Performance Comparison of III-V//Si Tandem Solar Cells in the Three -Terminal Configuration

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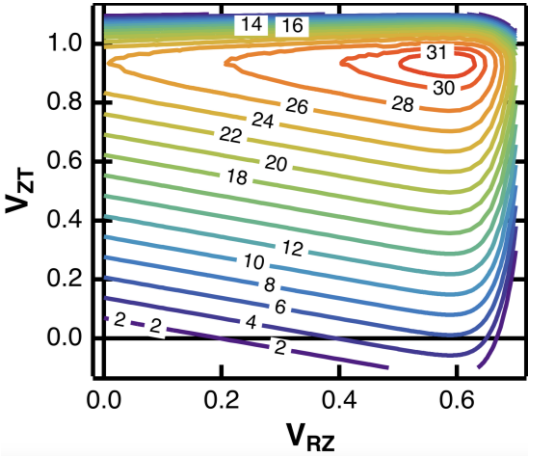
Motivation for 3T Research

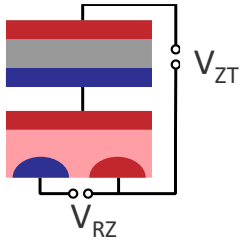
Device simulations suggest that III-V//Si 3T devices could provide a promising path towards >30% 1-sun efficiency. [1]

3T advantages:

- No need for intermediate grids
- Robust to spectral variations
- IBC Si bottom cell provides an additional back contact which allows:
  - Current extraction when Si bottom cell produces more photocurrent
  - Current injection when top cell produces more photocurrent



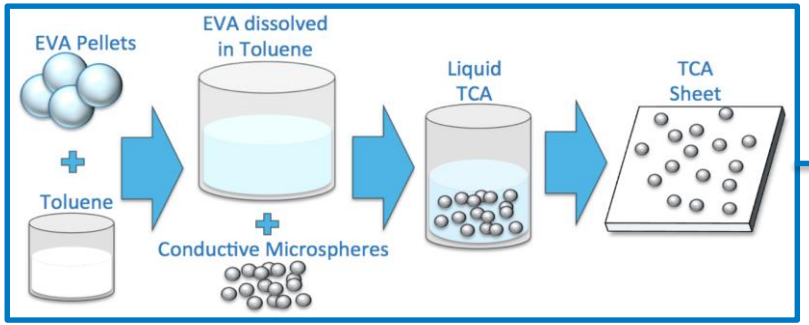
Simulated 3T performance for GaAs//Si (in Common Z - CZ)

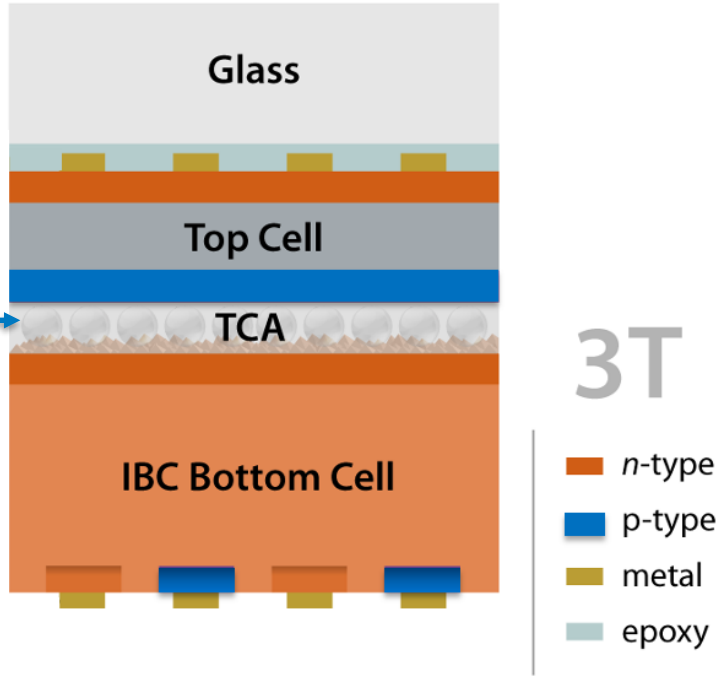


1. Emily Warren et al., Sustainable Energy & Fuels 2, 1141 (2018)
2. Emily Warren, et al,. ACS Energy Letters, 5, 1233 – 1242 (2020).

3T Cell Design: TCA-Bonded Superstrate Structure

- Glass provides mechanical support for top cell during processing
- Textured Si interdigitated-back contact (IBC) cells provided by ISFH[2]
- Transparent conductive adhesive (TCA) used to bond sub-cells together[3]





Simplified schematic for III-V/t/nuIBC Si

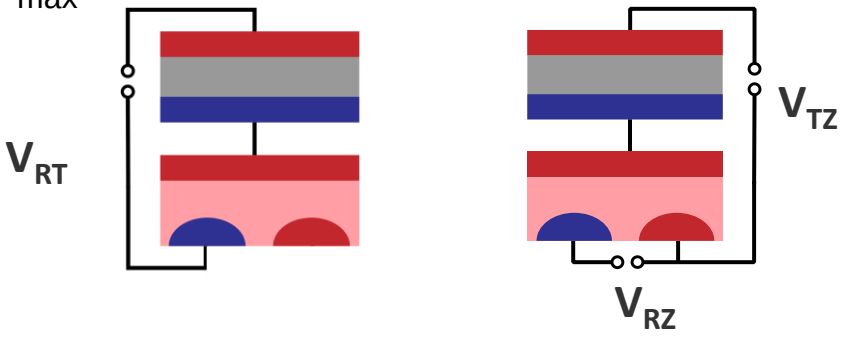
3. M. Rienäcker, et al., *Progress in PV* **27** (2019).
4. Klein, T. R. *et al. ACS Appl. Mater. Interfaces* **10** (2018).

Top Cell Limiting Case: 3T GaInP//Si

3T power contour map:

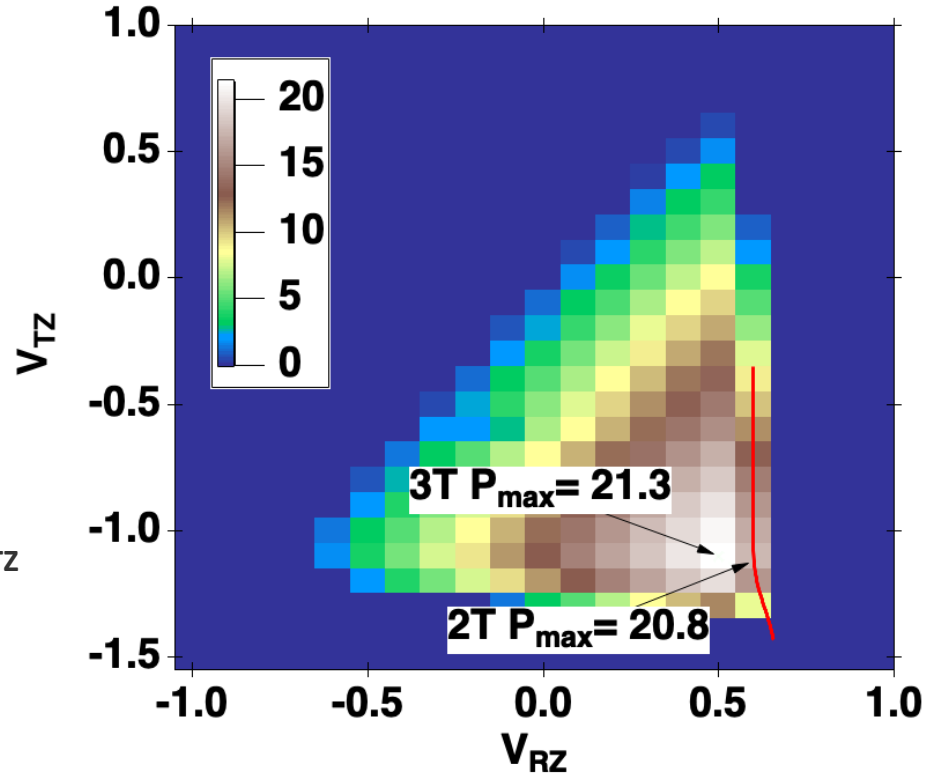
- 2T P_{max} is determined by measuring the 2T JV curve, prior to mapping the power
- 3T P_{max} is calculated from contour map

3T P_{max} is ~0.5 mW/cm^2 higher than the 2T P_{max}

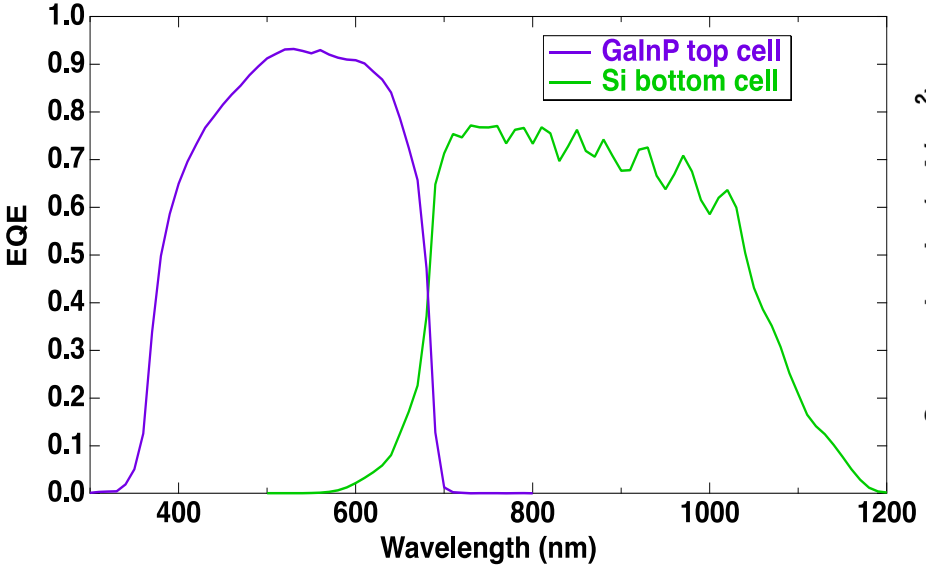


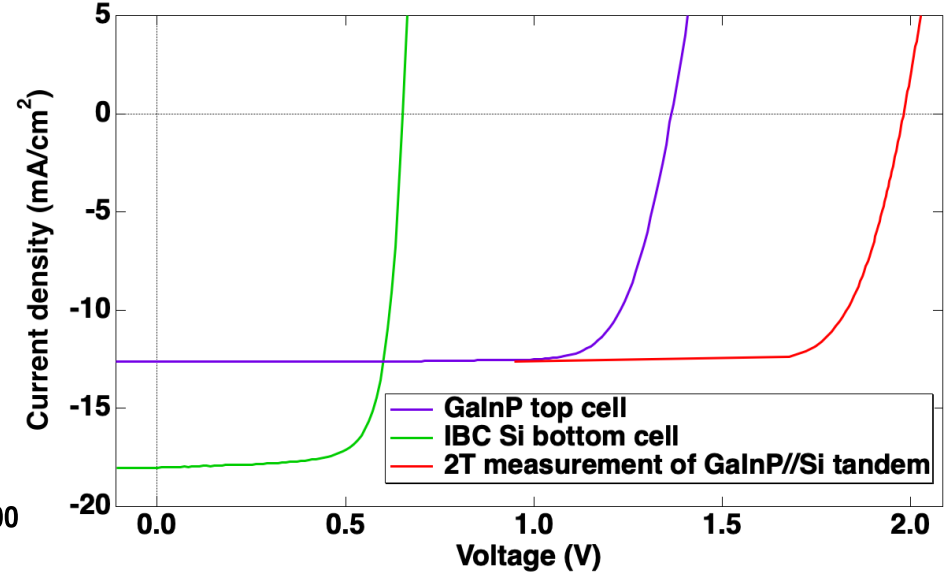
2T Measurement: V_{RT}

3T Measurement: Common Z (CZ)

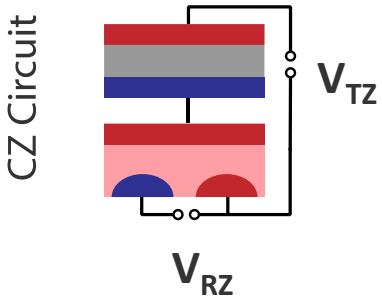


Top Cell Limiting Case: 3T GaInP//Si (cont.)





<u>Key Takeaway for 3T GaInP//Si</u>:
The 3T configuration enables slightly more photocurrent collection from the Si bottom cell than the 2T configuration



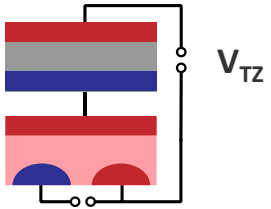
Bottom Cell Limiting Case: 3T GaAs//Si

3T power contour map:

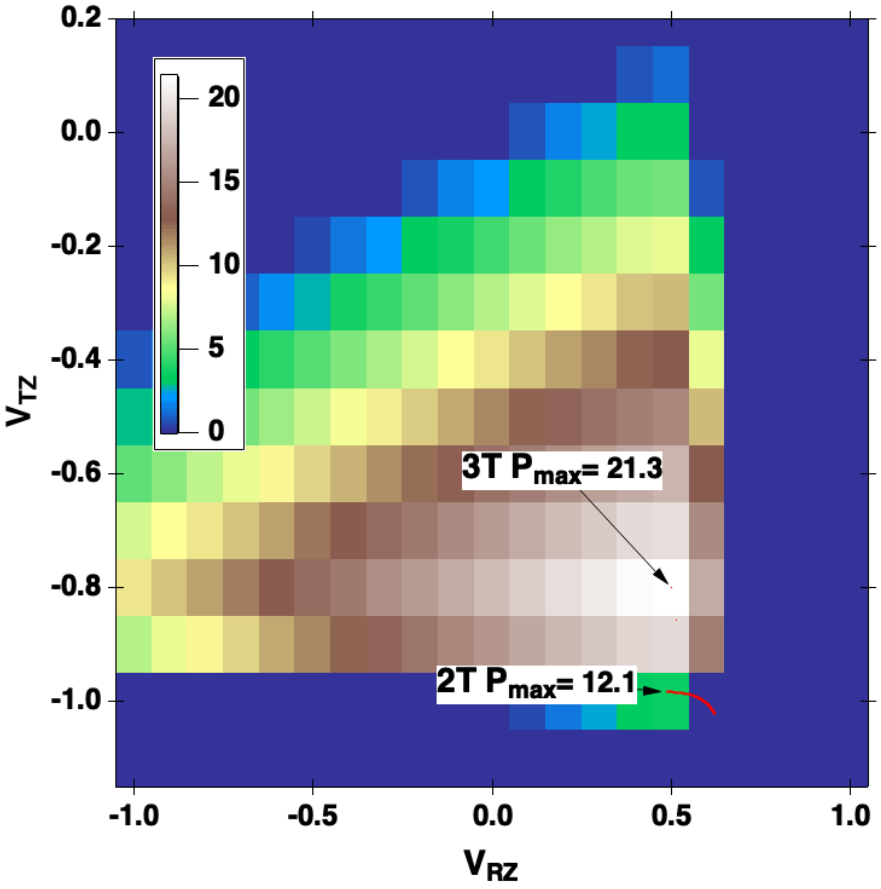
- The difference between the 2T P_{max} and the 3T P_{max} is significantly greater than that seen in the case of GaInP//Si

- This is due to considerable current mis-match between the sub-cells

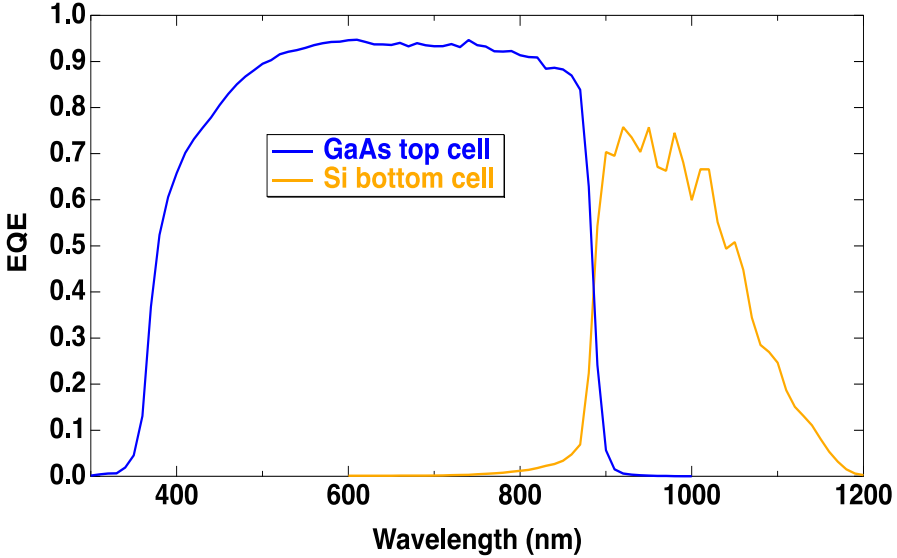
3T P_{max} is 9.2 mW/cm^2 higher than the 2T P_{max}

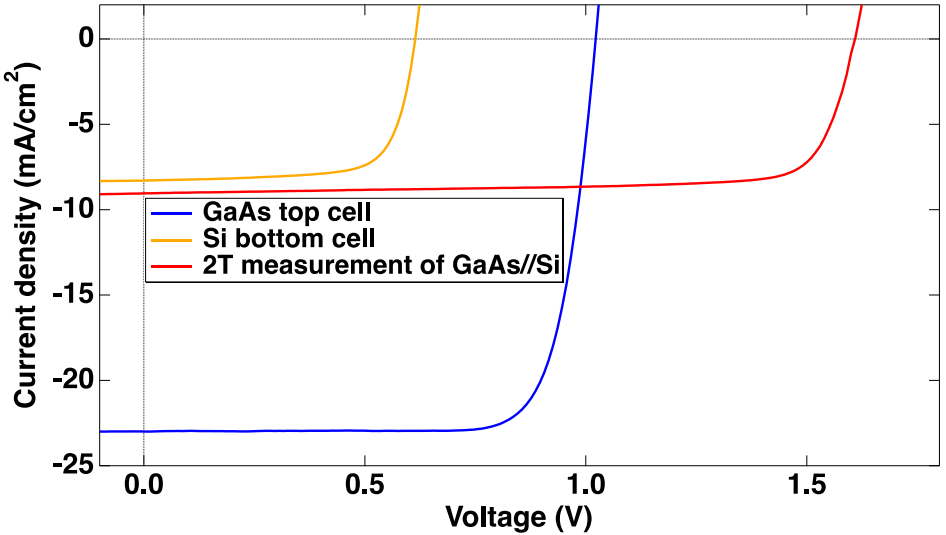


3T Measurement (CZ)



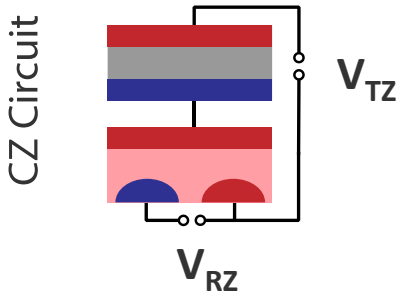
Bottom Cell Limiting Case: 3T GaAs//Si (cont.)





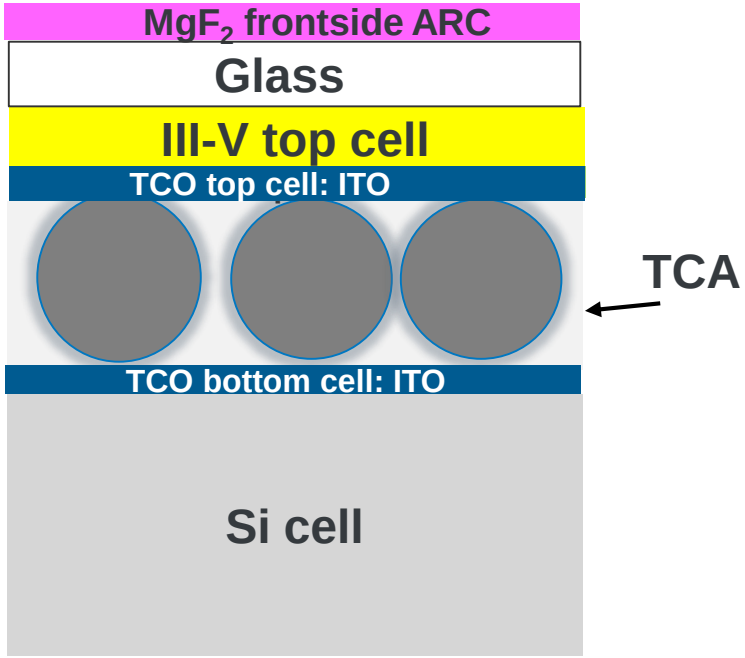
Key Takeaway for 3T GaAs//Si:

3T configuration enables the collection of additional photocurrent generated by the GaAs top cell



Optimizations to Attain Simulated 3T Performance

- Eliminate:
  - Series resistance issues between the sub-cells
  - 3T superstrate measurement artifact
- Co-optimize optical and electrical properties by improving:
  - Lamination conditions
  - TCA percent coverage
- Add a frontside anti-reflective coating (ARC)
- Substitute ITO for IZO at the back of the top cell

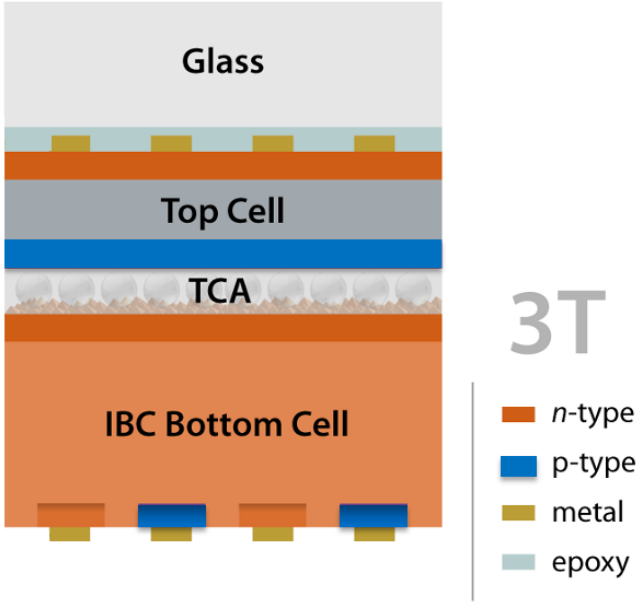


Simplified cell schematic
(Not to scale)

Summary

3T tandem cells are capable of collecting additional photocurrent generated from current mis-matched sub-cells

Tandem Cell	2T efficiency	3T efficiency
GaInP//Si	20.8	21.3
GaAs//Si	12.1	21.3



Additional processing improvements should enable 3T III-V//Si cells to achieve efficiencies above 30%

Thank You

NREL Staff
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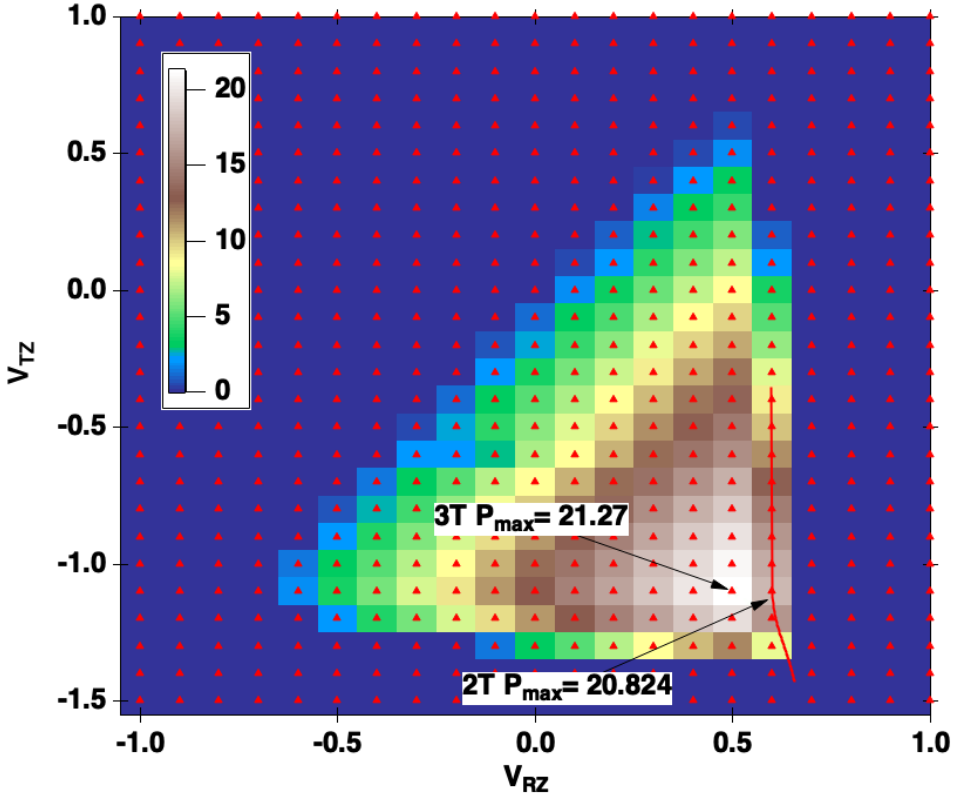
Robby Peibst (ISFH)

Lyndsey McMillon-Brown (NASA)
Tim Peshek (NASA)

*Joint appointment: NREL and Colorado School of Mines

Backup slides

3T Power Plot – with data points



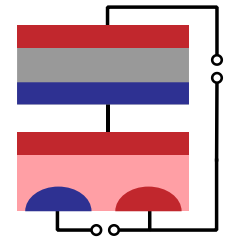
- The n-type Si contact is connected to both SMUs on the XT-10
  - III-V front contact SMU #1
  - P-type back contact SMU #0 (Hi)
- At each V_{TZ} increment along the y-axis, V_{RZ} is set at values increasing from -1 to 1 and I_{TZ} and I_{RZ} are measured at each step
- Raw data is:
  - J_{TZ} as a function of both V_{TZ} and V_{RZ}
  - J_{RZ} as a function of both V_{TZ} and V_{RZ}
- Power on the contour plot is calculated from:

$P_{RZ} = J_{RZ} \times V_{RZ}$ $\quad$ $P_{TZ} = J_{TZ} \times V_{TZ}$

$P_{TOT} = J_{RZ} + P_{TZ}$

CZ GaInP/t/nuIBC

CZ Circuit



3T Superstrate Cell Fabrication Process for GaInP//Si