Too Hot To Test

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Hot Packaging Solutions

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Ack. Madhusudan Iyengar (Google) on behalf of HIR Thermal TWG

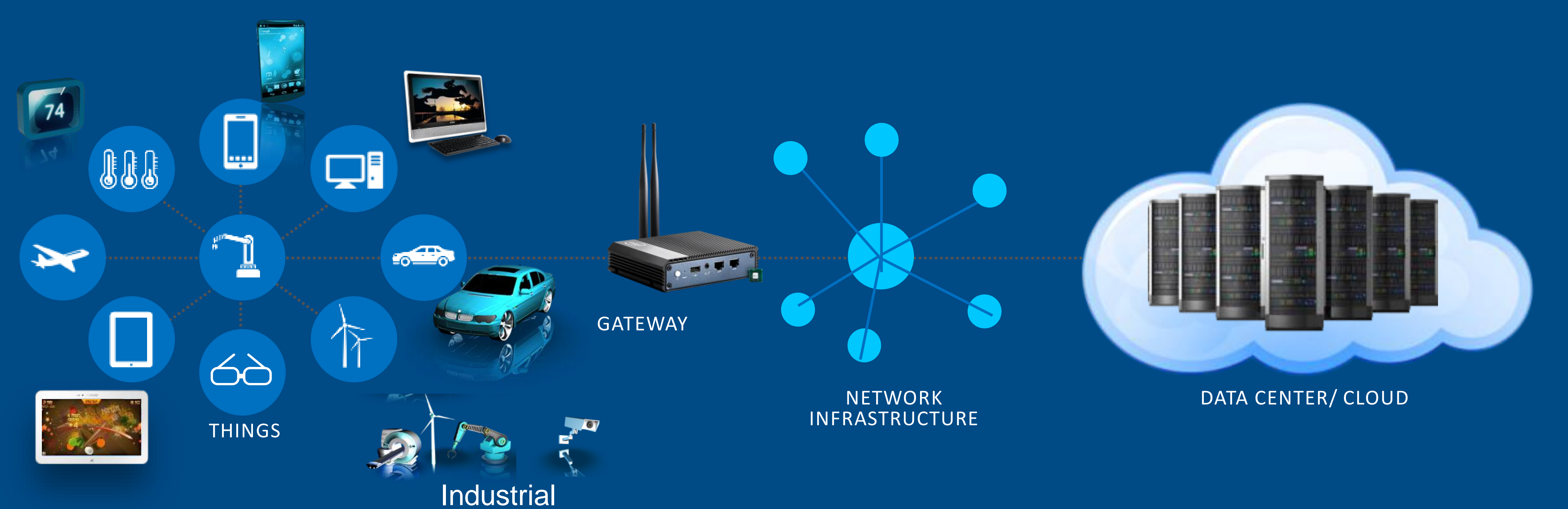
February 2021

Agenda

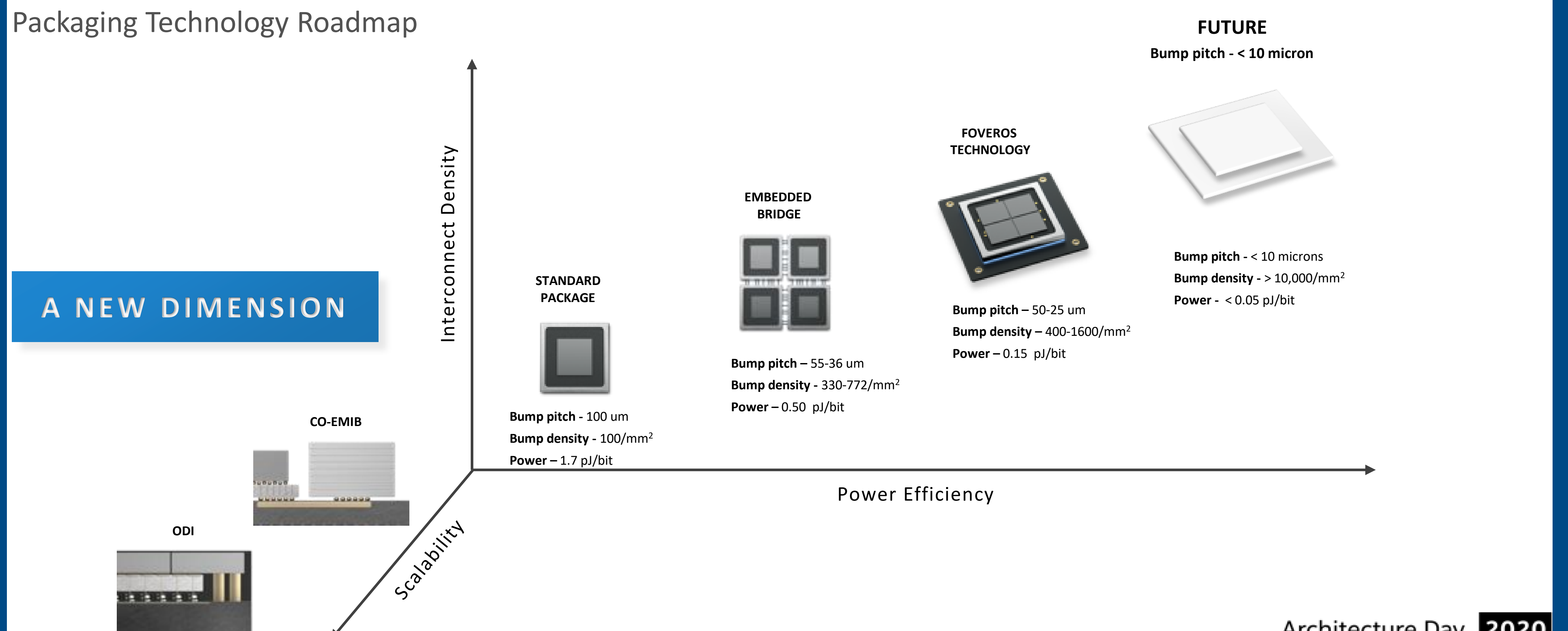
- Overview of the Evolution of Electronic Packaging
- Advanced Packaging & Associated Thermal Challenges
- Addressing Thermals at the Silicon, Package and System-level
- Call to Action

The Diversity of Connected Devices

- Broad Spectrum of Devices, Packages & Form Factors
- Power consumption from a few watts to several hundred watts
- Cooling solution and system boundary conditions are quite different and diverse

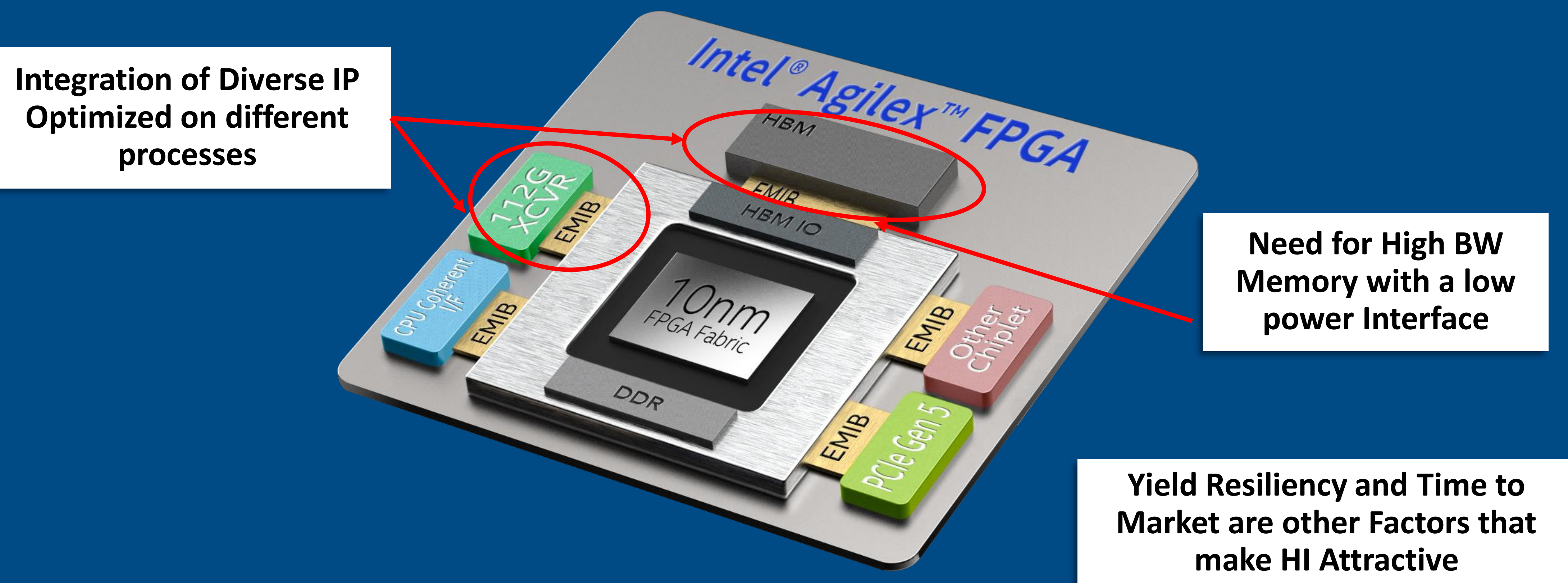


Packaging Technology Driven by Si Scaling, IO density and Heterogeneous Integration



Increased Interest in Heterogeneous Integration: Power, IO, Resiliency and TTM

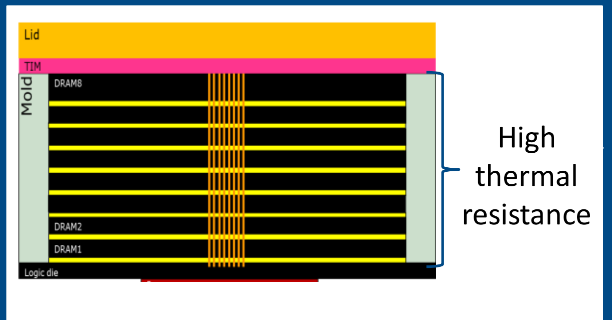
Integration of Diverse IP Optimized on different processes

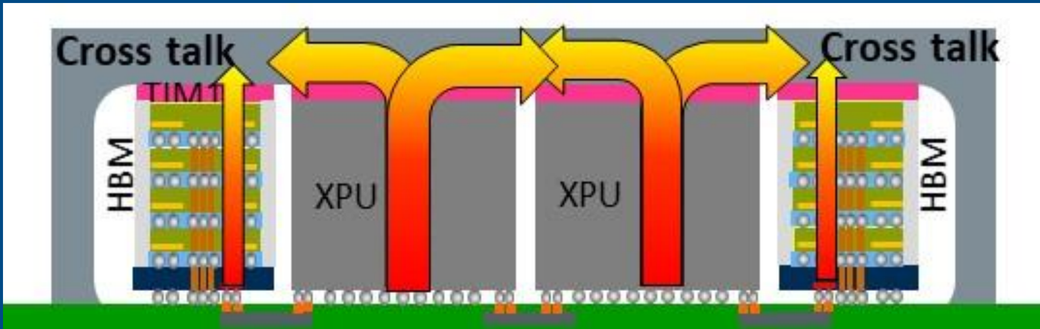


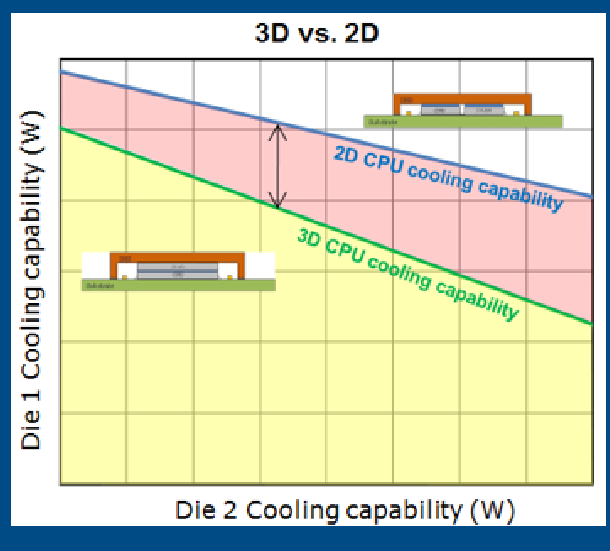
Need for High BW Memory with a low power Interface

Yield Resiliency and Time to Market are other Factors that make HI Attractive

Heterogenous Packaging: Thermal Challenges

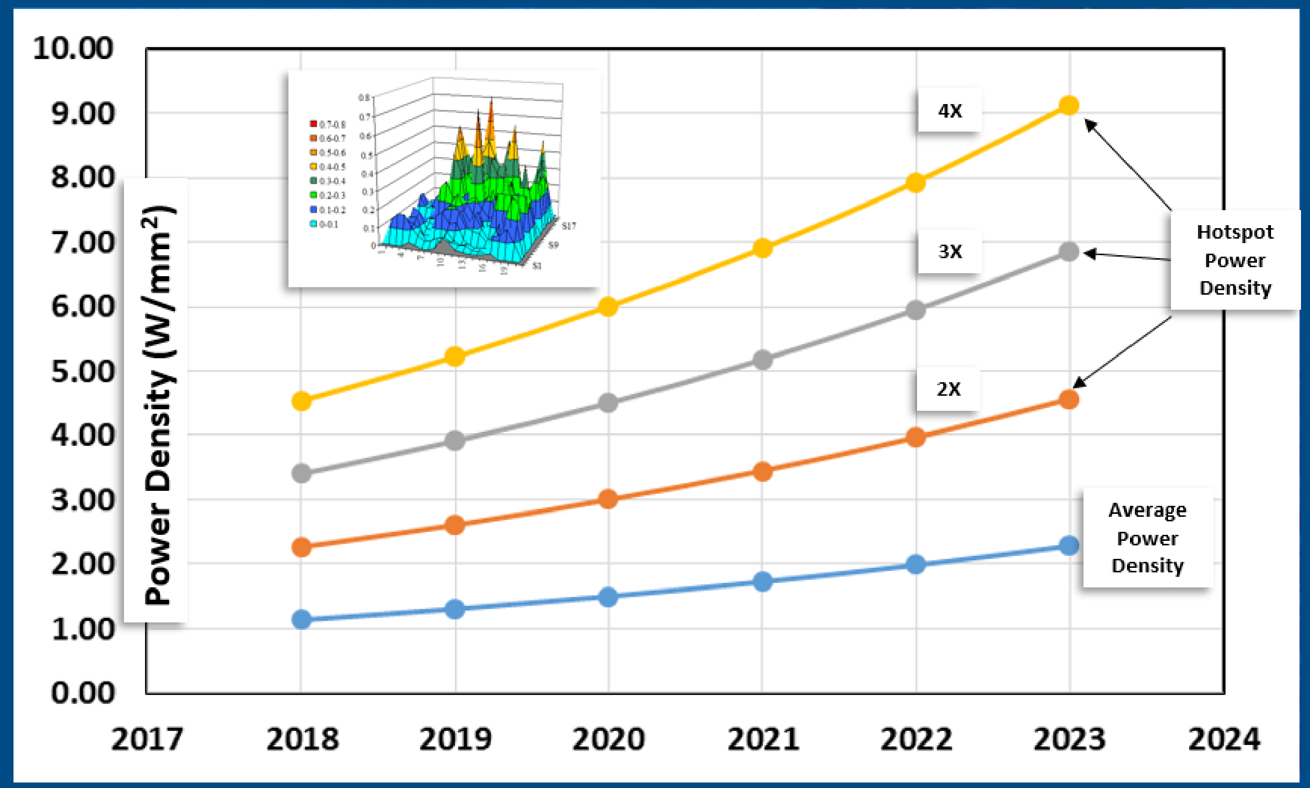






- Increasing power and power density
- Increasing package thermal resistance
- Thermal cross-talk, including thermal isolation
- Different thermal (Tj) requirements for each functional IC
- Thermo-mechanical enabling

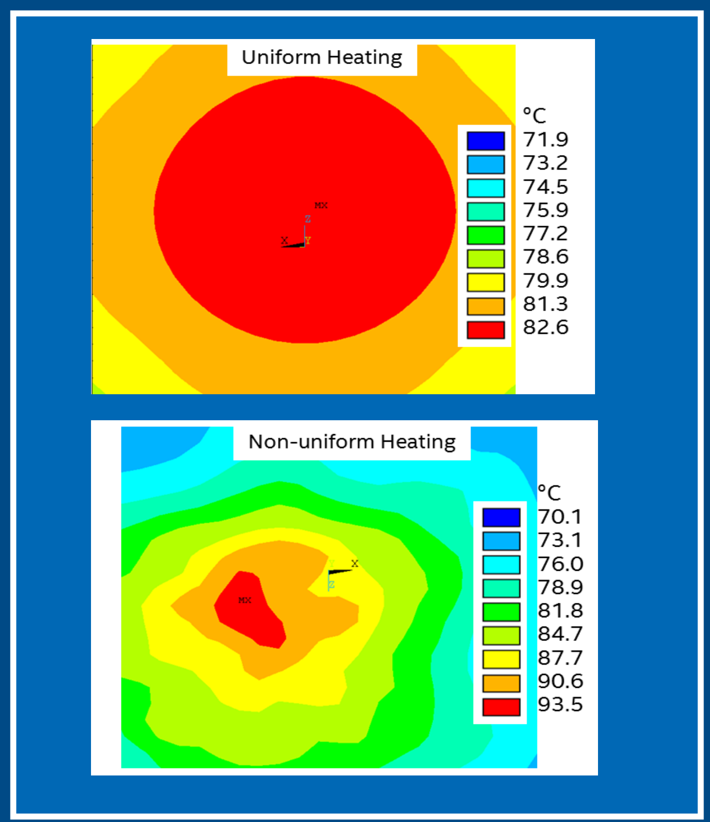
Thermal Demand Envelope



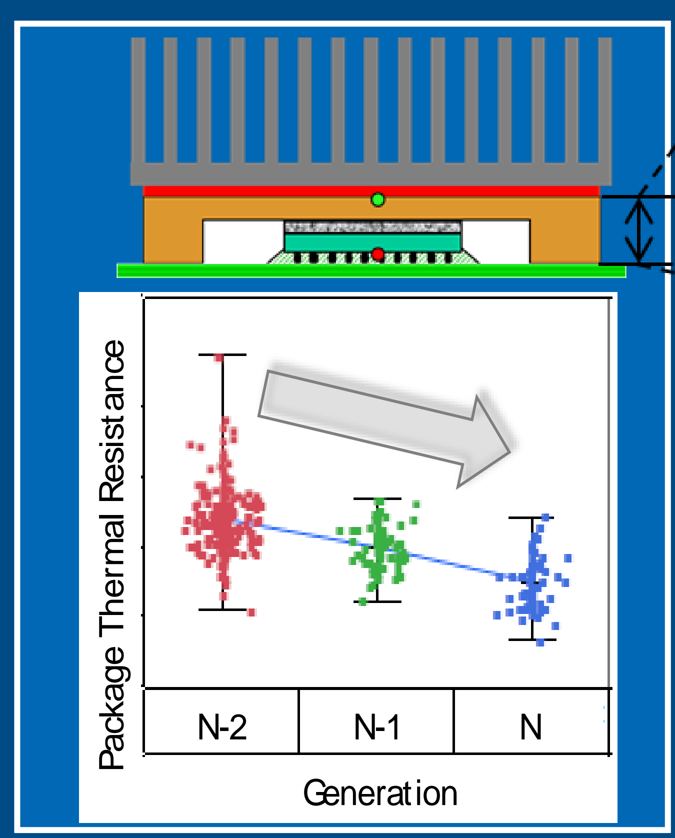
Thermal Technologies must typically cover a Hotspot Density Envelope in the (3x-4x)* range with an understanding of upside capability for both 2D & 3D Architectures

* It is important to recognize that these ranges are architecture and use case dependent. Thermal technologists must focus on developing technology building blocks to provide maximal, cost effective cooling

Need Holistic Thermal Solutions



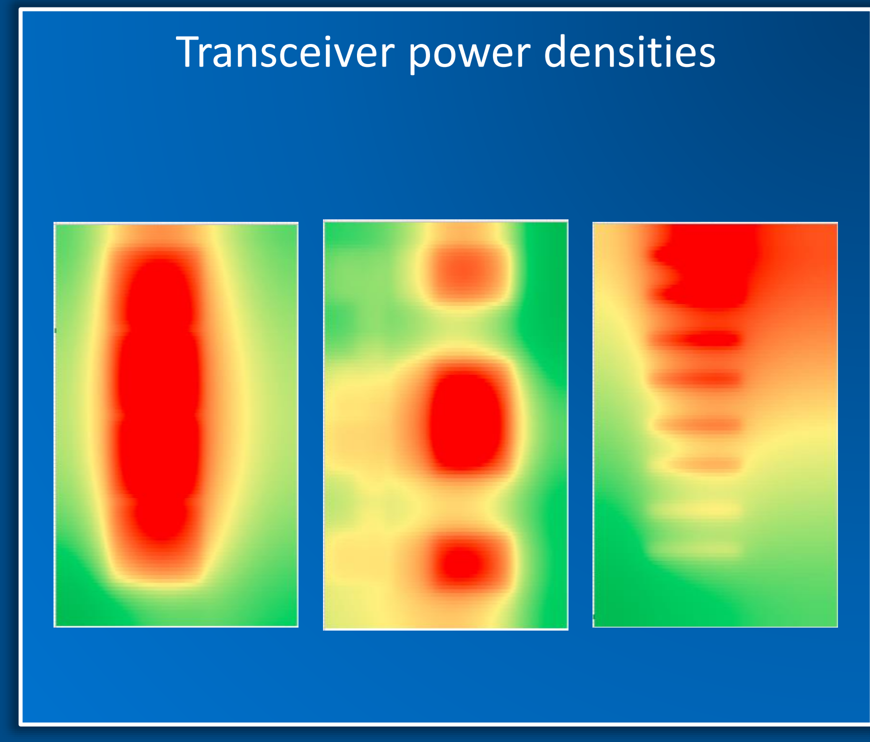
Thermally Aware Design



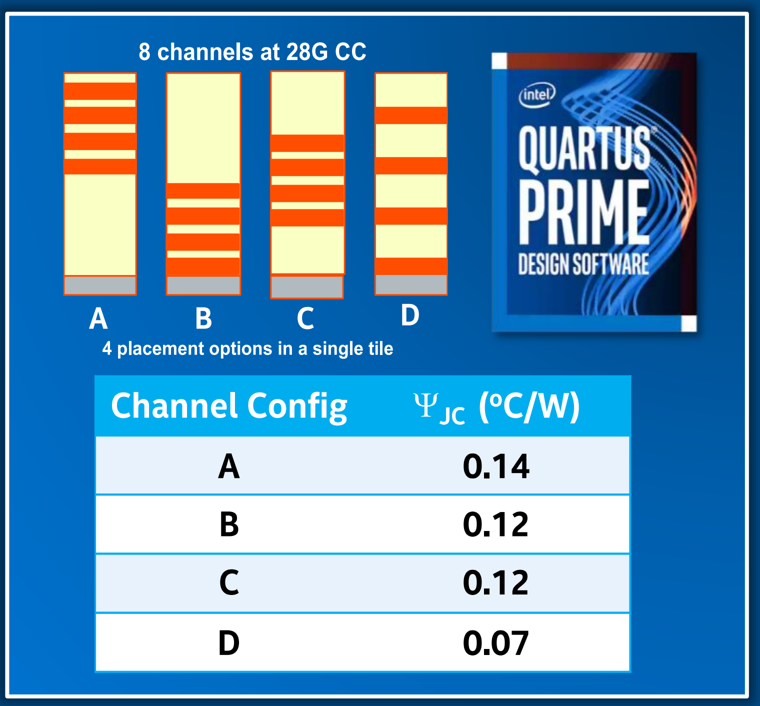
Package Thermal Improvement

Cooling Solutions & System Design

Thermally Aware Design: FPGA Example



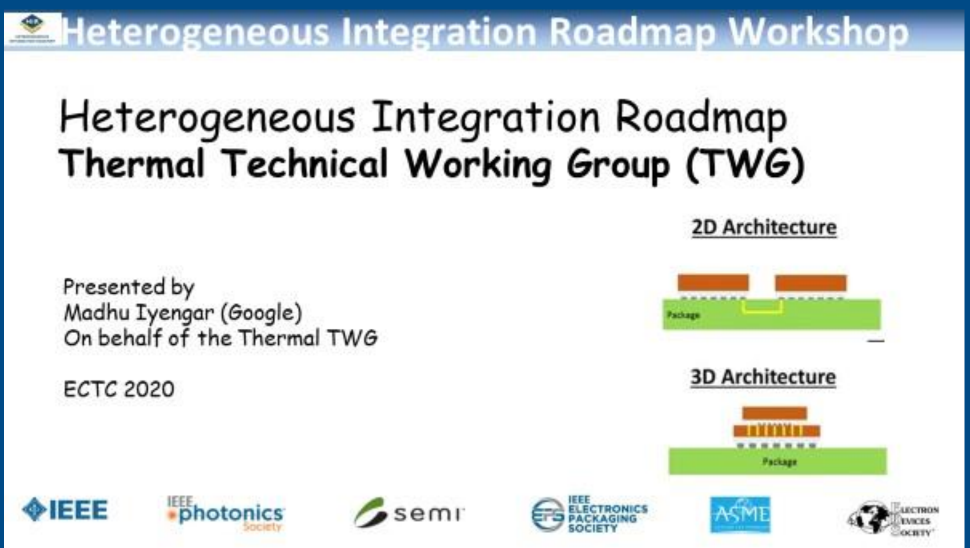
programming affects power density



Channel Config	Ψ_{JC} (°C/W)
A	0.14
B	0.12
C	0.12
D	0.07

Tools to minimize power density

Heterogeneous Integration Roadmap: Thermal TWG



HIR Thermal TWG - Work Status

- Year 1 (2018-2019)
- Thermal effort kicked off in March 2018.
- ~30 industry and university expert contributors.
- Final Chapter completed in June 2019.
- Published on EPS Website

- Year 2 (2019-2020)
- Receive and implement cross-TWG content.
- Address feedback received on 2019 edition.
- Opportunistically add new content if possible.

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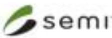

2020/2021 Chapter Thermal HIR Potential Topics

1. Hotspot thermal management
2. High Bandwidth Memory (HBM) cooling
3. Photonics thermal control
4. Power and power density trends
5. Silicon microchannels manufacturing
6. Thermal test protocols for heterogeneous packages

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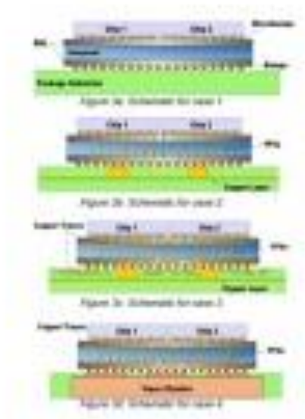
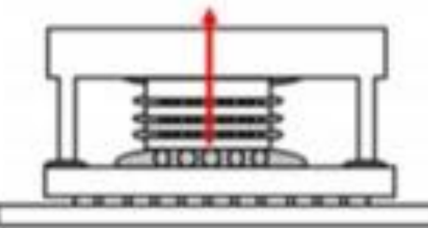
Thermal Problems Identified

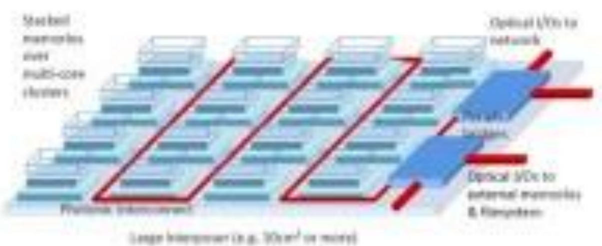
IEEE HIR Thermal TWG - ECTC 2020



1. 2D chip with stacked memory on a silicon/glass interposer

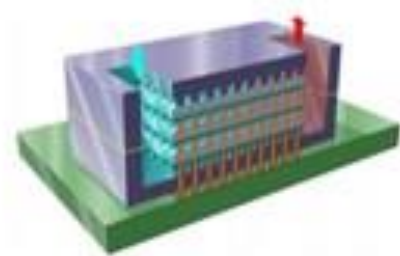


2. 3D stacked die with conduction interfaces



4. Optics/photonics based Heterogeneous package

2019 Chapter Canonical Thermal HI Problems



3. 3D stacked die with embedded liquid cooling

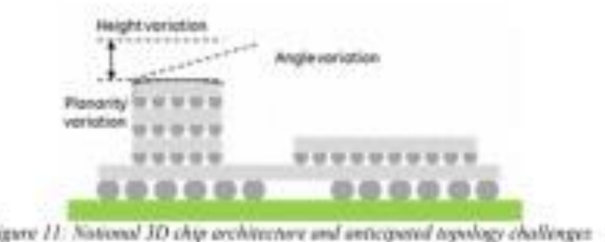
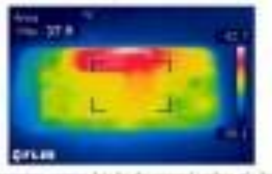


Figure 11: Notional 3D chip architecture and anticipated topology challenges

5. Harsh environment (military, aerospace, automobile)



6. Mobile application chipset (package on package, fan out, bridge)

7. Voltage Regulators in a Heterogenous Package

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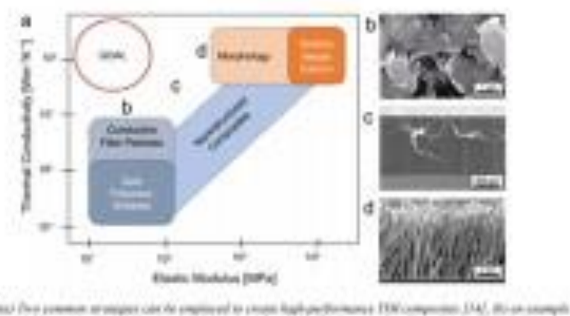
Advanced Research and Solutions

IEEE HIR Thermal TWG - ECTC 2020

2019 Chapter - Advanced Technologies & Research



1. Thermal Interface Materials

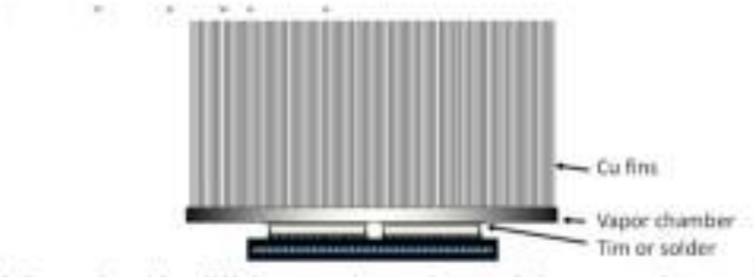
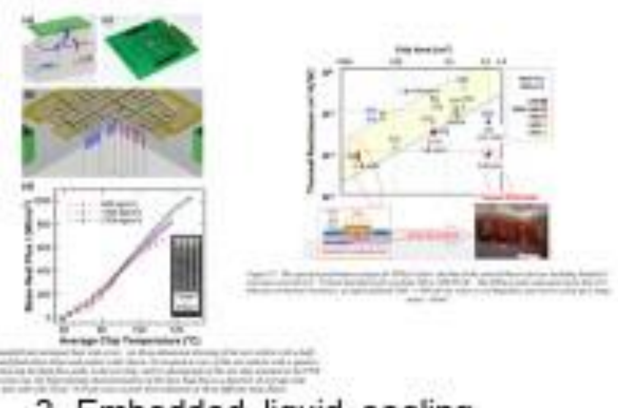
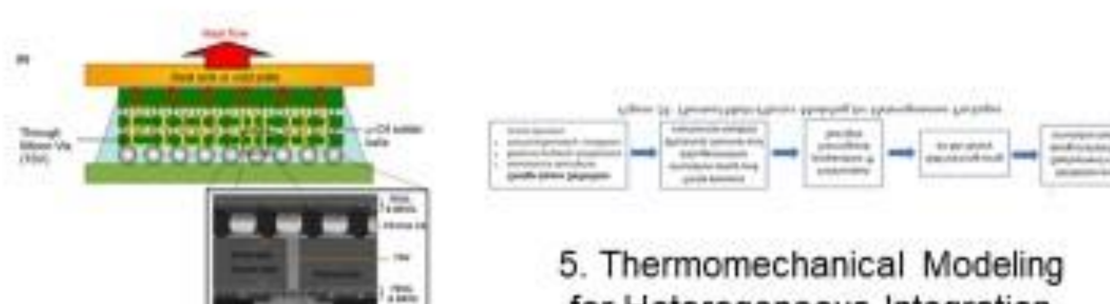


Figure 19: Figure adopted from [23] showing a schematic diagram of a heterogeneously integrated multi-chip module with a Thermal Interface Material (TIM) or solder attachment and a vapor chamber

2. System thermal limits for HPC multi-chip modules



3. Embedded liquid cooling of chip and chip stacks

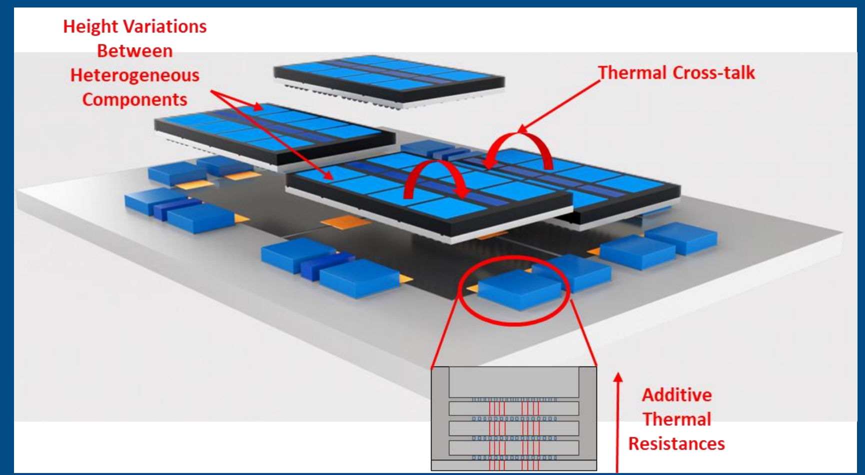


4. Advanced Thermal Materials for Thermal Management

5. Thermomechanical Modeling for Heterogeneous Integration

Call for Innovation on Thermal Management

- **Better TIMs and heat spreaders for MCPs**
  - ≥2.5x Rjc reduction – Near Term Target
  - 10x reduction should be a target for the next decade
- **Dual-purposed TIMs as a warpage control solution**
- **Complement package level solutions with System level solutions**
  - Research in liquid cooling (including immersion) material/design options
- **New Materials & Cooling technologies**
- **Improved metrologies**
- **Increased focus on transient responses**
- **Strengthen Co-Design Interfaces**
- **New technologies such as photonics, quantum computing**



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