IARPA SOLSTICE Proposers Day

Next-generation Microconcentrating Photovoltaic Arrays for Space Power Systems

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MICHIGAN

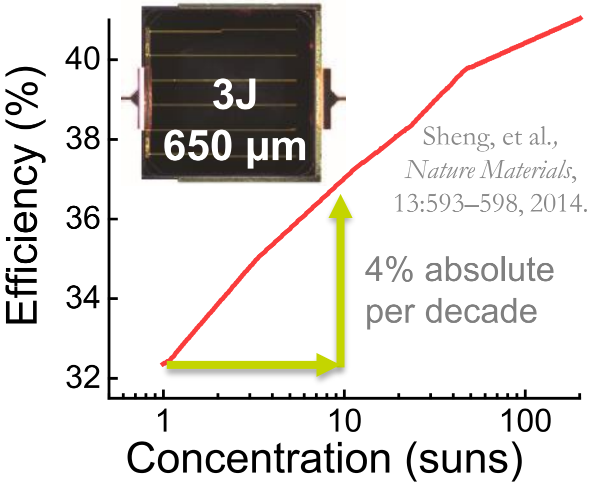
X-Celeprint

The case for CPV in space

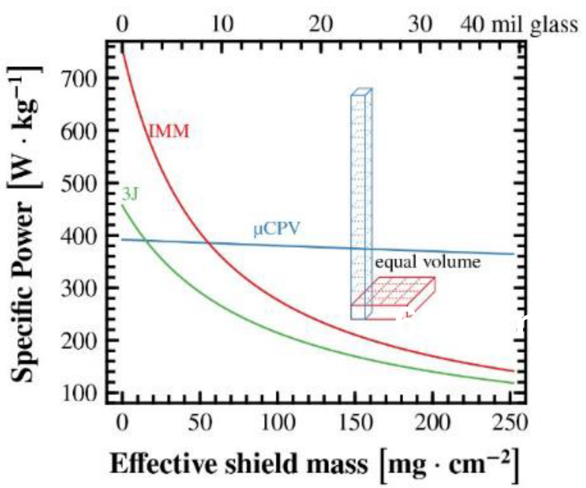
Environment

No clouds
No diffuse light

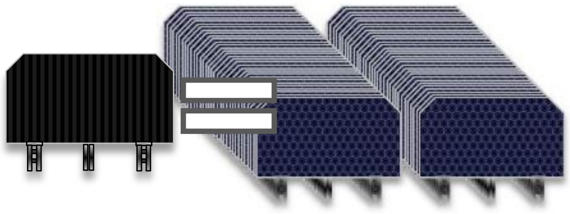
Cell Efficiency



Shielding

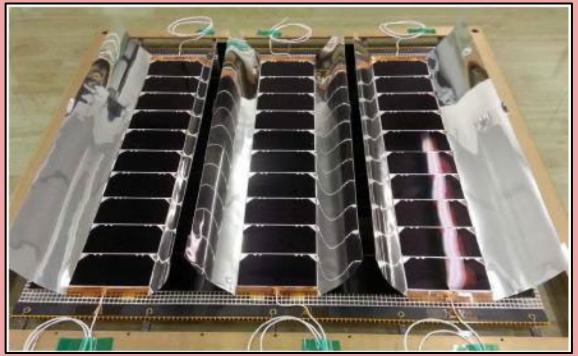


Cost & Capacity



Need, e.g. 100x less epi for the same power

Historically:



- Moving parts
- Low concentration
- Failed in orbit

Want a CPV solution in the same form factor as a traditional CIC

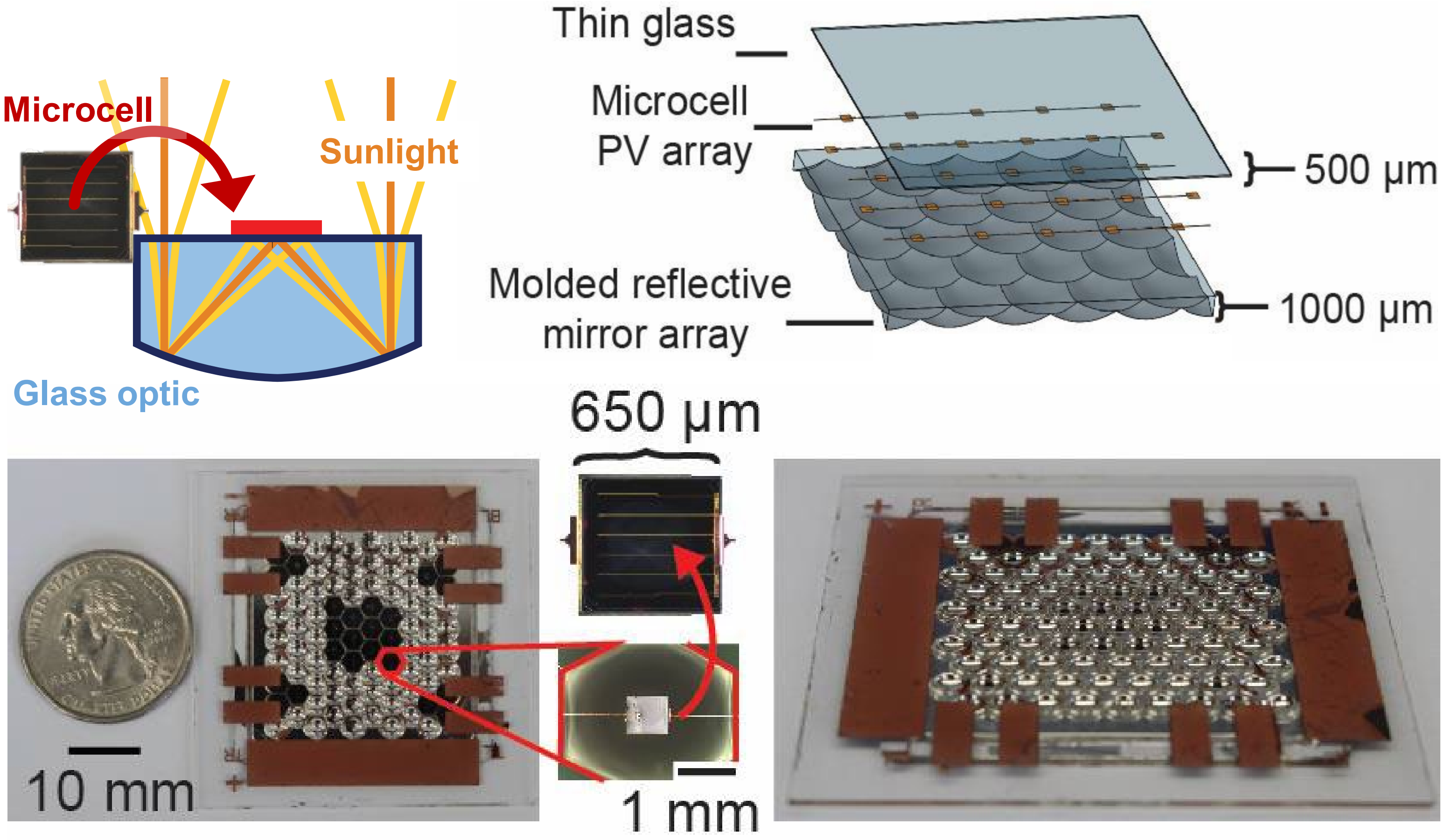
Team Capabilities

- **Micro-concentrating optics design and manufacturing**
- **Multijunction Cell Design, Epitaxy & Fabrication**
- **Microtransfer Printing**

- **Team members:**
  - RIT: extensive history in the modeling, development, growth, fabrication, and testing of radiation-hard space photovoltaics
  - UM: expertise in optical concentrator design, optics fabrication, µCPV integration, and system measurement
  - XLP: expertise interconnecting large scale µcell arrays using industrial scale transfer printing equipment

Microconcentrating photovoltaics (µCPV)

- ***Multi-junction III-V micro solar cells***
- ***Transfer-printed and interconnected on rad hard coverglass***
- ***Bonded to ultrathin, reflective lenslet array***
- ***20-100X concentration with >10º acceptance angle***

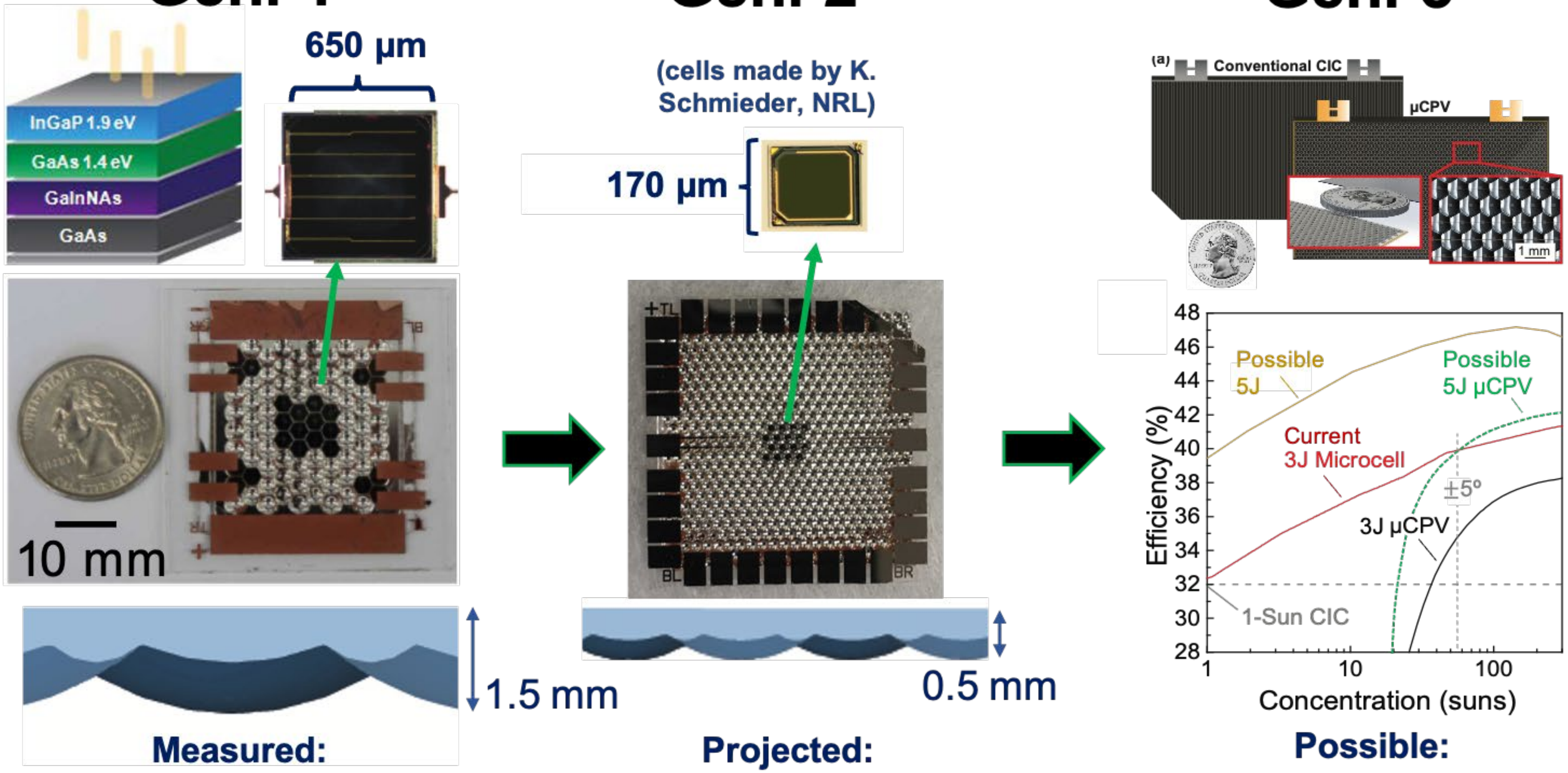


Monolithic, thin, lightweight, same materials & construction as a legacy CIC

What is possible: >38% and 400 W/kg

- ***Shrink to smaller cells***
- ***Eliminate parasitic optical loss***
- ***Increase µcell efficiency***
- ***Add local cell shielding***

Gen. 1 **Gen. 2** **Gen. 3**



Measured:
Eff. = 26%,
SP = 110 W/kg

Projected:
Eff. > 34%,
SP > 350 W/kg

Possible:
Eff. > 38%,
SP > 400 W/kg

µCPV evolution predicted by modeling

C. J. Ruud, J. M. Gordon, and N. C. Giebink, *Joule*, 2023.

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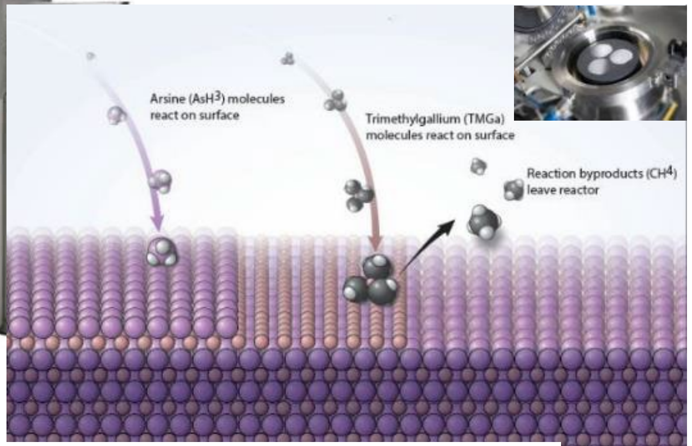
RIT III-V Solar Capability

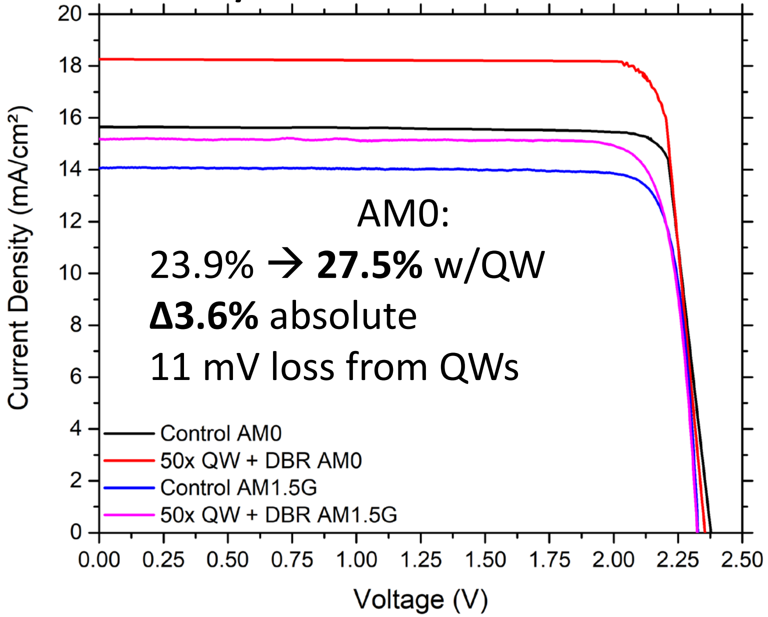
- Epitaxy of III-V compounds of As, P and Sb
  - State of the art in-situ diagnostics, temperature, stress, strain and surface roughness, full complement of ex-situ characterization tools and device fabrication
  - ***Proven solar cell capability***

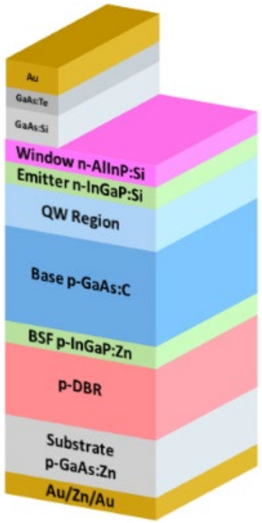


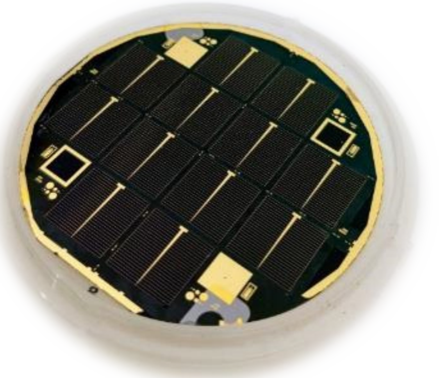
$Ga(CH_3)_3 + AsH_3 \rightarrow GaAs(solid) + 3CH_4$

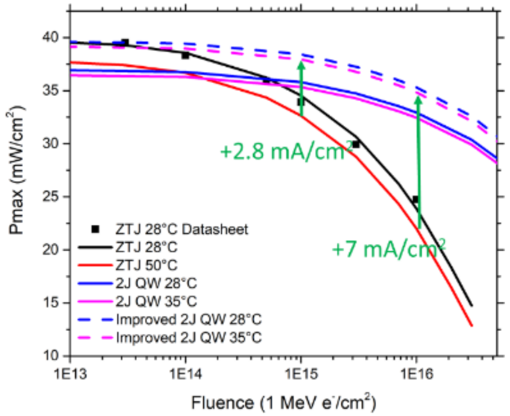
https://www.rit.edu/research/rit-epicenter

DII/NRO Prior Effort









S. J. Polly … S. M Hubbard, et al. ***Cell Reports Physical Science***, 2023

III-V Fabrication and Characterization

Device Characterization

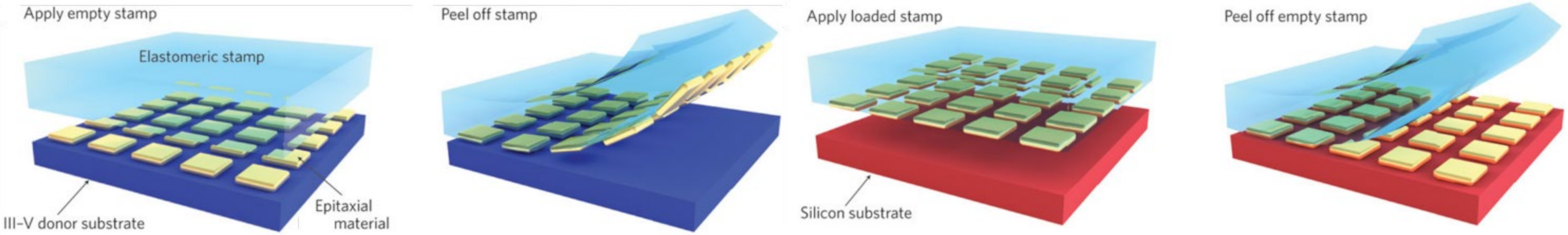
III-V Processing technology

- Wet/Dry Etching, lithography
- Dedicated III-V metallization tools
- Annealing furnace up to 150mm

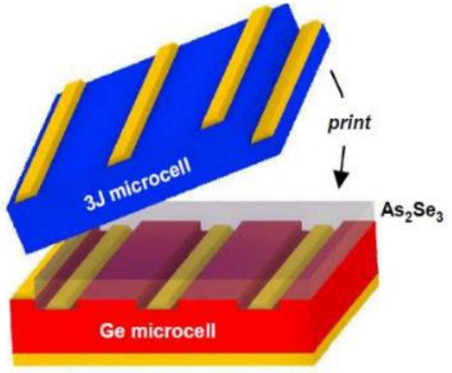
Characterization

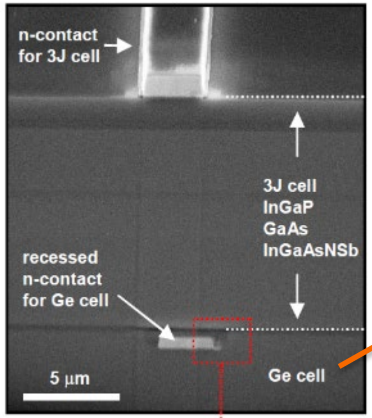
- TS Space systems 300 mm close-match solar simulator
- Bruker D8 HRXRD and XRR, Veeco D3100 AFM/STM
- Agilent B1500 Parametric Analyzer
- Cascade RF probe station
- Optronics and Newport spectral response
- Janis cryogenic (2K) probe station
- Photoluminescence and Photo-reflectance
- DLTS, FTIR, Raman, Hall
- Hitachi FE-SEM and Zeiss LEO SEM

Transfer Printing for Heterogeneous Material Integration



- **A means for integrating material and device structures onto non-native substrates**
  - Elastomeric stamp (PDMS) is brought into contact with target material,
  - As stamp is peeled off, target material is removed from donor substrate
  - Patterned stamp is placed in contact with final substrate. Target material remains on final substrate.
  - Adhesion between target material, stamp, and final substrate is controlled by peeling rates
    - Fast peeling: picks up target material from donor substrate
    - Slow peeling: releases target material from stamp
- **Prior efforts by NRL/Semprius gave close to WR efficiency!**





Isc (mA)	Voc	FF (%)	Eff	4T Eff est.
30.0	0.458	65.0	2.64%	**44.14%**
20.2	0.440	65.7	2.57%	**44.07%**
9.7	0.389	69.2	2.39%	**43.89%**

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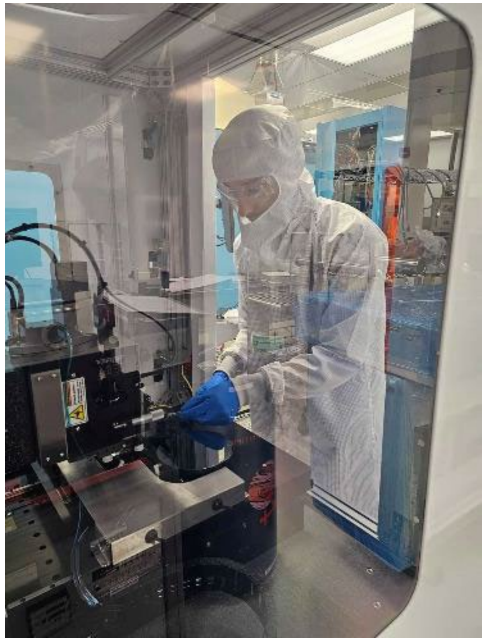
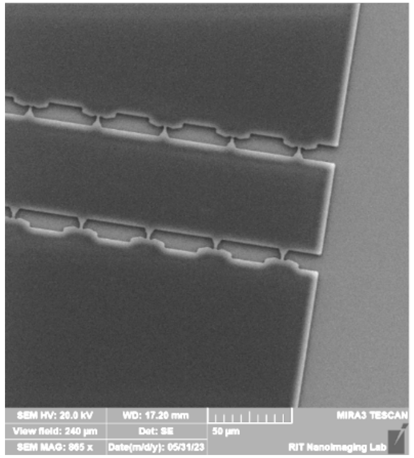
RIT Transfer Printing Capability

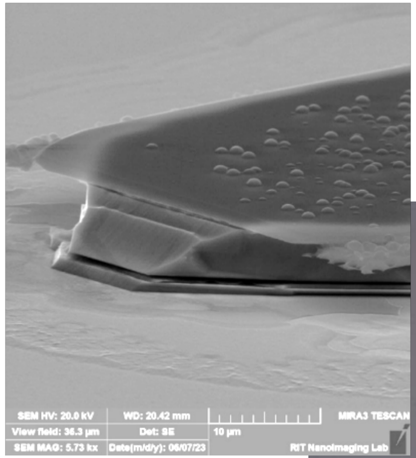
MTP-1003 µTP system, Installed Dec. 2022



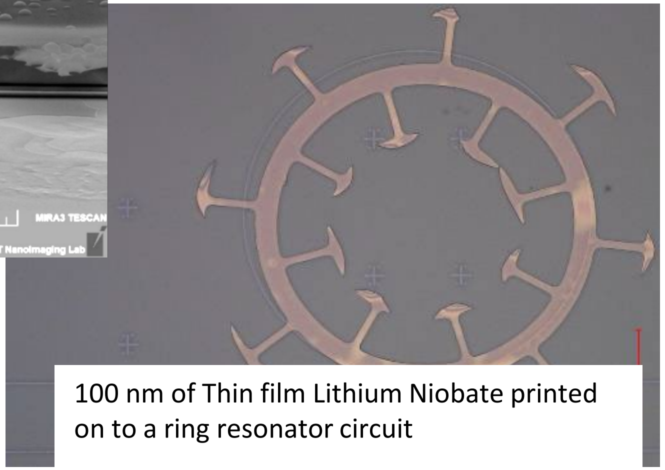
Laser Bars for Print



Release Layer Etched Laser Bar



InP and GaAs based optoelectronics



100 nm of Thin film Lithium Niobate printed on to a ring resonator circuit

- New transfer printing system recently installed at RIT, can work with X-Celeprint for prototyping, tech transfer and scaling
- We have demonstrate hybrid and heterogeneous integration of III-V and $LiNbO_3$ with Si-based PICs materials to benefit higher performance phased array systems
- Currently working on III-V based solar cell process

Summary

- **µCPV has the potential to outperform CIC designs along several metrics**
  - Transfer printing and cell stacking allows access to optimized bandgaps without strained buffer layers, enabling ove 40% AM0 cell efficiency at BOL.
  - Integrated optics and micro-cell design enables highly efficient use of the grown photovoltaic cell, reducing semiconductor cost per Watt.
  - Improved EOL efficiency with up to 10 × more shielding than a CIC without incurring a significant mass penalty.
  - Electrical interconnections and geometry within a µCPV array can be freely configured, enables more efficient packing on a space wing as well as a much greater range of voltages achievable than a CIC design.
- **Team has strengths and prior background in PV and optics as well as transfer printing**
- **Longstanding collaborations with potential Testing & Evaluation partners at Naval Research Lab and NASA Glenn Research Center**