

# The Center of **Innovation**

**2.5/3D Integration:  
A Difficult but Necessary Component  
of Next Generation Systems**

John Behnke  
June 29, 2017

*To be the premier, trusted provider of advanced integration solutions that accelerate our customers' complex chip technologies to market.*

*Better Performance Through Smarter Integration  
We Build on. Build in. Build up.*

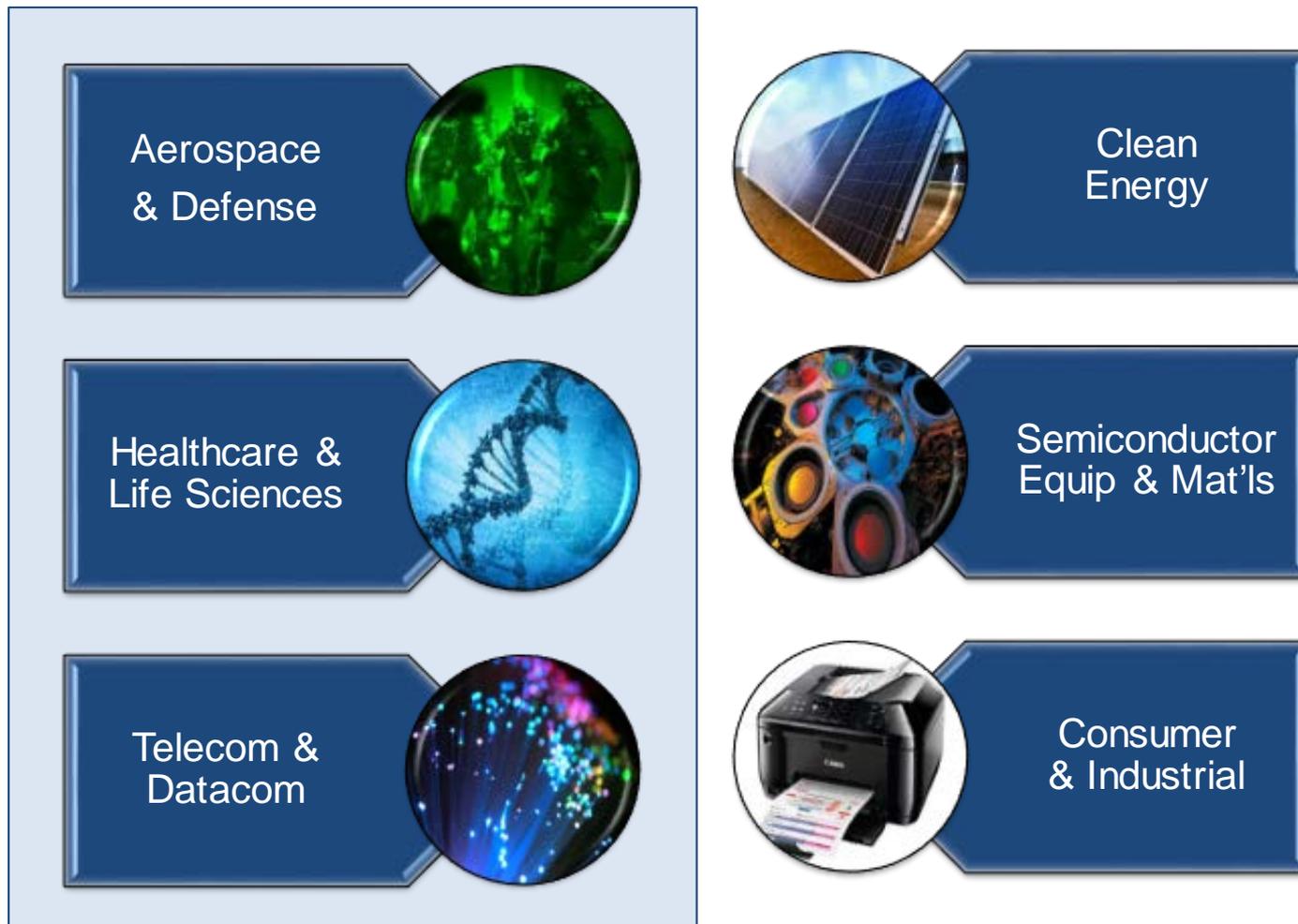
# Capabilities

- 68,000 sq ft Class 10 clean room (150 production grade tools)
- Full-flow 200mm silicon processing; 300mm back-end (Copper/Low-k)
- “More than Moore” 2.5/3D Leader
- Leading edge 200mm BEoL capability
- Novel materials (ALD, PZT, III-V, etc)
- Contact thru 193nm lithography (65nm CD)
- IP Secure Environment, Robust Quality Systems
- Silicon, SOI & Transparent MEMS substrates
- Onsite analytical tools and labs
- Split Fab processing expertise
- ITAR registered, Trusted Foundry



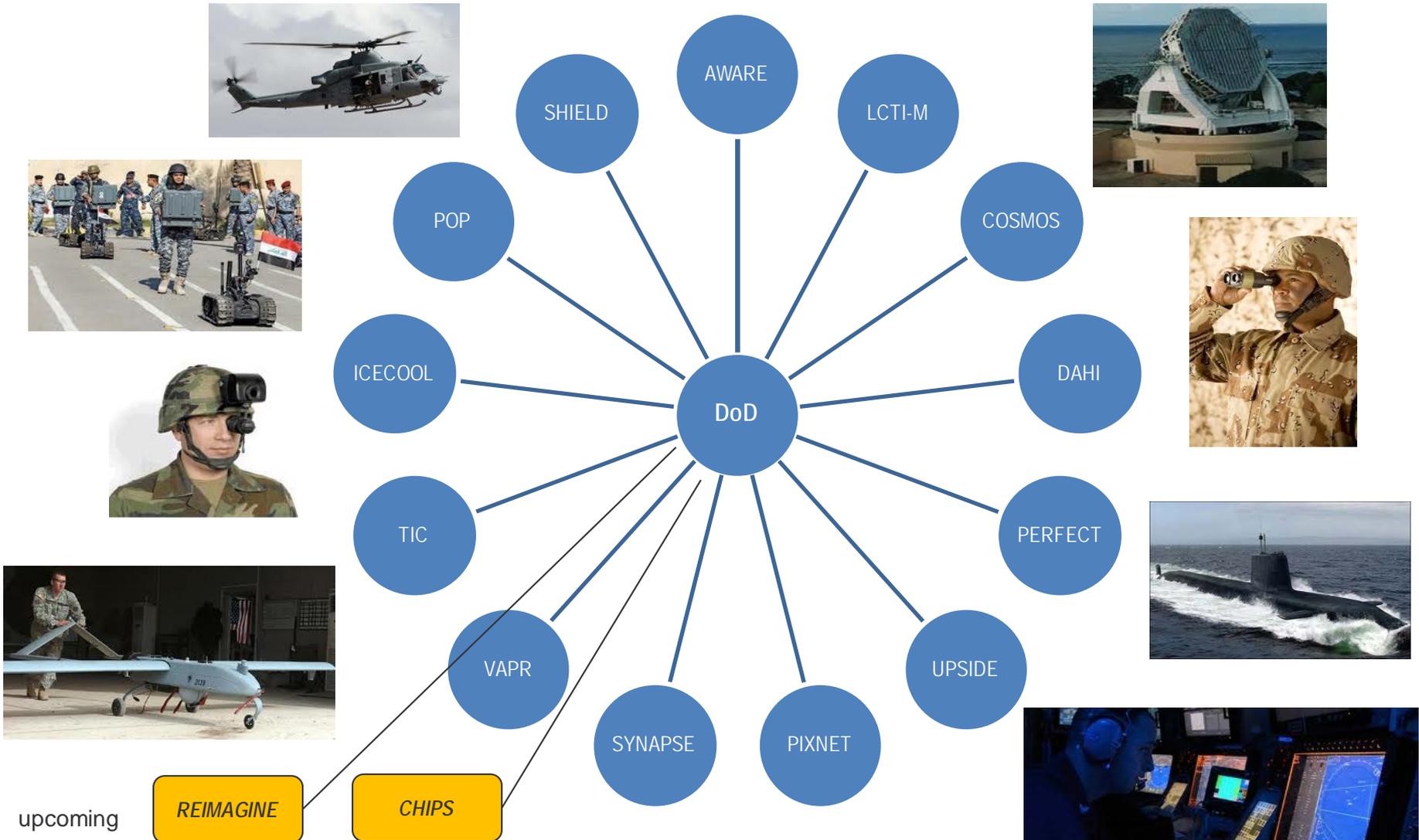


# Balanced Market Focus



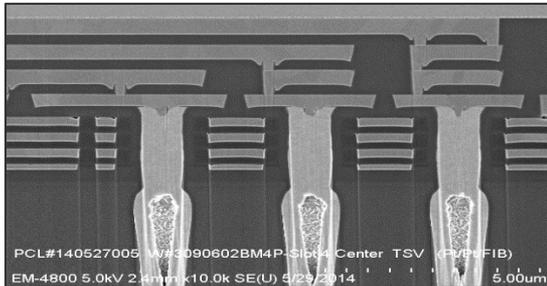
Primary Markets

# Participation in government programs



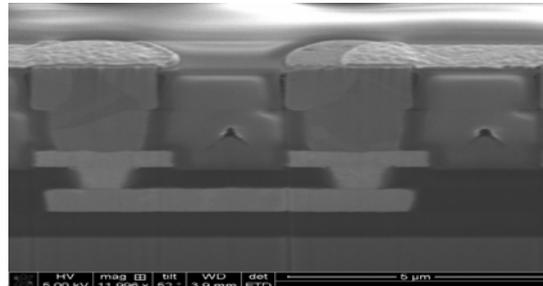
# Our Technology Platform

## Focused on Convergence of Three Critical Areas



### 2.5D & 3D Assembly

- Merchant Fab Licensee of Ziptronix Direct Bond technology
- Copper BEOI to support multi-level metal, redistribution, TSV



### Heterogeneous Integration

- Hybridization of Silicon and non-silicon (quartz, GaAs, InGaAs, GaN) substrates
- Non CMOS elements – ie: GaN HEMT's, photonic waveguides, etc

|                             |                              |                              |                              |                            |
|-----------------------------|------------------------------|------------------------------|------------------------------|----------------------------|
| 23 50.942<br>V<br>VANADIUM  | 24 51.996<br>Cr<br>CHROMIUM  | 25 54.938<br>Mn<br>MANGANESE | 26 55.845<br>Fe<br>IRON      | 27 58.933<br>Co<br>COBALT  |
| 41 92.906<br>Nb<br>NIOBIUM  | 42 95.96<br>Mo<br>MOLYBDENUM | 43 (98)<br>Tc<br>TECHNETIUM  | 44 101.07<br>Ru<br>RUTHENIUM | 45 101.07<br>Rh<br>RHENIUM |
| 73 180.95<br>Ta<br>TANTALUM | 74 183.84<br>W<br>TUNGSTEN   | 75 186.21<br>Re<br>RHENIUM   | 76 190.23<br>Os<br>OSMIUM    | 77 194.22<br>Ir<br>IRIDIUM |

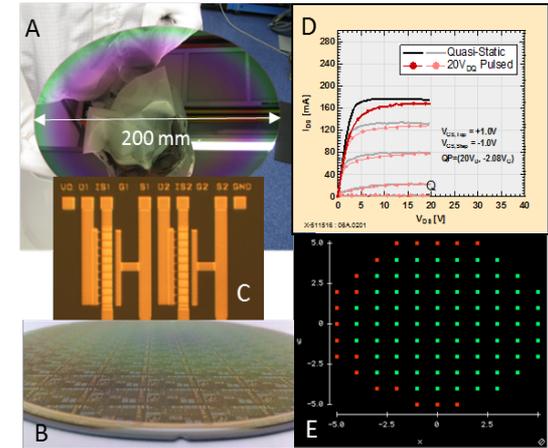
### Novel Materials

- More than 60 elements from periodic table can be leveraged in the fab today
- World's fastest most flexible on-boarding of new materials

***Enabling Smart Sensors, Advanced Imagers, RF/Power Electronics***

# Novati: *Beyond Silicon*

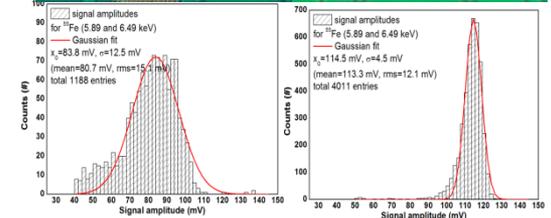
- Novati is the leading provider of advanced fab solutions to enable next-gen system functionality
  - **Compound Semiconductor Integration**
    - Integrated RF GaN on Si
    - Integrated Photonics (InP, InGaP) on Si
  - **3D (and 2.5D) Integration**
  - **Superconducting / Quantum Materials**
- Developing scalable solutions to leverage the 200mm domestic fab infrastructure



A/B) Raytheon GaN on 200 mm Si processed at Novati; C) Au-free FETs with Cu interconnect; D) test FET DC and pulsed I-V curves; and E) wafer map showing high yield of baseline GaN on Si fab process.

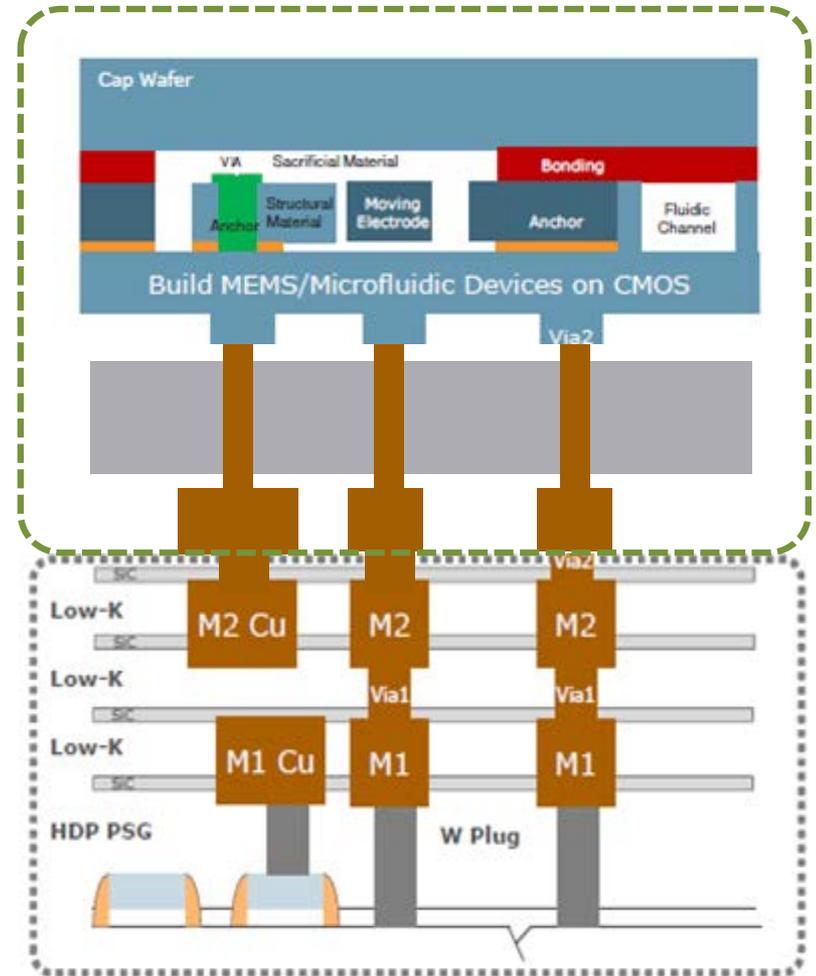
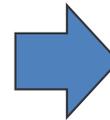
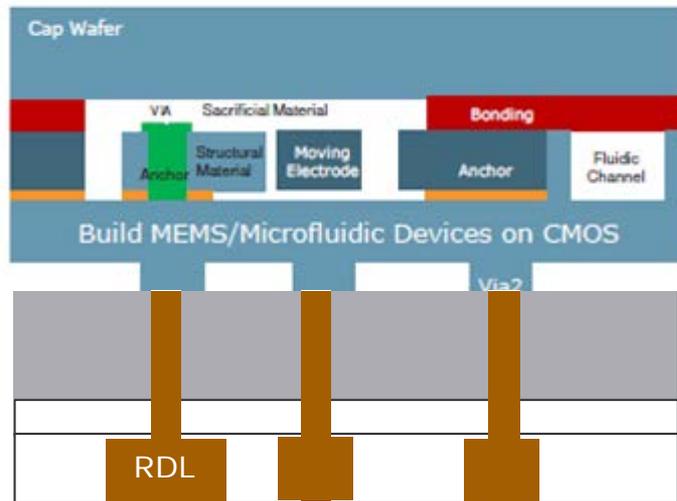
Traditional Bump-Bond

Novati DBIBond



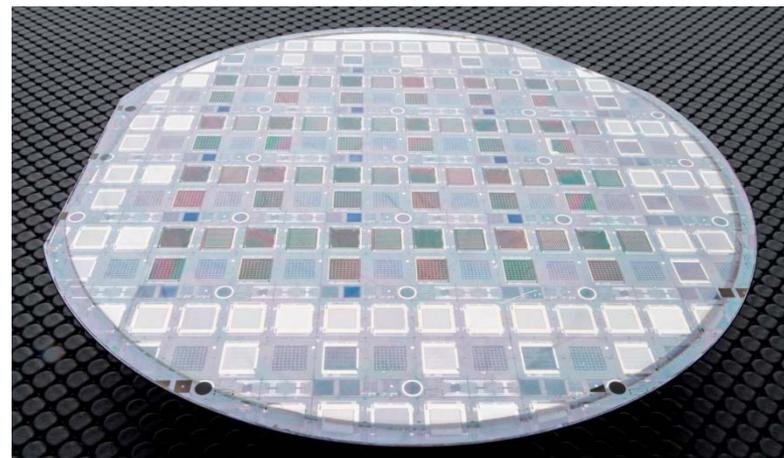
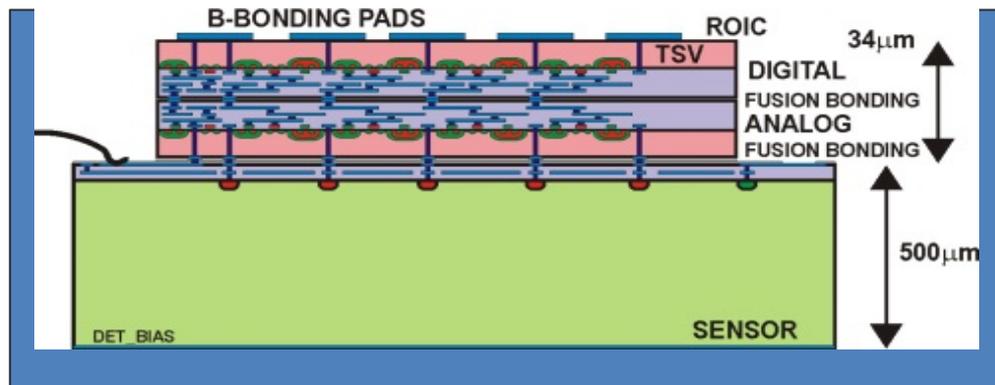
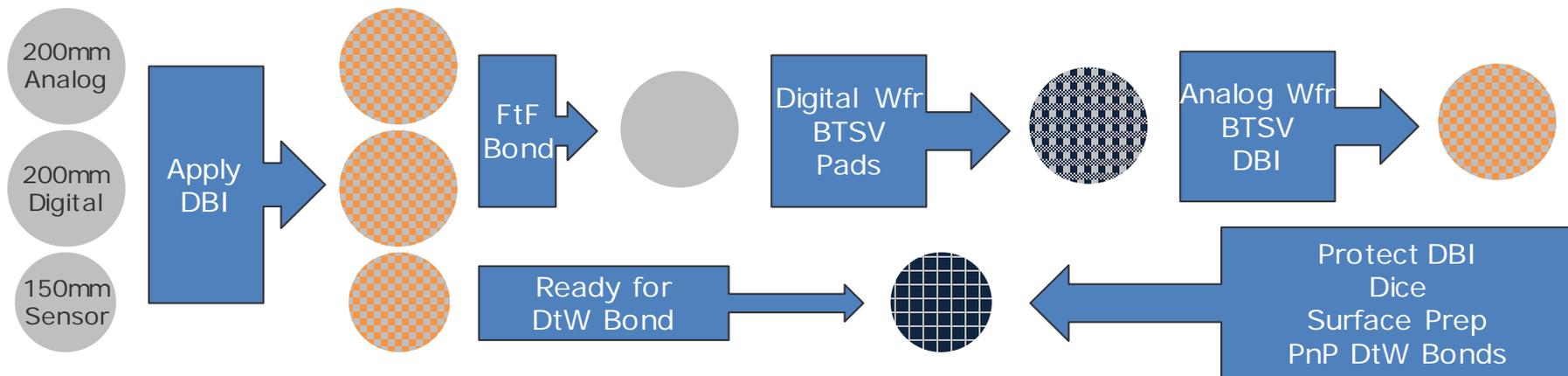
30% higher signal gain and 4x sensitivity improvement on same sensor DBI vs Bump

# 3D Integration Concept



1. Wafer thinning
2. Through-Si-Via (TSV) etch
3. TSV fill and DBI Bond layer
4. Bond to CMOS wafer

# Application to Sensors



- Optimize Digital, Analog, Sensor performance individually
- Ability to select KGD for bonding to sensor wafer



# Dramatic New Levels of Performance

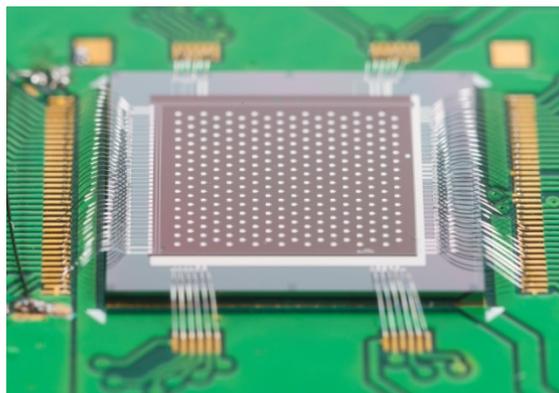
## - 3D Three Layer Bonded Sensor

### Traditional Bump-Bond



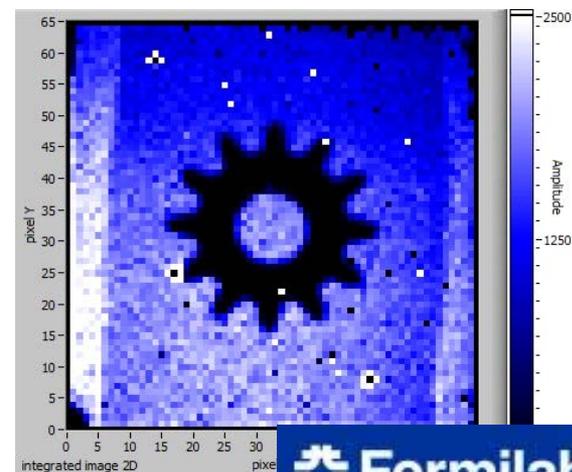
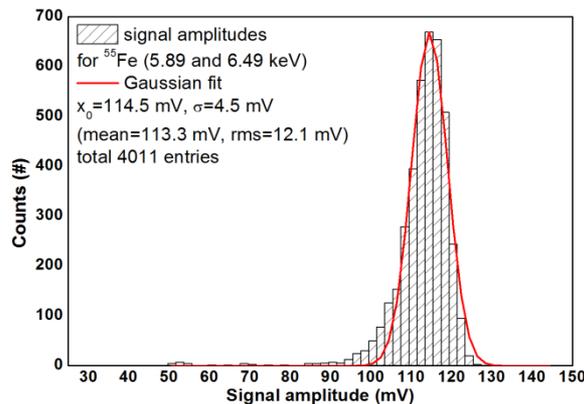
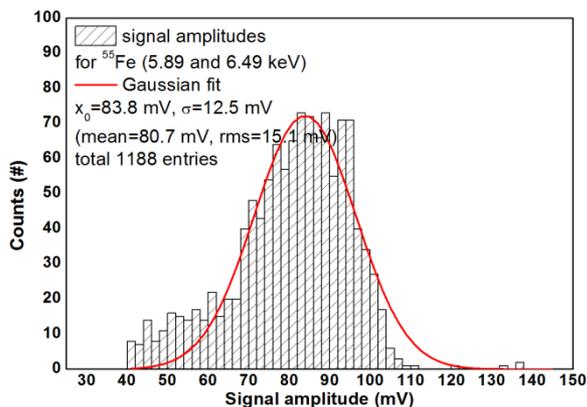
5.4 × 6.5 mm<sup>2</sup> VIPIC with  
32 × 38 pixels detector,  
traditional bump bond

### Novati Advanced DBI Bond



34 μm thick VIPIC DBI bonded  
to 64 × 64 with backside pads

- 30% higher signal gain
- 4X sensitivity improvement
- Driven through reduced parasitics
- Very hard >500MRad

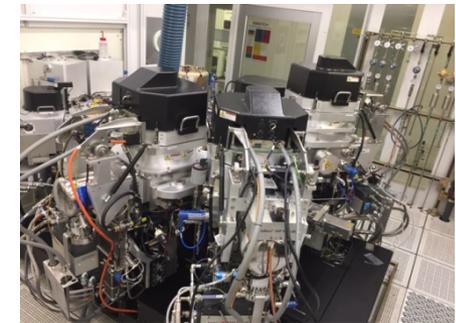
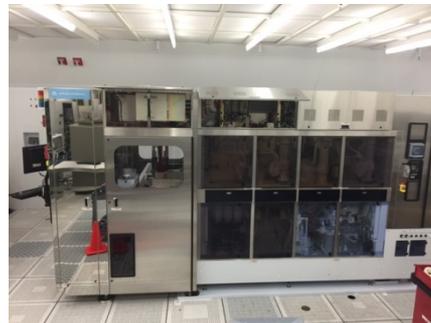


# Investment – Core Fab Capability

Creating One of the World's Most Advanced 200mm BEoL Fab Capabilities



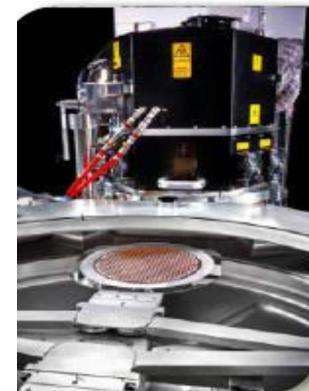
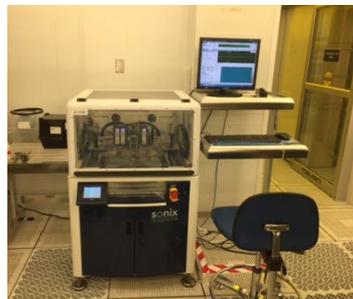
- Canon 5500iZa iLine, with IR alignment for 3D
- AMAT Mirra-Mesa
- AMAT Endura
- AMAT Raider



# Investment – Enabling 3D

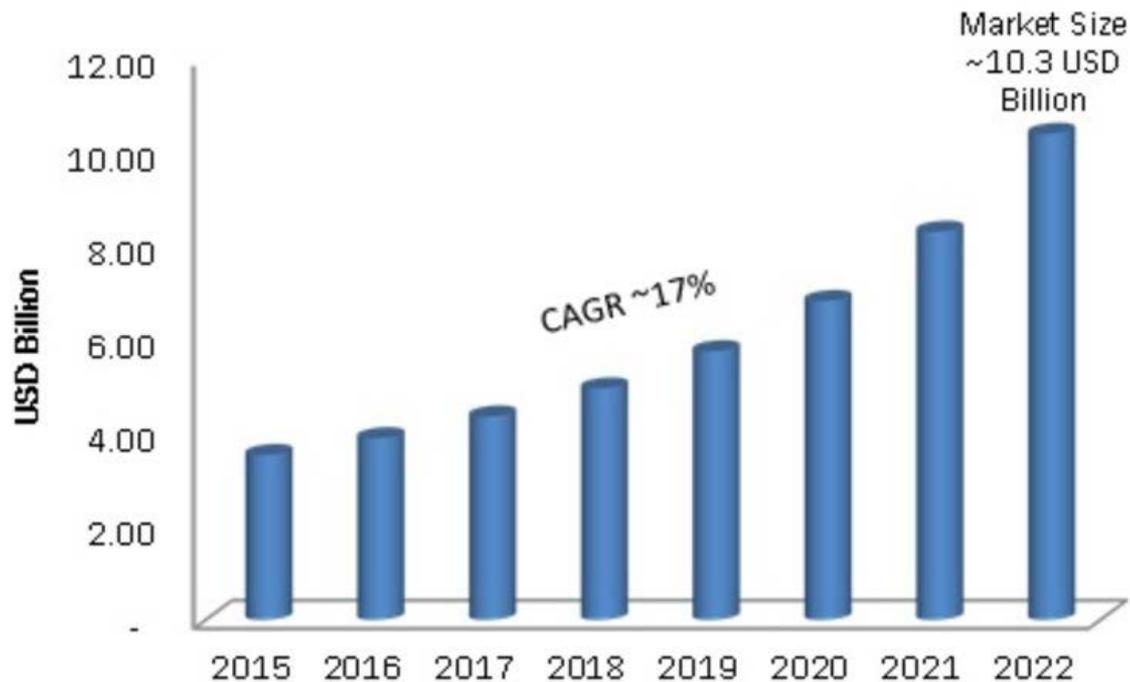
Delivering the World's Most Flexible 3D Integration Solutions

- EVG Gemini aligned bonder
- Revasum grinder & edge trim tools
- Sonix c-SAM bond void detection
- SPTS Etch and Deposition
- SPTS Plasma Singulation tool



# Global 3D IC Market (2016-2022)

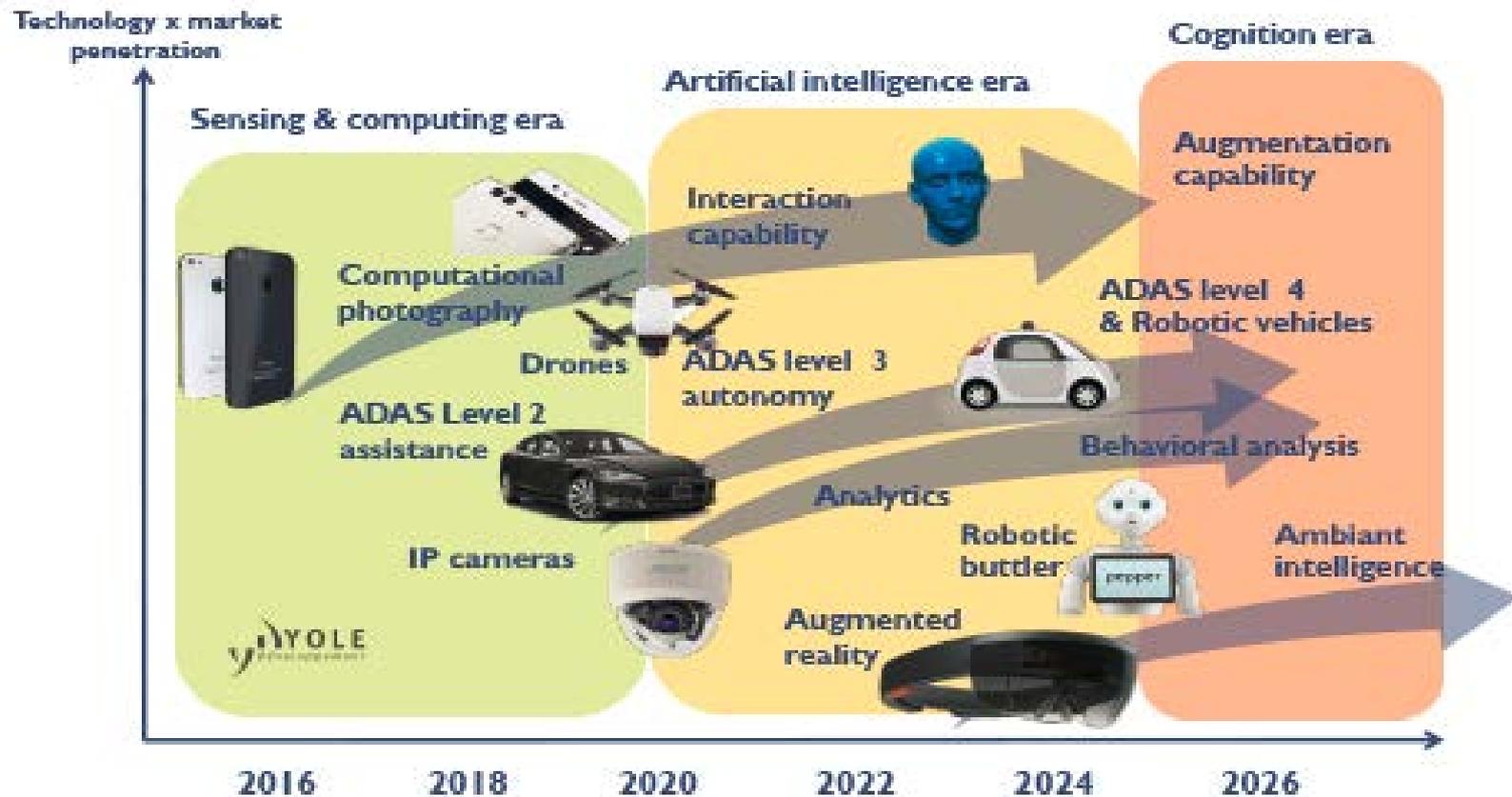
- Globally the market for 3D IC market is expected to grow at the rate of more than ~17% from 2016 to 2022.



# Sensor Proliferation will Drive 3D

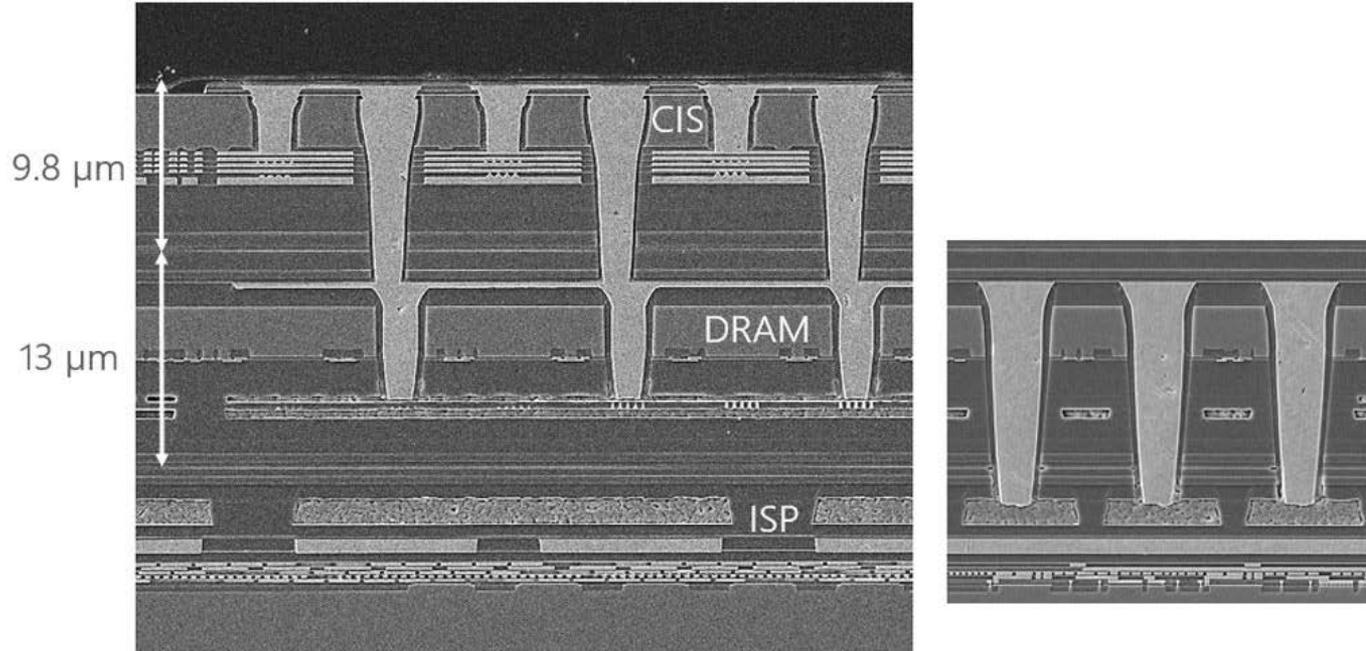
## Image sensor application: what is next

(Source: Status of the CMOS Image Sensor Industry 2017, June 2017, Yole Développement)



## Sony 3-Layer Stack

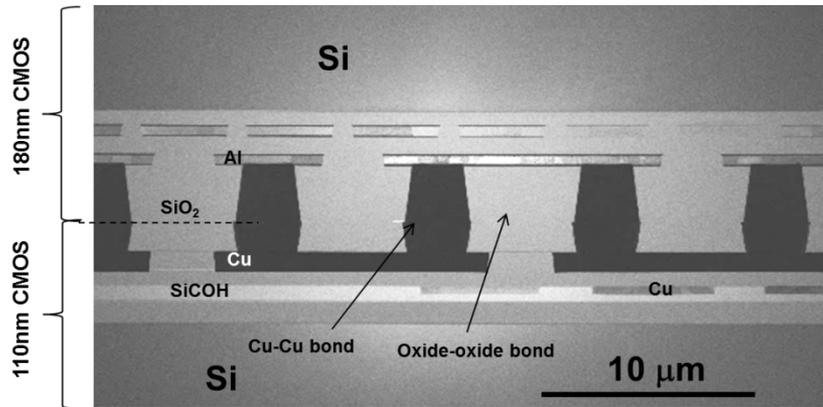
**SONY**



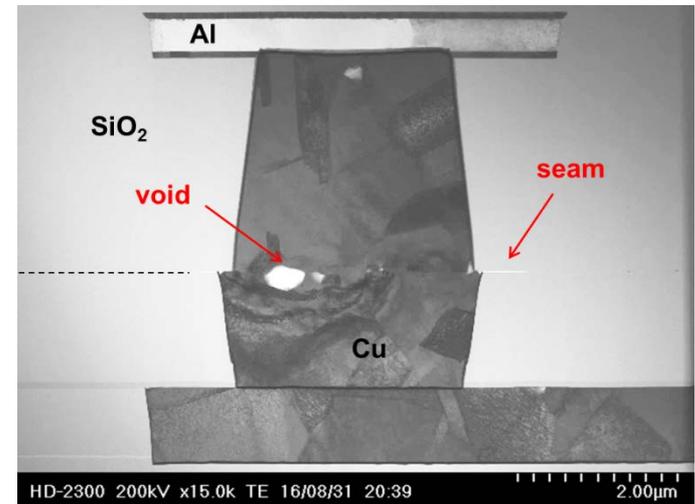
World's First 3-Layer Stacked CIS  
(2017)

**Tech**  
Insights

# Reliability of Hybrid Bond Interconnects



Low magnification STEM bright field image of hybrid bond interface showing multiple Cu-Cu bonds.



High magnification STEM bright field image of hybrid bond interface showing a single Cu-Cu bond.

| Test                           | Reference              | Test Conditions             | Sample Size | Results |
|--------------------------------|------------------------|-----------------------------|-------------|---------|
| HAST Unbiased (uHAST)          | JESD22-A110            | 130°C/ 85%RH for 96 hrs     | 5           | 0 fails |
| Temperature Cycling (TC)       | JESD22-A104C & AECQ100 | -40°C to 85°C 1000 cycles.  | 45          | 1 fail  |
| High Temperature Storage (HTS) |                        | 200°C, 500 hr (wafer level) | 150         | 0 fails |

Data provided by:  
ON Semiconductor and  
Ball Aerospace

# The Ultrafast X-ray Imager (UXI) Program

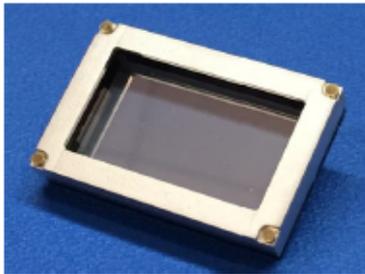
The UXI program has developed or has experience in the 3 key technologies required for an hCMOS imager



## Read-Out Integrated Circuit (ROIC)

Under the UXI program, SNL has developed a portfolio of ROICs demonstrating incremental improvements and features

- 25  $\mu\text{m}$  spatial resolution
- 448-512 x 1024 format
- $\sim 2$  ns integration time
- 2-4 frames native, 8 frames interlaced
- 500 k - 1.5 M  $e^-$  full well



Hippogriff in SOP package w/  
25  $\mu\text{m}$  Si photodiodes



## Detectors

Under the UXI program, SNL has developed a number of silicon detector variants:

- **25  $\mu\text{m}$  thick** – Vehicle for 4.7-6.1 keV X-ray, energetic electron, and visible light detectors
- **100  $\mu\text{m}$  thick** – Possibly useful for up to 13 keV X-ray detection (Absorption 30% @ 13 keV)

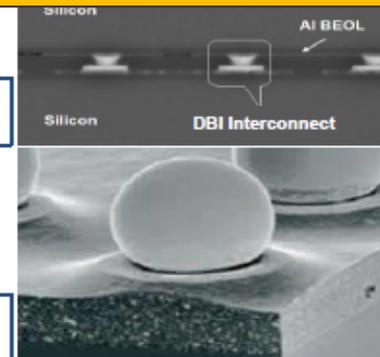
## Hybridization

Indium and Direct Bond Interface (DBI) are both options:

- DBI is licensed by SNL and in development in-house
- DBI off-site at Novati
- Indium available in house

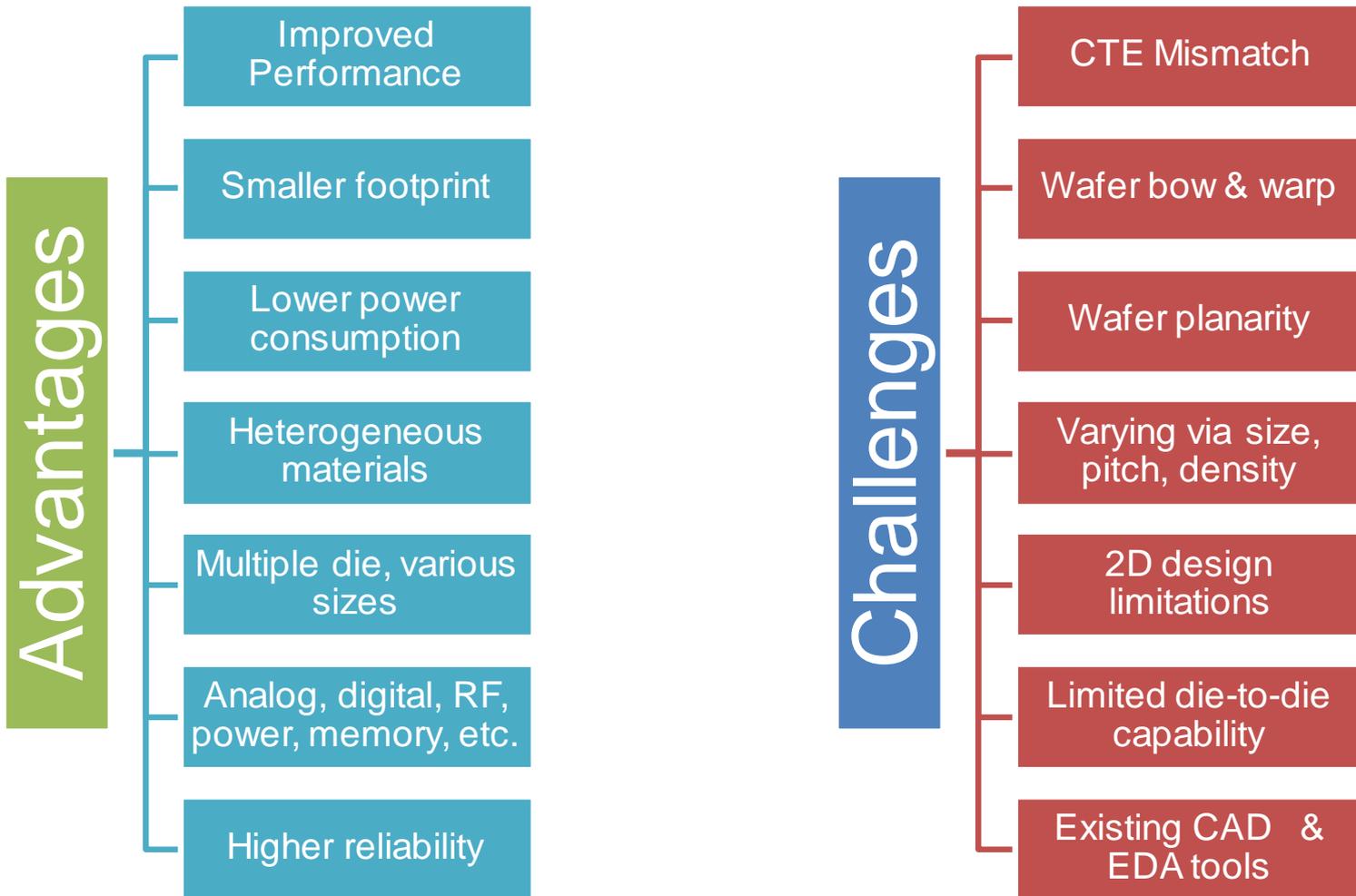
Oxide-to-oxide "Direct Bond Interface"

Indium Bump



A hybrid sensor enables independent optimization of the diode array & the readout electronics (ROIC).

# 3D advantages *will* outweigh the challenges!



- Market is driving demand
  - Need to reduce risk and difficulty/NRE; make 3D the only solution
  - Commercial leading *easier* apps, A&D leading *hard* apps
- EDA tools need significant improvement
  - Major players investing in support software
  - Need rules which comprehend cross bond interface routing
- Tool Capabilities
  - Semiconductor equipment manufacturers are improving 3D tools. Both for chip level integration and inspection tools
- Program costs and lead-times must come down
  - Program development can be significantly reduced by using standard modules/flows & leveraging improved 3D EDA tool capabilities *before* taping out a design