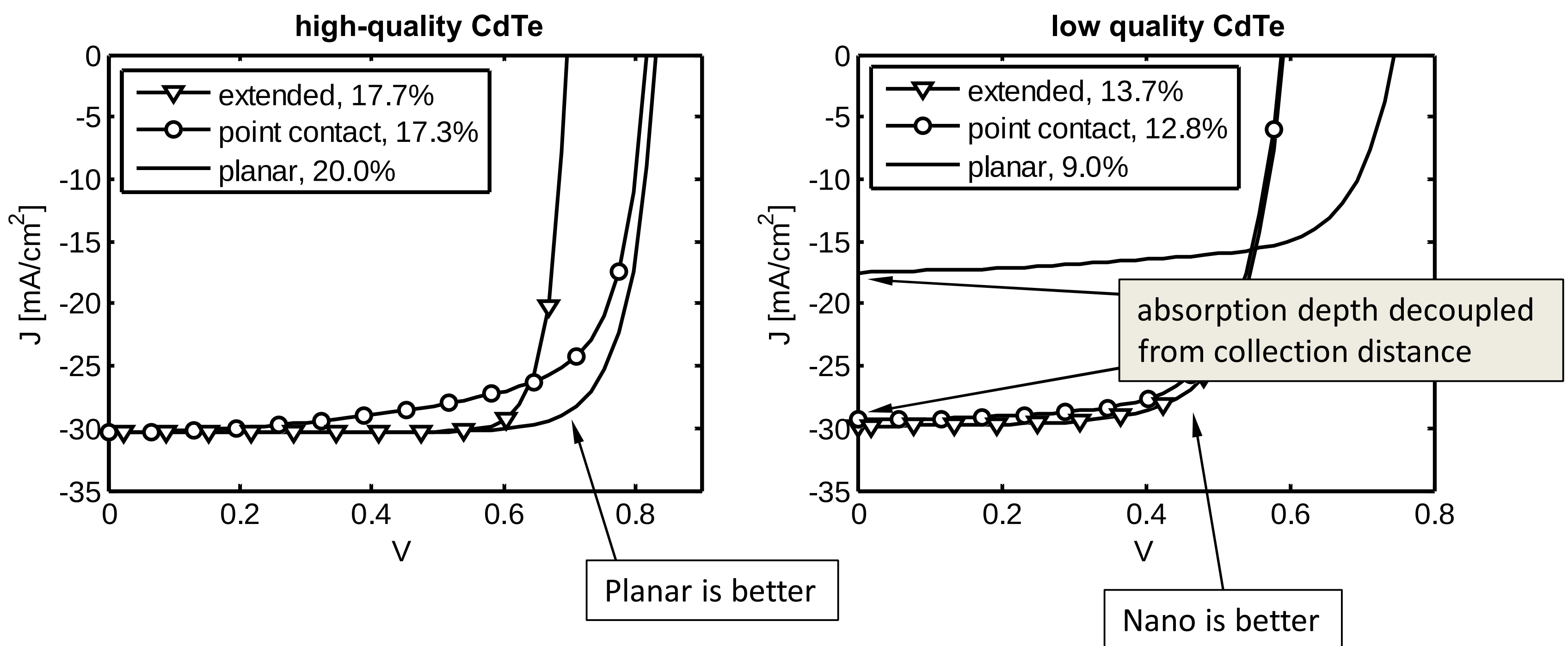
$$\varphi_1(r=a,z)=\varphi_2(r=a,z)$$

$$\left.\frac{\partial \varphi_1}{\partial r}\right|_{r=a}=\left.\frac{\partial \varphi_2}{\partial r}\right|_{r=a}$$

CdTe/CdS devices, high vs. low

Property	High	Low	
Acceptor doping, N_a (cm^{-3})	$2x10^{14}$	$1x10^{17}$	higher doping
Electron mobility, μ_n (cm^2/Vs)	320	100	lower mobility
Electron lifetime, τ_n (ns)	1	$1x10^{-2}$	lower lifetime
Diffusion length, L_n (μm)	0.910	0.050	lower diffusion length

ÅZ. Fan, *et al.*, *Nature Mater.* 8, 648 (2009).
ÅR. Kapadia, *et al.*, *Appl. Phys. Lett.* 96, 103116 (2010).
ÅS. Adachi, Properties of Group-IV, III-V and II-VI Semiconductors, *Wiley*, West Sussex, England (2005).
ÅM. Gleockler, *et al.*, Numerical modeling of CIGS and CdTe solar cells: setting the baseline, *Proc. World Conf. Photov. Energy Conv.*, 3, 491 (2004).



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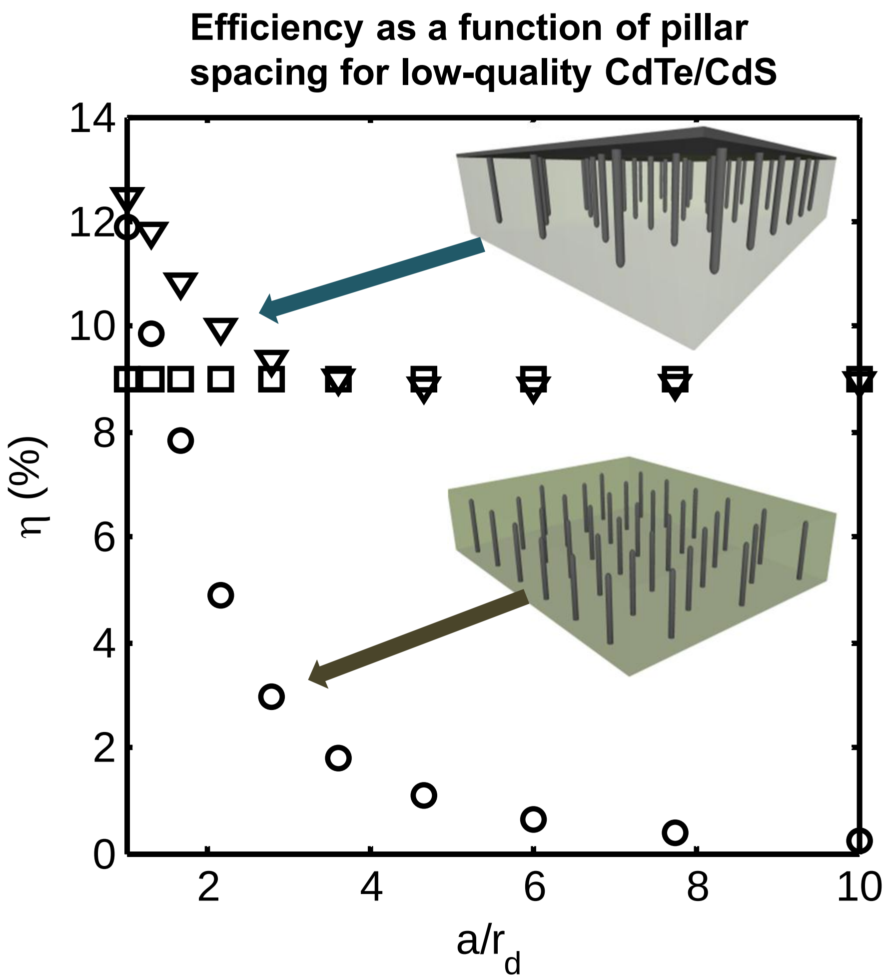
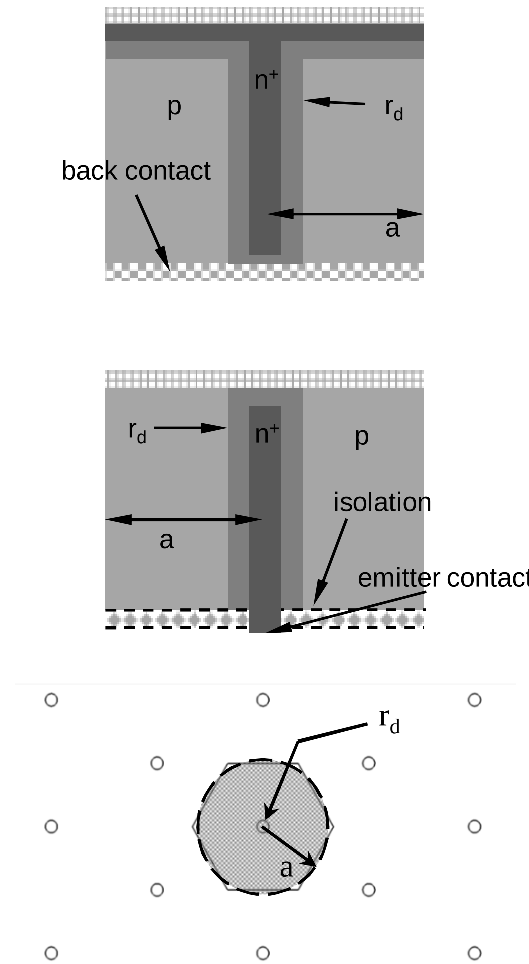
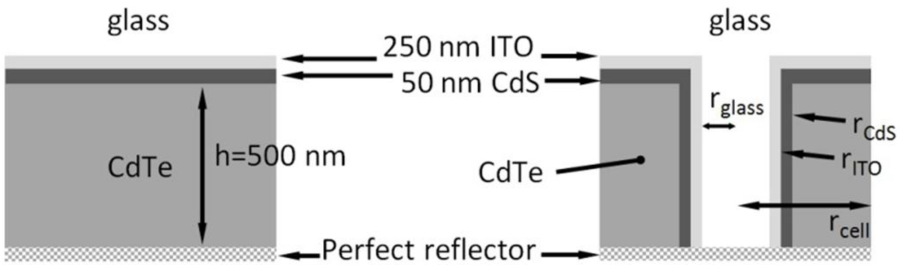
Extended device most robust

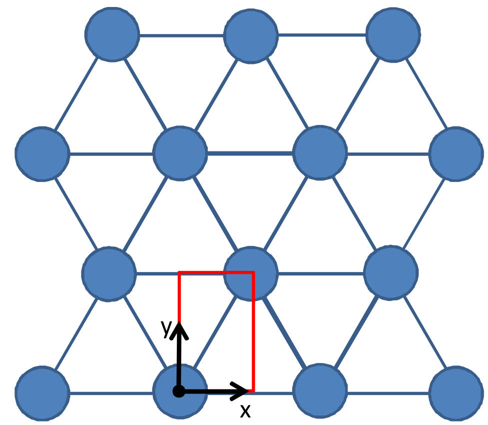


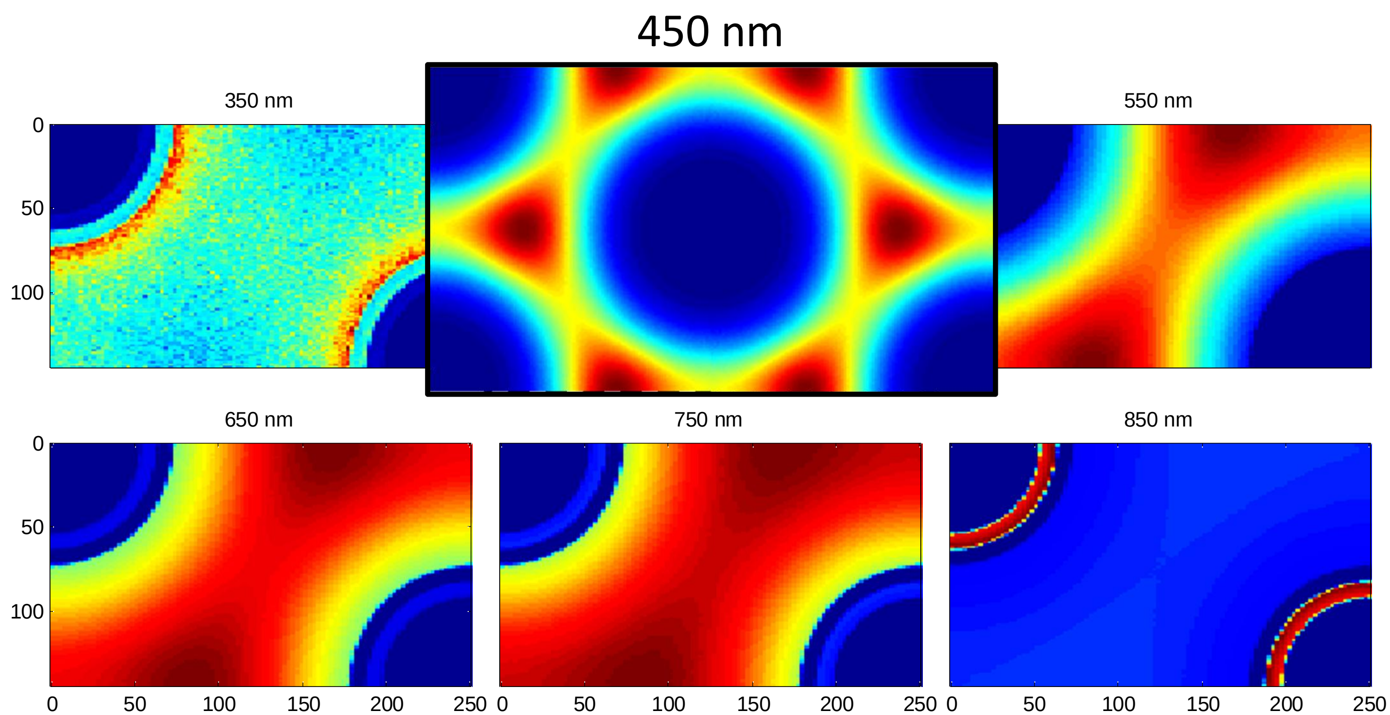


A. Wangperawong, S.F. Bent, *Appl. Phys. Lett.* **98**, 233106 (2011).

Absorption in CdTe/CdS/ITO/SLG







Conclusion

- We developed an analytical model for
  - diffusion in 3-D, interdigitated nanojunctions
  - both point-contact and extended architectures
  - any system involving diffusion, e.g. PEC, PV, etc.
- Nanojunctions can
  - decouple absorption depth from collection distance
  - improve performance of low quality PV absorbers, making use of inexpensive materials
- Modeling valuable for choosing the right nano-architecture
  - the efficiency of the extended nanojunction geometry is superior to other designs considered
  - point-contact nanojunction, isolated radial nanojunction, planar
- Various geometries and materials systems can be further explored
  - there could be an even better design out there

Acknowledgements

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Center on Nanostructuring
for Efficient Energy Conversion

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cneec.stanford.edu
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Questions?