2008 Solar Annual Review Meeting

Session: CPV
Company or Organization: University of Delaware
Funding Opportunity: High Performance PV

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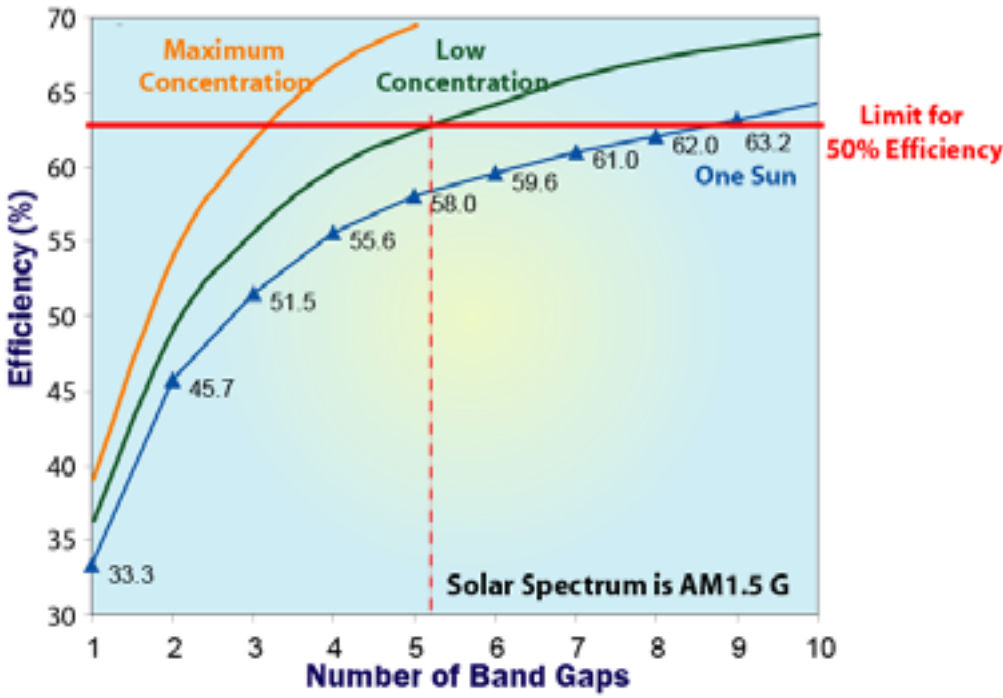
Overview: High Performance PV

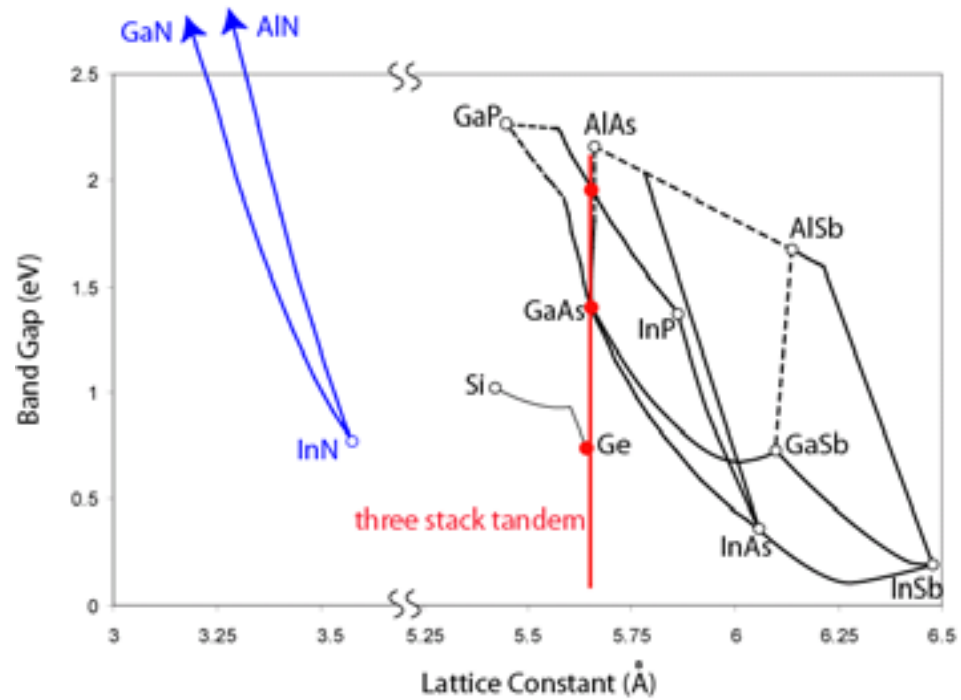
- Reaching thermodynamic limits requires:
  - Concentration
  - Large number of materials with specified Eg
  - Advanced PV
- Approaches >50%
  - New materials: InGaN
  - Multiple transition/ “intermediate band” approaches



Project Overview: III-nitride solar cells

- Monolithic multiple junction cells tied to material band gaps
- Existing tandems limited by lattice matching & direct Eg < 2 eV
- III-nitride system has direct band gap materials from 0.67 eV to 3.4 eV
- Challenges:
  - Material quality
  - Device design/ inclusion of polarization
  - P-type doping

E_1	E_2	E_3	E_4	E_5	E_6	E_7	E_8	$\eta(\%)$
0.70	1.01	1.33	1.67	2.14	-	-	-	57.61
0.69	0.96	1.20	1.47	1.79	2.24	-	-	59.41
0.69	0.93	1.14	1.37	1.60	1.90	2.33	-	60.78
0.51	0.75	0.98	1.18	1.40	1.63	1.92	2.35	61.42



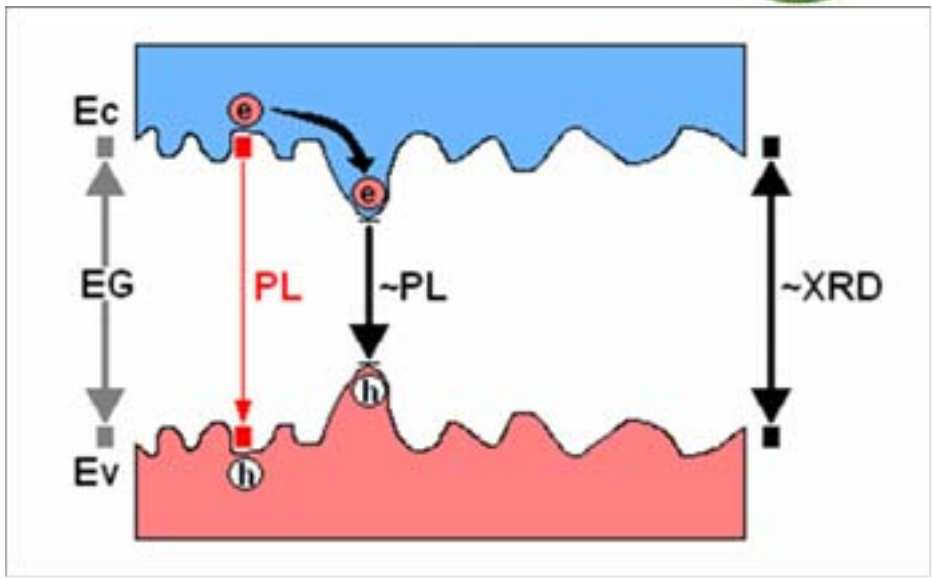
Budget

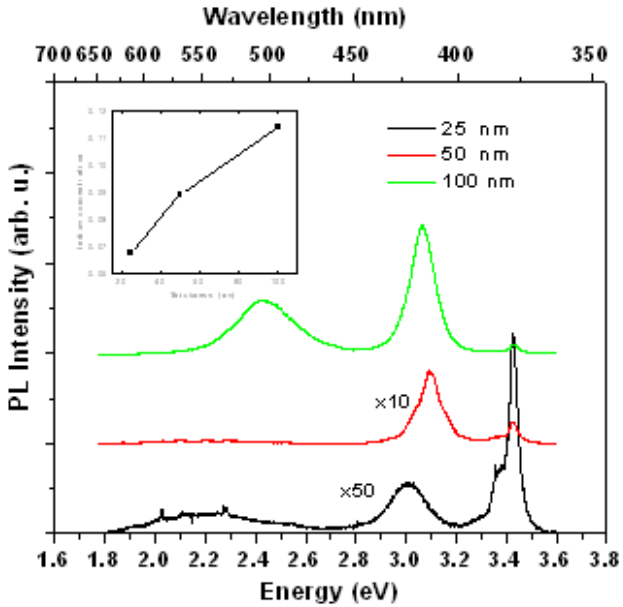
Company or Organization			
Project Beginning Date	**FY07 Budget**	**FY08 Budget**	**Total Budget**
10/1/2006	$0.161 million	$0.086 million	$0.36 million

- This project supports the Roadmap:
  - Developing approaches to high efficiency (48%) concentrator solar cells

III-nitride solar cells: Material Quality

- Phase separation introduces low Eg recombination path
  - Voltage controlled by low Eg region (seen by PL)
  - Current controlled by non-phase separated region.
- Phase separation minimized by optimization of growth conditions, control of growth rate, and using thi`n layers
- MBE and MOCVD grown layers of InGaN with Eg = 2.6 eV with minimal ph`ase separation.

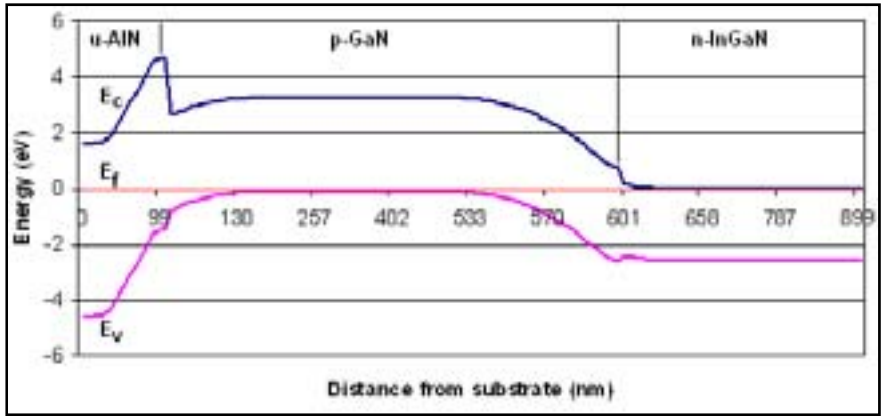




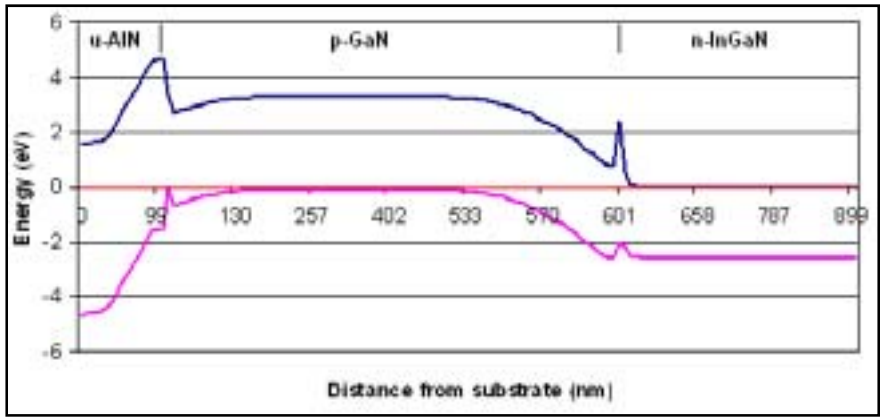
III-nitride solar cells: Modeling

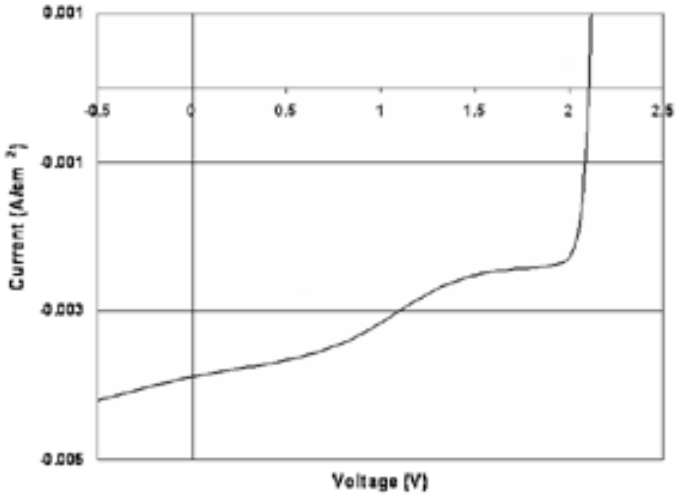
- InGaN has strong polarization and piezoelectric effect.
- Introduces additional electric fields at interfaces.
- Modified PC1D to take into account polarization effects.
- Can be beneficial or detrimental
- Changes device design rules

Without polarization



With polarization

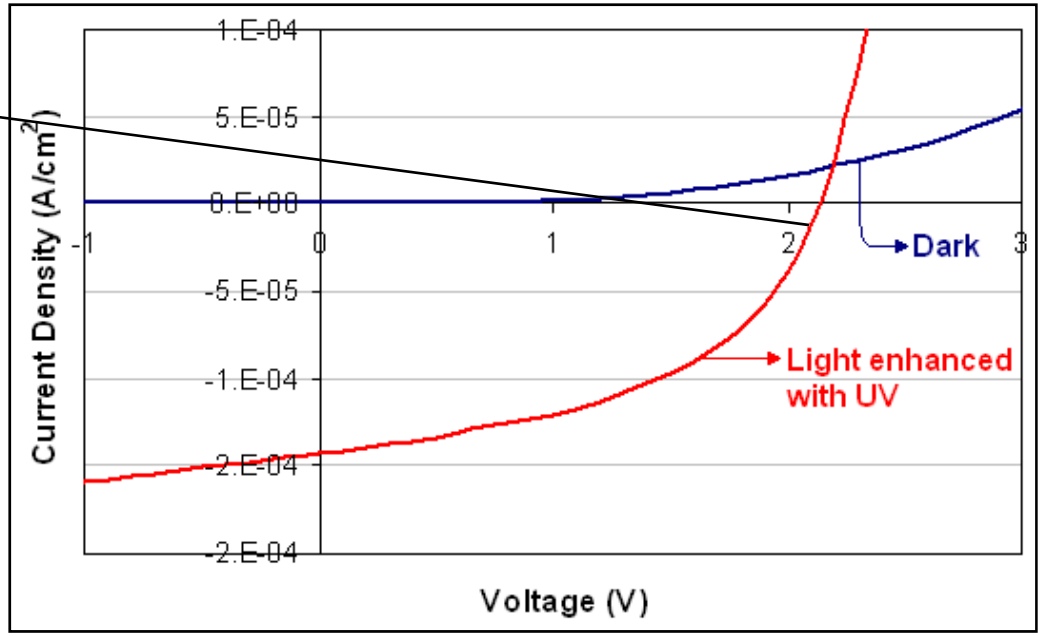




III-nitride solar cells: Device Results

- Optimization of material, thickness, polarization allowed high open circuit solar cells with band gap of 2.5 eV

V_{OC} = 2.1V

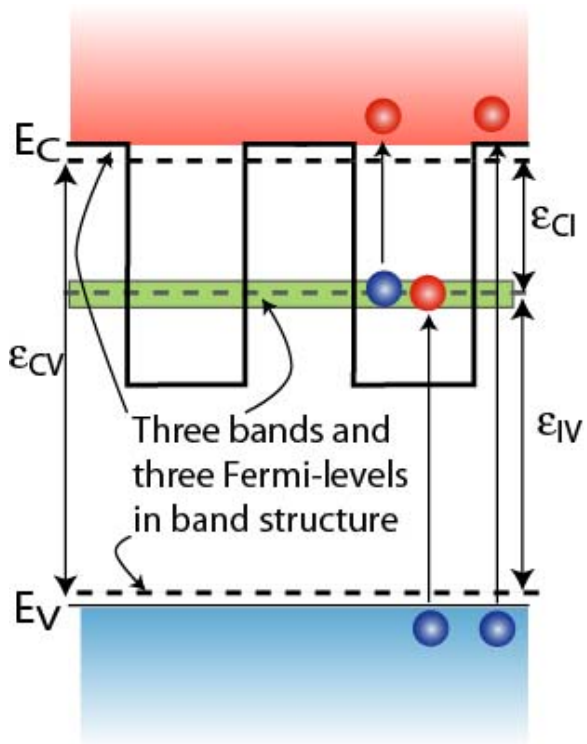


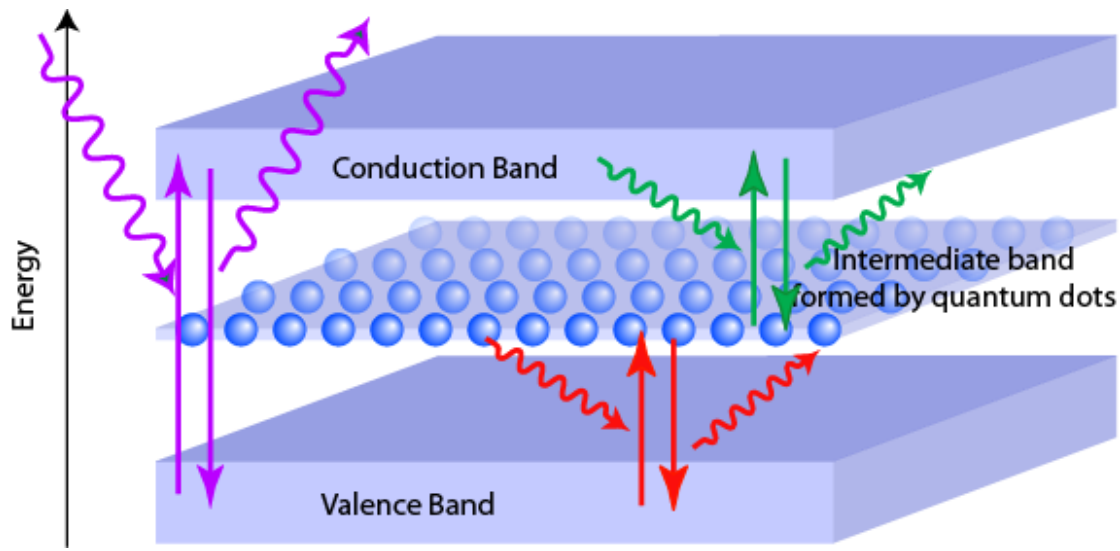
- Thin test structures: 100nm
  - **Strong photovoltaic effect**.
  - Band gap: **2.5eV**
  - V_{OC} → 2.1V; corresponds to E_G – 0.4.

Project Overview: Multiple transition solar cells

Requirements:

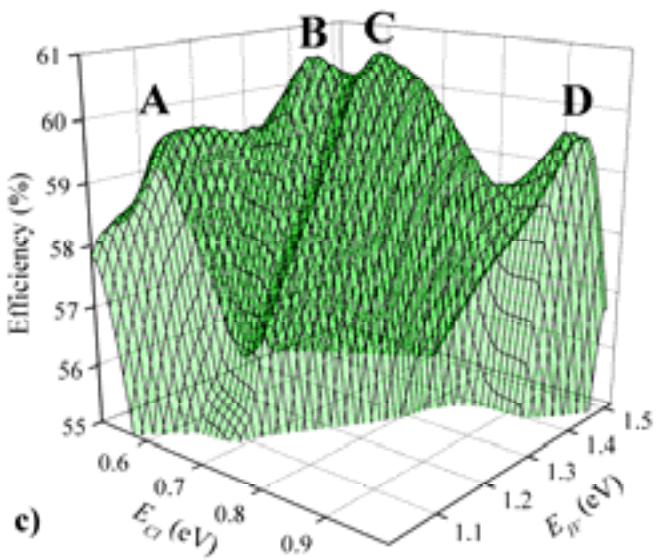
1. Three (or more) carrier populations in steady state that are not in thermal equilibrium with each other
2. Absorption/emission rates which of similar magnitude for all processes

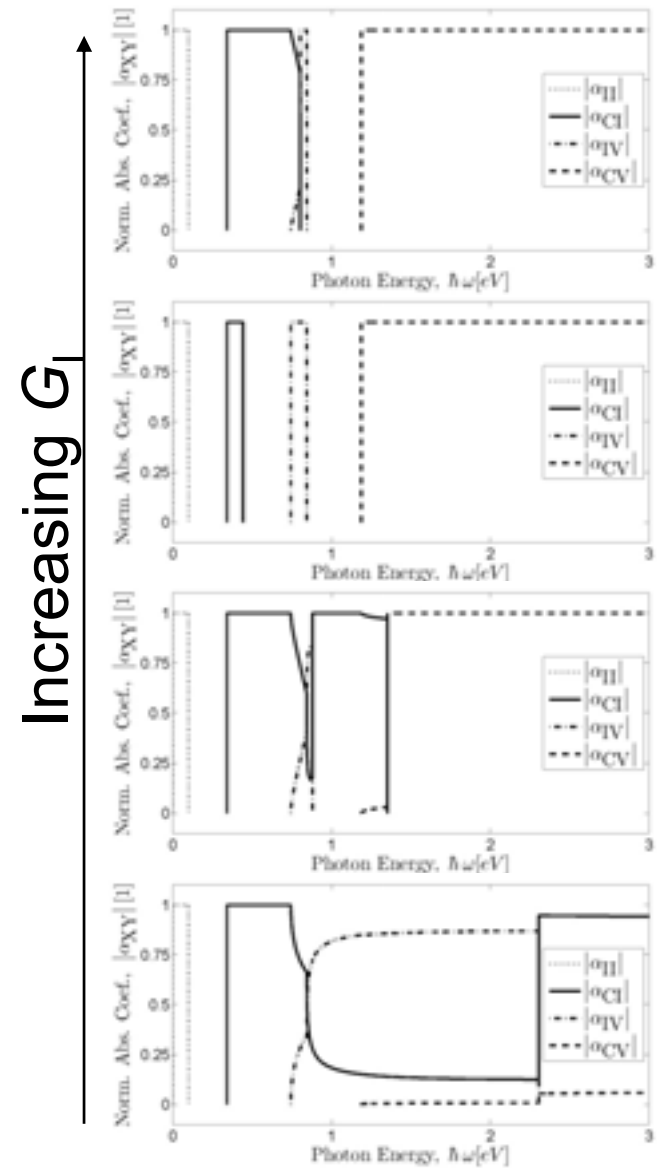




Advanced Concept: Design Rules

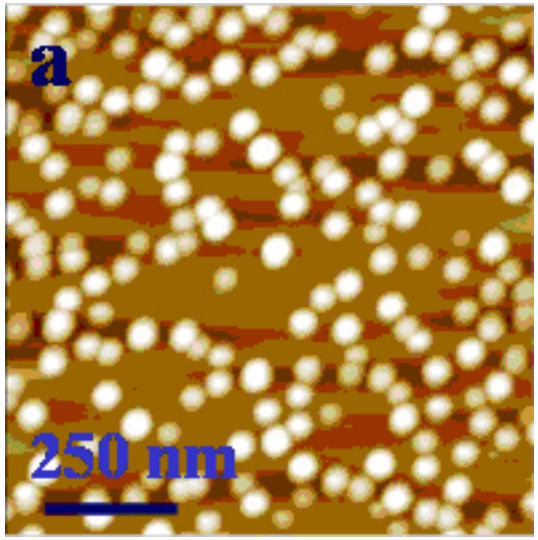
- Wide flexibility in “band gaps” dependent of concentration and spectrum
- IB band width minor effect on efficiency
- Density of states critical in absorption and efficiency



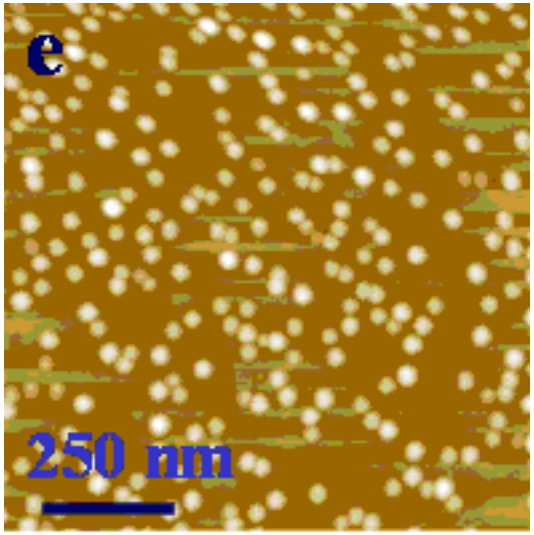


Advanced Concept: GaAsSb/InAs QDs

- No valence band offset, close to ideal band gaps
- Kp modeling confirms low ΔEv, but also lower ΔEc
- InAs QDs grown on 12-20% GaAsSb with low defect densities
- Increasing Sb composition decreases QD size and increases QD density



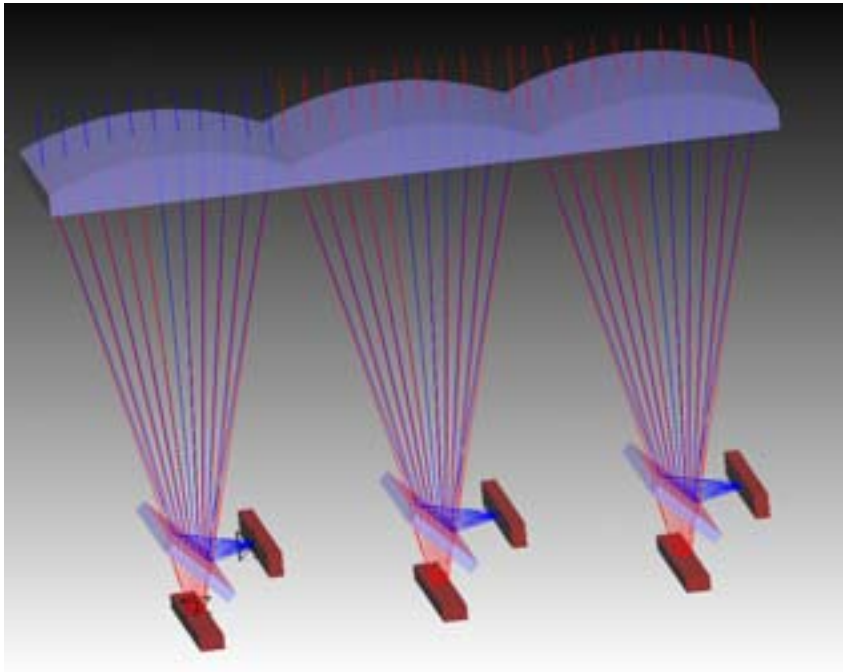
InAs QDs on GaAs



InAs QDs on GaAs (5 ML) / $GaAs_{1-x}Sb_x$ (5nm) buffer layers with x = 23%, with density 2.6×10^6 cm^{-2}

Very High Efficiency Photovoltaic Modules

- Co-design and integration of optical components and solar cells
- Allows >40% low concentration photovoltaic modules

6-junction solar cell at 20X

6J Solar Cell Band Gaps	Thermodynamic efficiency	De-rating factor	Ideal target efficiency
High Eg 2.4 eV	14.9%	0.89	13.3%
GaInP 1.84 eV	16.6%	0.86	14.3%
GaAs 1.43 eV	13.9%	0.84	11.7%
Si 1.12 eV	9.7%	0.80	7.8%
0.95 eV	5.0%	0.74	3.7%
0.70 eV	4.1%	0.70	2.9%
	Total $\eta = 64.2\%$		**Total $\eta = 53.5\%$**