SAND2022-12989C

Sandia National Laboratories

Exceptional service in the national interest

Low Volume, High Mix R&D and High Reliability Production at Sandia

Scott List, HI Manager

Sandia National Laboratories

October 3, 2022

Many thanks to Erica Douglas, Gary Patrizi and Drew Hollowell !

MESA
Research | Develop | Produce

SAND2022-XXX

NNSA U.S. DEPARTMENT OF ENERGY

Sandia National Laboratories is a multimission laboratory managed and operated by National Technology and Engineering Solutions of Sandia, LLC., a wholly owned subsidiary of Honeywell International, Inc., for the U.S. Department of Energy's National Nuclear Security Administration under contract DE-NA-0003525.

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Outline:

- Mission
- MESA Complex and Technologies
- Heterogeneous Integration (HI) Capabilities
- Packaging Capabilities
- Current and Future Partnerships
- Summary

SANDIA IS A FEDERALLY FUNDED RESEARCH AND DEVELOPMENT CENTER (FFRDC) MANAGED AND OPERATED BY

National Technology & Engineering Solutions of Sandia, LLC, a wholly owned subsidiary of Honeywell International Inc.

Government owned, contractor operated

FFRDCs are long-term strategic partners to the federal government, operating in the public interest with objectivity and independence and maintaining core competencies in missions of national significance

Providing what industry cannot, will not or should not do.

Sandia's Five Major Program Portfolios

A Broad Range Of Government And Other Work, Much of Which Is Classified

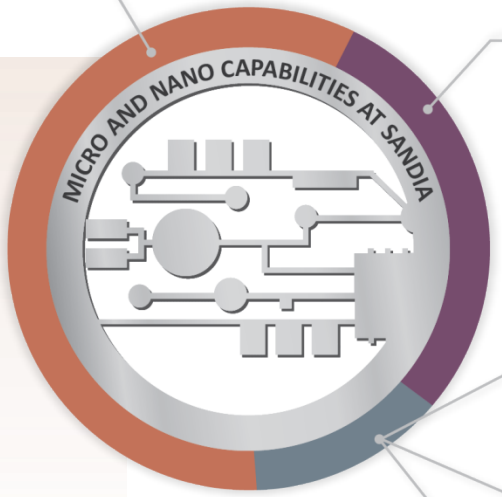
CAPABILITIES FROM OUR NUCLEAR WEAPONS PROGRAM HELP US SOLVE COMPLEX NATIONAL SECURITY PROBLEMS:

- Weapon Component and System Surveillance and Assessment
- Radiation Effects and High Energy Density Physics
- Materials Science & Engineering, and Advanced Manufacturing
- Engineering Sciences and Testing
- Physical and Biological Sciences and Engineering
- Codes, Models, Data Analytics
- Advanced Experimental Diagnostics and Sensors
- Agile Component and System Surveillance and Assessment
- High Performance Computing
- Cyber and Intelligence Science
- Synergistic Global Security Engineering
- Microsystems R&D and Manufacturing

UNIQUE FACILITIES DIFFERENTIATE SANDIA'S MICRO/NANO R&D

MESA

MICROSYSTEMS ENGINEERING SCIENCES AND APPLICATIONS



CDC

COUNTERFEIT DETECTION CENTER

CINT

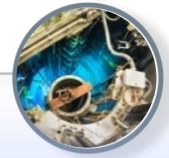
CENTER FOR INTEGRATED NANOTECHNOLOGIES

IBL

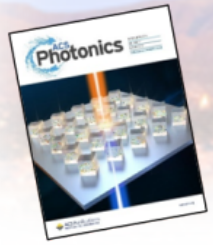
ION BEAM LABORATORY

ACRR

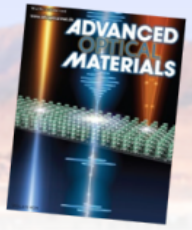
ANNULAR CORE RESEARCH REACTOR

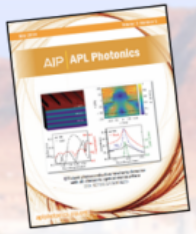


- Only source for custom strategic rad-hard microelectronics
- Largest government-owned foundry
- FFRDC with the broadest and deepest micro and nano expertise [derived R&D-product delivery work mix]

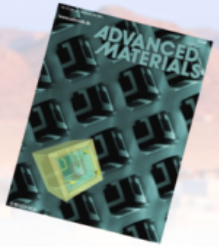


Microsystems Enabled Photovoltaics





T-QUAKE (Transceiver for Quantum Keys and Encryption)

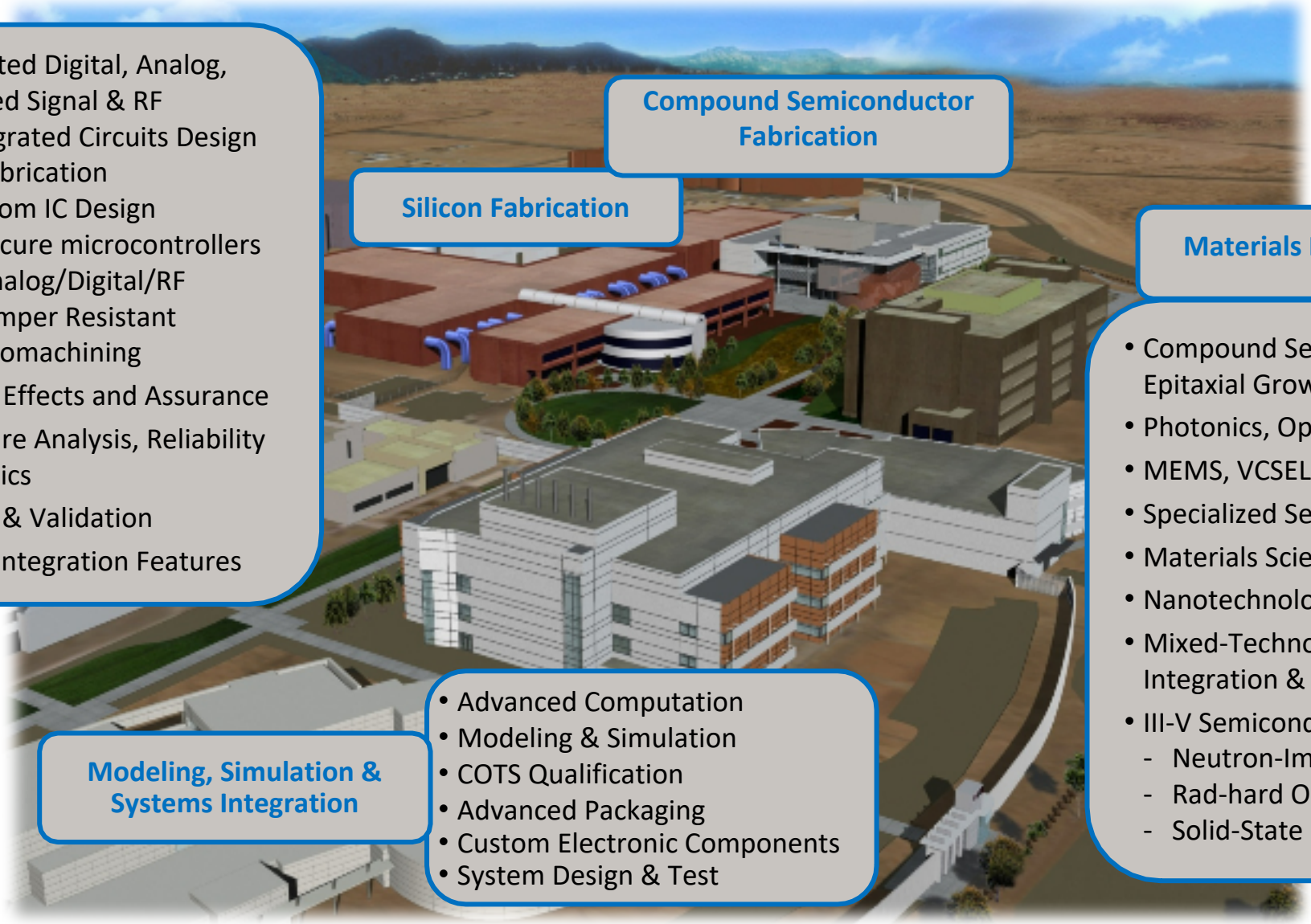


2009 Ultralow-power Silicon Microphotonic Communication Platform

MICROSYSTEMS AND ENGINEERING SCIENCES APPLICATIONS (MESA)

400,000 Sq-ft Complex with >650 Employees (65,000 Sq-ft cleanroom)

- Trusted Digital, Analog, Mixed Signal & RF Integrated Circuits Design & Fabrication
- Custom IC Design
  - Secure microcontrollers
  - Analog/Digital/RF
  - Tamper Resistant
- Micromachining
- RAD Effects and Assurance
- Failure Analysis, Reliability Physics
- Test & Validation
- 3-D Integration Features



Compound Semiconductor Fabrication

Silicon Fabrication

Materials Research

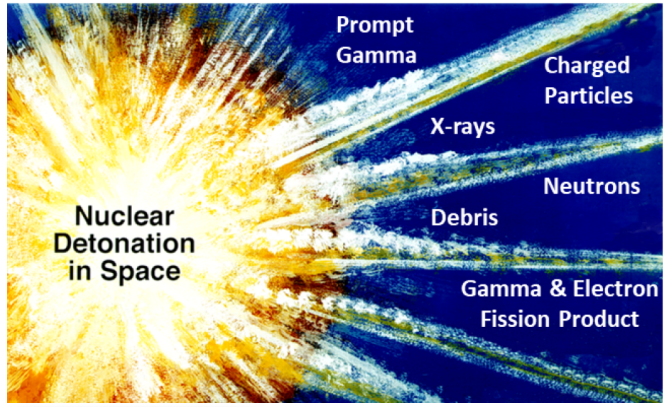
- Compound Semiconductor Epitaxial Growth
- Photonics, Optoelectronics
- MEMS, VCSELs
- Specialized Sensors
- Materials Science
- Nanotechnology, Chem/Bio
- Mixed-Technology Integration & Processing
- III-V Semiconductor Devices
  - Neutron-Immune HBT
  - Rad-hard Optical Links
  - Solid-State RF Devices

Modeling, Simulation & Systems Integration

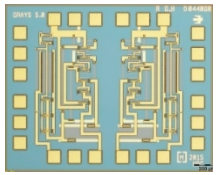
- Advanced Computation
- Modeling & Simulation
- COTS Qualification
- Advanced Packaging
- Custom Electronic Components
- System Design & Test

MESA bridges science to systems, providing an environment where multidisciplinary teams create ***microsystems-enabled*** solutions to our nation's most challenging problems.

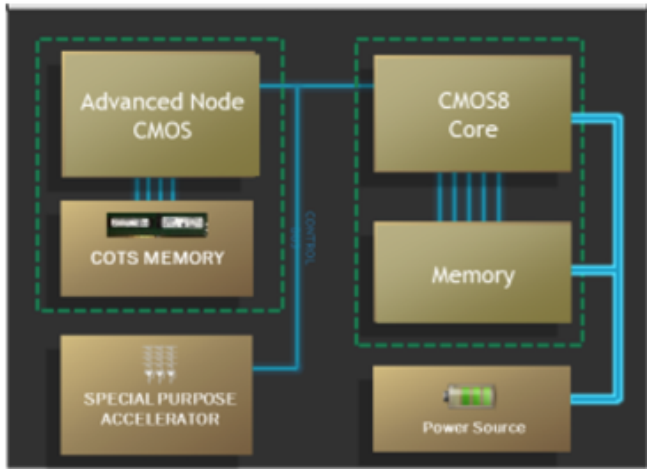
Breadth of Technologies to Address National Security Needs

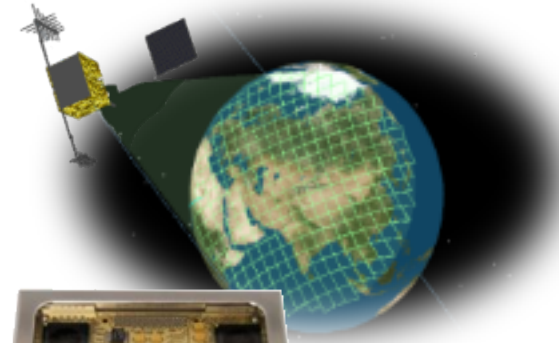


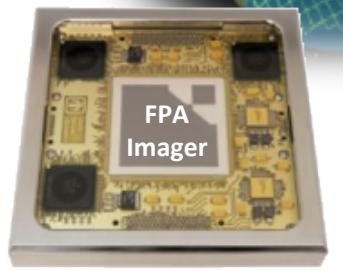
Rad Effects & Mitigations Leader
Space & Man Made Environments



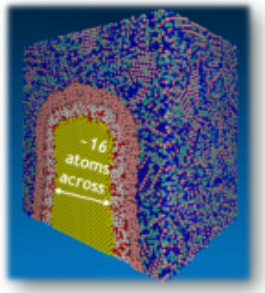
Power Solutions & Photonics
Opto-Isolators, Laser/Detector Arrays, High-Voltage ICs, Photonics

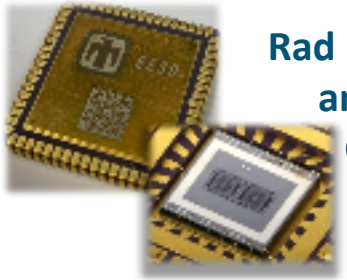




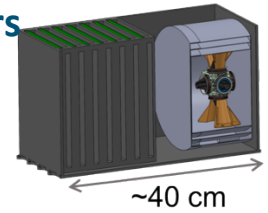


Next Gen Remote Sensing
Heterogeneously Integrated 3D Stacked Focal Plane Array



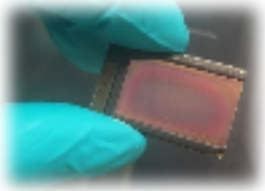


Rad Hard Accelerometers and Inertial Sensors
Chip Scale MEMS And Atom Interferometer

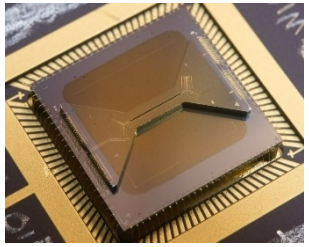


Secure, Efficient, Extreme Environment Computing (SEEEC)
Heterogeneously Integrating a Supervisor Core with a Commercial SOTA Processor

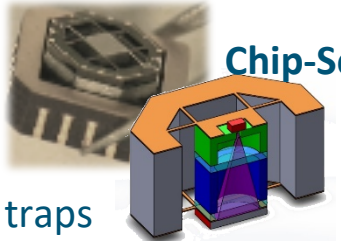
State-of-the-Art CMOS
Understanding & Mitigating Rad Effects



Ultra-Fast X-Ray Imager (UXI)
Worlds fastest multi-frame image sensors



Quantum Information Processing
Sandia is the world leader in design and realization of microfabricated (MEMS) ion traps



Chip-Scale Atomic Clock (CSAC)
lowest power Vertical-Cavity Surface-Emitting Laser (VCSEL) available

Advanced Packaging
Integration Solutions

Employing Commercial Technologies When They Meet Needs, Maturing Unique (Or Hybrid) Technologies When They Don't

Heterogeneous Integration at Sandia National Laboratories

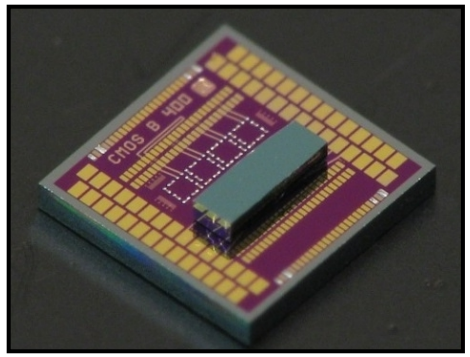
Materials

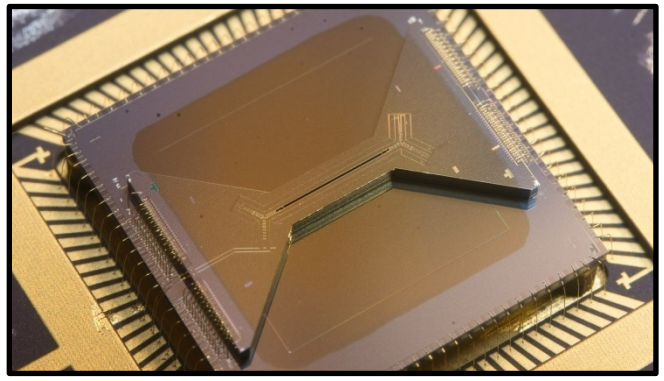
Si-to-Si

Si-to-GaAs

Si-to-InP

InP- $LiNbO_3$





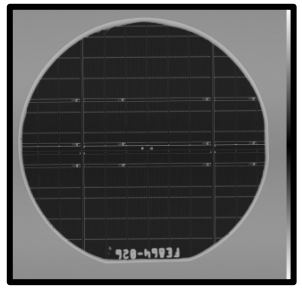
Technologies

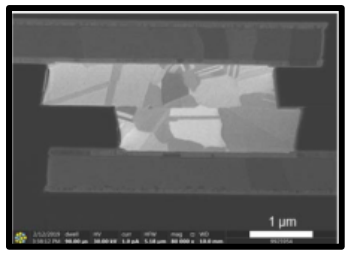
Photonics

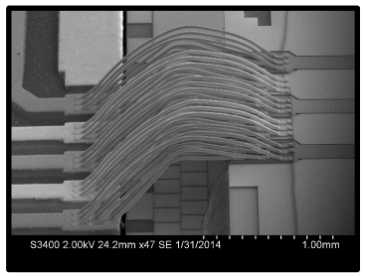
Imaging

Quantum

Communication







Bonding Techniques

Direct Bond

Oxide-to-Oxide

Eutectic

In-to-In

Cu/Au

Cu Pillar

Au Stud Bumps

Au-Au, Au-Pd Thermocompression

Solder Jetting

Sandia's role in HI as an FFRDC is to bring together multiple materials and external/internal technologies to achieve high performance, trusted, rad-hard solutions.

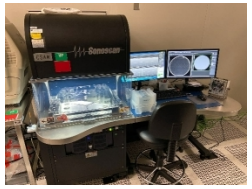
REPRESENTATIVE MESA HI CAPABILITIES

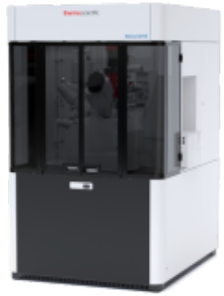
Bonding

- Wafer-to wafer DBI
- Die-to-wafer DBI
- Bump Bonding
- Oxide bonding
- Thermo-compression bonding
- Vacuum reflow
- Epoxy underfill and cure

Metrology

- Atomic Force Microscopy
- Confocal Scanning Acoustic Microscope
- 3D contour mapping
- Infrared inspection
- Scanning Electron Microscopy
- Energy Dispersive X-ray Spectroscopy
- Focused Ion Beam-SEM cross-sectioning
- Automated on-wafer test up to 300mm





Metallization

- Thermal Evaporation for complex metal stacks
- Sputter deposition for stoichiometric and novel metal films
- Plating for Through Silicon Via, Direct Bond Interconnect, bump bonding
- Indium Plating

Singulation

- Wafer Dicing
- IR wafer alignment for meeting front-side trench
- Wafer Coring
- Pick-and-place

Planarization

- Chemical Mechanical Polish of Silicon Oxide and metal Micron scale mechanical milling for bulk removal
- Wet chemical thinning

Etch

- *Deep-Si etch*
  - *Bosch etch*
- *XeF_2*
- *Atomic Layer Etch*
- *Metal etch*

Thin Films

- Oxide & Nitride deposition (PECVD and Thermal)
- Atomic Layer Deposition

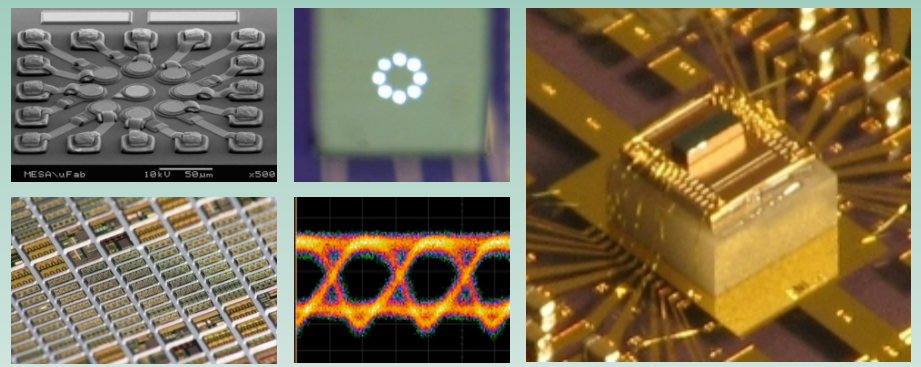
Solder Jetting

- C4 solder jetting

MESA has suite of HI tools for co-located R&D & production

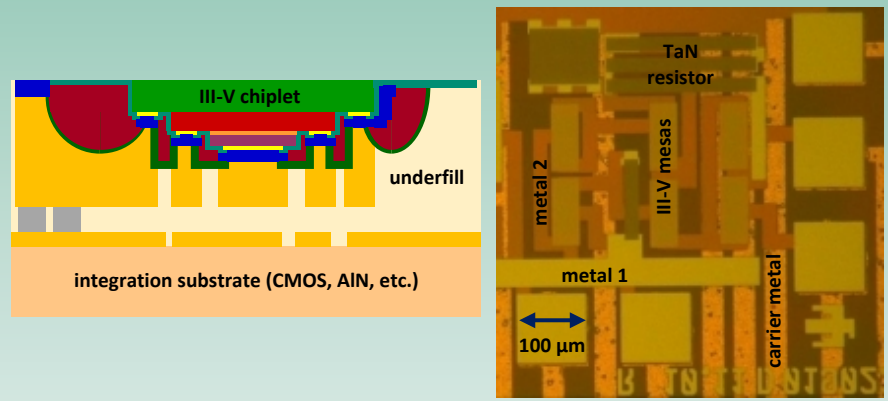
HETEROGENEOUS INTEGRATION FOR NATIONAL SECURITY

Optical Data Communications



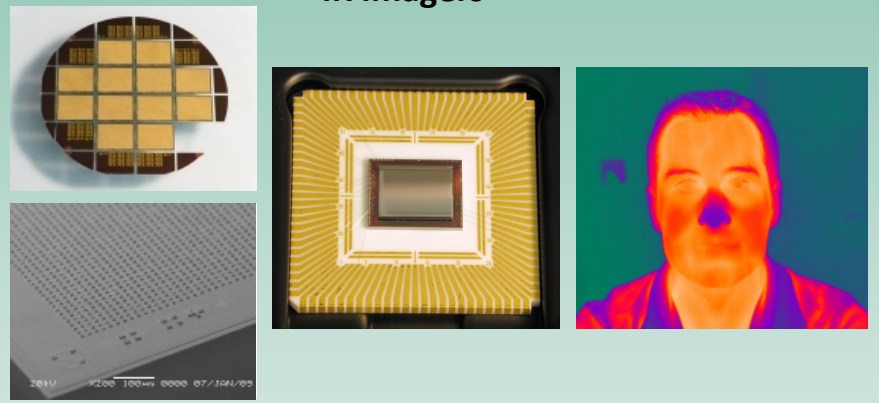
- GaAs- and InP-based VCSELs, modulators, photodiodes
- dense integration onto 32-nm and 45-nm CMOS

Heterogeneous III-V/CMOS Microelectronics



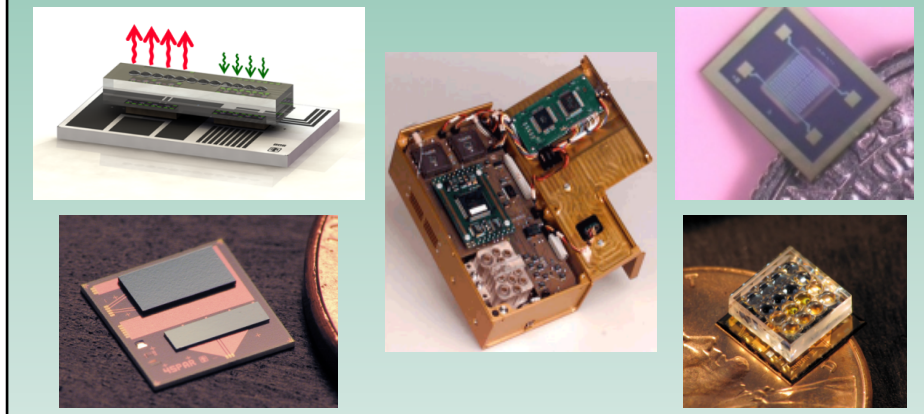
- complementary integration of GaAs and InP microelectronics
- III-V microelectronics circuitry on CMOS ASICs

IR Imagers



- GaSb-based MWIR/LWIR detector arrays for large-format FPAs
- 10µm indium bump bonding, underfill, thinning, AR coating
- hybridization to silicon ROICs with >99.99% interconnect yield

Optical and MEMS-based Microsensors



- chemical and bio sensors using MEMS and SAW devices
- g-hard optical microsensors with in-house photonics
- hybrid device integration with custom micro-optics

SNL MESA HI Enables Current & Future Applications

SNL MESA Design and prototyping

Enabling Expertise:

- Heterogeneous Integration
- Deep subject matter expertise (SME) in diverse range of technologies
  - CMOS, III-Vs, RF Microsystems, MEMS, Si photonics, FPAs/Sensors, Quantum, HI technologies
- Modeling & Simulation
- Materials Characterization
- Processing and integration
- Assembly
- …

External Supplier Production capabilities

- State of the Art CMOS
- Commercial foundries (CMOS, III-V,…)
- Assembly
- Heterogeneous integration capabilities
- KCNSC system integration
- …

SNL MESA production capabilities

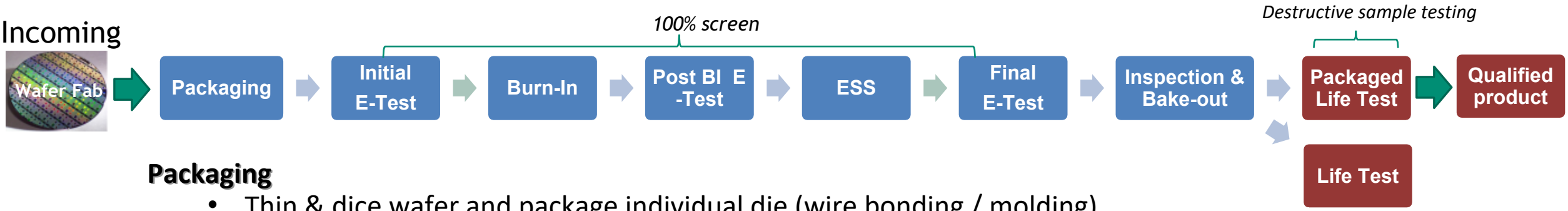
"When industry can't, won't, or shouldn't"

- Si Electronics
- III-V Electronics
- III-V Optoelectronics
- MEMS
- FPA/ Sensors
- Heterogeneous Integration capabilities
- Si Photonics (potential in future)
- Quantum (potential in future)

NNSA Products and Applications

HI will enable future National Security needs through tight integration of commercial technologies with MESA's trusted and rad-hard technologies

Representative ASICs Post Fab Production (Packaging and Test)



Packaging
- Thin & dice wafer and package individual die (wire bonding / molding)

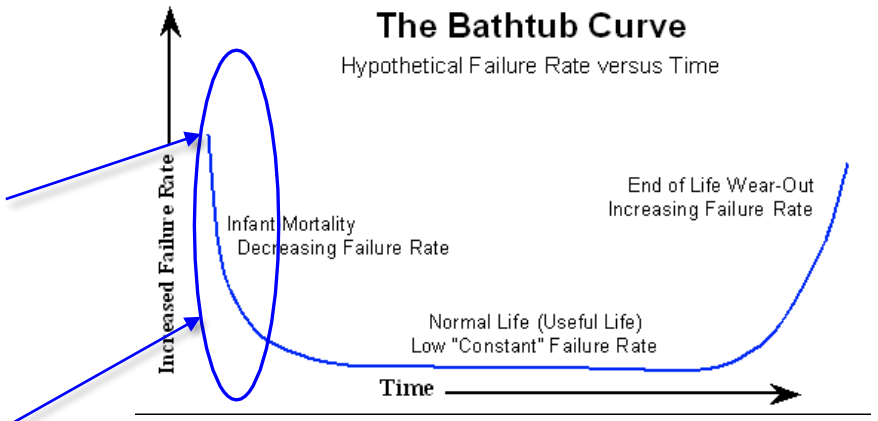
Initial Electrical
- Test to see if packaging affected electrical functionality

Burn-in
- Dynamic stimulation of part in operating conditions

Post Burn-in Test
- Electrical test after burn-in to screen out **infant mortality functional failures**

Environmental Stress Screen
- Temperature cycling

Final Electrical
- Screen out **infant mortality** failures due to **packaging related defects**



Packaged Life Test
- To detect systemic defects that would lead to latent failures of the product in service

Life Test
- Accelerated life test of the die meant to represent a lifetime or more of service

Post-Fab flows can be realized with both internal and external suppliers

SANDIA'S COLLABORATIONS

- Sandia currently has many industrial partnerships in the RF, CMOS, HI, system integration and packaging spaces to meet its current and future mission needs.

- Sandia works closely with KCNSC to integrate our components into robust systems.

- **Our partnerships generally require:**
  - **trusted / DMEA facilities**
  - **low volume / high reliability processing capabilities**
  - **long term stability / commitments (10-30 years).**

- In the near term, Sandia anticipates a growing need for partnerships to meet increasingly demanding system requirements.

- Sandia is also actively participating in collaborations involving future CHIPS+ funding.

- Sandia provides what industry cannot, will not or should not do.

SUMMARY

- Sandia's extensive technology portfolio, co-located R&D with production, as well as national security mission has provided unique capabilities for tackling unique HI applications.
- Sandia's role is to integrate multiple materials and external/internal technologies to achieve high performance, trusted, reliable, rad-hard solutions.
- Sandia developed low volume internal packaging capabilities to ensure long term access to trusted packaging.
- Sandia partners with industry whenever possible and anticipates a large increase in partnerships for both SOTA chips and HI capabilities in the near future.
- **Please contact me directly if you have interests in partnering in this unique product space- rlist@sandia.gov.**