Monolithic, Ultra-Thin GaInP/GaAs/GaIn s Tandem Solar Cells

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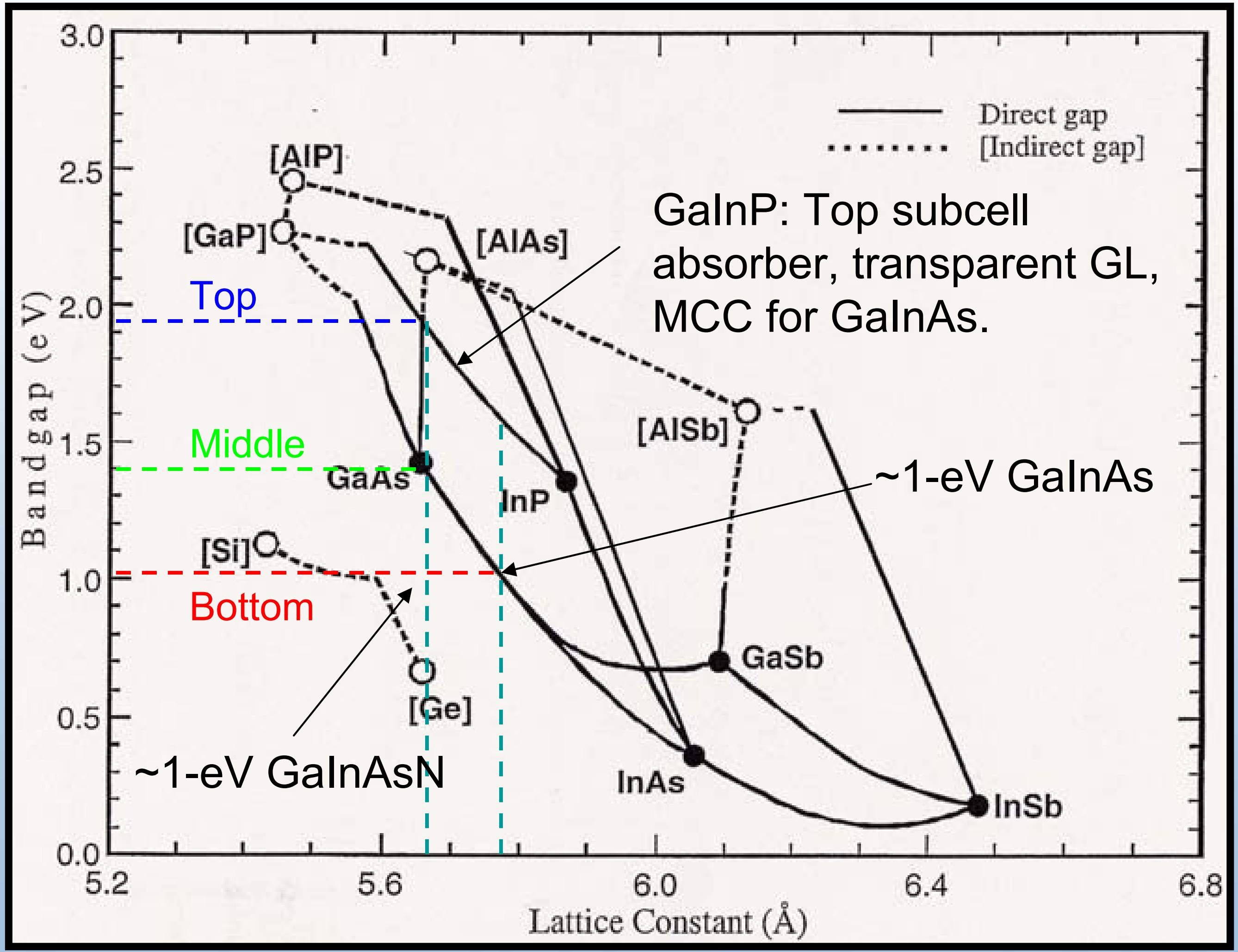
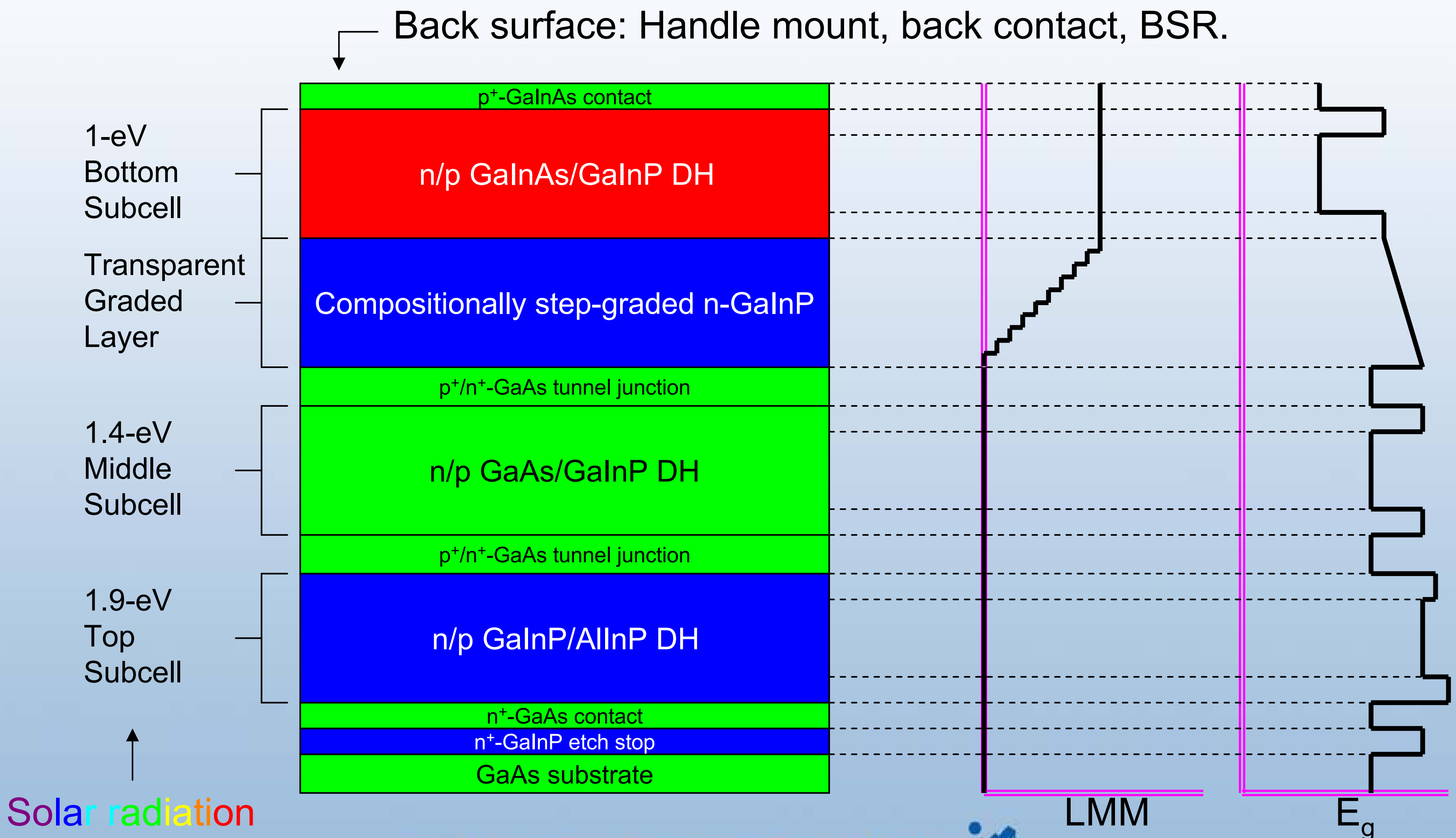
Monolithic, Ultra-Thin GaInP/GaAs/GaInAs Tandem Solar Cells

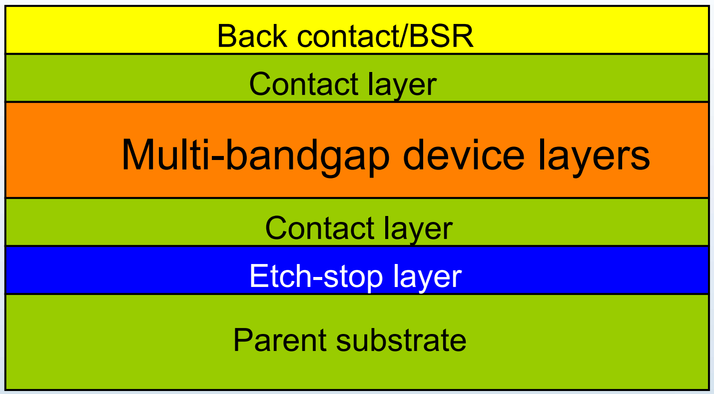
- NREL IR # 05-05, patent pending.
- Near-optimum subcell bandgaps.
- ~300 mV voltage output boost compared to conventional Ge-based triple-junction tandems.
- Bottom subcell E_g is variable.
- Basic approach is expandable to 4-6 subcells.



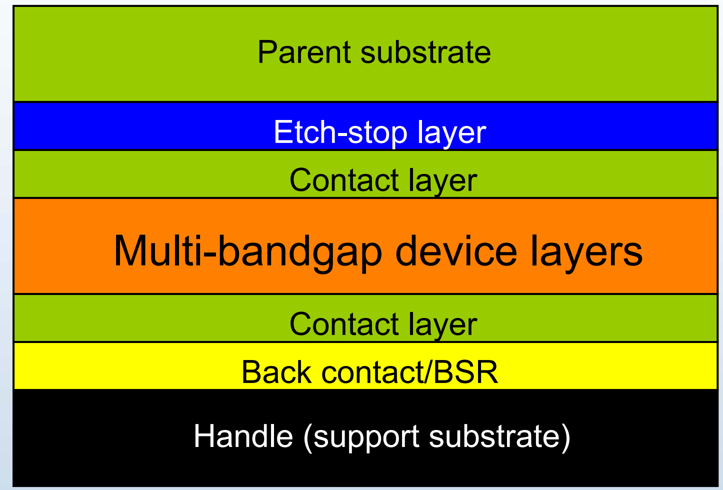
Inverted GaInP/GaAs/GaInAs Tandem Structure



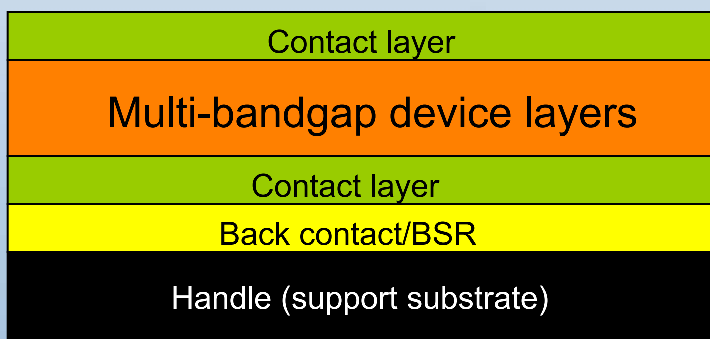
Ultra-thin Tandem Cell Processing Sequence



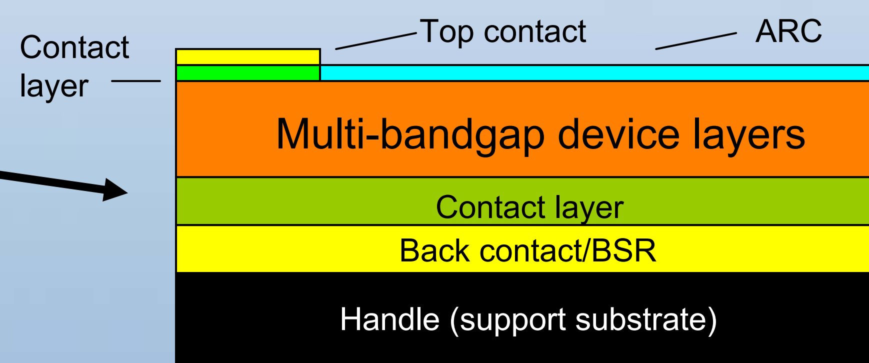
1) Inverted tandem structure is grown on the parent substrate, and the back contact/BSR is formed.



2) Epistructure is mounted upside down on a handle material (secondary support substrate).



3) Parent substrate is removed.



4) Front-surface processing is completed.

Advantages of Ultra-Thin, Handle-Mounted Tandem Solar Cells

- Handle material can be engineered to have a wide range of advantageous characteristics.
- Thermal management can be optimized.
- Highest specific power (W/kg) for space applications.
- Reuse and/or reclamation of the parent substrate also possible, reducing cost.
- Parent substrate can be impure to reduce cost.
- Benefits of BSR: thin GaInAs subcell, lower J_0, improved radiation hardness, reduced operating temperature.

Semi-Realistic Performance Modeling GaInP/GaAs/GaInAs

Low-AOD Direct Spectrum, 250 suns, 25°C
QE = 0.95, realistic $J_0(E_g)$, no parasitic losses

Subcell parameters

Subcell Absorber	E_g (eV)	V_{oc} (V)	J_{sc} (A/cm^2)	FF (%)
GaInP	1.87	1.53	3.40	91.57
GaAs	1.42	1.12	3.40	89.23
GaInAs	1.01	0.74	3.63	85.21

Series-connected tandem parameters

V_{oc} (V)	Jsc (A/cm^2)	FF (%)	V_{max} (V)	J_{max} (A/cm^2)	P_{max} (W/cm^2)
3.38	3.40	90.32	3.11	3.34	10.38

Tandem efficiency: 41.5%

Semi-Realistic Performance Modeling

Conditions
AM0, one sun, 25°C
QE = 0.95, Realistic $J_0(E_g)$

Tandem efficiency
~33% (one sun)
~36% (10 suns)

Subcell parameters

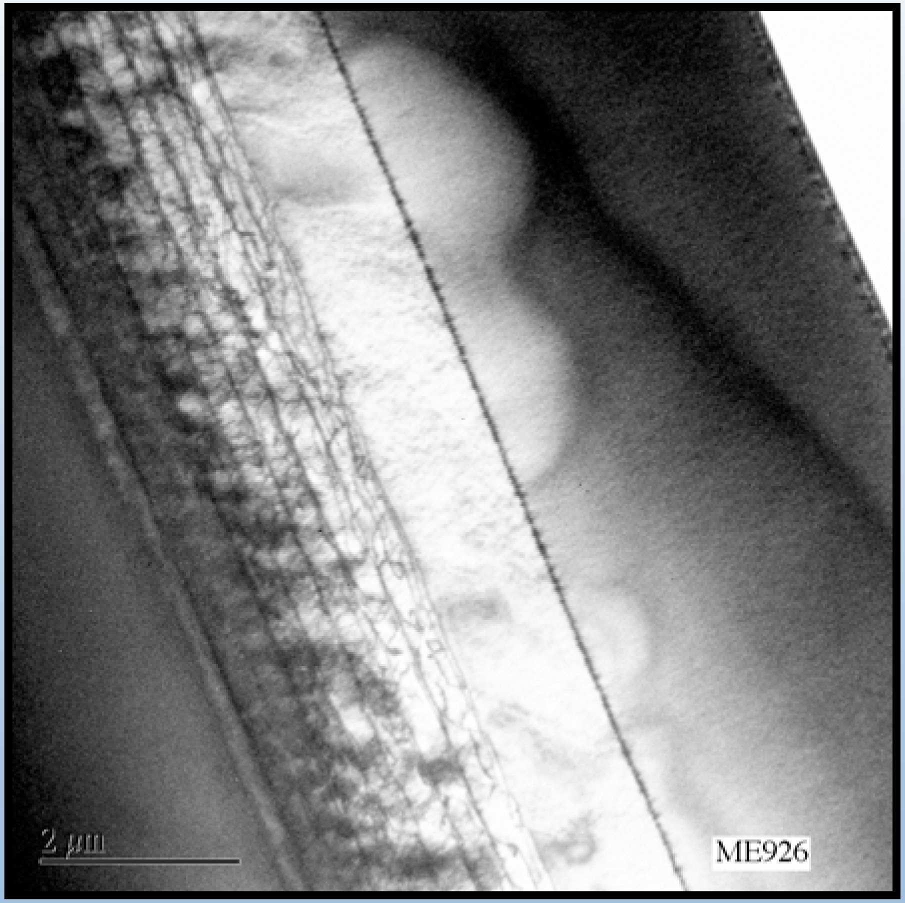
Subcell Absorber	E_g (eV)	V_{oc} (V)	J_{sc} (mA/cm^2)	FF (%)
GaInP	1.87	1.393	17.00	90.94
GaAs	1.42	0.981	17.00	88.09
GaInAs	1.02	0.608	18.13	83.01

Series-connected tandem parameters

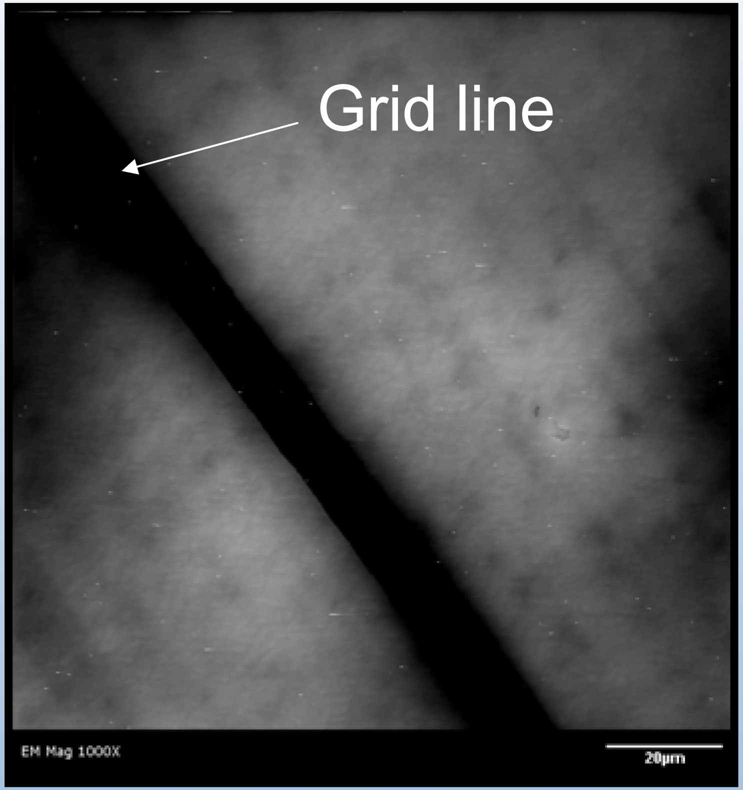
V_{oc} (V)	Jsc (mA/cm^2)	FF (%)	V_{max} (V)	J_{max} (mA/cm^2)	P_{max} (mW/cm^2)
2.98	17.00	89.27	2.72	16.65	45.26

Defects in LMM, ~1-eV GaInAs

XTEM



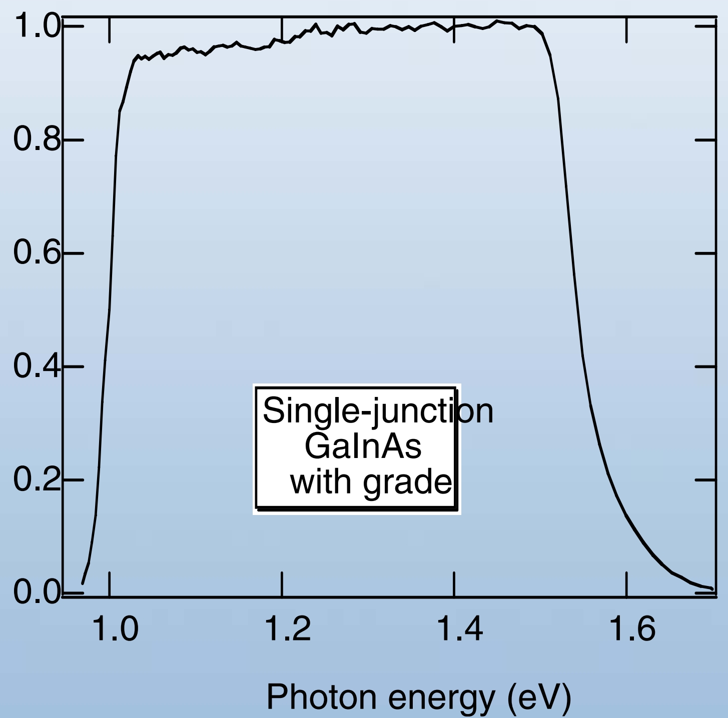
Plan-view CL



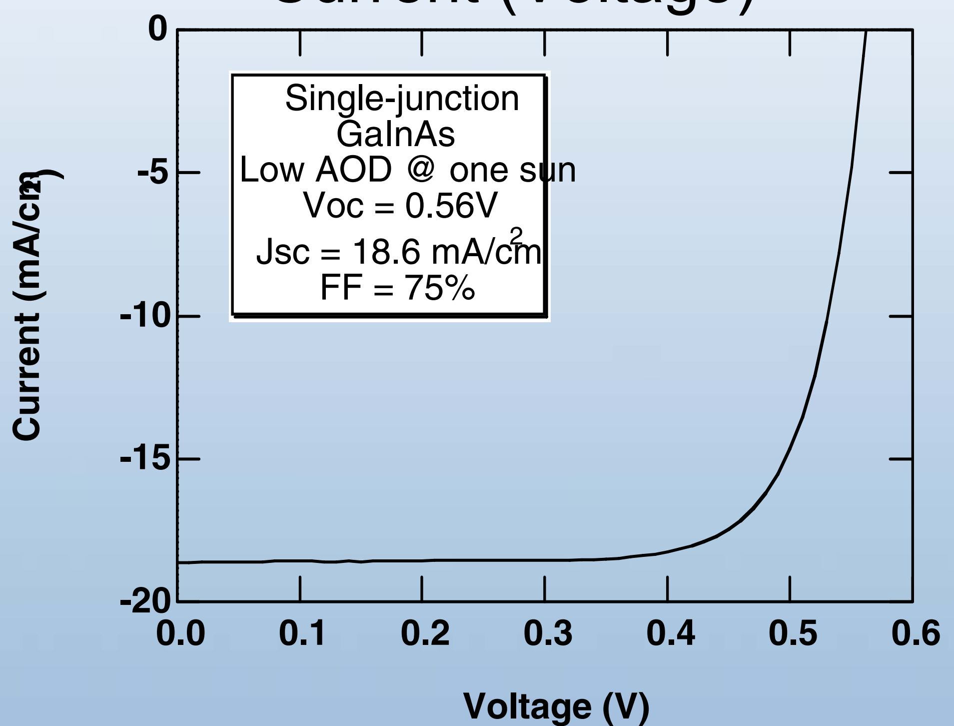
TD density ~ 2E6 cm^{-2}

~1-eV, LMM (2.2%) GaInAs/GaInP DH Cell Performance

Internal Quantum Efficiency

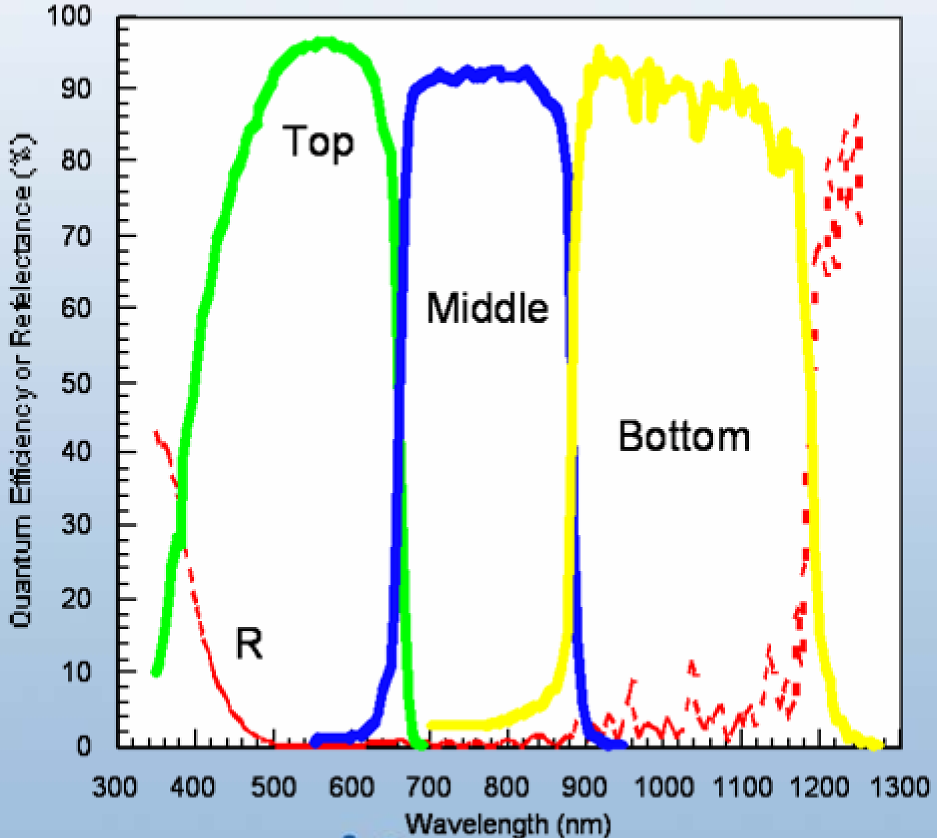


Current (Voltage)



Ultra-Thin, Handle-Mounted GaInP/GaAs/GaInAsTandem AEQE & R Data

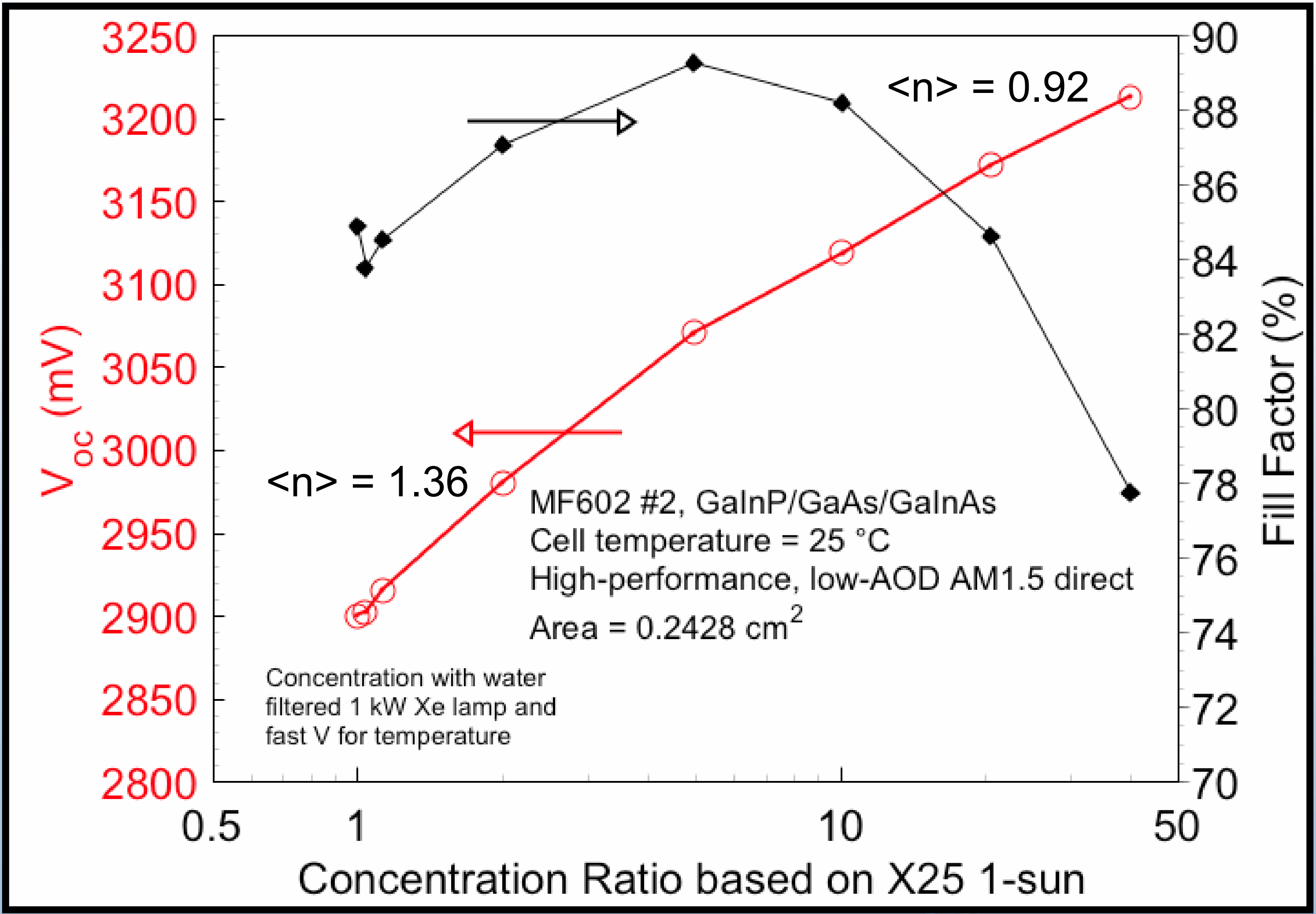
- QE is excellent for all subcells, but some improvement is still possible (reduce parasitic absorption and reflection).
- ZnS/MgF_2 ARC is not optimal.
- Interference evident in thin bottom subcell.



Reported Performance

PVSC	1/3-7/05	Global, 25°C	31.1%
SPW	4/18-21/05	AM0, 1 sun, 25°C	29.7%
ISCC	5/1-5/05	Direct, 10.1 suns, 25°C	37.9%
SPRAT	9/20-22/05	AM0, 1 sun, 25°C Kapton handle	26.5%
SPRAT	9/20-22/05	AM0, 8.9 suns, 25°C	31.4%

V_{oc}, FF (Concentration Ratio)



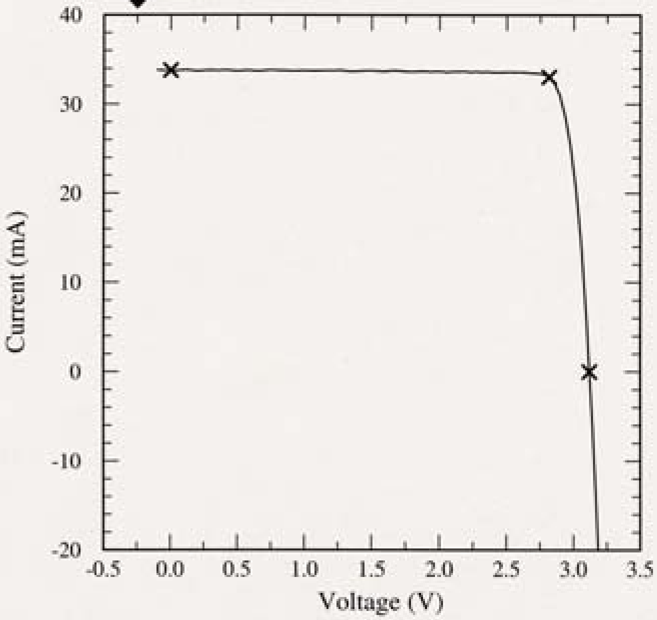
I-V Data at Peak Efficiency

- η = 37.9% (10.1 suns).
- On 4/25/05, a new record for solar PV conversion.
- With continued development, η > 40% possible at higher concentration ratios.

NREL
GaInP/GaAs/GaInAs Cell

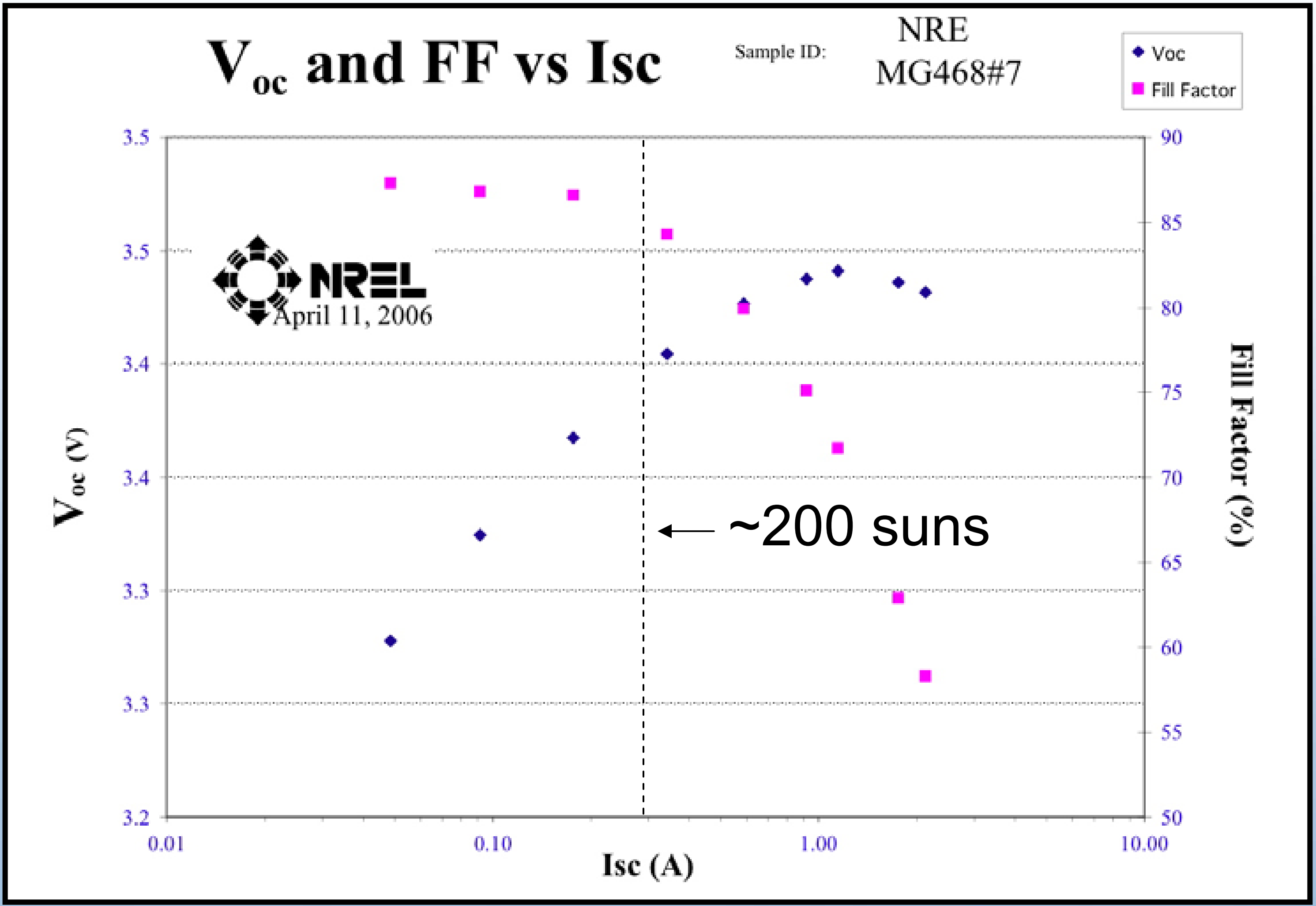
Device ID: MF602 #2	Device Temperature: 25.0 ± 1.0 °C
Apr 25, 2005 2:26 PM	Device Area: 0.2428 cm^2
Reporting Spectrum: AM1.5 Direct	Irradiance: 10109.1 W/m^2

NREL Concentrator IV System
PV Performance Characterization Team



V_{oc} = 3.1199 V	I_{max} = 33.04 mA
I_{sc} = 33.78 mA	V_{max} = 2.8146 V
J_{sc} = 0.1392 A/cm^2	P_{max} = 92.99 mW
Fill Factor = 88.22 %	Efficiency = 37.9±2.3 %

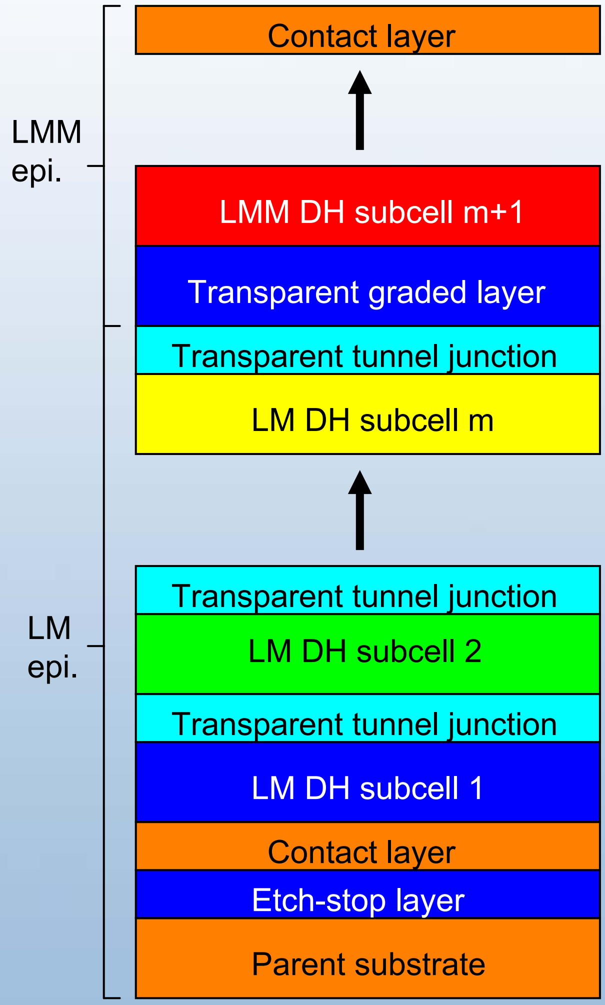
Recent progress



Research Issues

- High-yield processing of handle-mounted, ultra-thin devices.
- Develop process enabling reuse of parent substrate.
- Tandem cell efficiency testing more difficult w/ 1-eV subcell - even more difficult as we consider more than three subcells.
- Inverted tunnel junctions.
- Radiation effects.
- Push efficiency limits by including more subcells - can we achieve 40-50% (terr. conc.), 35-40% (AM0)?

Advanced Design Options



- Concept applies to two, or more, subcells.
- A wide range of substrates, subcell materials, tunnel junction materials, and transparent compositional grades are possible.
- Substrates: GaAs, Ge, Si, SiGe.
- Subcells, etc.: AlGaInPAsSb.

Legend:
LM = lattice matched.
LMM = lattice mismatched.
DH = double heterostructure.