

Fortifying the Future: A Secure US Germanium Supply Chain for Space Solar Cells

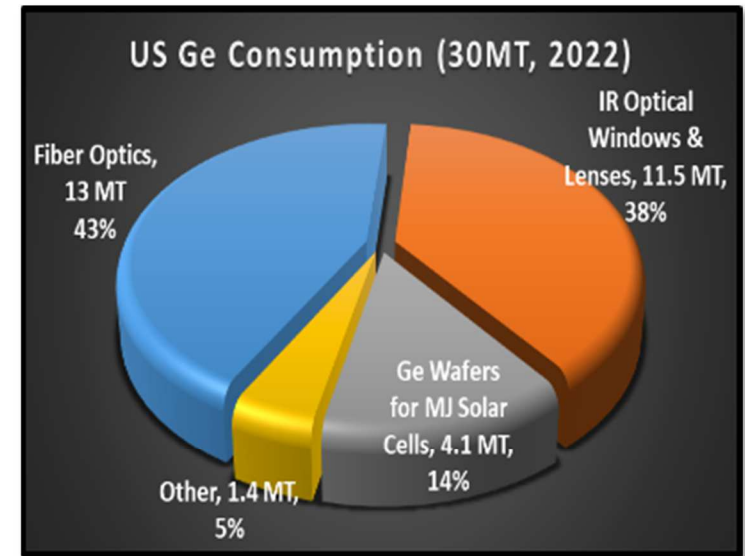
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5N+ Semiconductors, Space Power Workshop 2024

5N+
Enabling
Performance

Outline

- 5N+ Company overview
- 5N+ Semiconductors overview
- Space Solar Power Ecosystem overview
 - Importance in face of Chinese germanium embargo
- Potential North American Ge supplies
- 5N+ Ge crystal growth evolution and products
- 5N+ operating within N.A. solar power ecosystem: wafer and materials characterization
- Conclusions



Forms of Ge from scrap to HP bar

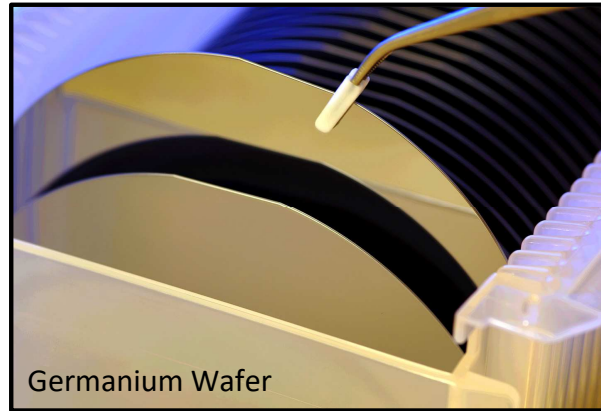
5N Plus Worldwide



- High Purity Metals
- Specialty Semiconductors
- Solar Cells
- Chemicals
- Low Melting Point Alloys



5N Plus Semiconductors - Defense Industrial Base – DPA Title III



- Founded 2005 as Sylarus Technologies
- Part of the US National Security Space Industrial Base
- Only North American manufacturer of germanium wafers for space solar power
- Approx. 50 Employees
- Joined 5N Plus in 2014
- Specialty Semiconductor Substrates:
 - Germanium – Space Solar
 - InSb – Night Vision, Magnetic Sensor
 - CdTe – Medical Imaging, x-ray Sensor
 - (211) CZT – MCT Infrared Sensor Substrate

Government Stakeholders

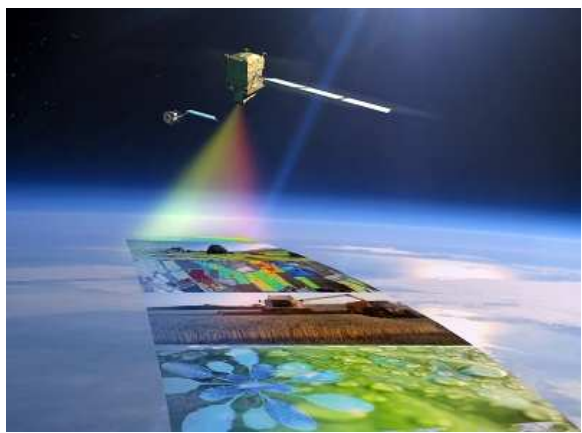


5N+ Enabling Performance Space Solar Power Ecosystem

PRIME
TIER 1
TIER 2
TIER 3
TIER 4

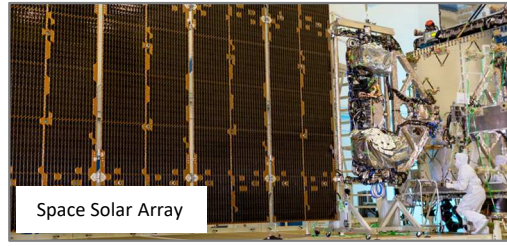
Design and Integration of Final Satellite System or Service

Not a complete list of satellite companies

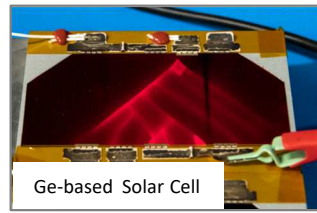


Subsystems – e.g., Satellite Payload, Bus, Tracking, Propulsion...

Assemblies – e.g., Solar Arrays, Imagers & Cryocoolers...



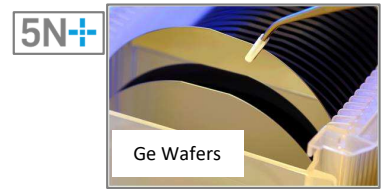
Components & Parts – e.g., Solar Cells, Infrared Sensors, Focal Plane Arrays...



Hardware and Materials – e.g., Ge wafers, CdZnTe substrates, Rare Earths, Transistors...

Germanium Wafers

China Ge Wafer Competitors



Potential North American Ge Supply



Zinc Ore Concentrate



GeO₂
Germanium Dioxide

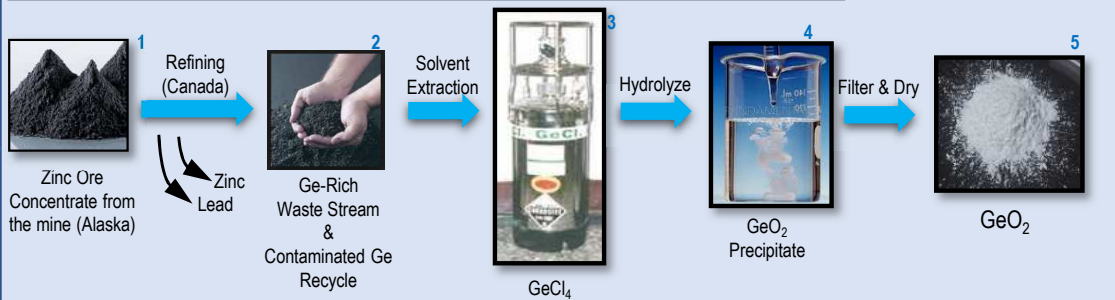


5N+ Semiconductors
St. George, Utah
USA

Red Dog Mine
Alaska (Operator is Teck)
USA

Teck Resources
Trail, BC
Canada

Teck extracts germanium from zinc ore – supplies GeO₂



5N+ produces high purity germanium metal



H₂ Reduction,
Oxide → Ge Metal



Zone Refining (5N → 7N)



Germanium Ingots

Teck supplies several grades of germanium:

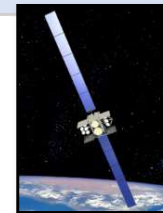
- Germanium Dioxide (GeO₂):
- Technical Grade GeO₂ powder
- Fast Dissolving Grade GeO₂ powder
- Germanium Tetrachloride (GeCl₄):
- Fibre Optic Grade GeCl₄

5N+ produces high purity germanium metal useable by the world community.

5N+ uses Ge metal to produce Solar Cell Substrates for space applications.



Ge Wafers



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Infrared Windows
&
Target Acquisition
Sights



Crystal Growth Evolution – Supported by DPA Title III



2010

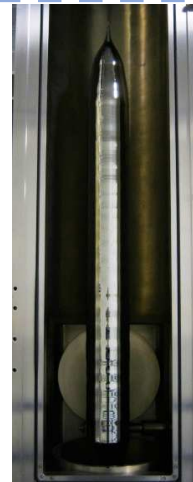


Jan 2012

DPA Title III



Dislocation
free



Aug 2013
Length >2m

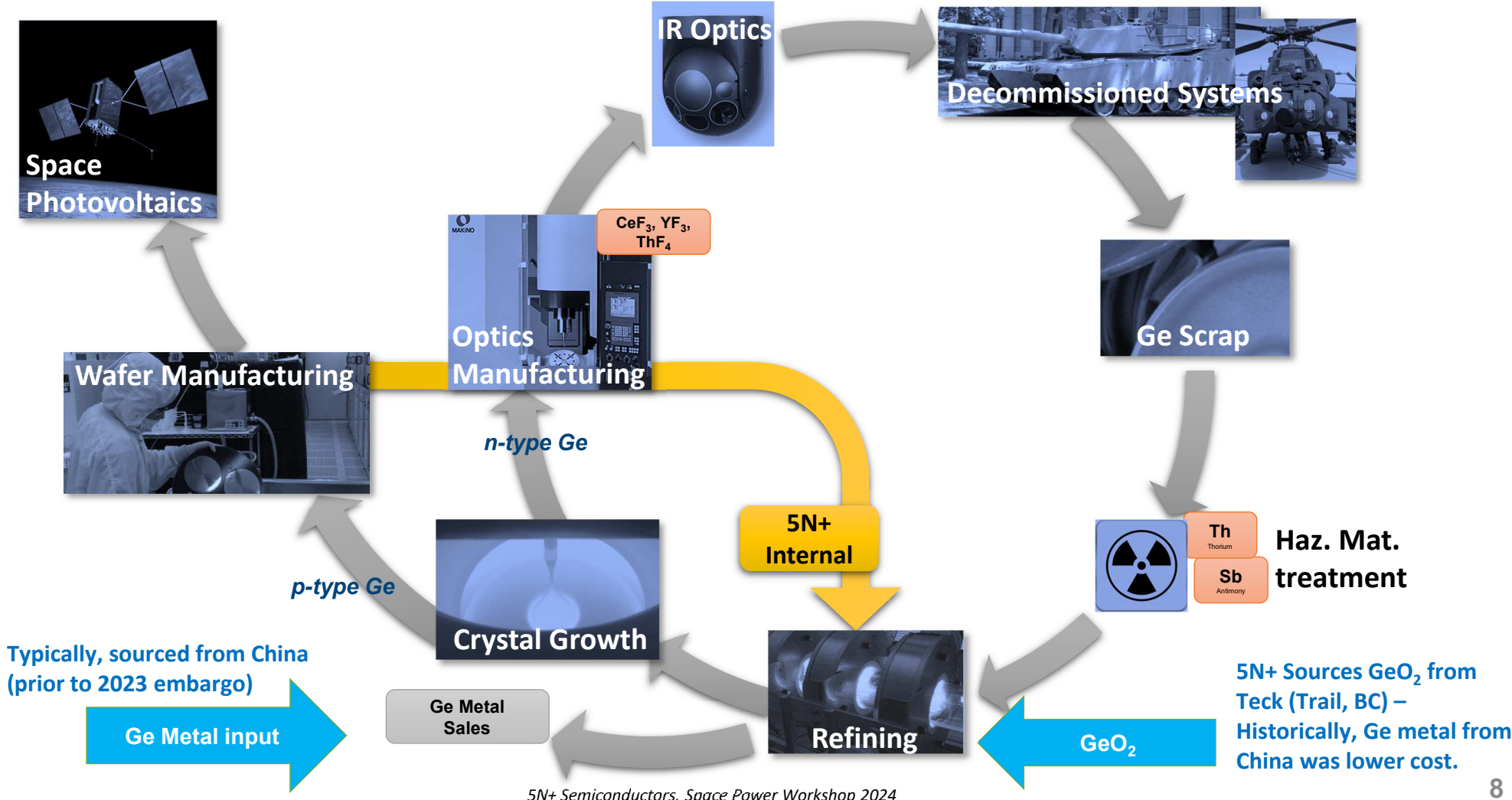


Czochralski crystal growth



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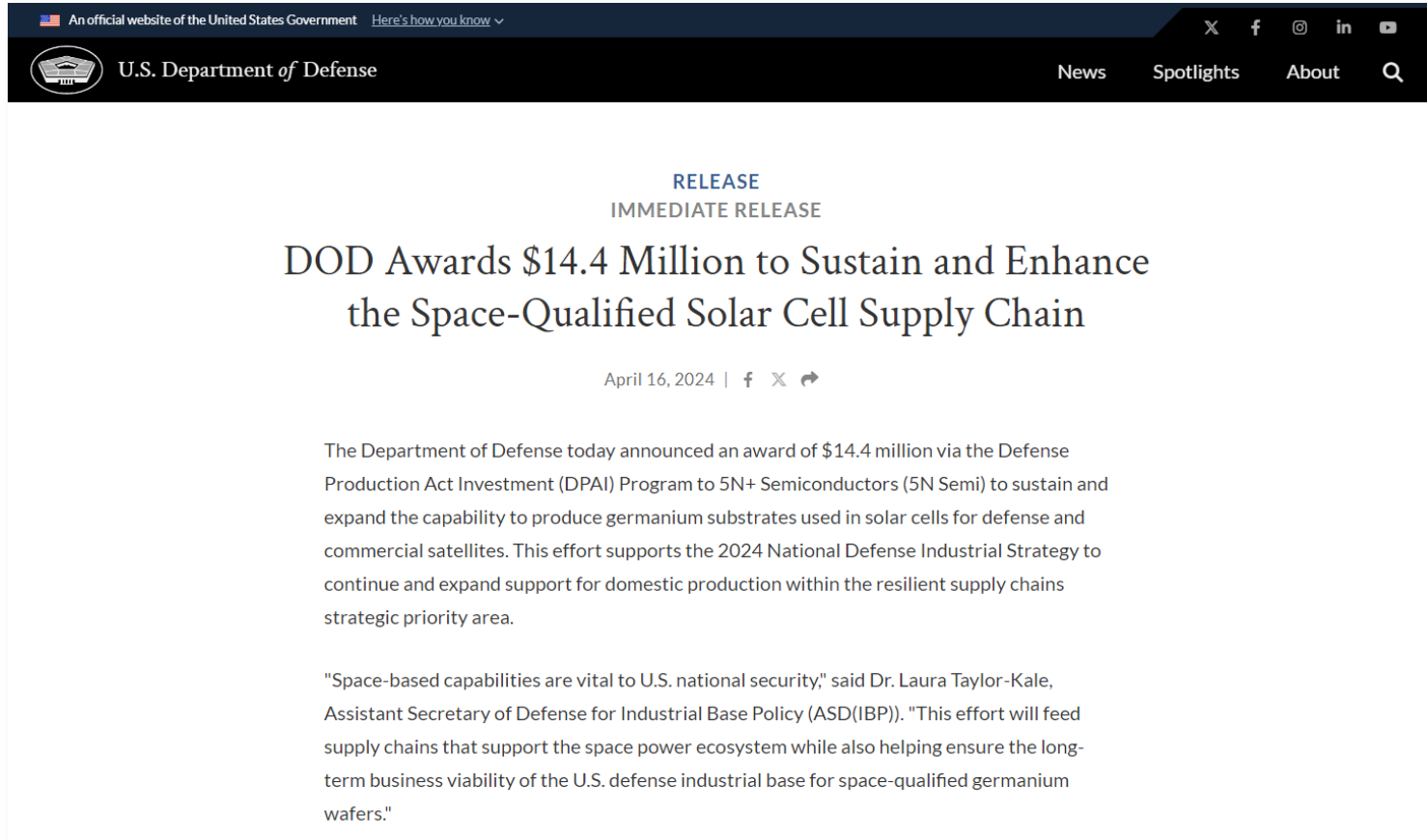
Germanium Metal and Recycling Loop



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5N+ Sources GeO₂ from Teck (Trail, BC) – Historically, Ge metal from China was lower cost.

DOD Support for U.S. Solar Cell supply chain: Recent Press Release



The screenshot shows a web browser displaying a press release from the U.S. Department of Defense. The browser's address bar shows "An official website of the United States Government" and "Here's how you know". The page header includes the U.S. Department of Defense logo and name, along with navigation links for "News", "Spotlights", and "About". The main content area features the text "RELEASE IMMEDIATE RELEASE" followed by the title "DOD Awards \$14.4 Million to Sustain and Enhance the Space-Qualified Solar Cell Supply Chain". The date "April 16, 2024" and social media sharing icons are visible below the title. The body text describes an award of \$14.4 million to 5N+ Semiconductors (5N Semi) for producing germanium substrates for solar cells. A quote from Dr. Laura Taylor-Kale, Assistant Secretary of Defense for Industrial Base Policy (ASD(IBP)), is also included.

An official website of the United States Government [Here's how you know](#) ✕ f @ in ▶

 U.S. Department of Defense News Spotlights About Q

RELEASE
IMMEDIATE RELEASE

DOD Awards \$14.4 Million to Sustain and Enhance the Space-Qualified Solar Cell Supply Chain

April 16, 2024 | f ✕ ↻

The Department of Defense today announced an award of \$14.4 million via the Defense Production Act Investment (DPAI) Program to 5N+ Semiconductors (5N Semi) to sustain and expand the capability to produce germanium substrates used in solar cells for defense and commercial satellites. This effort supports the 2024 National Defense Industrial Strategy to continue and expand support for domestic production within the resilient supply chains strategic priority area.

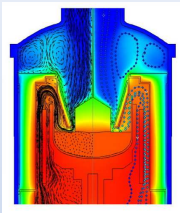
"Space-based capabilities are vital to U.S. national security," said Dr. Laura Taylor-Kale, Assistant Secretary of Defense for Industrial Base Policy (ASD(IBP)). "This effort will feed supply chains that support the space power ecosystem while also helping ensure the long-term business viability of the U.S. defense industrial base for space-qualified germanium wafers."

5N+ 5N PLUS SEMICONDUCTOR PRODUCTS: GERMANIUM WAFERS

Enabling Performance

PRODUCT:

Epi-ready single crystal substrates

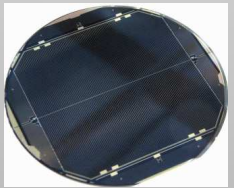
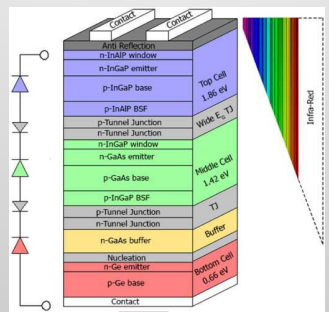


4" and 6" diameters



TECHNOLOGY:

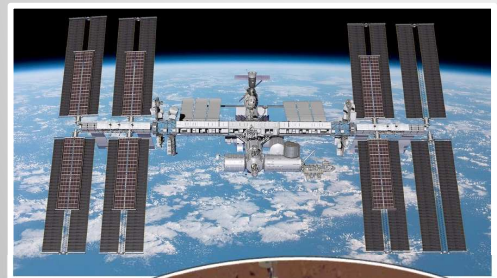
Ultra-High Efficiency Solar Cells



- Triple junction Ge/GaAs/InGaP heterostructure
- Epitaxially grown on Ge substrate
- >30% efficient solar energy conversion

APPLICATIONS:

Space Qualified Photovoltaic



NS space and defense satellites



Mars Insight Lander



Ge Optics

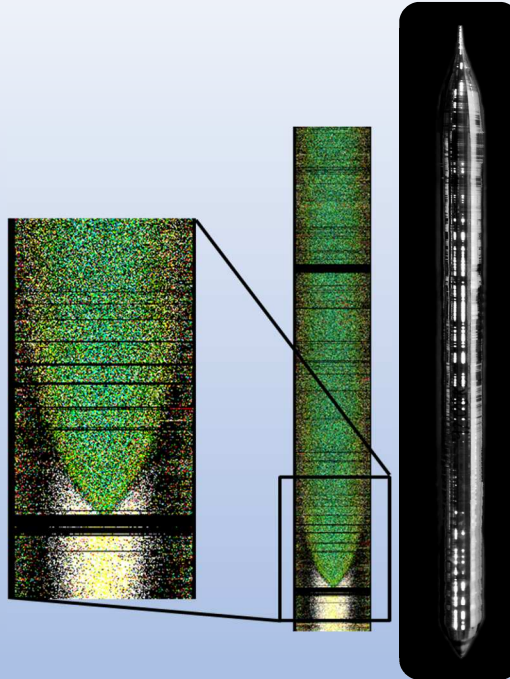
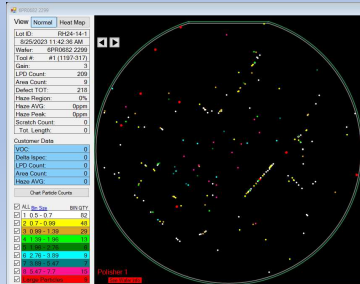
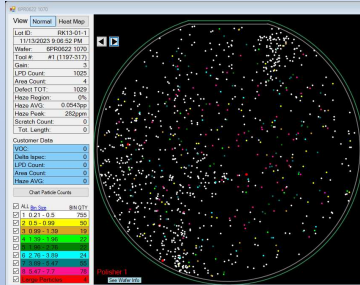
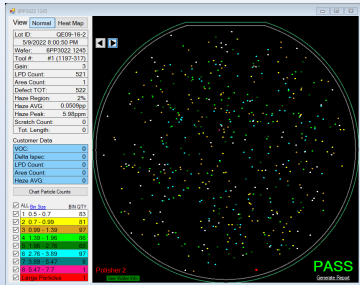
Wafer and Materials Characterization

In-house characterization

Typical void distribution for dislocation-free single crystal

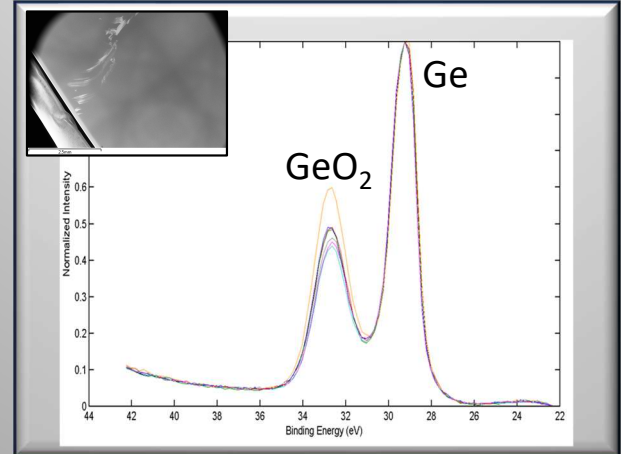
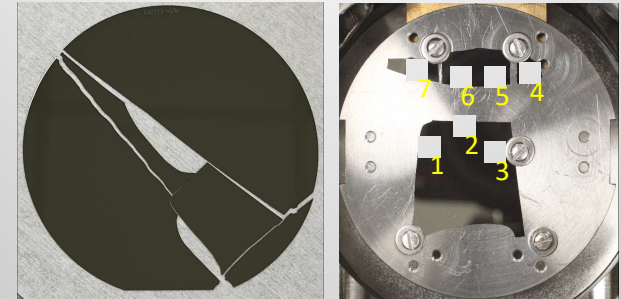
Particle Stain

Crystallographic Slip defect



Simulated axial slice shows void distribution and defects throughout entire ingot

Outsourced characterization



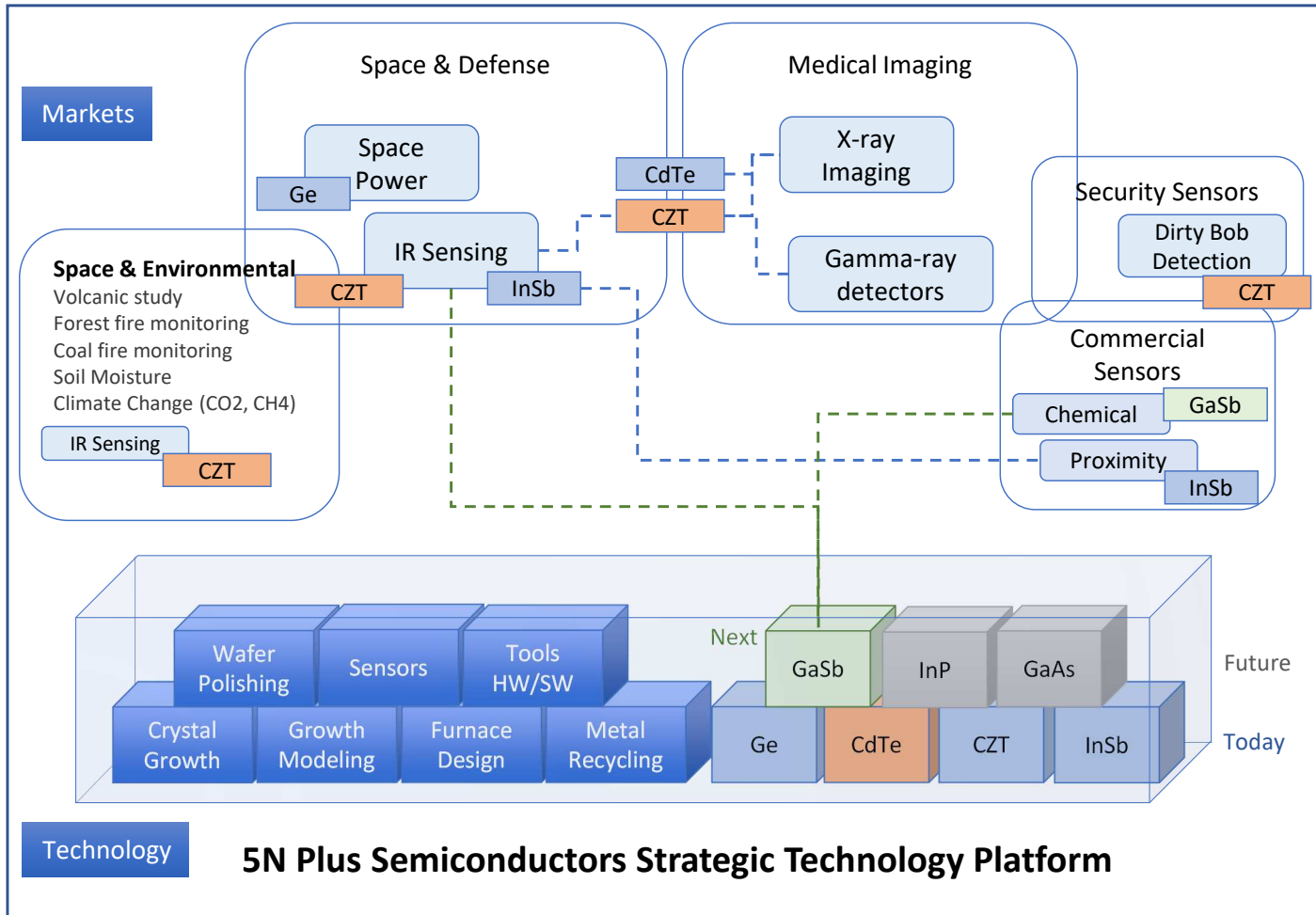
**XPS & SEM/EDS at
Aerospace Corp.**

5N+

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APPENDIX

TECHNOLOGY PLATFORM AND ROADMAP



InSb



CdTe