Comparison of Novel 3D Nanoarchitectures for Solar Cells

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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

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

Experimental interdigitated devices

2. Point-contact nanojunctions

3. Extended nanojunctions


Limited 3D modeling work reported thus far

- Only on isolated radial junctions, i.e. nanowires.
- Interdigitated design ≠ isolated radial junctions.
- 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:

\[
\frac{1}{r} \frac{\partial}{\partial r} \left( r \frac{\partial \phi_m}{\partial r} \right) + \frac{\partial^2 \phi_m}{\partial z^2} - \frac{1}{L^2_m} \phi_m = 0 \quad m = 1, 2
\]

2. Extended nanojunctions

Boundary conditions due to continuity:

\[
\phi_1(r = a, z) = \phi_2(r = a, z)
\]

\[
\frac{\partial \phi_1}{\partial r} \bigg|_{r=a} = \frac{\partial \phi_2}{\partial r} \bigg|_{r=a}
\]

More details 2pm 15A
CdTe/CdS devices, high vs. low

<table>
<thead>
<tr>
<th>Property</th>
<th>High</th>
<th>Low</th>
</tr>
</thead>
<tbody>
<tr>
<td>Acceptor doping, ( N_a ) (cm(^{-3}))</td>
<td>2x10(^{14})</td>
<td>1x10(^{17})</td>
</tr>
<tr>
<td>Electron mobility, ( \mu_n ) (cm(^2)/Vs)</td>
<td>320</td>
<td>100</td>
</tr>
<tr>
<td>Electron lifetime, ( \tau_n ) (ns)</td>
<td>1</td>
<td>1x10(^{-2})</td>
</tr>
<tr>
<td>Diffusion length, ( L_n ) (µm)</td>
<td>0.910</td>
<td>0.050</td>
</tr>
</tbody>
</table>

higher doping
lower mobility
lower lifetime
lower diffusion length

Planar is better
Nano is better


Planar is better
Nanowires are better
Extended device most robust

Efficiency as a function of pillar spacing for low-quality CdTe/CdS

Absorption in CdTe/CdS/ITO/SLG

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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
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Questions?