



National Laboratory
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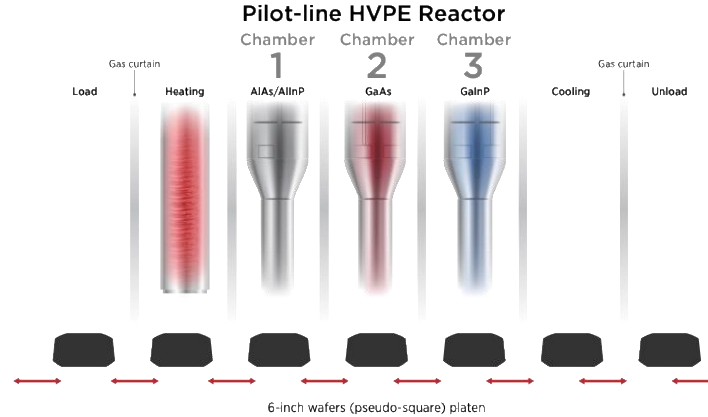
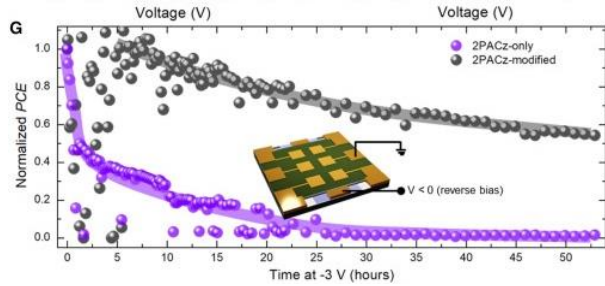
Radiation damage and recovery
in high-lifetime, thin, antimony
doped silicon wafers for space
power applications.

- David L. Young, William Nemeth, Aditya Ratnapagol, Rabin Basnet*, Thien Truong, Paul Stradins

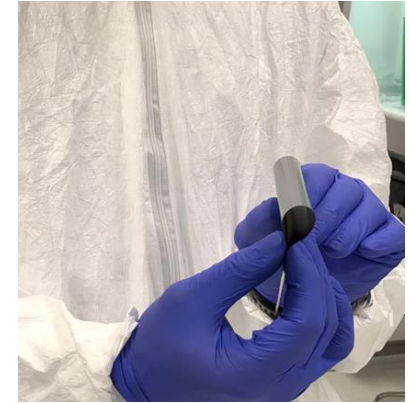
*Australian National University

Hydride Vapor Phase Epitaxy of III-V materials

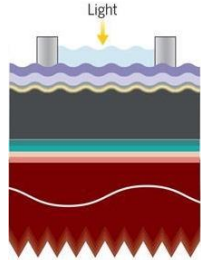
Perovskites for space PV



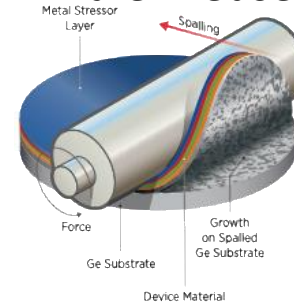
Thin silicon for space PV



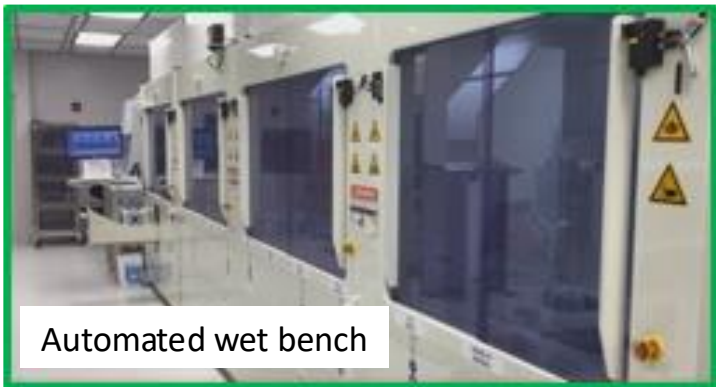
Perovskite/Silicon tandems



Wafer Reuse



Dedicated Silicon Cleanroom – wafer level processing tools



Automated wet bench



4-tube diffusion furnace

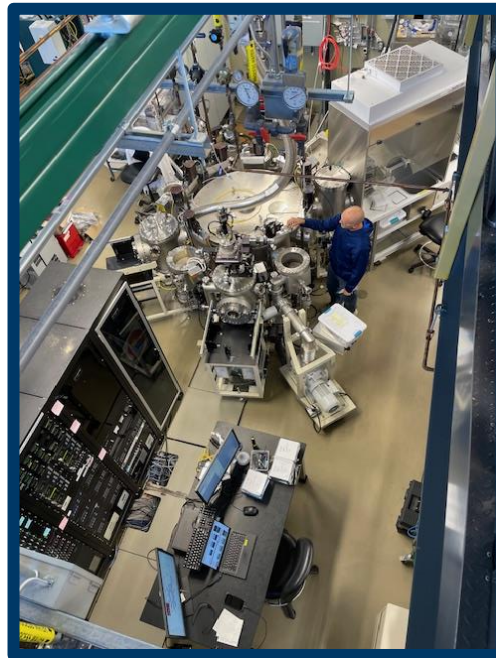


Single-side wet etch



3-tube low-pressure CVD and PECVD furnace

10-Chamber PECVD Cluster Tool



Gases:

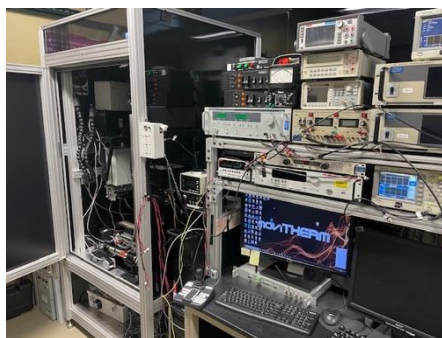
- SiH_4
- BF_3
- B_2H_6
- PH_3
- GeH_4
- NH_3
- CF_4
- SF_6
- C_2H_6
- H_2
- N_2
- Ar

- Atomic Layer Deposition (ALD)
- Laser processing
- Metal deposition (evap, e-beam, screen printing)

Electron Spin Resonance



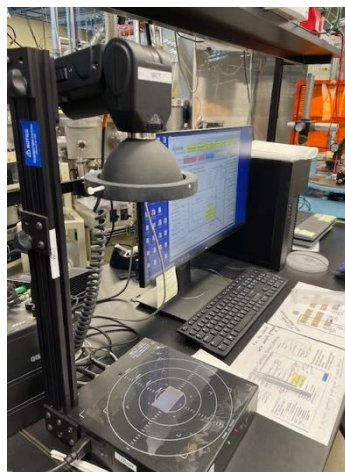
Photo-, Electro-luminescence Imaging



Proton Radiation Orbital Simulation Beamlines (RBS)



Silicon carrier lifetime



Other Characterization Techniques

- Sinton lifetime/SunsVoc
- DC and Flash JV
- Contact resistivity
- Quantum Efficiency
- Ellipsometry
- Dark Lock-in Thermography
- Raman Spectroscopy
- UV-Vis-IR spectrometers
- Capacitance (C/V, C/f
DLTS, Photocapacitance)
- Photothermal deflection spectroscopy
- SEM – FIB, EDX, EBD, EBIC, CL
- STEM – EDX, EELS, 4D Scan
- XRD
- Auger, X-ray, UV photoelectron spec
- SIMS (dynamic, TOFS)
- Rutherford backscattering
- Hydrogen Effusion
- FTIR

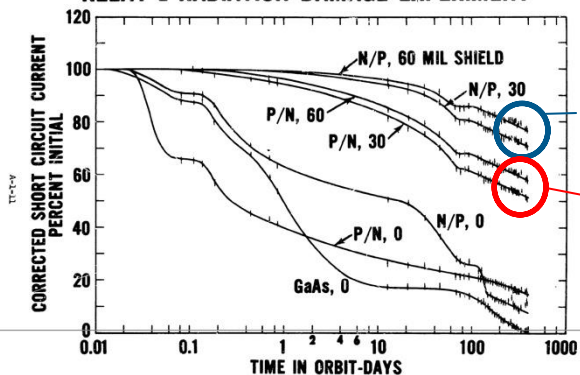
Modeling

- Device (Quokka3)
- Module (SunSolve)
- Physics (COMSOL)
- Radiation damage (SRIM)
- CFD, DFT

Literature Review: Properties of space-ready silicon solar cells

1) p-type wafers (defect type, e mobility)

RELAY I RADIATION DAMAGE EXPERIMENT



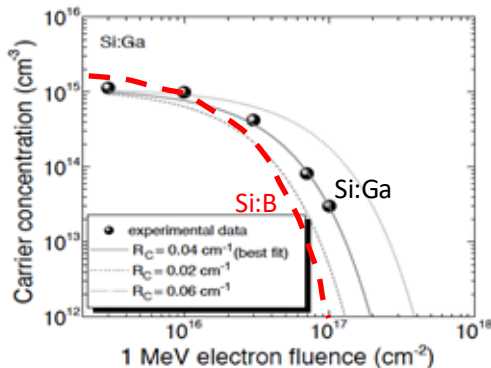
P-wafers
"N on P"

N-wafers
"P on N"

RADIATION DAMAGE TO SOLAR CELLS ON RELAY I AND RELAY II
Ramond C. Waddel Goddard Space Flight Center, Greenbelt, Maryland
Proceedings of the fourth photovoltaic specialist conference, 1964

2) Si:Ga wafers are more rad hard than Si:B

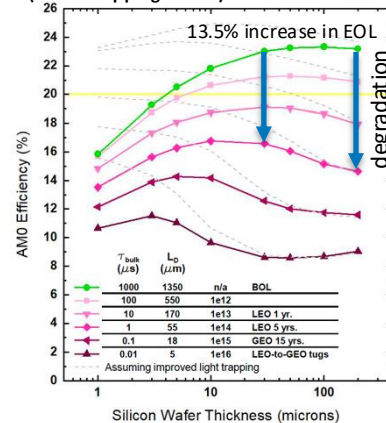
(mass and size of Ga atom, shallow defects)



Khan et al, Solar Energy Materials & Solar Cells 75 (2003) 271-276

3) Thin wafers degrade less

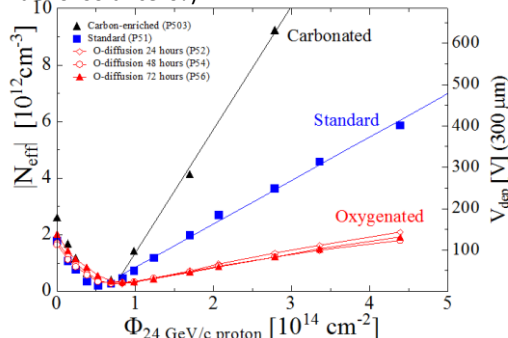
(fewer stopping events)



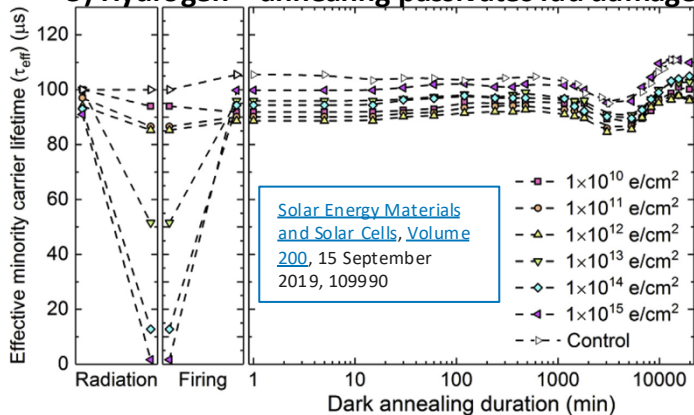
Herasimenka SPRAT 2022

4) Oxygen-rich detectors are rad hard

(True for solar cells?)

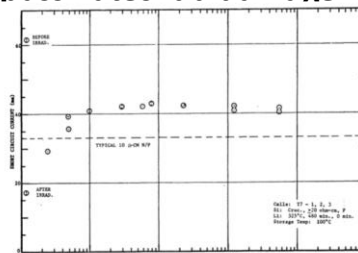


5) Hydrogen + annealing passivates rad damage



Solar Energy Materials and Solar Cells, Volume 200, 15 September 2019, 109990

6) Li passivates rad damage



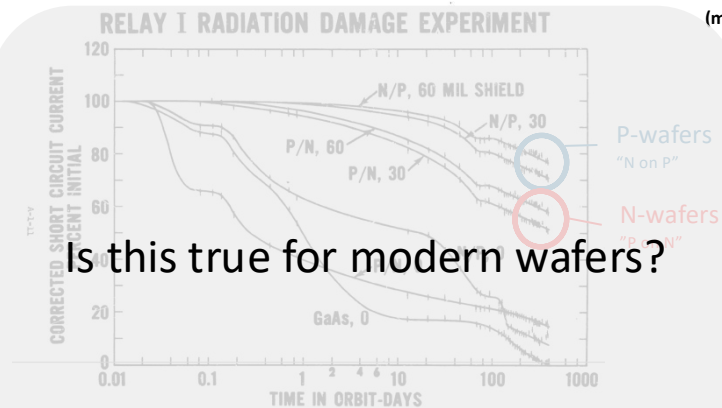
Study of radiation effects in Li doped Si solar cells JPL, 1969

7) Wafer resistivity influences EOL

NLR 2025; Yang et al. PIP:RA 34, 544 2026

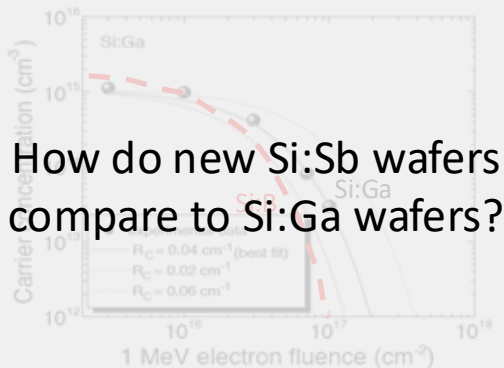
Properties of space-ready silicon solar cells

1) p-type wafers (defect type, e mobility)



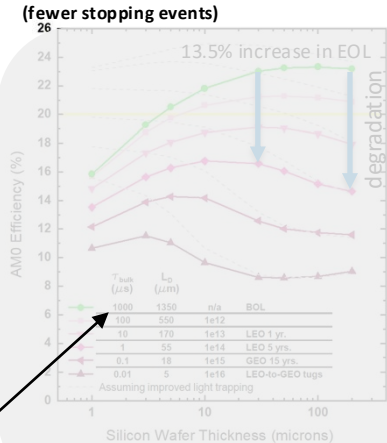
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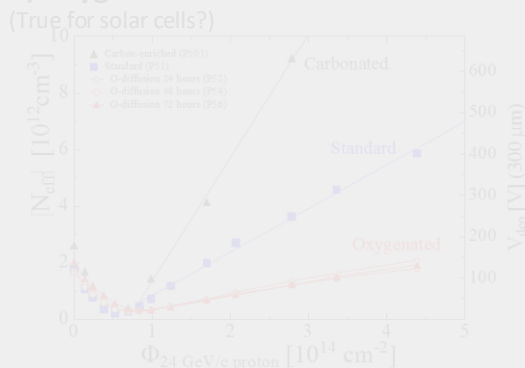
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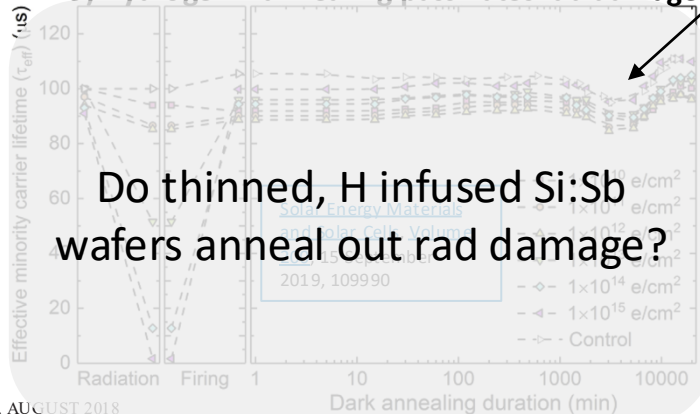


Herasimenka SPRAT 2022

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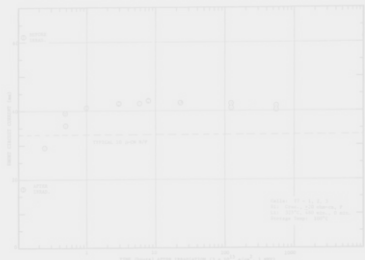
2019, 109990

1 $\times 10^{14} \text{ e/cm}^2$

1 $\times 10^{15} \text{ e/cm}^2$

Control

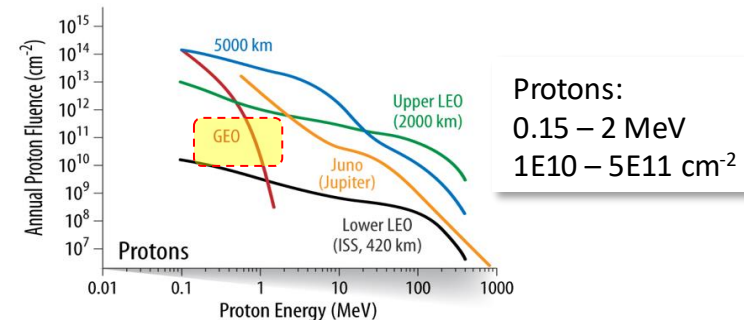
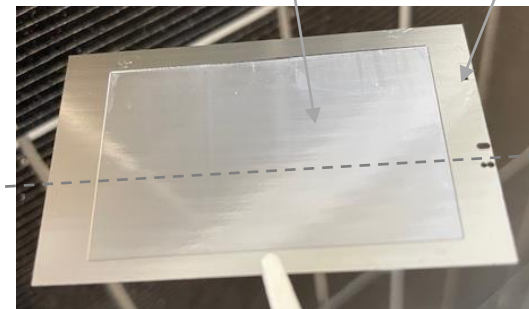
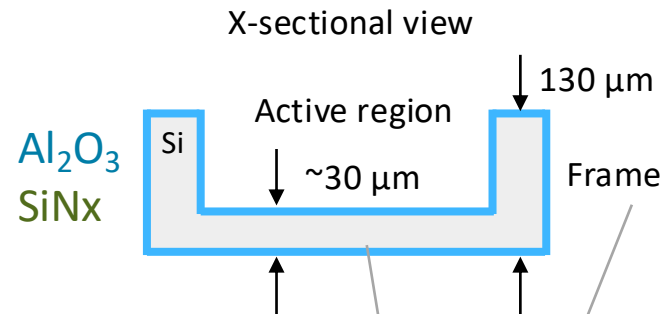
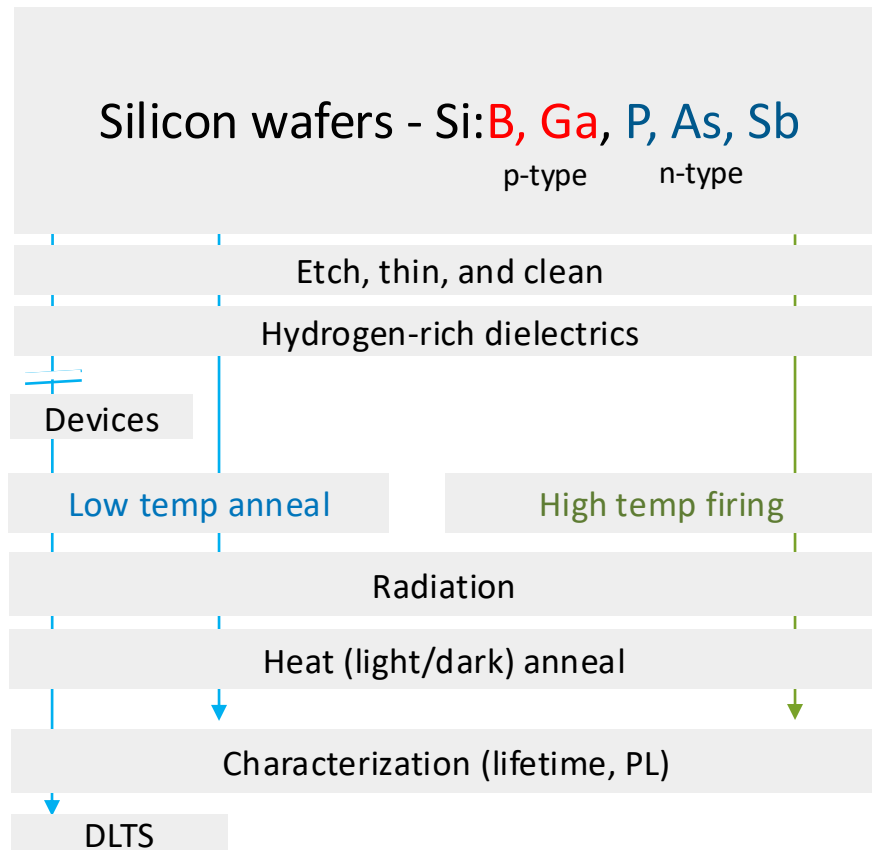
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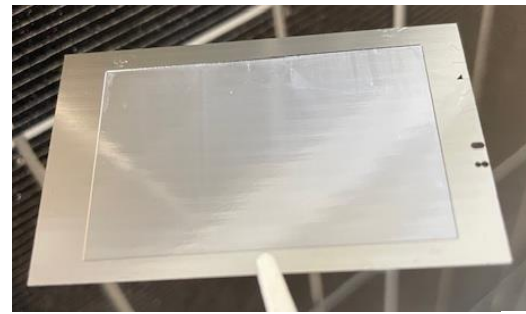
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Experimental Plans

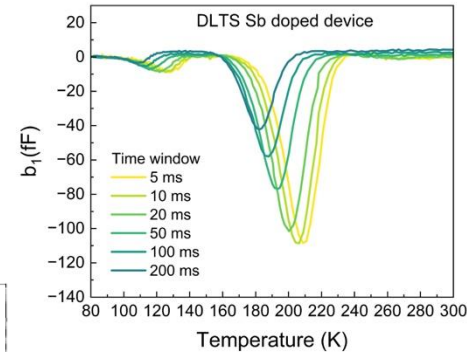
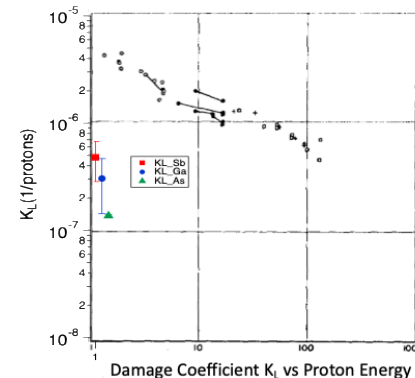
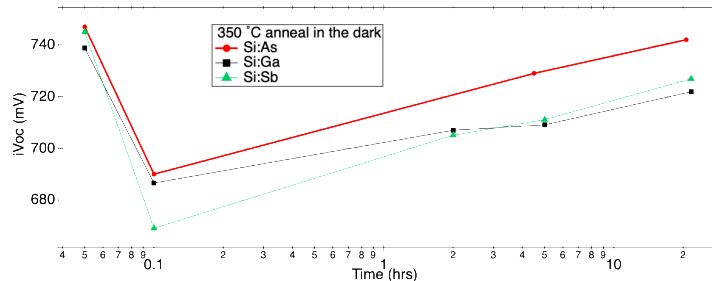


Summary



Thinned wafers Si:B, Ga, P, As, Sb were subjected to hydrogenation, proton radiation, and annealing

- 1) Ga and Sb retained highest iV_{OC} post 2-MeV proton irradiation
- 2) New DLTS data for Si:Sb found electron traps at $E_C = 0.19, 0.39$ eV
- 3) Proton K_L at 1-MeV: Si:B > Si:Sb > Si:Ga > Si:As
- 4) Partial iV_{OC} recovery with 350 °C dark anneal





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Thank You

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