

Materials Science Innovation in Advanced Packaging

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Our Journey

- Materials Science Changes the World
- Key Trends, Packaging and Materials Science
 - Automotive Electrification
 - 5G: Base Stations and Front-End-Modules
 - Networking and Edge Computing
- Sustaining Constructive Disruption
- Discussion and Questions
- The Manufacturer's Pledge – a Covid-19 digression

If source not mentioned, generally created at Indium Corporation

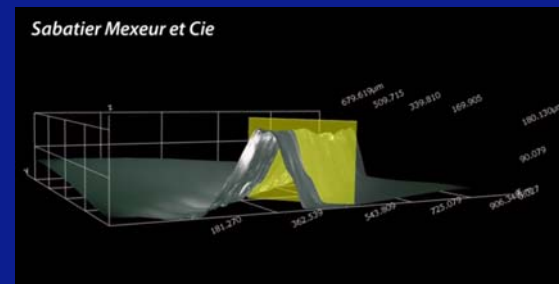
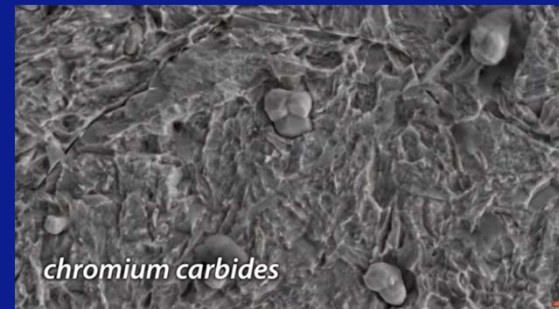


2 2020

Materials Science & “knives that would not cut”



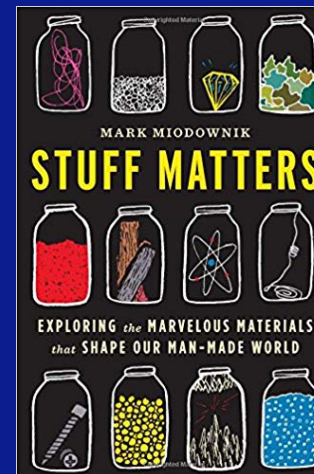
Source: www.AllenBrothers.com
used with permission.



Source: America's Test Kitchen

Lessons from Stainless Steel

- Exploratory
- Iterative – many contributors
- Small Science (vs Big Science)
- Non-linear
- Careful Observation
- Failures are opportunities
- Trade-Offs

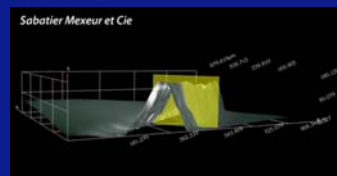
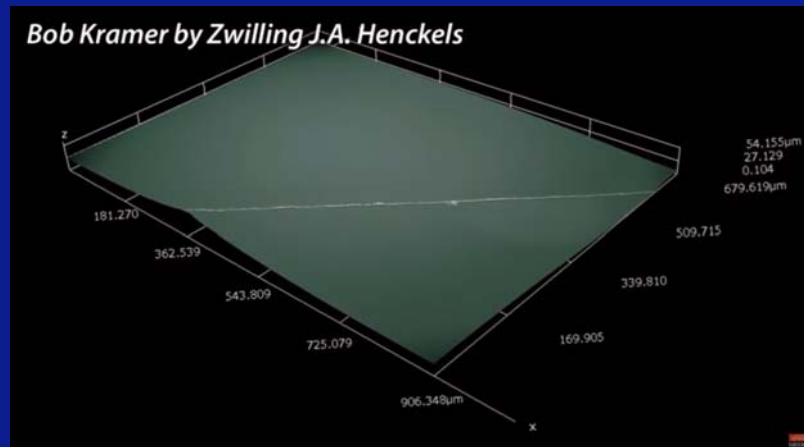
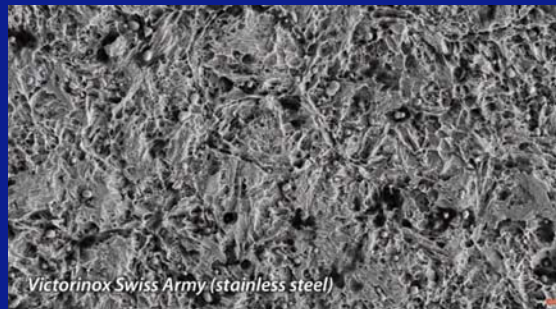


Materials Science – Stainless has Improved!

\$300

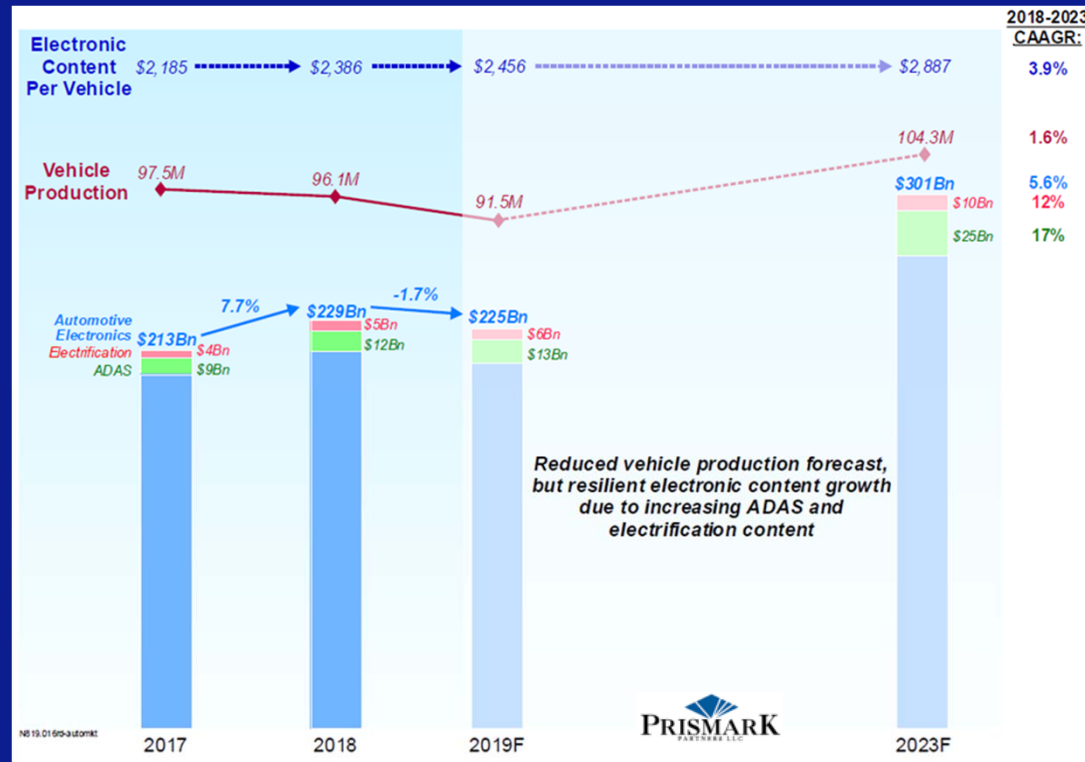


\$40

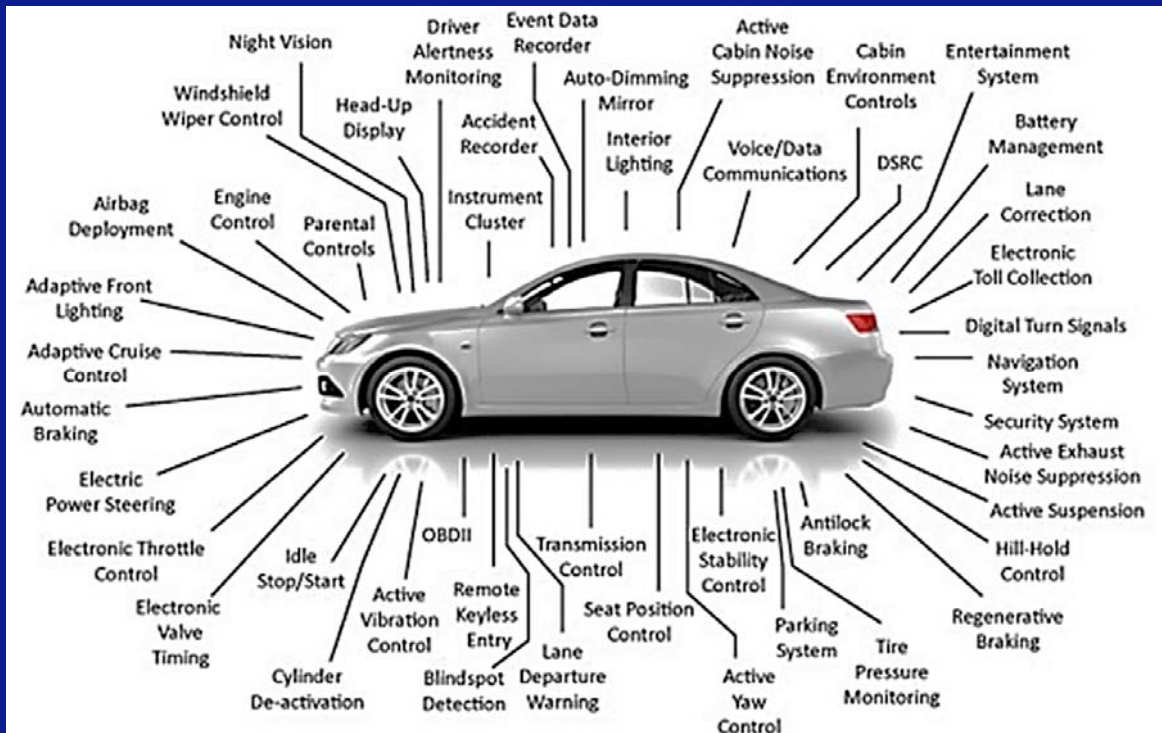


Source: America's Test Kitchen

Automotive: Electronics Growth

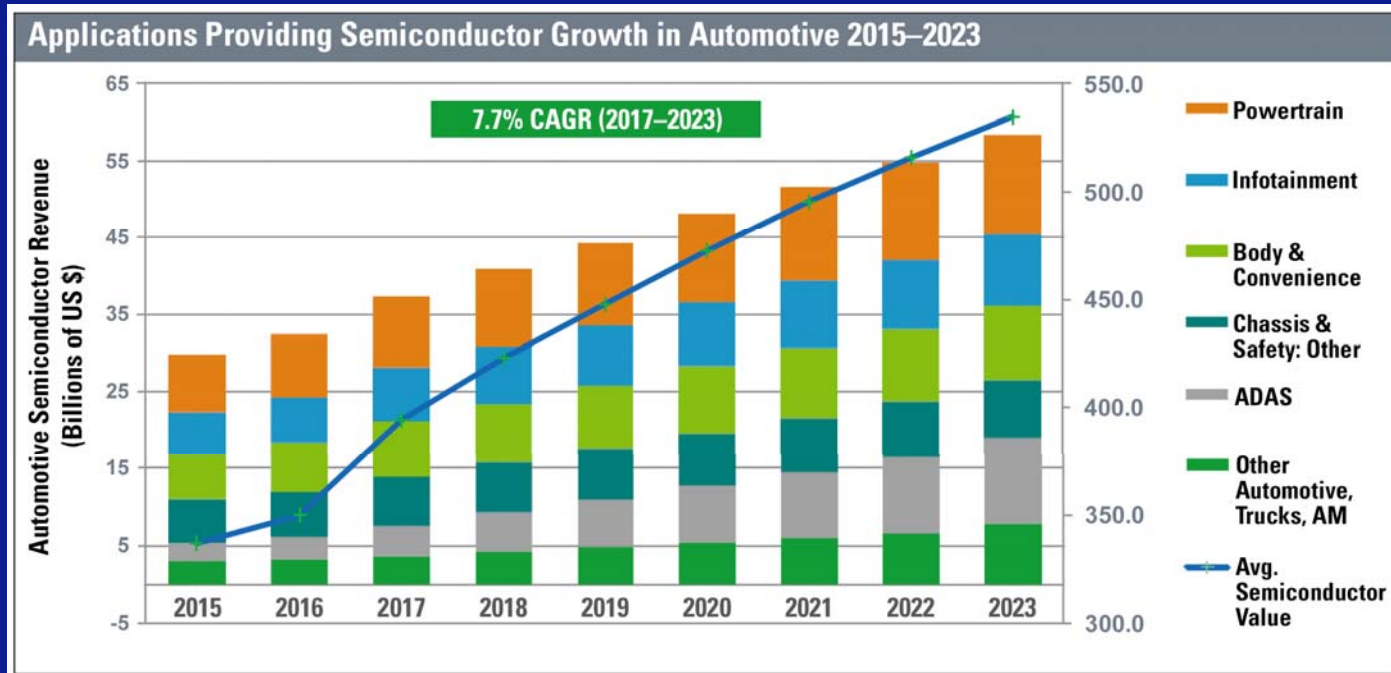


Automotive: Types of Electronics in Vehicles



Source: iNEMI
Used with Permission

Automotive: Electronics Content per Vehicle Driven by AD, EV, Connectivity



Automotive: Automobile of 2025

Mission profile for autonomous city vehicle

- Pure electric vehicle (EV)
- 24 / 7 usage
- 400V battery
- Fast charging (10mins @1000Amps)
- Max power load >60kW
- 15year life
- 300,000mile warranty



Automotive: Temperature Ranges

AEC Q100 Qualification

Definition of Part Operating Temperature Grade

The part operating temperature grades are defined:

Grade 0: -40C to +150C

Grade 1: -40C to +125C

Grade 2: -40C to +105C

Grade 3: -40C to +85C

Grade 4: 0C to +70C

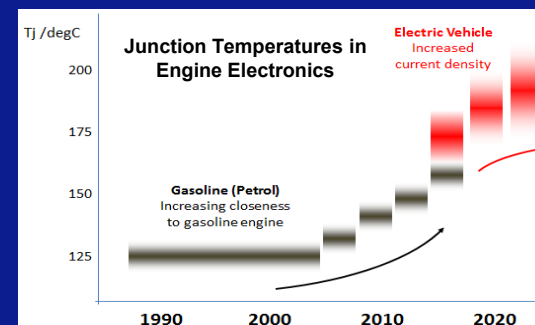
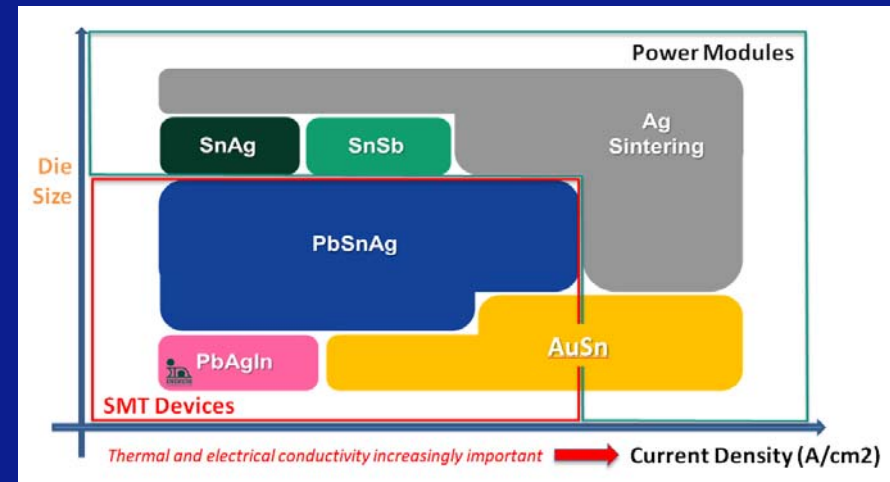
ambient operating temperature range

- **Infotainment**
 - Car Navigation
 - Car Audio
 - Heads-up display (HUD)
 - Automotive LCD monitor
- **Body ECU**
 - Body control module
 - Door & Mirror control
 - **HVAC control module**
 - **LED module**
- **EV/HEV**
 - **Main inverter**
 - **Onboard charger**
 - **DC/DC converter**
 - **Battery management system**
- **Power Train**
 - **Engine control unit**
- **Electronic power steering(EPS)**



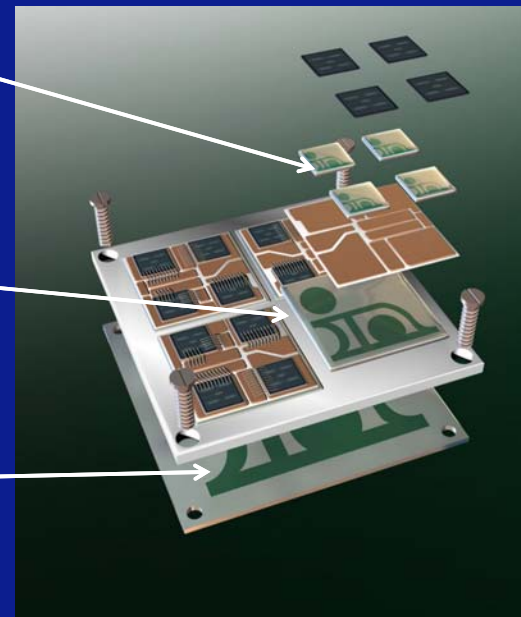
Automotive: Electronics Assembly Materials

- System level integration of different sensor types and control electronics
- Higher voltage:
 - ICE: 12V → 48V
 - EV: 350V → >600V
- Increased reliability
 - 10 → 15 year mission profile
 - 1,000 → 3,000 thermal cycles
 - Low-voiding
- Increased temperatures:
 - ICE: Under the hood / transmission fluid
 - EV: In specific areas of high current density
- Vibration/Environmental exposure:
 - EV: Power control integrated with electric machines



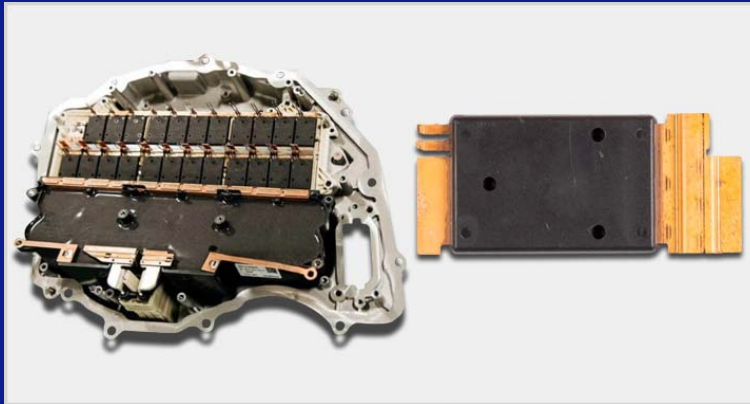
Automotive: Power Modules

- Die-Attach to DBC
 - Solder and Sinter Materials
 - Thermal and electrical conductivity
 - Tilt control
 - Stressor:
 - Extreme CTE mismatch
 - High temp / extreme thermal cycling
- DBC to Baseplate
 - Solder/TIM
 - Thermal conductivity
 - Tilt control
 - Stressor:
 - Thermal cycling / larger DT stresses – large area
- Baseplate to Heat Spreader
 - Thermal interface material (TIM)
 - Thermal conductivity
 - Stressor:
 - Thermal cycling / smaller DT stresses – very large area

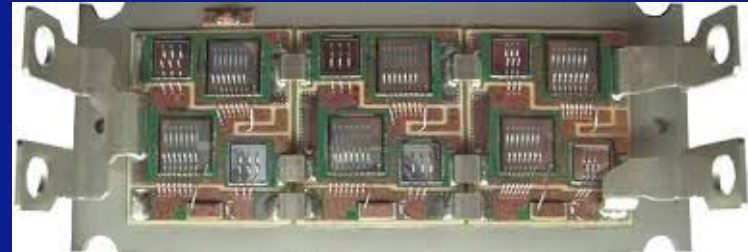


Automotive: Electric Vehicle Drive Train

Tesla Model 3 Traction inverter, showing the SiC MOSFET power modules



Source: appliedmaterials.com and PntPower

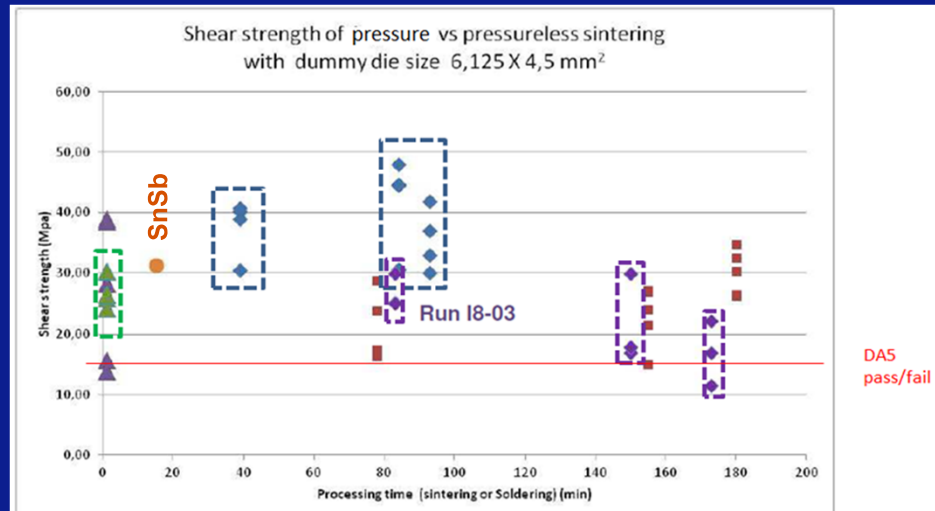


Source: Semikron

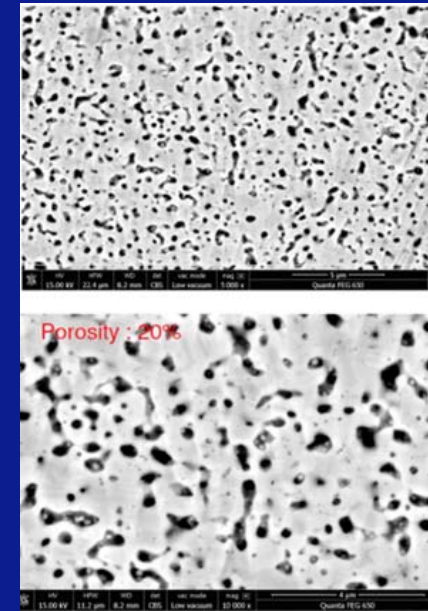


1st Generation Chevy Volt
Source: Weber.edu

Automotive: Power Module Materials



Ag-Sintering; Cu-Sintering
Sintering Processes (Air, N₂, Fast, Pressure)
Revisiting SnSb



Automotive: Power Modules

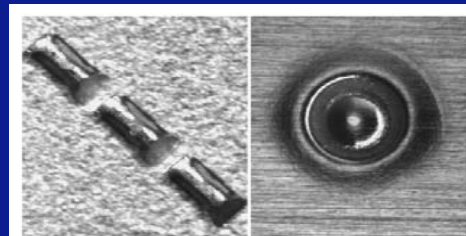
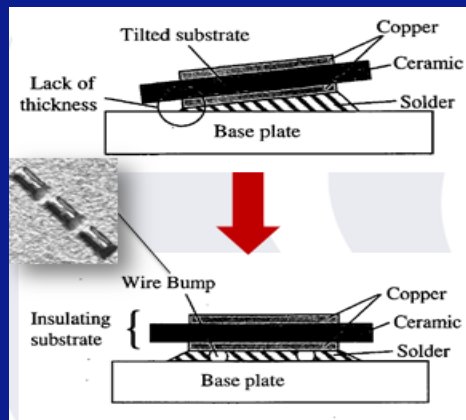
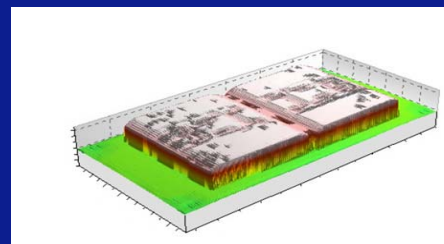
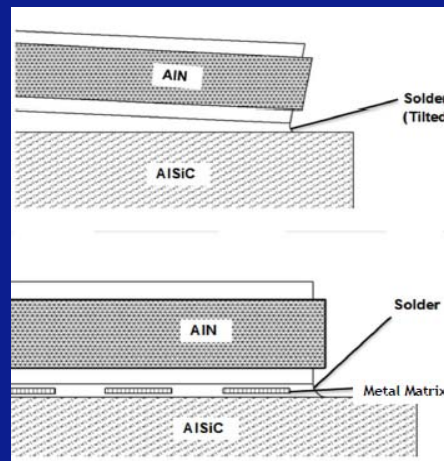
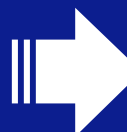
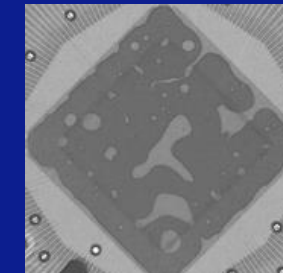
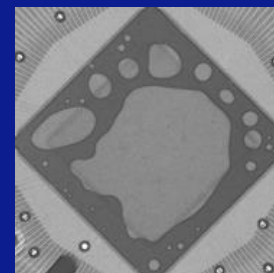
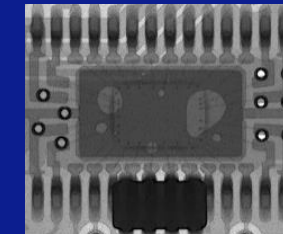
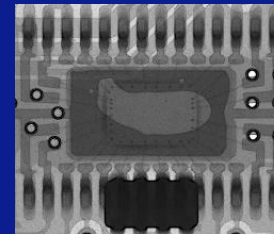
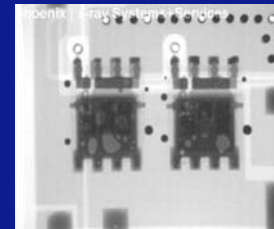
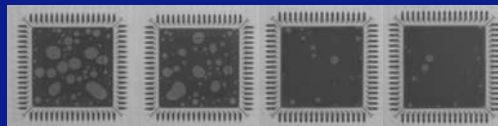
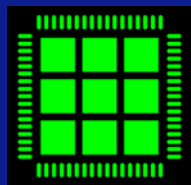
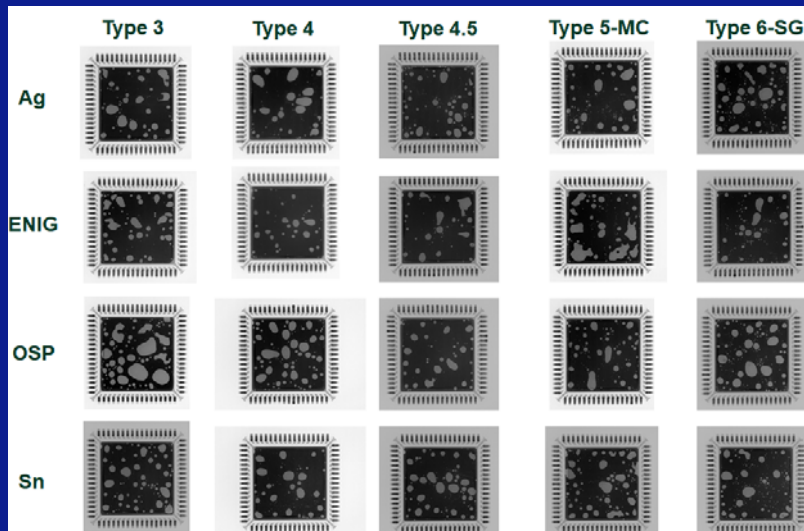


Figure 1.2: Traditional bondline control methods, aluminum wirebonds on AISiC baseplate (left) & stamped 'bump' in copper baseplate (right)



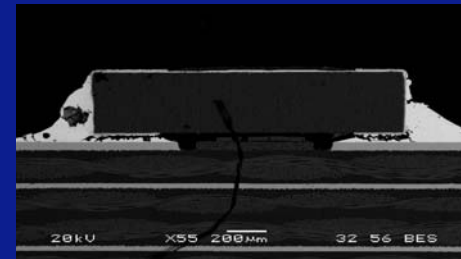
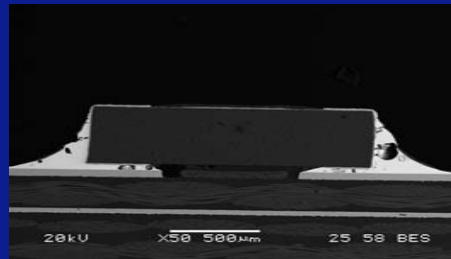
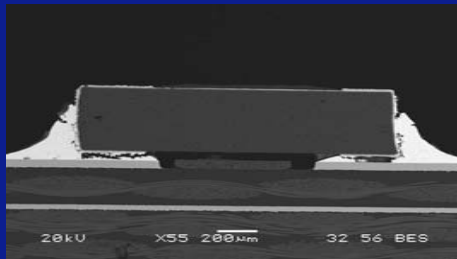
Co-Planarity Variation = 52.5μm
Max Deflection = 60μm

Automotive: Assembly & Low Voiding

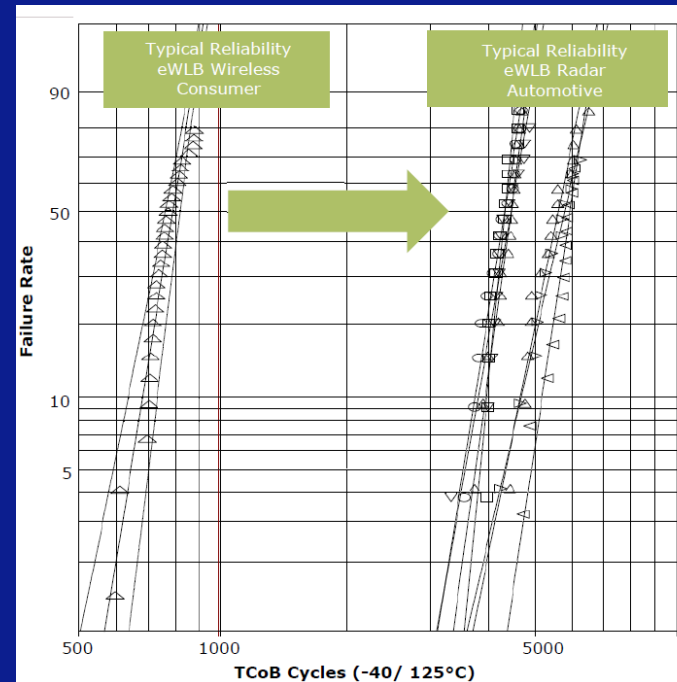
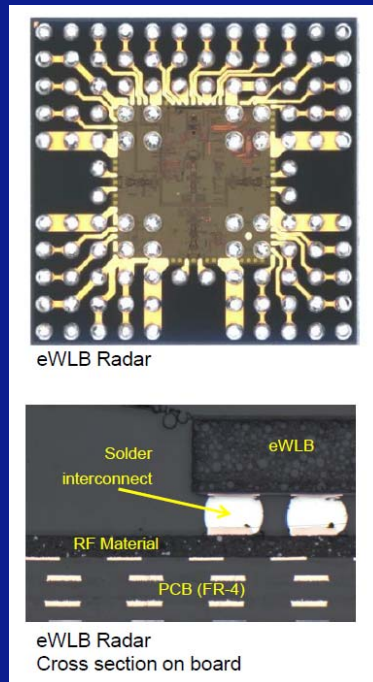


Automotive: Extreme Thermal Cycling

- -40C to 150C
- 51 min per cycle, 10 min dwell time at each extreme, ~28 cycles per day

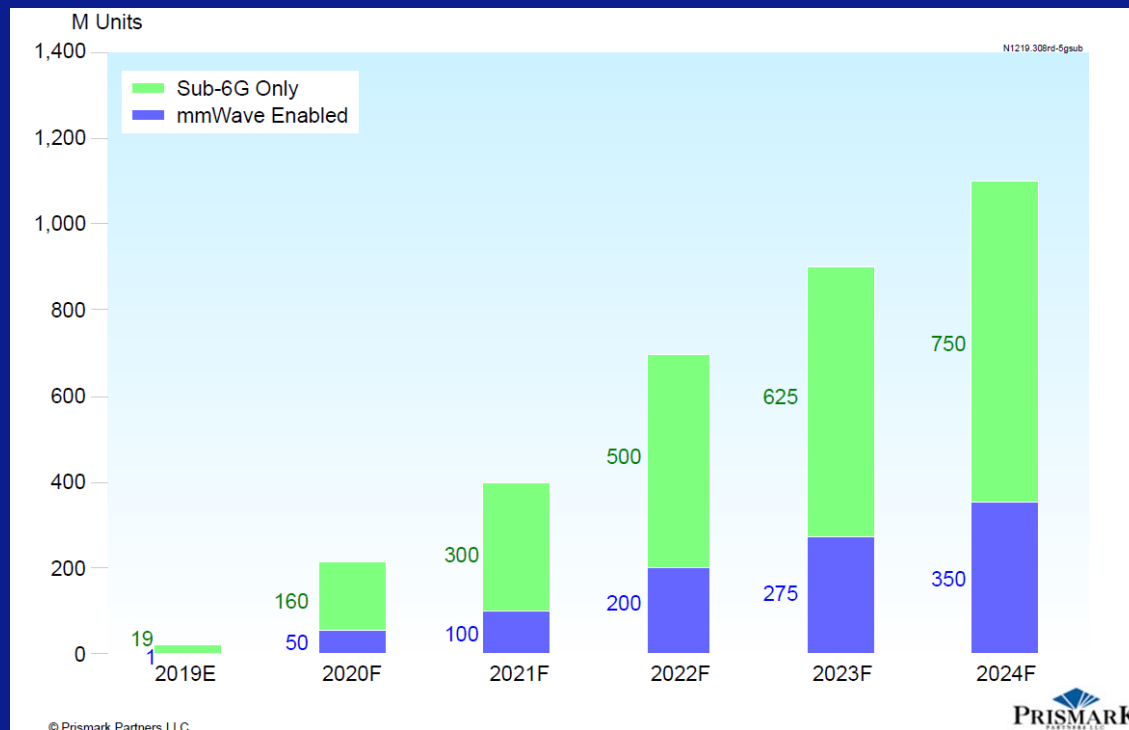


Automotive: Consumer Electronics meet Automotive Standards

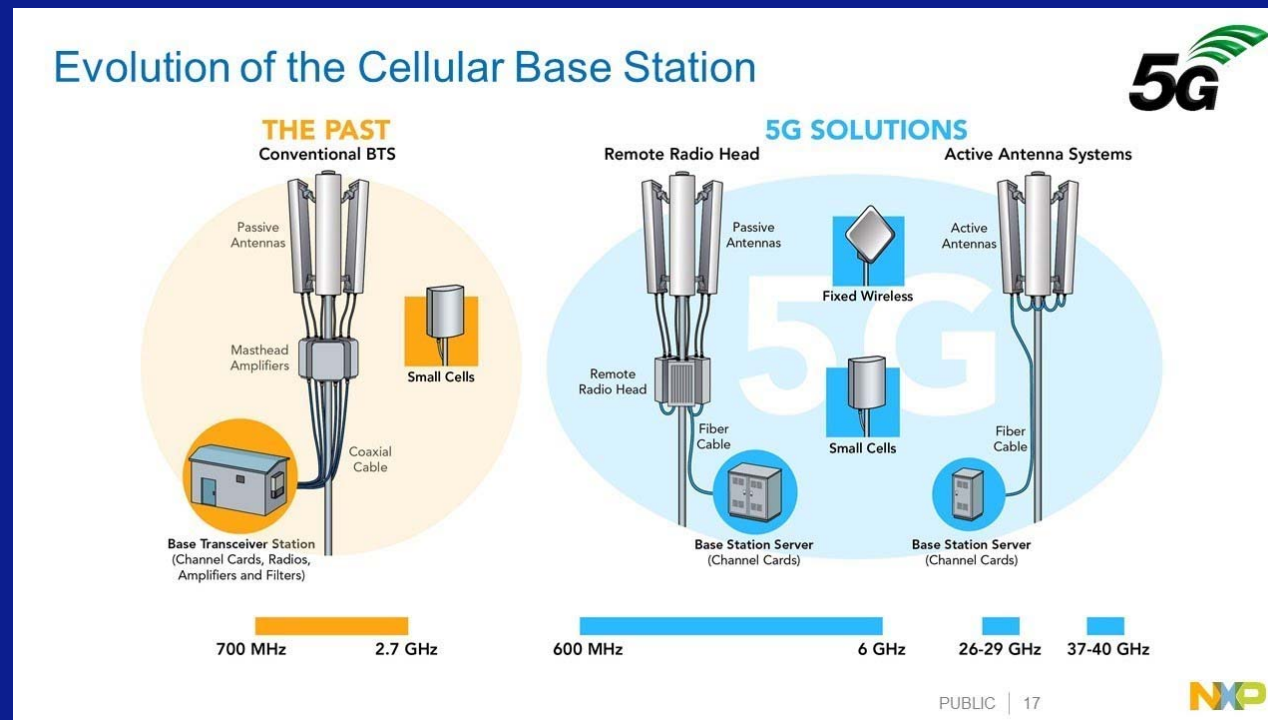


Source: Infineon

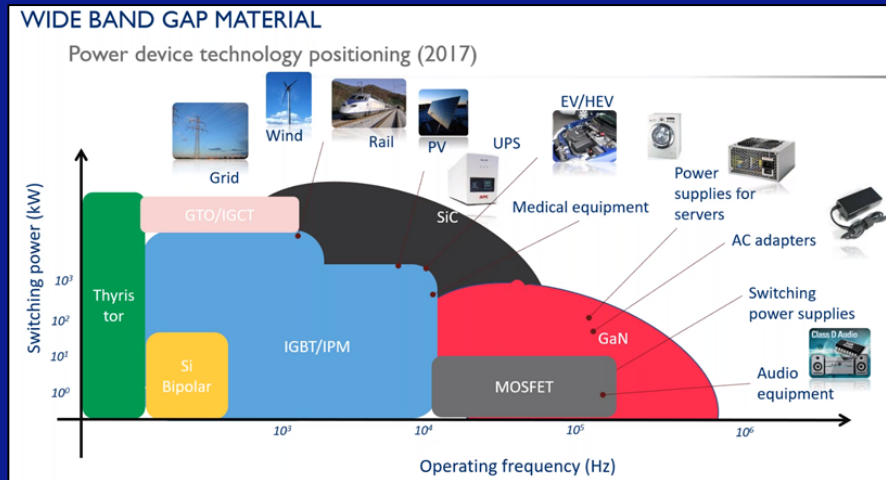
5G: Growth – Mobile Phone Units



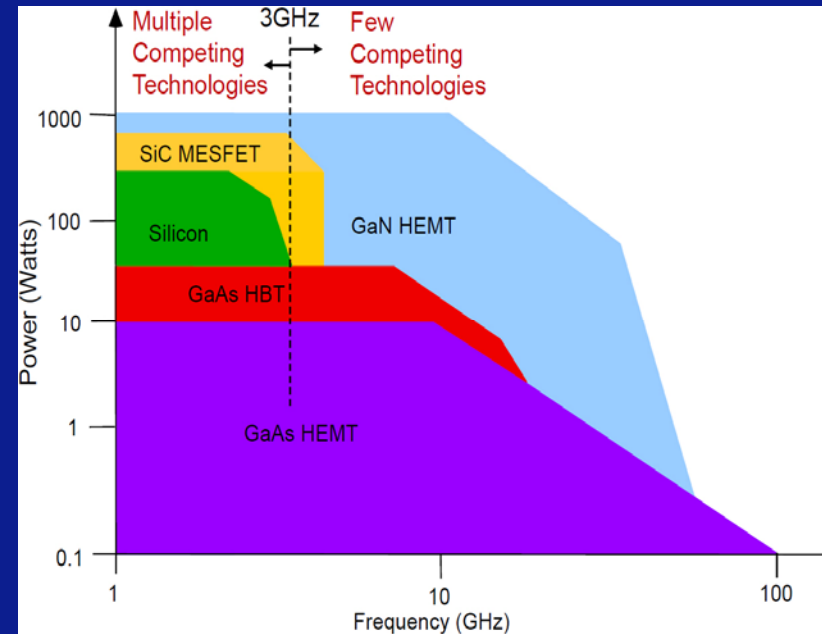
5G: Architecture



5G: Power Device Technology

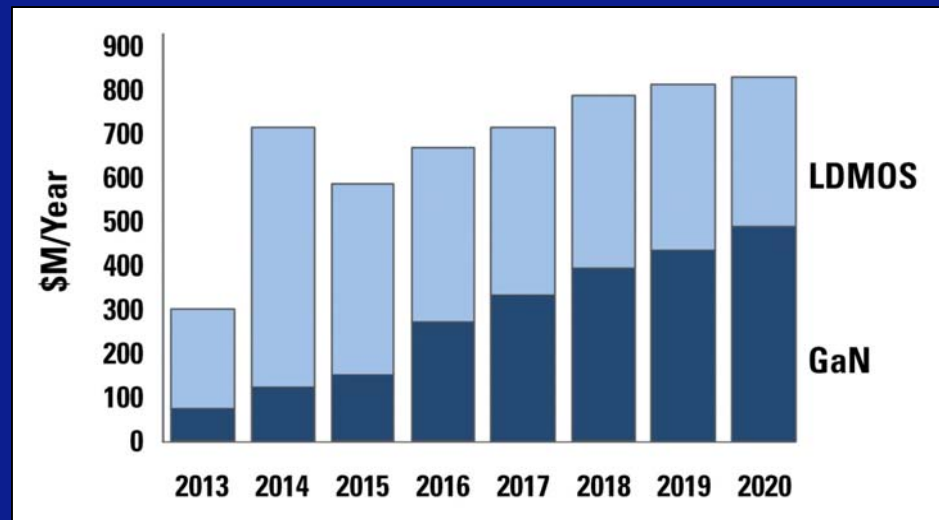
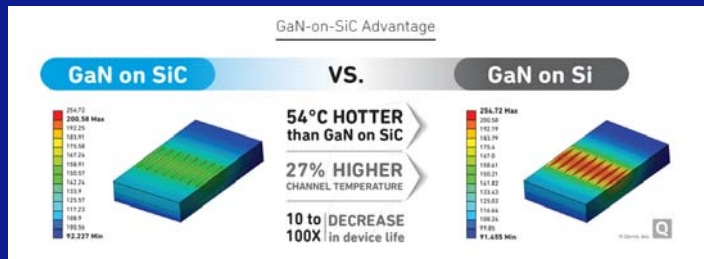
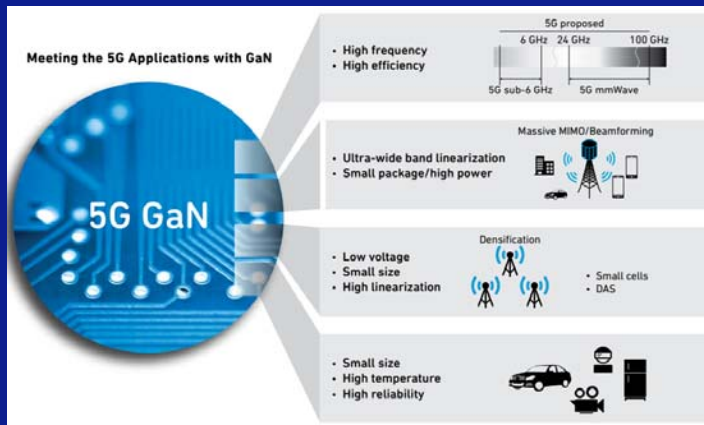


Source: Yole "Power Electronics Devices: Technology and Markets," May 2018



Source: RFMD

5G: Powered by GaN

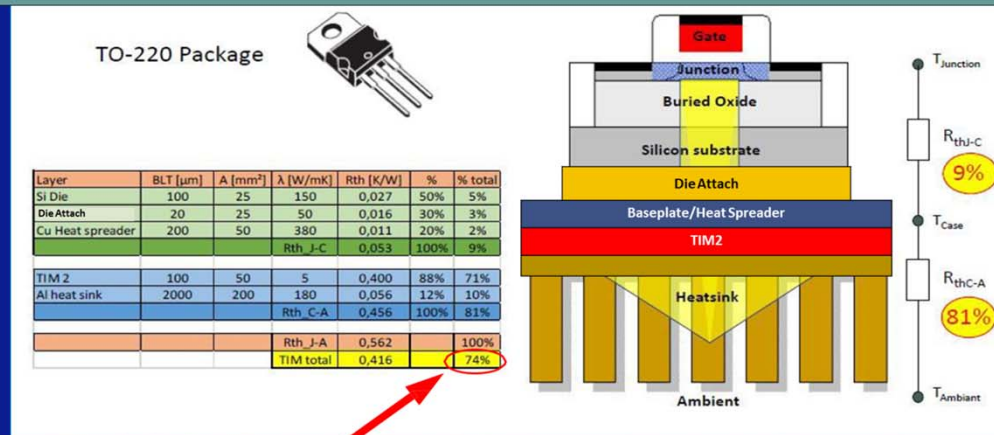


Source: <http://rf-design.co.za/tag/qorvo/page/3/>

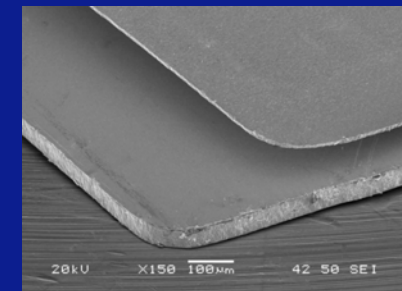
Source: Qualcomm

5G: GaN Packages

Heat Flow Path and Relevant TIM Placement: Common Discrete Power Semiconductor Applications

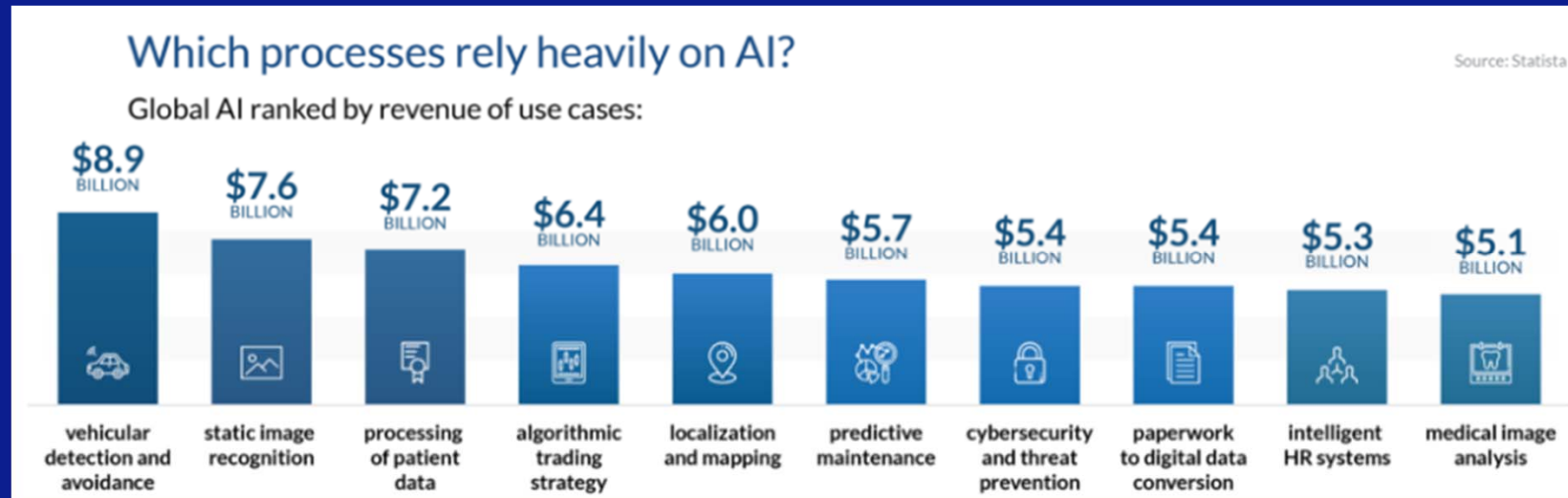


TIM2 and the die attach material are responsible for approximately 74% of the thermal budget through this discrete power semiconductor package (considering solder die attach as an equivalent for TIM1)



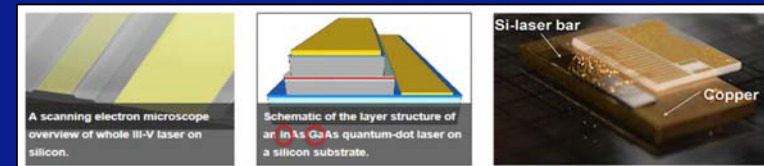
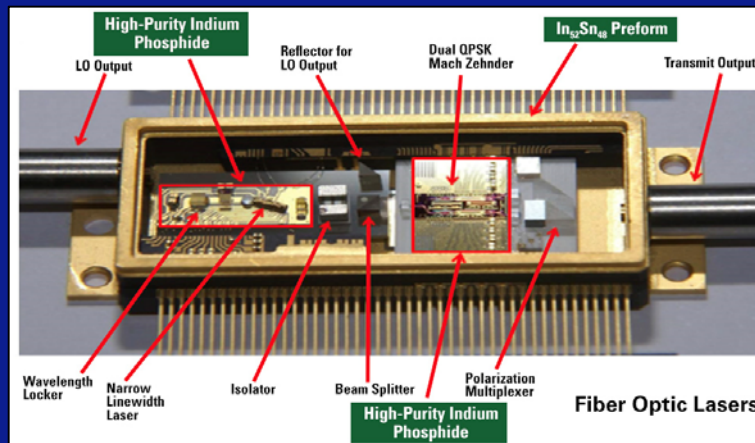
5G: Growth of Edge Computing & AI 2019 - 2020

Revisit with CPUs



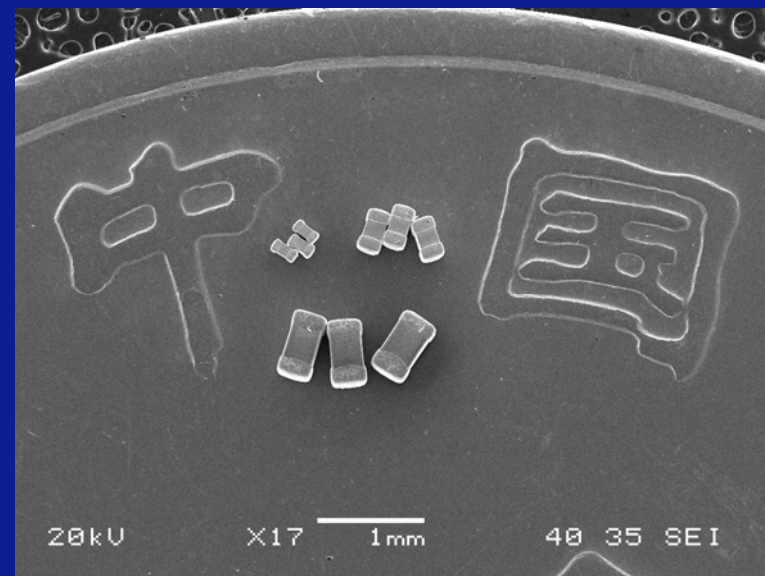
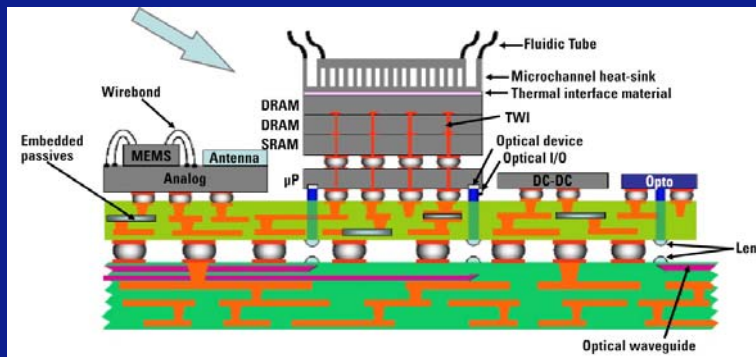
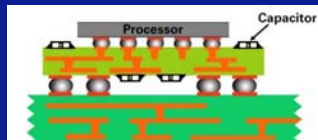
Source: Statista

5G: Fiber enables Edge Computing



Source: <https://www.cardiff.ac.uk/news/view/214296-step-towards-holy-grail-of-silicon-photonics>

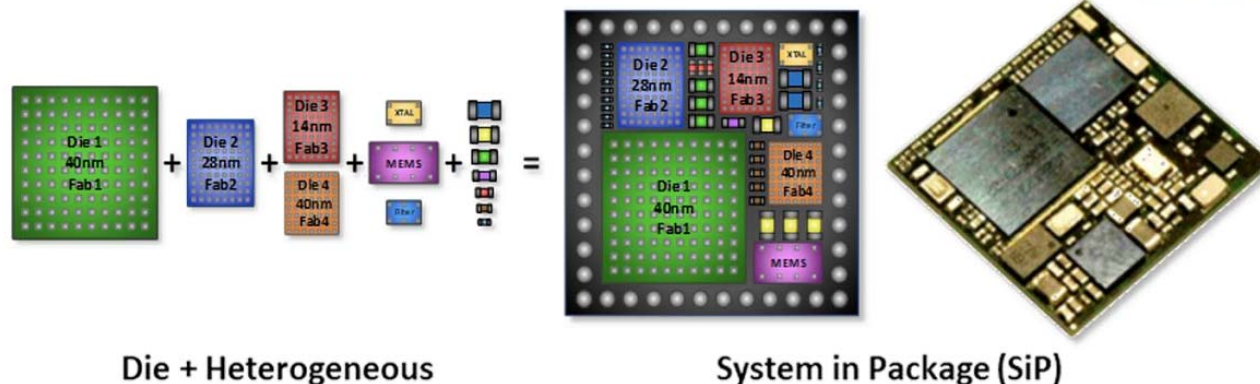
5G: Pushing Heterogeneous Integration



0201 / 01005 / 008004 capacitors

5G: Heterogeneous Integration

The Definition of Heterogeneous Integration



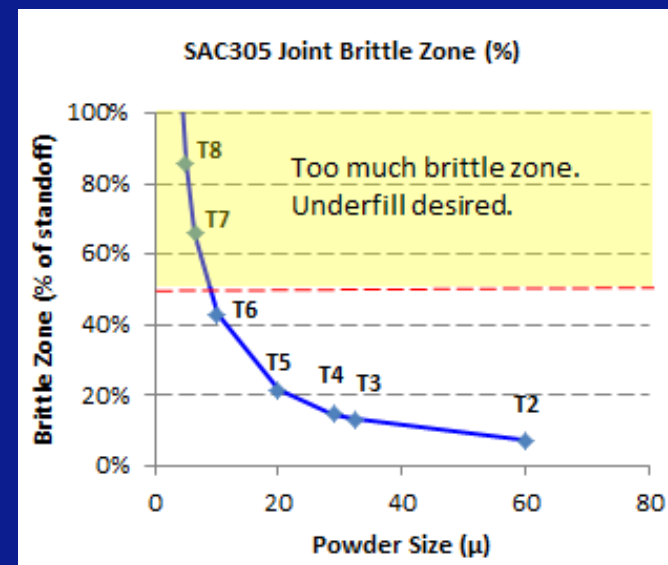
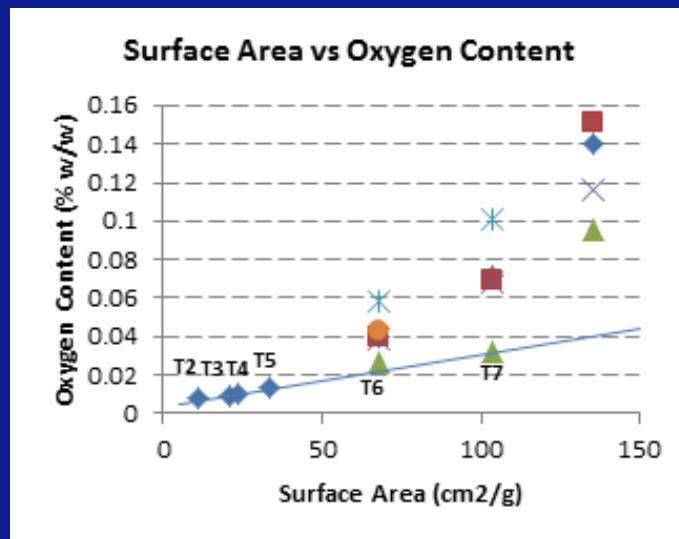
Graphics Source: John Hunt (ASE)

Heterogeneous by material, component type, circuit type, node and bonding/interconnect method & sources

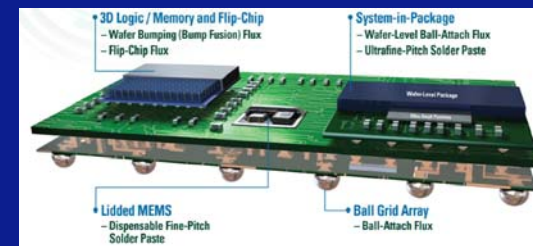
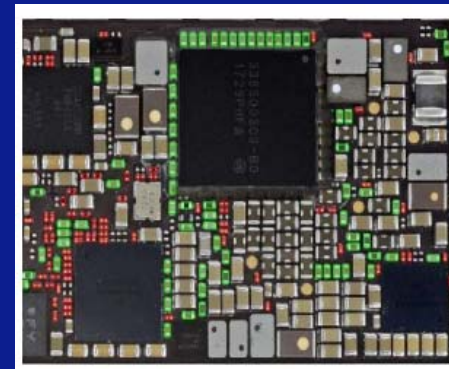
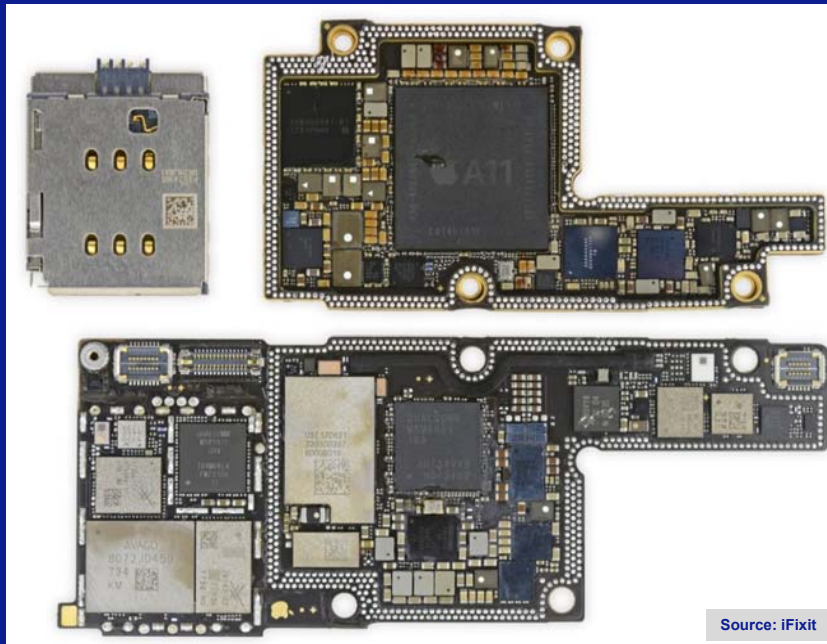


Source: HIR Roadmap

5G: Materials Challenges to Overcome



5G: Examples of Heterogeneous Integration

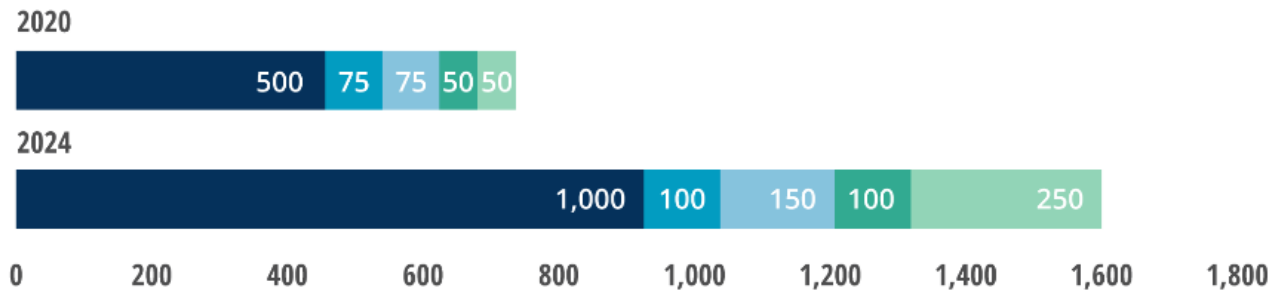


CPUs: Growth of Networking and Edge Computing

The edge AI chip industry is poised for growth

Edge AI chips by device, 2020 and 2024 (millions of units)

■ Smartphone ■ Tablet ■ Speaker ■ Wearable ■ Enterprise edge



Sources: MarketsandMarkets, *Edge AI hardware market by device (smartphones, cameras, robots, automobiles, smart speakers, wearables, and smart mirrors), processor (CPU, GPU, ASIC, and others), power consumption, process, end user industry, and region—global forecast to 2024*, April 4, 2019; Deloitte analysis.

Deloitte Insights | deloitte.com/insights

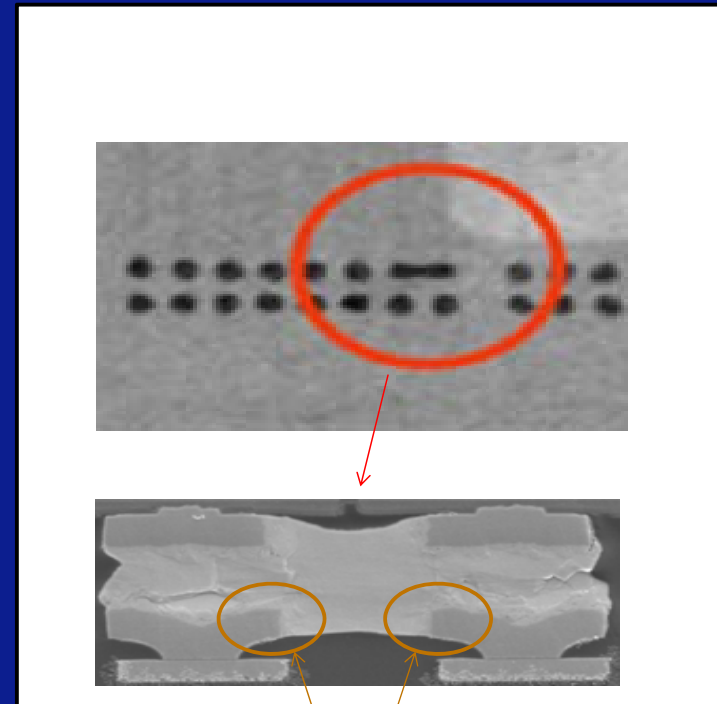
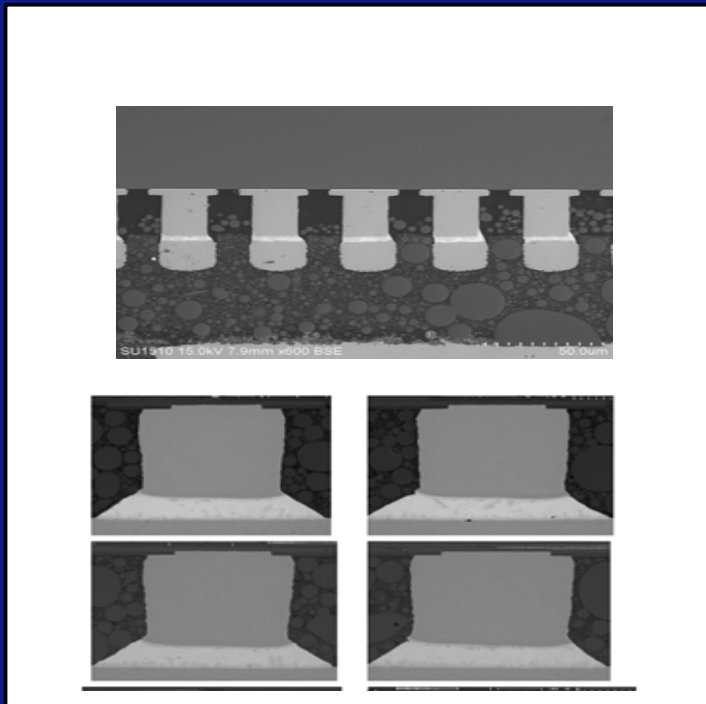
Source: Deloitte



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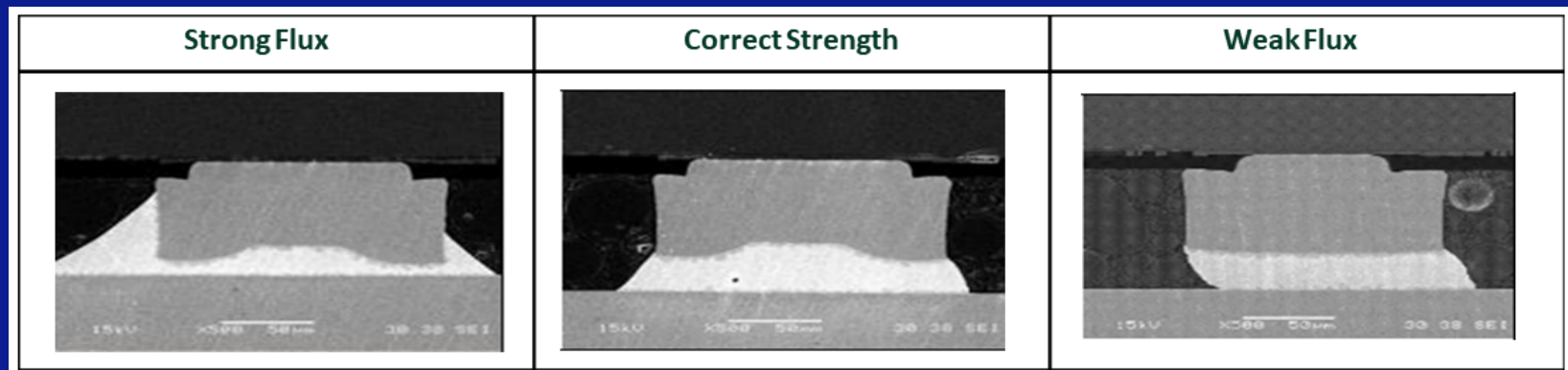
2020

CPUs: Ultralow Residue Fluxes



Excessive solderability

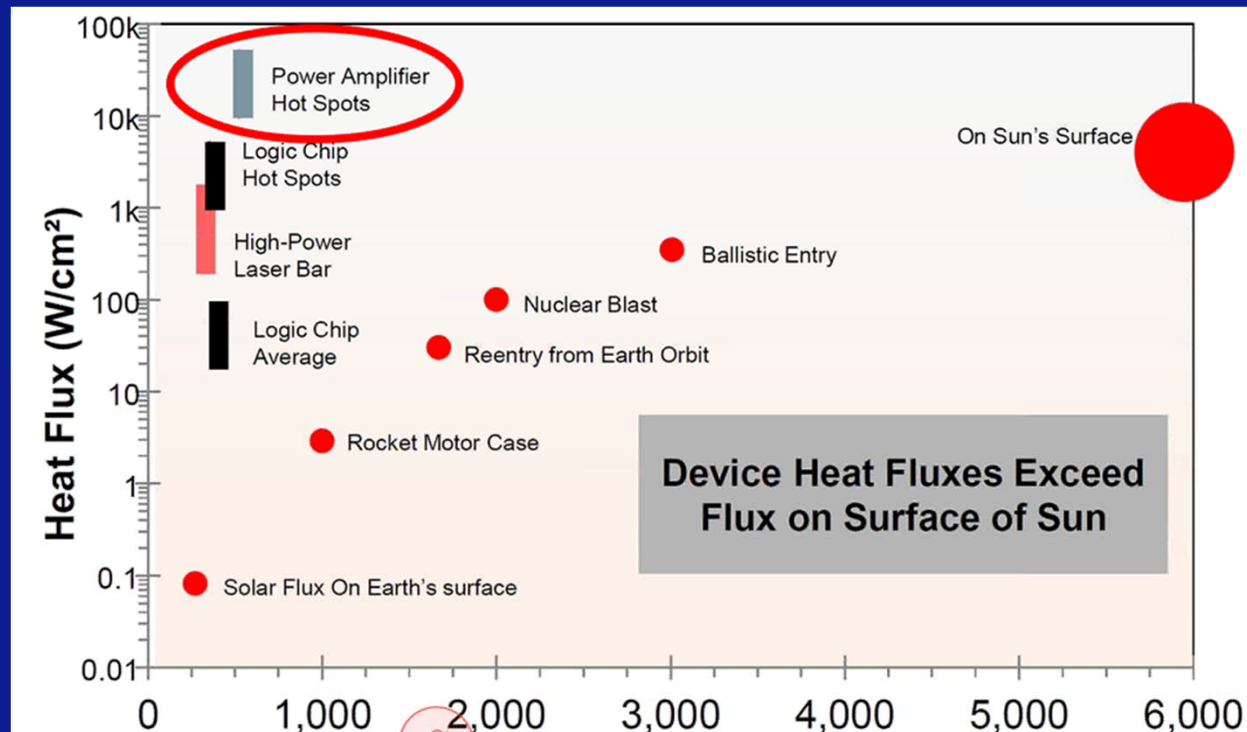
CPUs: Flux Technology Tuning



Reliability of the device, especially cracking of the ILD, is affected by reduced clearance. Solder should stay at solder joint, but can wick up the pillar or wet excessively.

An Ni layer between solder cap and copper pillar is common. Flux can also ensure solder stays on the joint by adjusting wetting power.

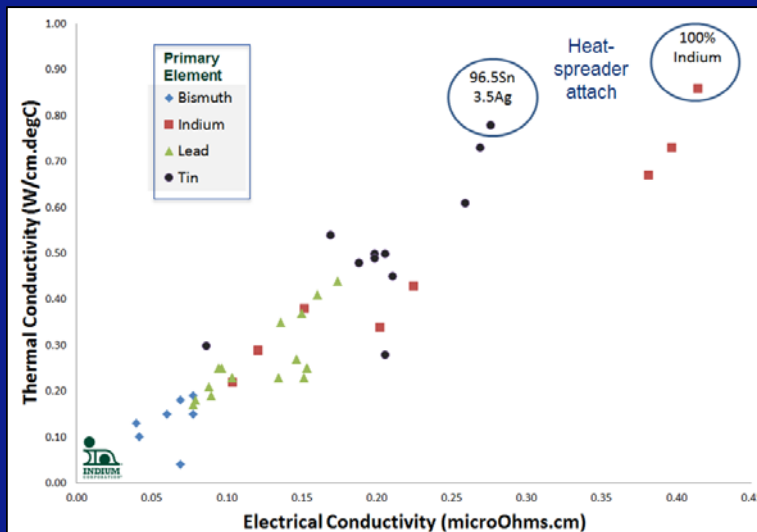
CPUs: Reaching Thermal Limits



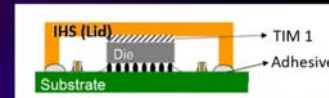
Source: Avram Bar-Cohen, Raytheon

CPUs: Thermal Design

Solders: Conductivities



SOLDER THERMAL INTERFACE MATERIAL (STIM)



STIM is a solder based thermal interface material (TIM) between the integrated heat spreader (IHS) and processor die

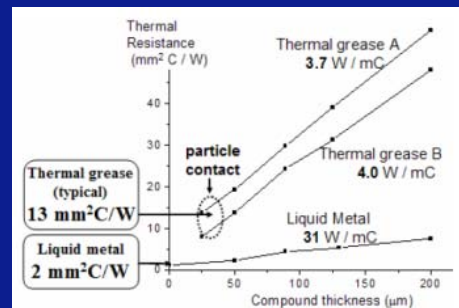
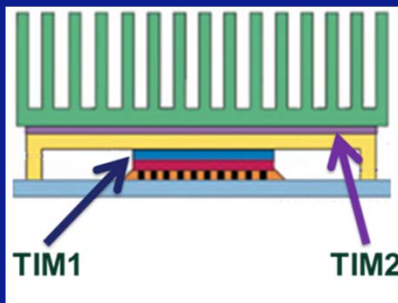
- STIM provides increased thermal conductivity between the CPU die and the integrated heat spreader (IHS)
- Heat dissipation is improved, allowing for more thermal headroom
- STIM can provide benefits for high frequency segments of the business

IMPROVED OVERCLOCKING CAPABILITY

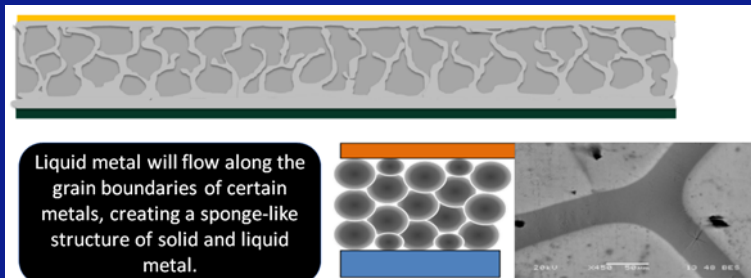


Source: Intel.com

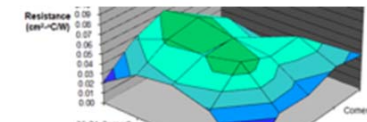
CPUs: Liquid Metal and Liquid-Solid Hybrids



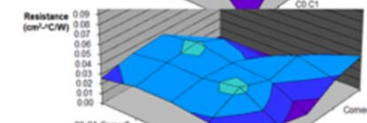
Source: IBM Research Division, Yves St. Martin and Theodore van Kessel, "High Performance Liquid Metal Thermal Interface for Large Volume Production", IMAPS Symposium 2007, San Jose CA USA, November 2007.



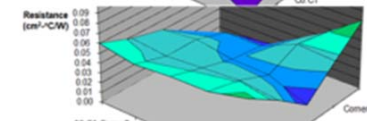
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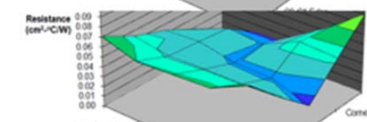
4021 Cycles



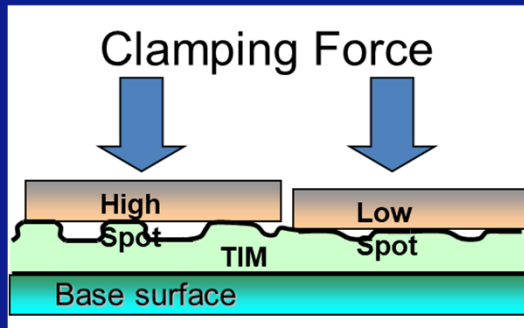
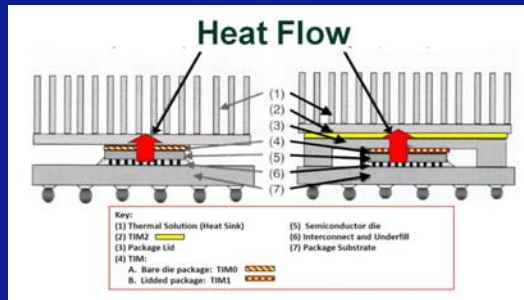
10,247 Cycles



20,250 Cycles



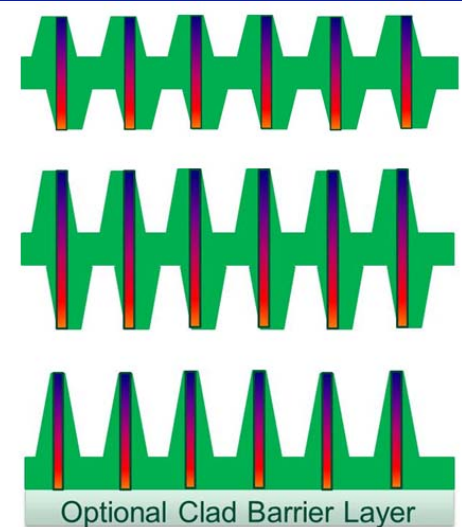
CPUs: Compressible Metal TIM



Pattern 1: Designed for interfaces with tight surface control (smooth and parallel)

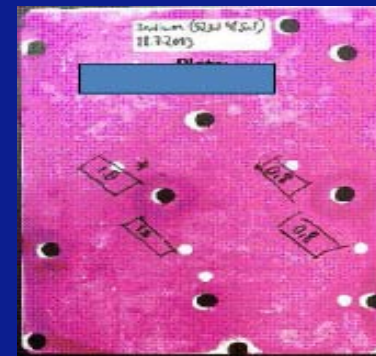
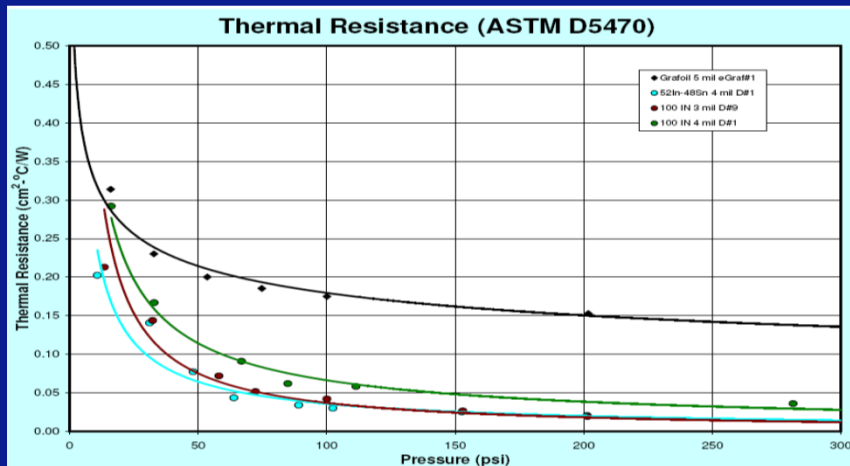
Pattern 2: High profile variant for surfaces with more warpage; 2X compressibility

Pattern 3: Single-sided pattern designed for clad multiple insertion burn-in and test applications



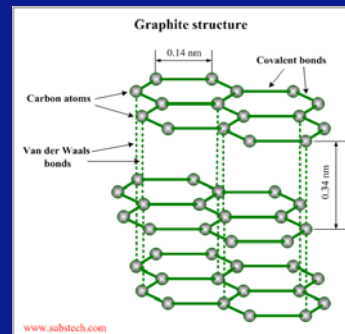
Source: US Patent 7,593,228-B2

CPUs: Compression Force: Graphite Foil vs. Soft Metal



Soft Metal

Graphite foil has poor thermal conductivity in Z-axis due to its structure



Graphite Foil

CPU's: Previously @ BITS: Burn-In Roadmap

Joe Lin
KYE
Jason Wang
KYE USA

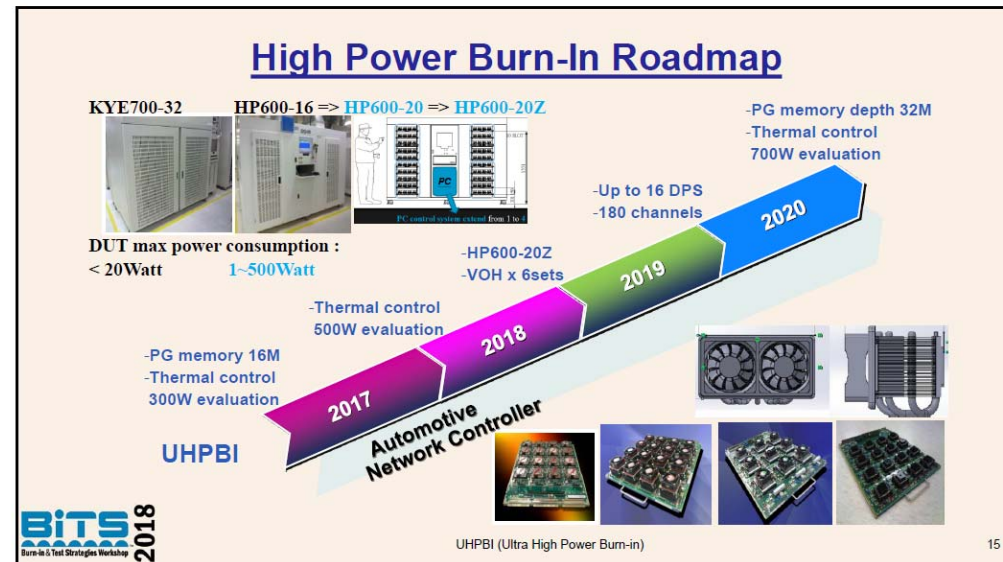


BITS 2018

Session 1B Presentation 4

A Better Workhorse

- Burn-in Printed Circuit Boards & Solutions



Burn-in & Test Strategies Workshop

www.bitstestworkshop.org

March 4-7, 2018

CPU's: Previously @ BITS: Package Complexity

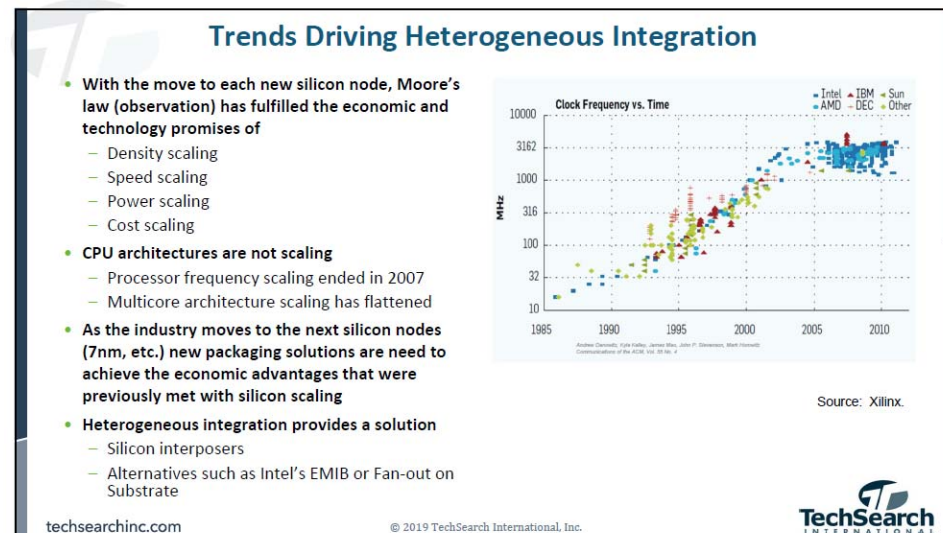
E. Jan
Vardaman
TechSearch
International



TestConX China 2019

Keynote

The Future of Advanced Packaging: Meeting the Challenges



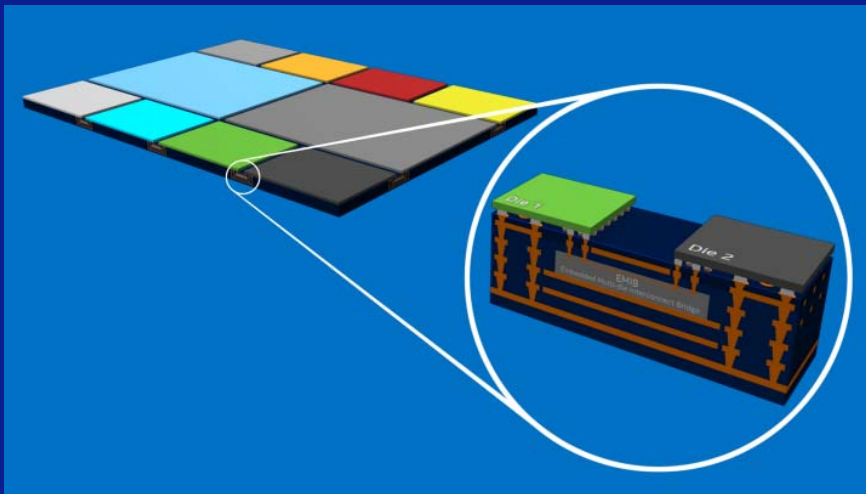
TestConX China Workshop

TestConX.org

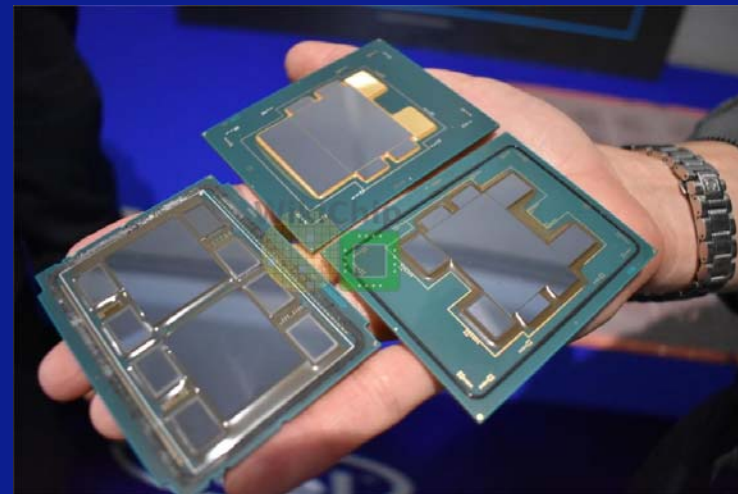
October 29, 2019

39 2020

CPUs: CPU Architecture - EMIB

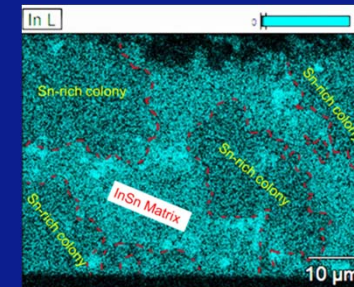
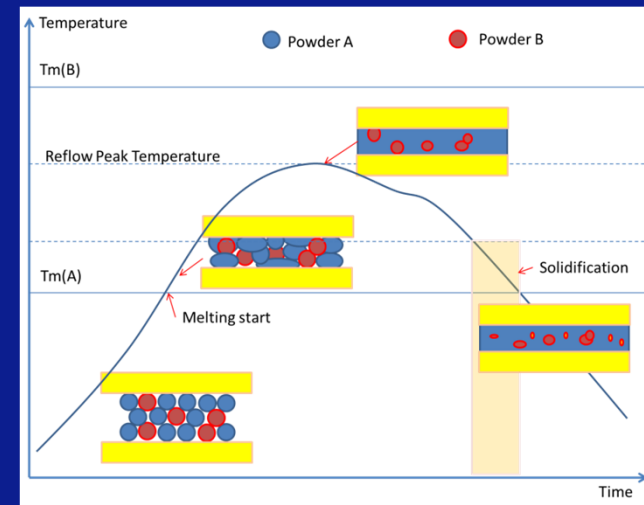
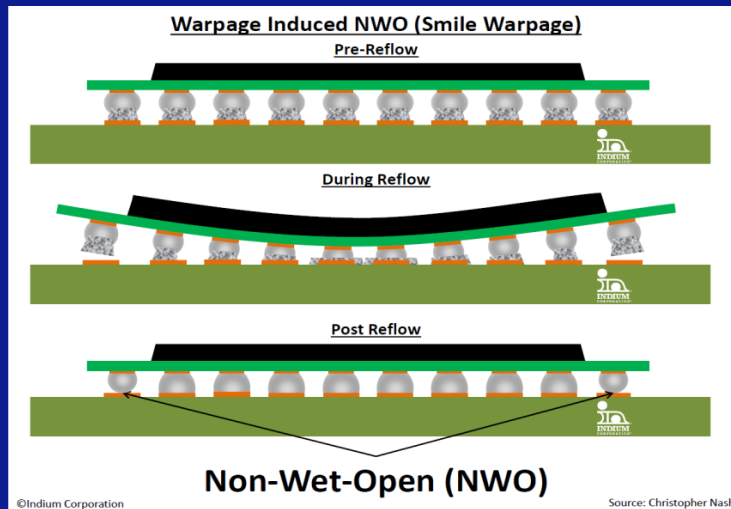


Source: Intel



Source: David Schor

CPUs: Managing Warpage during Assembly



Summary

Automotive

- New Alloys (and Old Alloys repurposed)
- New Class Materials (sintering)
- New Forms
- New Thermal Systems
- New Assembly Processes

5G

- New Powders
- New Alloys (and Old Alloys repurposed)
- New Solder Forms
- New Fluxes
- New Potting Compounds
- Heterogeneous Integration
- New Assembly Processes

Networking & Edge Computing

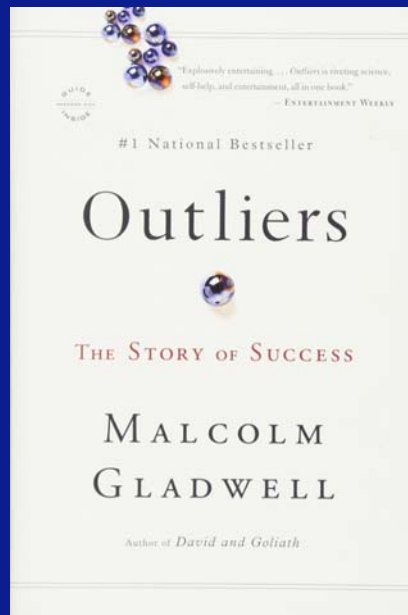
- New Powders
- New Alloys (and Old Alloys repurposed)
- New Fluxes
- New Thermal
- Heterogeneous Integration
- New Assembly Processes



42 2020

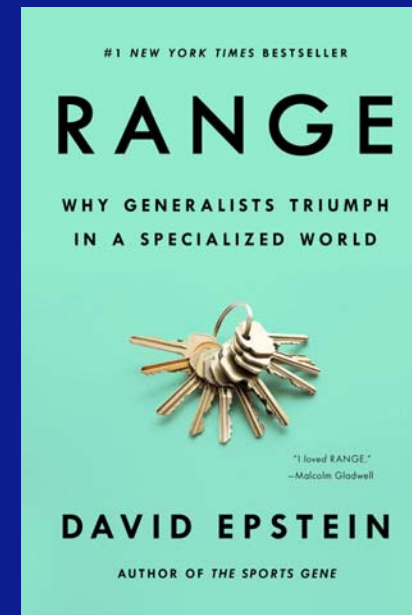
Meeting this Challenge

Specialists



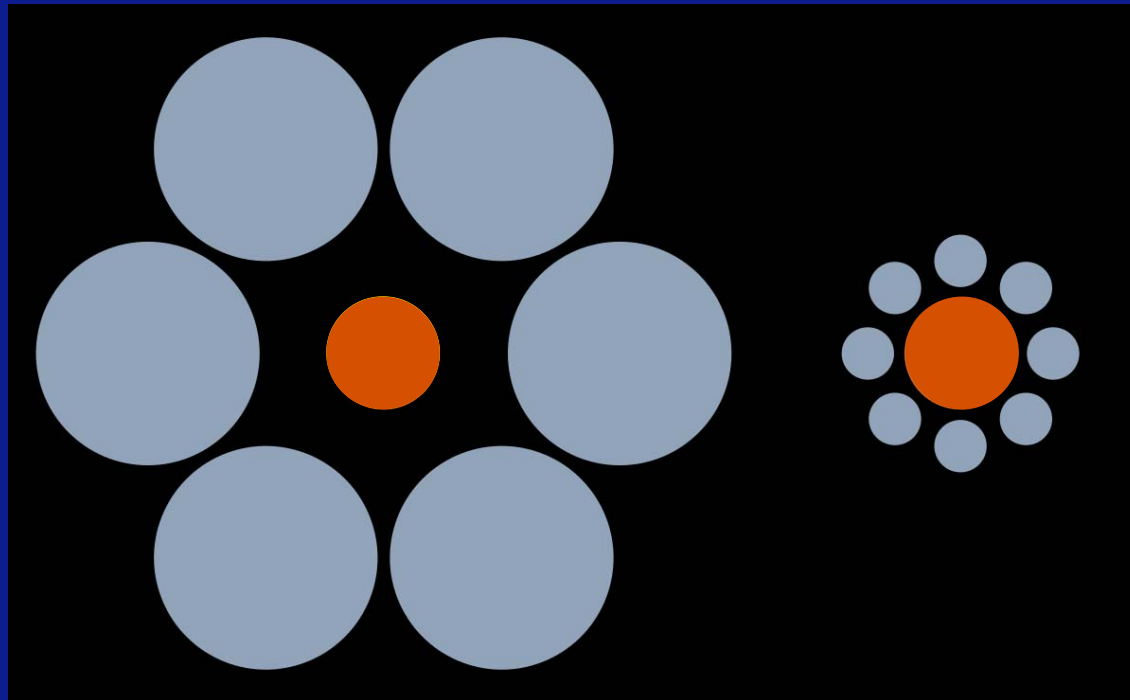
10,000 hour rule

Generalists



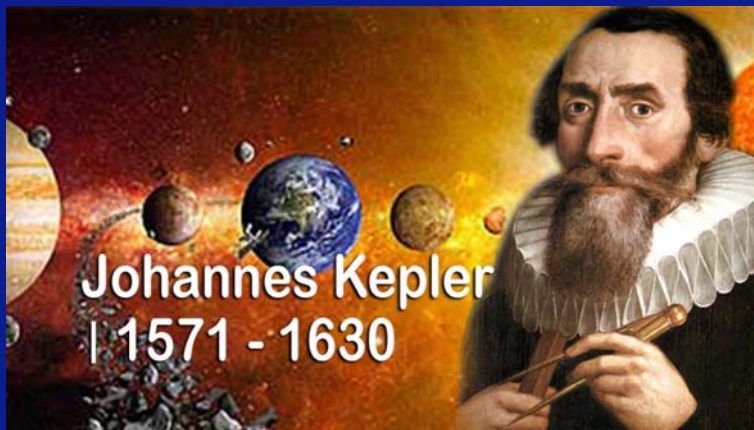
INNOCENTIVE®

The Ebbinghaus illusion



Avoiding Einstellung Effect

Einstellung refers to a person's predisposition to solve a given problem in a specific manner even though better or more appropriate methods of solving the problem exist. The **Einstellung effect** is the negative effect of previous experience when solving new problems.



Source: Clickntech

- Analogies
- Leave the Routine
- Engage with Peripheral Domains
- Diversity (of ideas)
- Daydream (hard with smartphones)
- Embrace Range & Inefficiency
- Fight Hierarchy
- Free Play

Need: **Focused Frogs & Visionary Birds** Hedgehogs & Foxes



Freeman Dyson

The Greek poet Archilochus wrote, "the **fox** knows many things, but the **hedgehog** knows one big thing."



Discussion

Staying Safe in Covid-19 Era: Manufacturer's Pledge

Ensuring the SAFETY and INTEGRITY of the New York State Production Supply Chain:
Pledge To Enhance Manufacturing Workplace Safety Amid the **Novel Coronavirus Outbreak**

Manufacturer's Pledge

Company Name	Locations	Contact Information

By signing this document, I PLEDGE on behalf of my Company, in this era of Novel Coronavirus and for the duration of New York State's state of emergency, to follow and improve upon the best practices herein listed which are intended to promote employee and community safety at our factories.

I will, to the fullest extent possible,

- Ensure the highest standards of workplace safety that meet or exceed recommendations for virus containment
- Protect employees, their families and our communities
- Secure critical supply chains and employment

I will adhere to all applicable guidelines established by NYS DOH, the CDC and the WHO.

I will not operate business as usual, but will make the following key structural changes: 1) control site traffic, 2) enhance hygiene, 3) engender social distancing and reduce density, 4) deploy emergency response and quarantine procedures and 5) communicate regularly to all stakeholders.

I will meet or exceed the expectations for these structural changes as detailed below:

NYC Manufacturing Coalition's Best Practices for Combatting Coronavirus

- Control Site Traffic:** To ensure each of our sites is safe for employees to work, the first step is to control who enters the site to minimize risk. All entrants must be known and confirmed to not have symptoms including no elevation in body temperature per CDC guidelines.
 - Stop all non-essential travel, visitors, site-to-site movement, contractors, outside services and face-to-face meetings
 - No entrance with elevated body temperature per CDC guidelines
 - No entrance if sick or symptomatic
 - Collect a health questionnaire for each necessary visitor and control and document their access points and contacts
 - Control Shipping/Receiving Areas by refusing entry of drivers, limit access of delivery personnel to the shipping area, avoid direct contact, deploy enhanced hygiene protocols for shipping/receiving areas such as personnel protective gear and enhanced cleaning
- Enforce coronavirus exposure protocols:**
 - Follow NYS DOH guidelines
 - Follow a prescribed procedure prior to reentry to sites for all returning travelers from outside the normal employee base
 - If test ordered by medical professional, follow NYS DOH guidelines with a minimum requirement to reenter of a confirmed virus free test result
 - If test positive, follow medical professional direction and NYS DOH guidelines, and no reentry

NYC Manufacturing Coalition

Page 1 of 2

Ensuring the SAFETY and INTEGRITY of the New York State Production Supply Chain:
Pledge To Enhance Manufacturing Workplace Safety Amid the **Novel Coronavirus Outbreak**

- Enhance Hygiene Protocols:** To ensure the overall site and high frequency touch points are not areas of transmission, most importantly, aggressively promote hand washing through social pressure, training and reminders. In addition, deploy staff to increase frequency and total area cleaned with antibacterial cleaning agents especially the high frequency touch points.
 - Provisional programs around hand washing and other best practices ("On The 5")
 - Enhanced door, stairwell handle, light switch, time clocks, surfaces, etc. wipe down
 - Increase availability of soap, hand sanitizer and cleaning materials
- Social Distancing to Reduce Density:** To meet or exceed appropriate standards: All employees are protected by reducing the density and frequency of contact through flexible senior staff reporting to work (shift adjustments and teleworking) and through making social distancing inherent in physical layout of the site (ie: clearly work areas, break rooms, break times and break locations)
 - Reduce personnel density in all areas by redesigning workspaces and workflows to minimize person-to-person contact
 - Teleworking whenever possible for all departments while maintaining appropriate levels of safety and support
 - Staggering breaks, separate break rooms, separated tables and reduced seating per table
- On-Site Emergency Response:** Aggressive containment, quarantine and deep cleaning positioned in advance of a case developing at a site. Although plans to control site traffic are designed to prevent such occurrence, preparation is key to success, should the unexpected happen.
 - Upon identification of a suspected Novel Coronavirus case at the site, the individual will be quarantined in a designated location until health officials can be contacted or the individual can safely return home or to a health facility
 - All staff who has contact with the individual will be asked to follow the latest NYS DOH health guidelines for exposure
 - All work spaces contacted by the individual will have deep cleaning
- Communication to Employees, Community and Customers:** Regular and robust communication to all our stakeholders is critical to the healthy functioning of our communities and our companies. Because for many, the employer is considered a voice of authority, we take our communication regarding Novel Coronavirus seriously and are communicating educational insights, best practices, methods to mitigate transmission in addition to how our companies are managing the challenge.
 - Daily updates to all staff on the latest facts concerning the virus in our communities, impacts on our business and their employment
 - Establish chains of communication to enable rapid transmission of information to all staff without large meetings
 - Through multiple media platforms, promote best practices from the CDC, WHO and NYS DOH
 - Create a crisis leadership team to collect and respond to concerns from our employees and our community

This Pledge Signed on ____ Day of ____, 2020

Signature: _____

Name: _____
Title: _____
Company: _____
Location: _____

This Pledge Certified on ____ Day of ____, 2020

Signature: _____

Name: _____
Title: _____
Company: _____
Location: _____

Resource Review Date: _____

Resource Name: _____

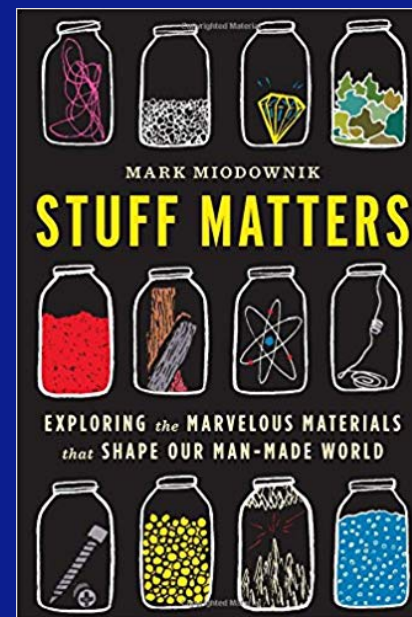
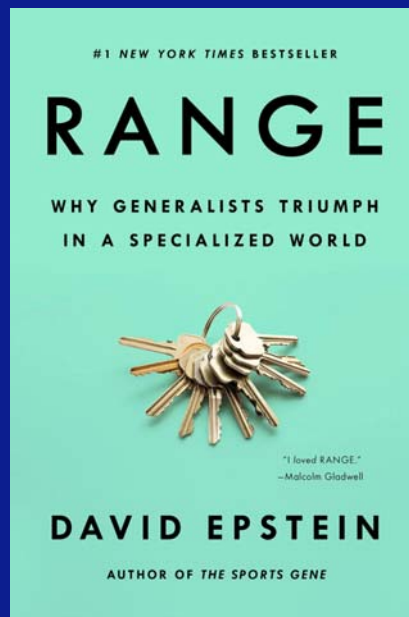
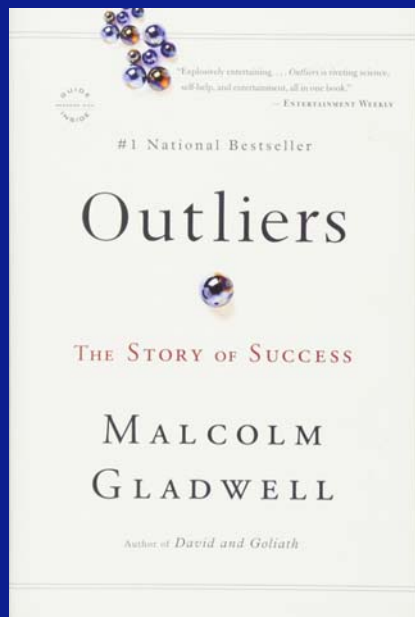
Resource Company: _____

NYC Manufacturing Coalition

Page 2 of 2

1. Control site traffic
2. Enhanced hygiene
3. Social distancing and reduced density
4. Emergency response and quarantine procedures
5. Robust communication.

Recommended Reading



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