A Direct Comparison of Inverted and Non-inverted Growths of GaInP Solar Cells

Myles Steiner, John Geisz, Robert Reedy Jr., Sarah Kurtz

33rd IEEE Photovoltaic Specialists Conference
San Diego, CA
May 13, 2008

NREL/PR-520-43289
Presented at the 33rd IEEE Photovoltaic Specialist Conference held May 11-16, 2008 in San Diego, California

Motivation

Growing inverted cells may enable technological advances in solar cell fabrication, leading to higher efficiencies.

Differences in dopant diffusion during inverted vs. upright growths may lead to:

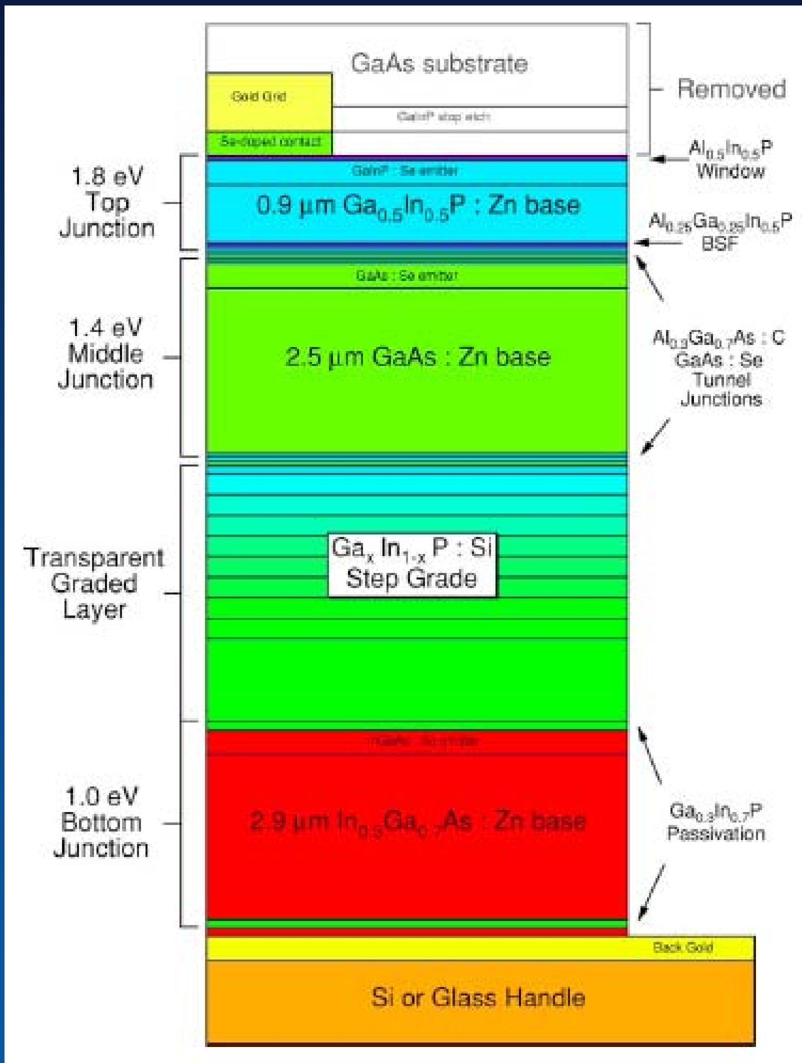
→ Differences in atomic depth profiles

→ Changes in carrier concentrations

→ Higher contact resistance

→ Lower overall performance

Inverted triple junction



Geisz *et al.*, APL **91**, 023502 (2007)

Geisz *et al.*, 33rd PVSC (2008)

1.0-eV lattice-mismatched InGaAs bottom subcell enables a higher total efficiency: 39.2% @131 suns.

Growing the bottom subcell last avoids threading the middle and top subcells with dislocations.

This talk…

Solar cell characteristics

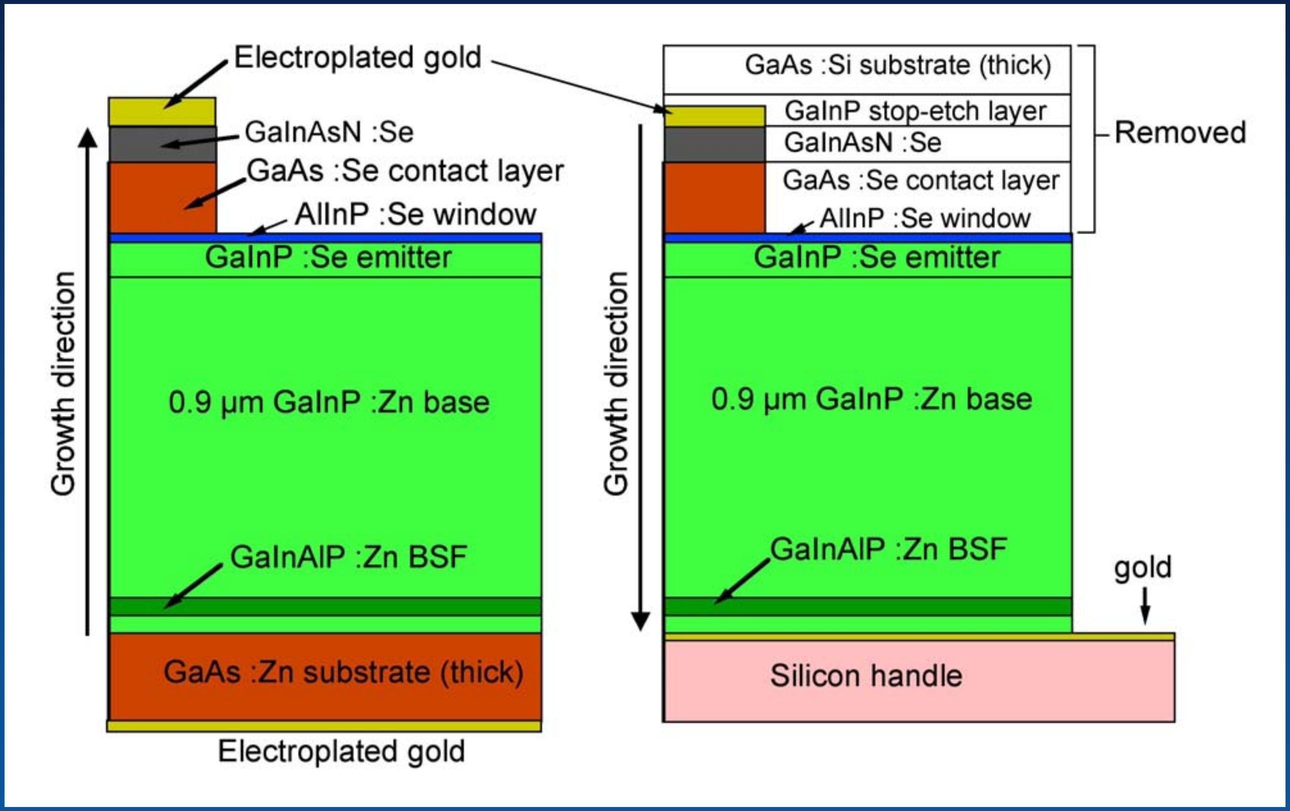
SIMS depth profiles analysis

Top contact resistance

Selenium diffusion in GaInAsN

Layer structures

Upright growth | Inverted growth

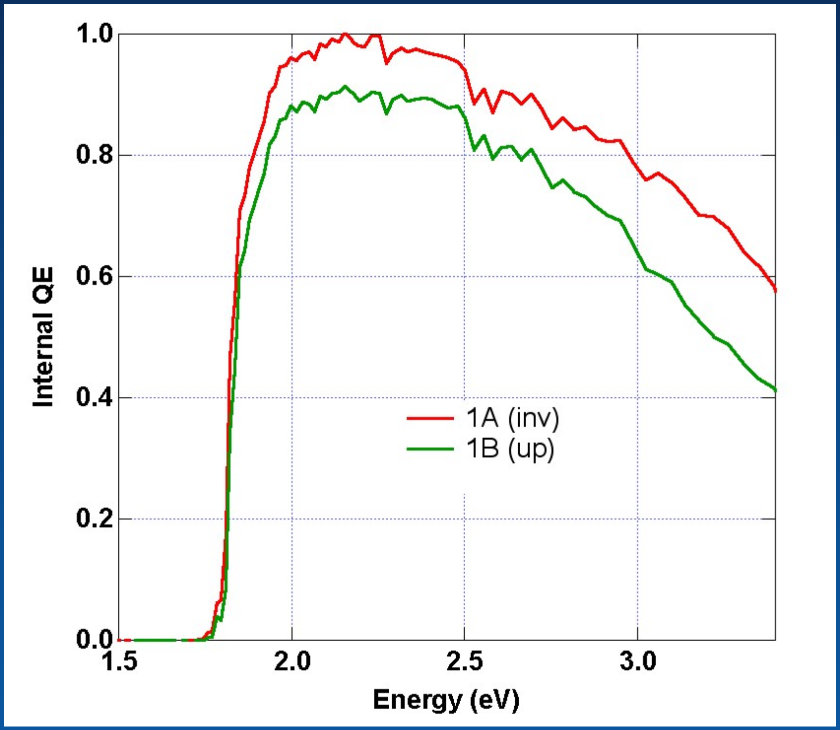


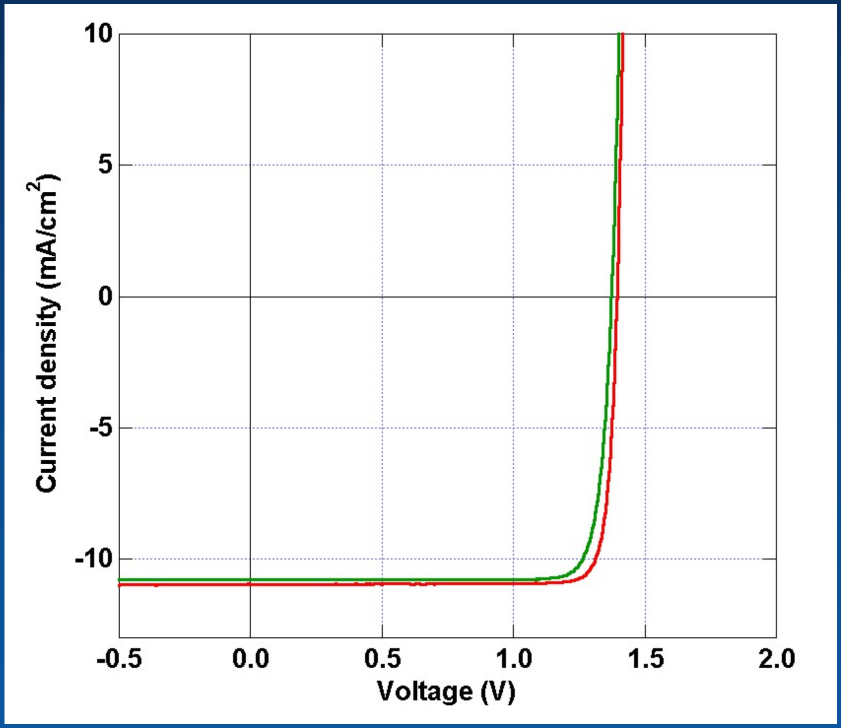
OMPVE
Atmospheric pressure
Vertical reactor

Precursors:
Trimethylgallium
Triethylgallium
Trimethlyindium
Trimethlyaluminum
Arsine
Phosphine
Dimethylhydrazine
Diethylzinc
Hydrogen selenide

Solar cell characteristics
(optimized for inverted growth)

		R_s (Ω/sqr)	R_c (mΩ-cm²)	Emitter (10^{18} cm^{-3})	Base (10^{16} cm^{-3})	Voc (V)	Jsc (mA/cm²)	FF (%)	Eff (%)
1A	inv	326	0.088	-3.2	1.4	1.395	10.97	88.3	13.5
1B	up	981	0.11	-0.98	0.34	1.372	10.79	86.8	12.9



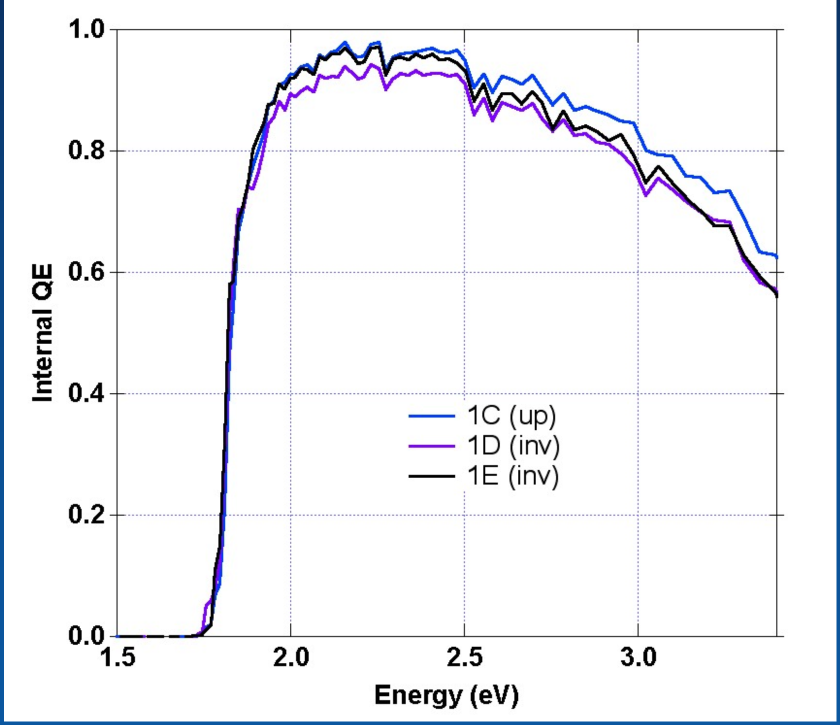


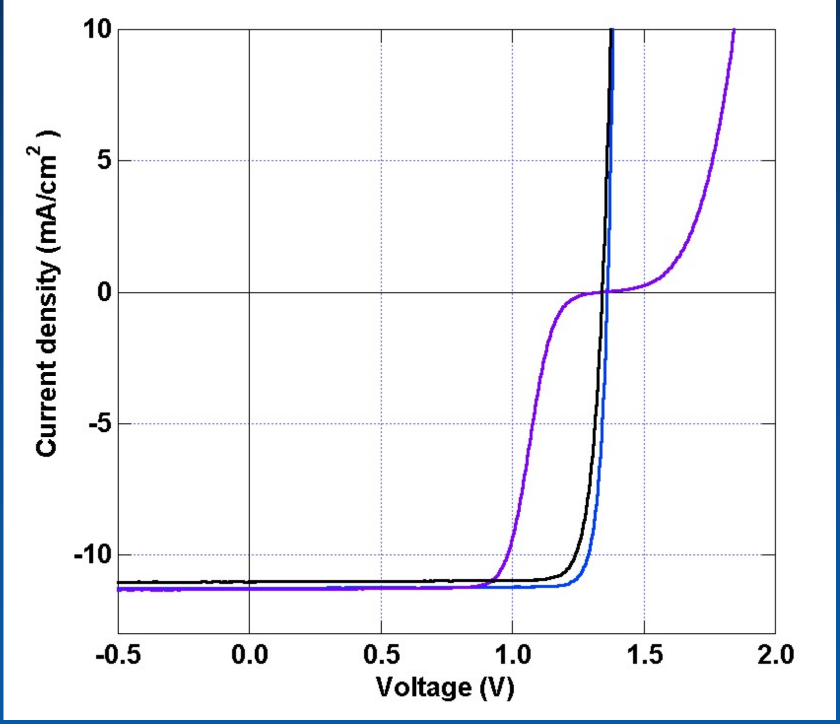
GaInAsN contacts for 1A and 1B

XT-10
GaInP reference cell calibrated for lowAOD

Solar cell characteristics
(optimized for upright growth)

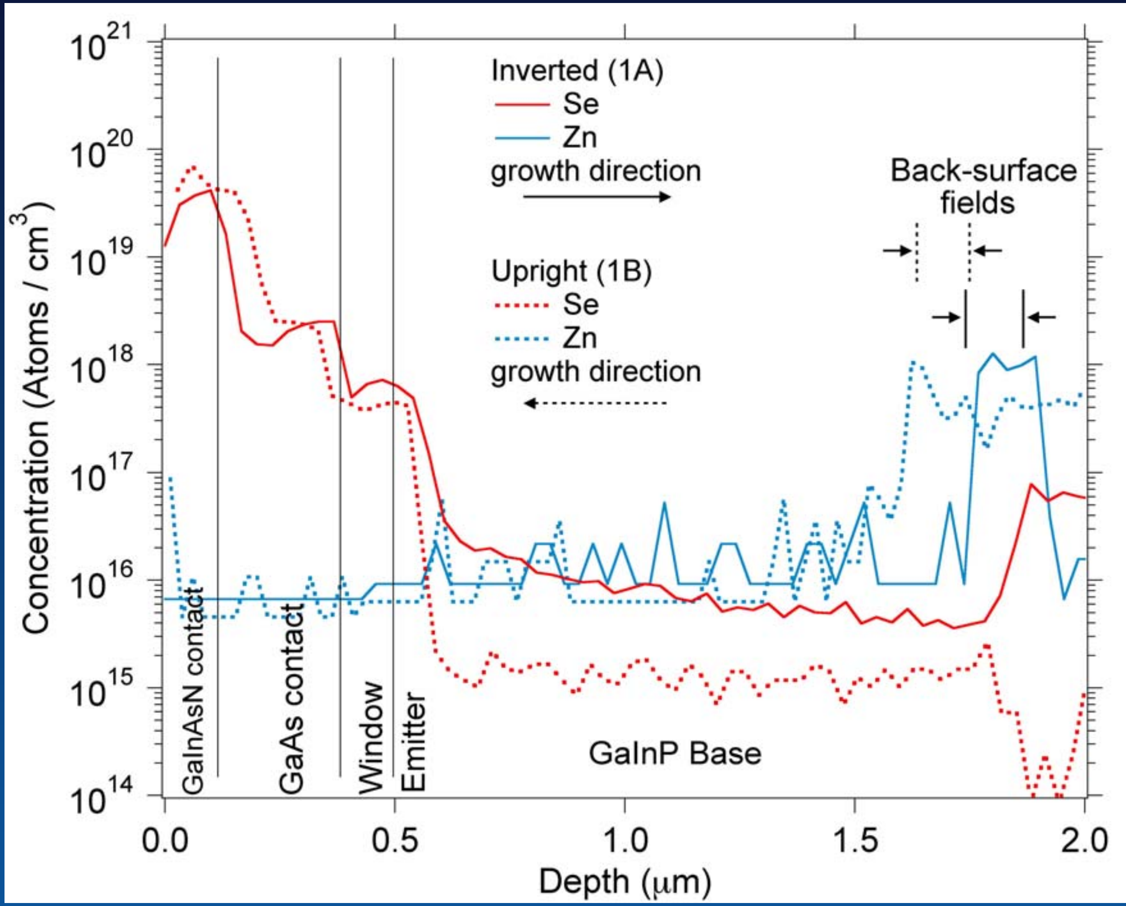
		R_s (Ω/sqr)	R_c (mΩ-cm²)	Emitter (10^{18} cm^{-3})	Base (10^{16} cm^{-3})	Voc (V)	Jsc (mA/cm²)	FF (%)	Eff (%)
1C	up	600	0.50	-1.7	9.1	1.361	11.27	88.6	13.6
1D	inv	--	--	--	4.5	1.306	11.31	68.7	10.2
1E	inv	516	0.22	-2.1	3.1	1.340	11.03	86.3	12.8





GaAs contacts for 1C and 1D; GaInAsN contacts for 1E

SIMS on inverted-upright pair (1A-1B)



Junction depth

Selenium tails

Zinc tails at BSF

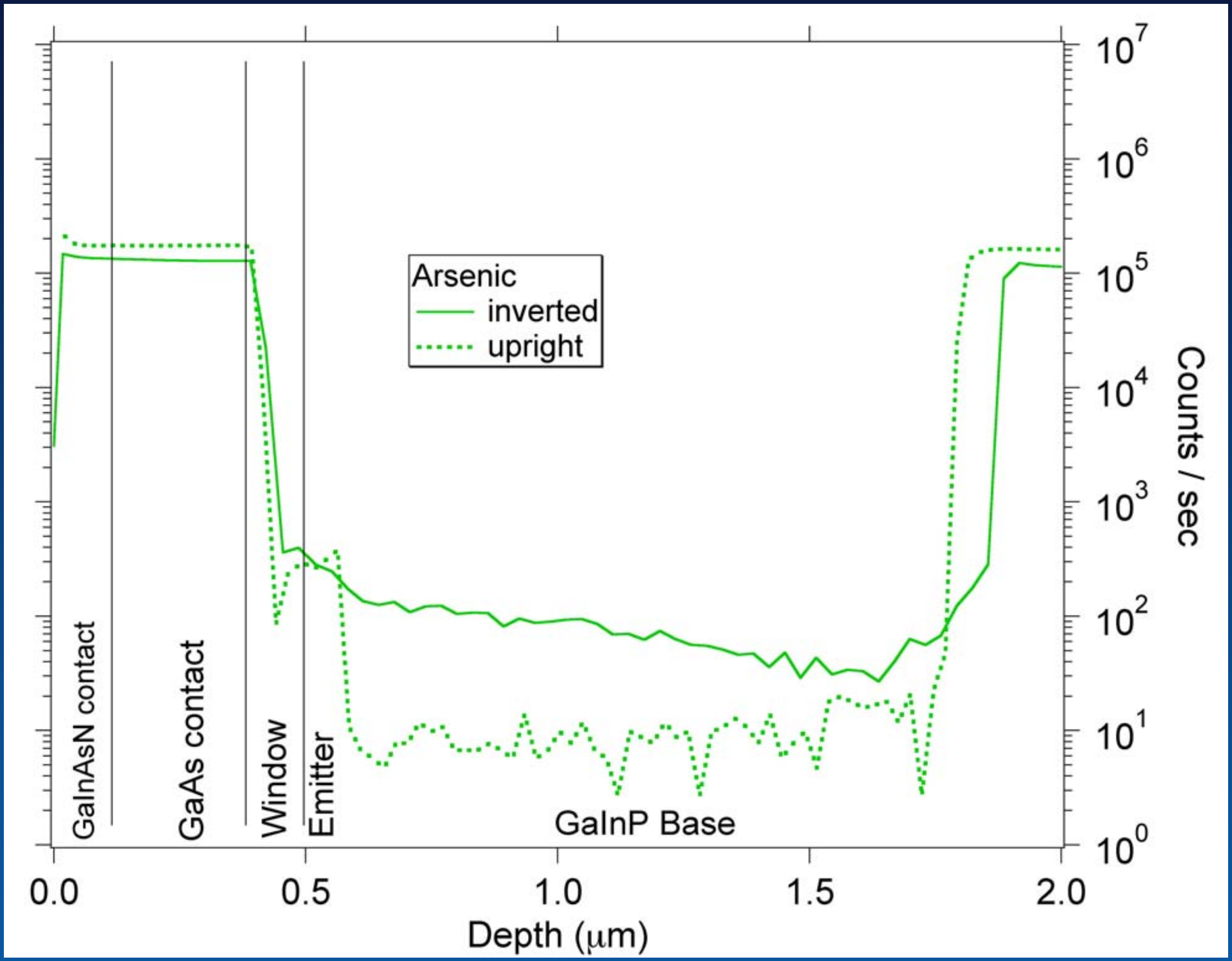
Window layer doping

Contact layer doping

Cell thickness

		R_s (Ω/sqr)	R_c (mΩ-cm^2)	Emitter (10^{18} cm^{-3})	Base (10^{16} cm^{-3})	Voc (V)	Jsc (mA/cm^2)	FF (%)	Eff (%)
1A	inv	326	0.088	-3.2	1.4	1.395	10.97	88.3	13.5
1B	up	981	0.11	-0.98	0.34	1.372	10.79	86.8	12.9

SIMS, cont'd (arsenic)

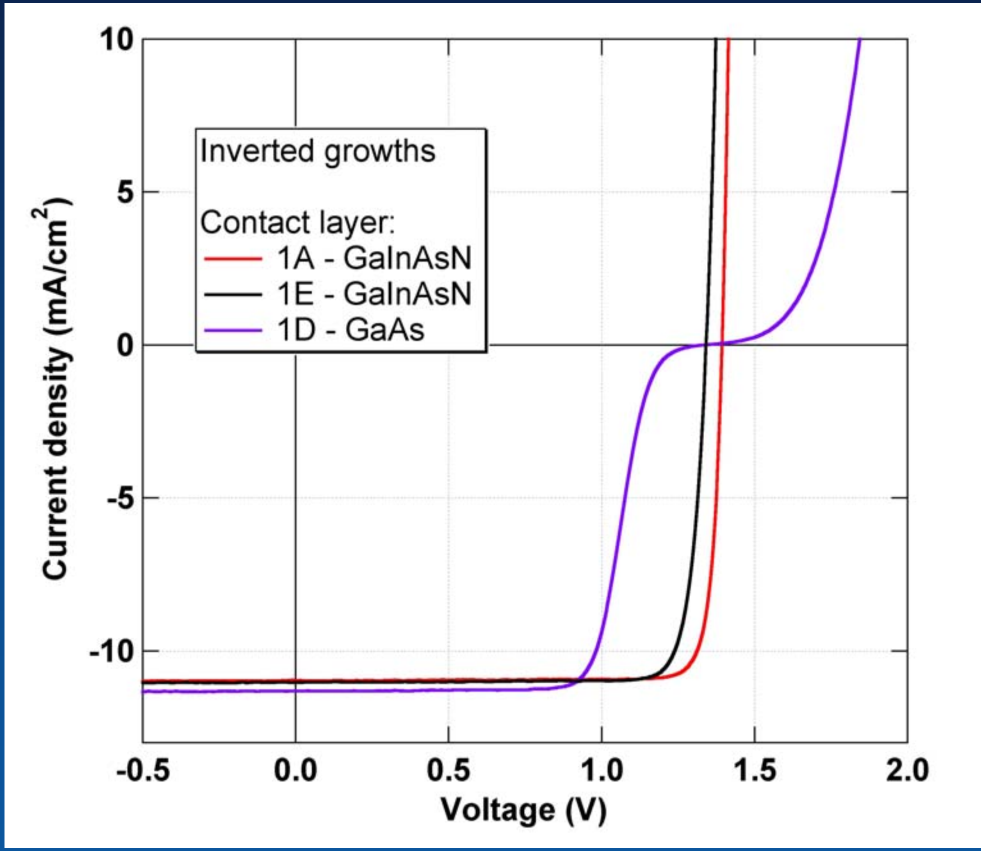


Long arsenic tail in the inverted cell

→memory effect in the growth reactor.

Effect of the top contact layer

JV curves for all inverted growths



Introducing N has been found to:

(1) lower the bandgap
(GaInAsN with ~1% N
has E_g ~ 1.1 eV)

→ Lower contact resistance

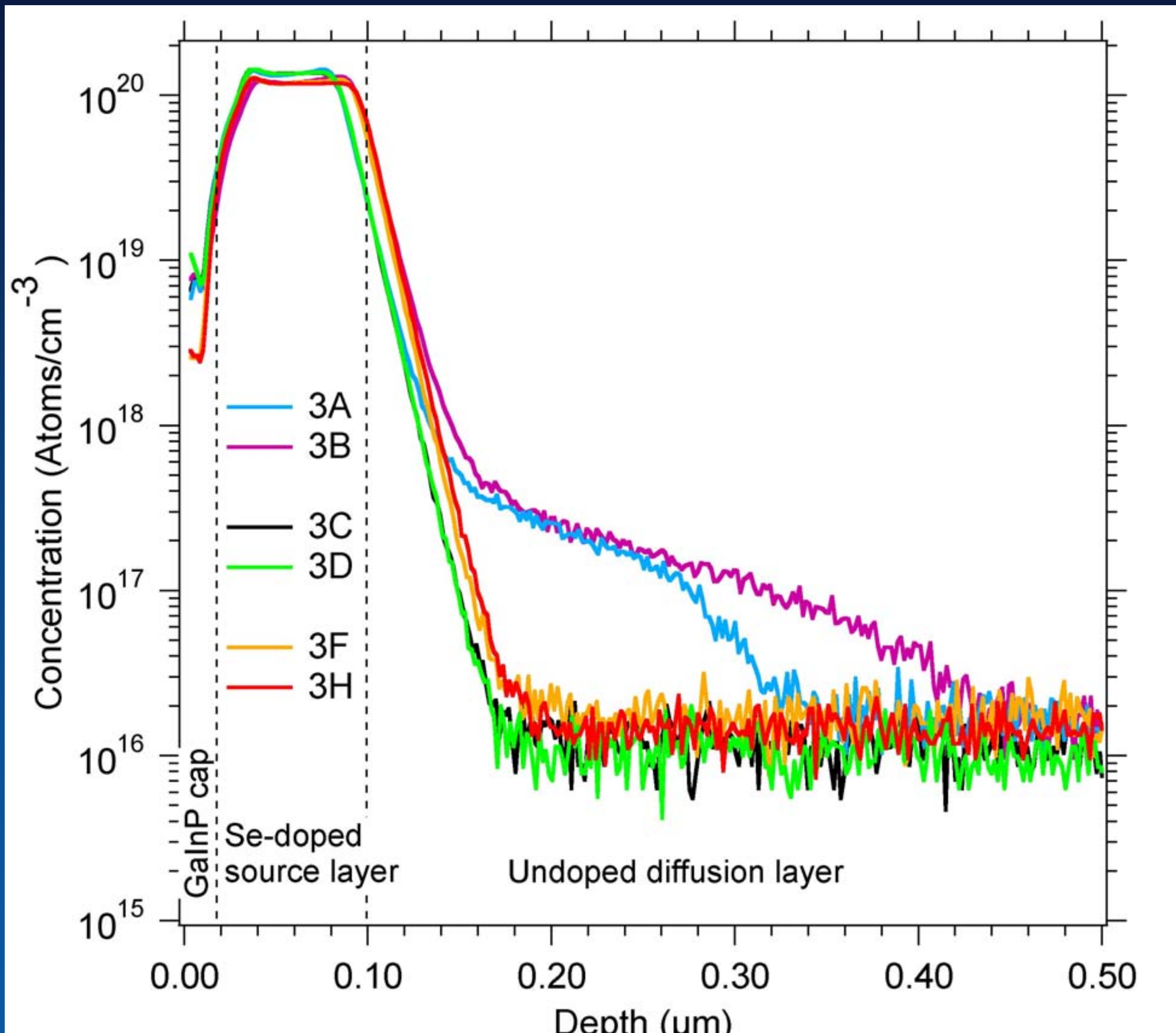
(2) increase the effective mass

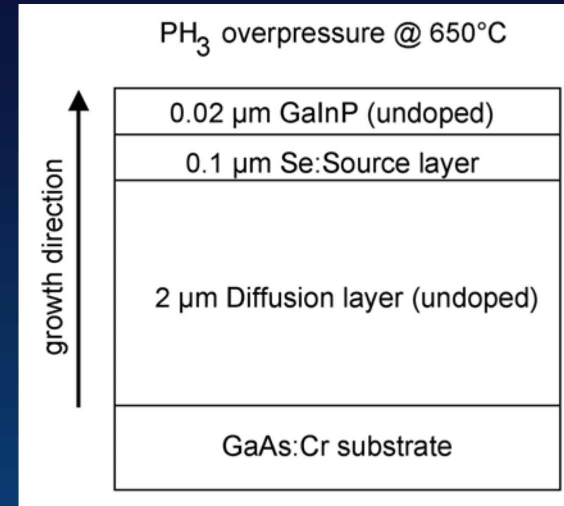
→ Higher carrier concentration

We speculate that it will also:

(3) inhibit diffusion

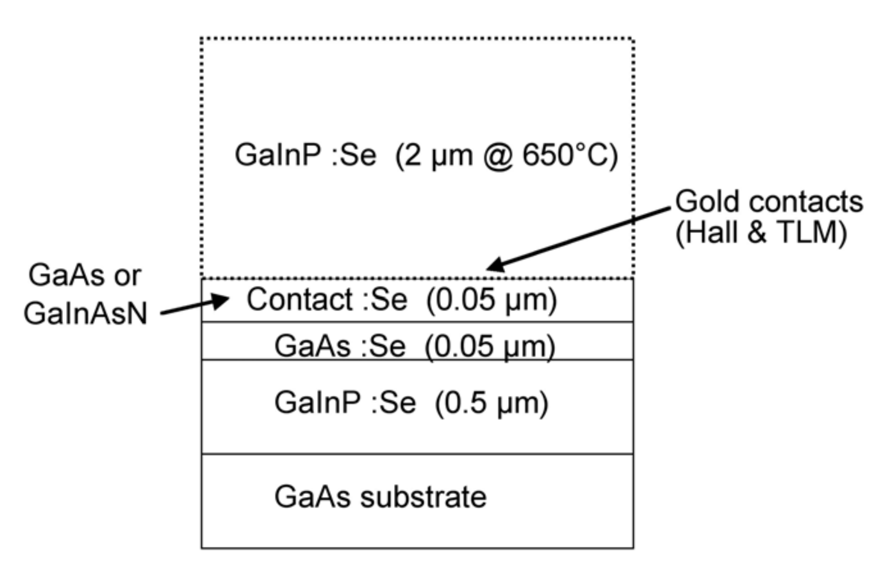
Diffusion in GaInAsN





3A	Se:GaAs / GaAs (not annealed)
3B	Se:GaAs / GaAs
3C	Se:GaAs / GaInAsN (not annealed)
3D	Se:GaAs / GaInAsN
3F	Se:GaInAsN / GaInAsN
3H	Se:GaInAsN / GaAs

Contact resistance study



GaInAsN composition:
~1% N
2% In for lattice-matching to GaAs

Contact layer grown at 570°C

Sample	Contact layer	Specific contact resistance ($m\Omega$-cm^2)
2A	GaAs (not annealed)	0.013
2B	GaAs (annealed)	1.98
2C	GaInAsN (not annealed)	0.003
2D	GaInAsN (annealed)	0.020

Summary

Excellent performance is achievable in both upright and inverted configurations with proper consideration.

Subtle differences in depth profile, QE and JV between upright and inverted growths due to dopant diffusion.

GaInAsN contact layer is resilient to lengthy annealing; more work necessary to determine why.

Acknowledgements

Michelle Young

Waldo Olavarria

Charlene Kramer

III-V group at NREL

This work was supported by the U.S. Department of Energy under Contract No. DE-AC36-99GO10337 with the National Renewable Energy Laboratory.

---

myles_steiner@nrel.gov

(303) 384-7675