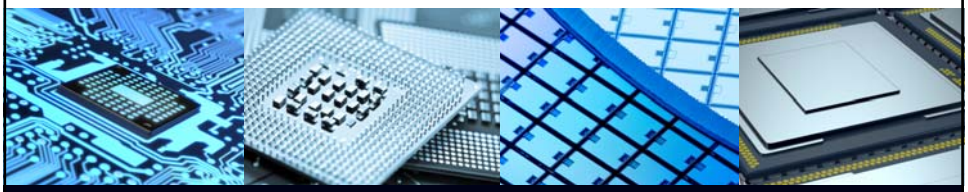
Supporting Microelectronic Research,
Development & Manufacturing in the UK



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Welcome to the

DIRECTIONS IN ADVANCED PACKAGING Webinar

Advanced Packaging—Where Have We Been Are Where Are We Going?
– E. Jan Vardaman, TechSearch International, Inc

Future Direction, Challenges and Technologies – The times they are a changin'…
– Grace O'Malley, International Electronic Manufacturing Initiative (iNEMI).

Webinar starts at 2.30pm GMT

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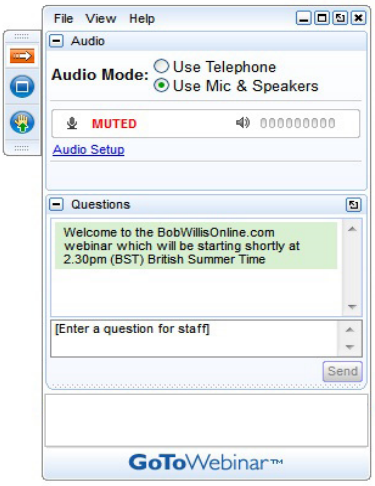

Submit text questions during or at the end

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IMAPS

International Microelectronics Assembly and Packaging Society

IMAPS leads and enables communication, education and interaction

- For the Microelectronics Packaging, Interconnect and Assembly Community

Worldwide IMAPS Chapters represent their local regions

IMAPS-UK is your local Chapter!

About IMAPS-UK – membership your local chapter:

- Approximately 140 members (Sept 2017):
  - Student, Individual, Academic & Corporate Membership Categories
- Managed by elected volunteers (registered charity)
- Host of Discounted Technical Conferences & Educational Workshops
- Search the IMAPSource Portal
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Forthcoming Event Programme

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The Next Webinar:

"Free"….

IMAPS – UK

Advanced Circuit Boards

1st November

PCB - Polymer Substrates - Jim Francey – Optiprint
The future for substrates - Piers Tremlett – Microsemi

Highlights from the IMAPS Advanced Circuit Board Workshop
Recording download will be available to members

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Forthcoming Event Programme:

pOp II 2018

The 2nd International Conference
on
Photonics and Opto Packaging

"Linking Optoelectronics Designers & Manufacturers"
Tuesday 23 October 2018
The University Centre, South Devon College, Paignton, TQ4 7EJ

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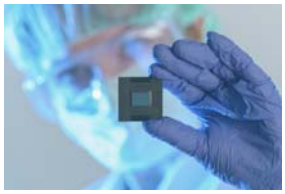
Forthcoming Event Programme:

DIE ATTACH WORKSHOP
The MTC, Coventry, UK
November 22, 2018



- An IMAPS-UK Educational Workshop
- Sessions on: Processes, Manufacturing Know How & Optimisation, Reliability and Test, Plus presentations on Materials and a Short Surgery
- Counts towards Continuing Professional Development "CPD"
- Training for those involved with die bonding processes, those new to the microelectronics industry, or for people wanting to expand their knowledge

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Future Events are being planned for 2019 :

- **IoT Packaging Workshop - Feb 2019**
- **Basic Packaging Workshop – June 2019**
- **Thermal Design Workshop – September 2019**
- **Aerospace & Space Packaging – Oct/Nov 2019**

AGM

MicroTech 2019
The Annual Conference and Exhibition

Will be held in Cambridge – late March/early April 2018

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Future Direction, Challenges and Technologies

Grace O'Malley,
Vice President of Operations

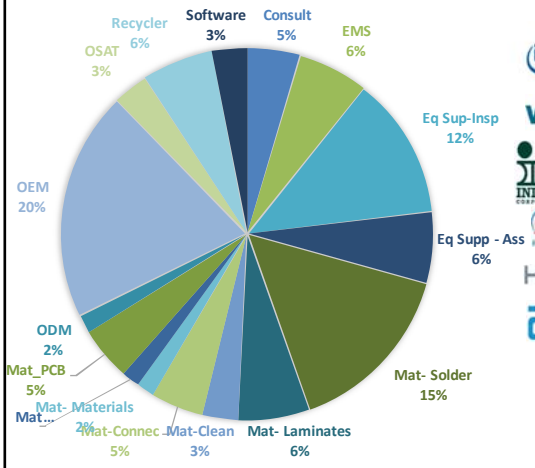
iNEMI
Advancing manufacturing technology

The times they are a changing'….

iNEMI

Find out more at https://www.imaps.org.uk/

International Electronics Manufacturing Initiative (iNEMI): Represents the full breadth of the design / supply chain



Example of membership on 1 project

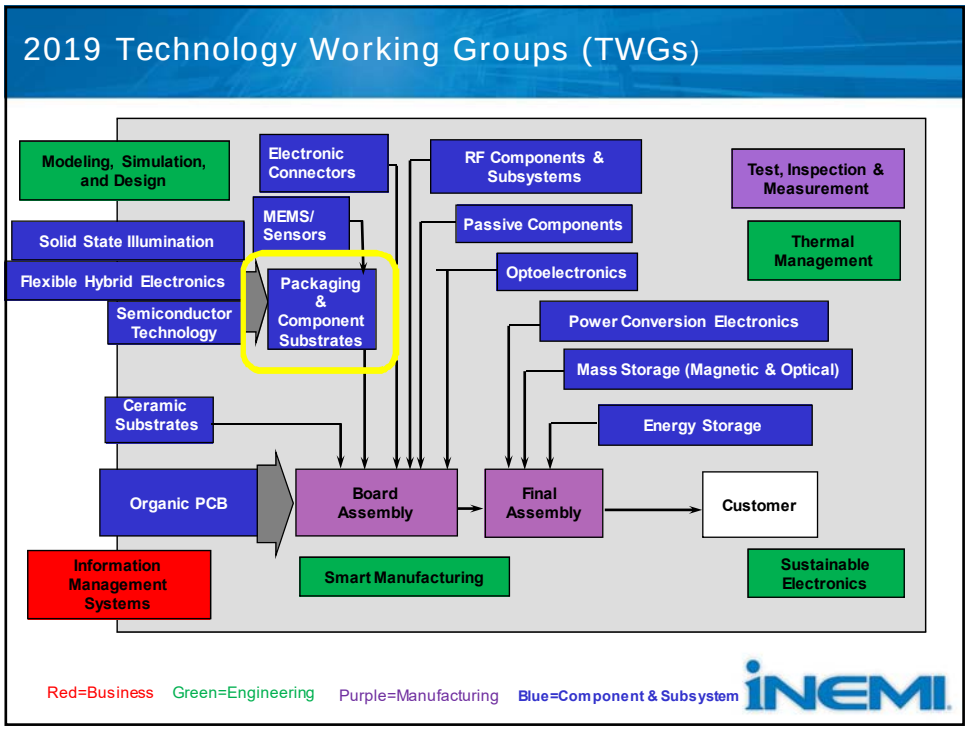
Forecast and Accelerate improvements in the Electronics Manufacturing Industry for a Sustainable Future via Collaborative Innovation

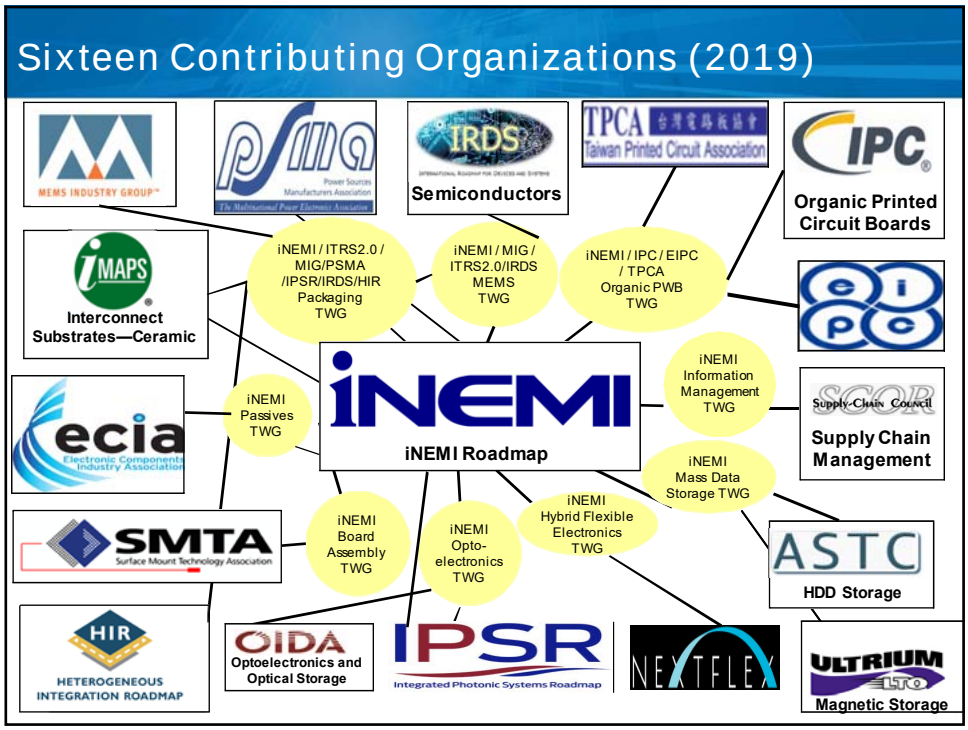
iNEMI Roadmap for Electronics Industry

Statistics for 2017 Roadmap

- > 500 participants
- > 350 companies/organizations
- > 20 countries
- Greater than 10 man years of resources in the development
- 21 Technology Working Groups (TWGs)
- 7 Product Emulator Groups (PEGs)
- Nearly 2000 pages of information
- Roadmapped the needs for 2017-2027
- 2019 RoadMap map update will be published in early 2019

Find out more at https://www.imaps.org.uk/





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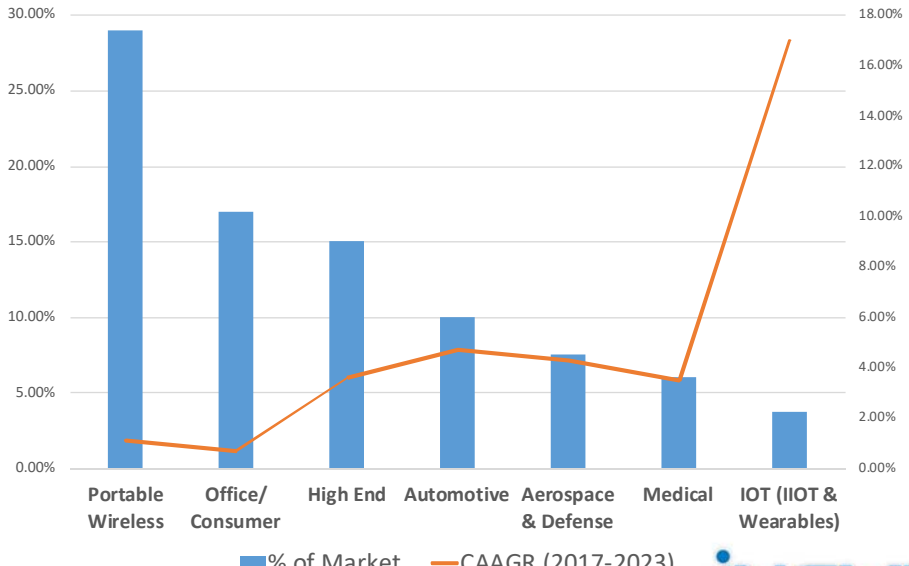
Acknowledgement:

iNEMI Roadmap Packaging & Component Substrates Technical Working Group (TWG)

Chairs:
Bill Bottoms, 3MTS
William Chen, ASE
Raja Swaminathan, Intel (2017)

iNEMI
Advancing manufacturing technology

Market Forecasts (2017 to 2023)



(Prismark for 2019 iNEMI Roadmap Feb 2018)

20

iNEMI

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2015-2017 Key Trends

- The end of Moore's Law scaling
- Rise of the Internet of Things
- Migration of data, logic and applications to the Cloud
- Consumerization of data and data access

2018-2023 Key Trends

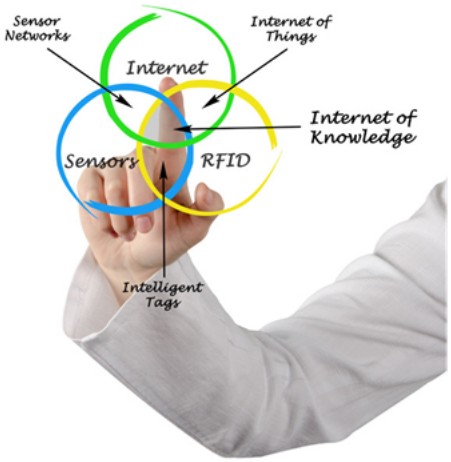
- Migration of data, logic and applications to the Cloud
- Consumerization of data and data access
- Smart Everything
- Handling Big Data
- 5G Networking
- High speed and computing requirements of applications such as autonomous driving and cryptocurrency mining

Find out more at https://www.imaps.org.uk/

Smart Everything

Many challenges

- Billions or trillions of devices;
- New security risks
- A range from low cost, high latency to high cost low latency
- Environments from deserts and glaciers to in-body and under the hood
- Onetime use to lifetime of many years



Migration To The Cloud

Challenges

- Power requirements
- Latency
- Physical density of bandwidth
- Increasing reliability and security

Find out more at https://www.imaps.org.uk/

Consumerization Of Data

Challenges

- Big data
- High performance
- Battery life
- Latency
- Reliability
- Security

Enabling Technologies

Infrastructure - all systems and components for:

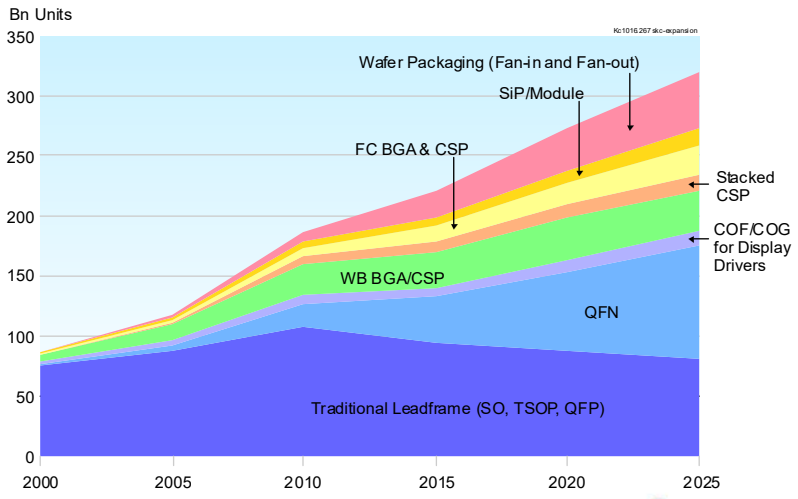
- physical devices to create, store, secure and exchange all forms of data
- Networking for all forms of data movement and sharing
- Physical devices and software to transform data into information and make it available worldwide in real time.

Enabling Packaging Technologies

Addressing more diverse applications and performance envelops

- ✓Meeting electrical, mechanical and thermal, performance and durability requirements
- ✓Integrating of diverse architectures
- ✓Continuous cost reduction
- ✓Adaption to form factor requirements
- ✓Integrating sensing capabilities

Technology Change and Market Expansion



Prismark Partners 2018

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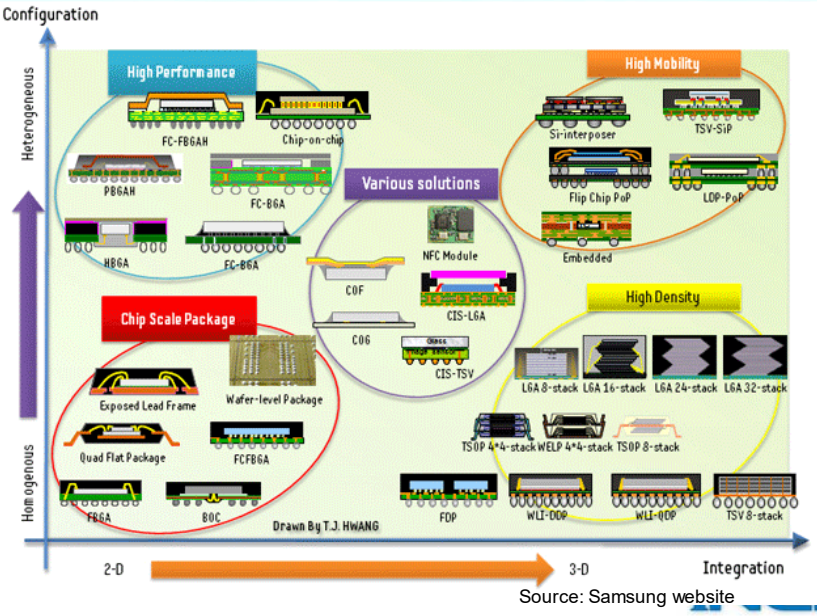
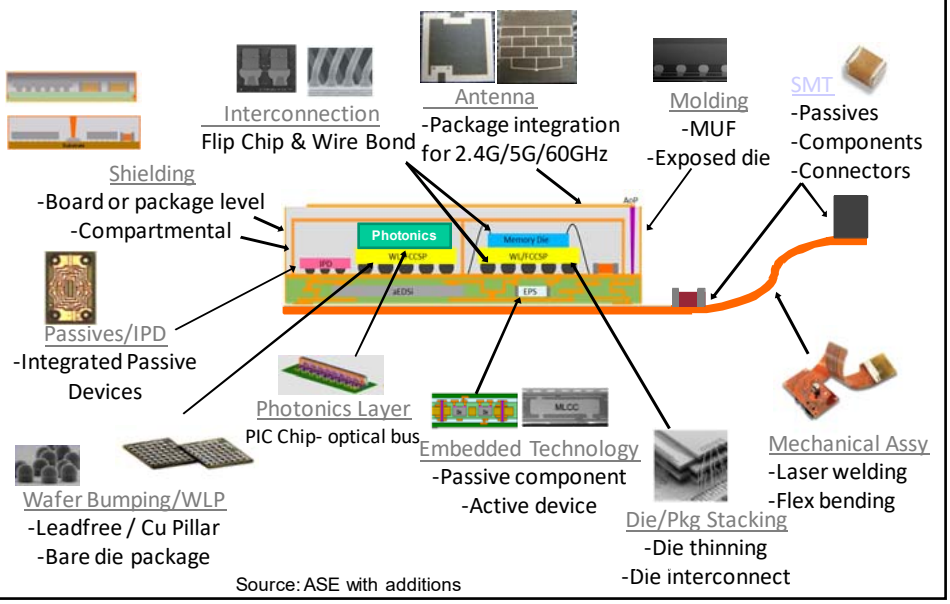
Situational Analysis



Source: Samsung website

3D SiP in the future



Shielding
-Board or package level
-Compartmental

Interconnection
Flip Chip & Wire Bond

Antenna
-Package integration
for 2.4G/5G/60GHz

Molding
-MUF
-Exposed die

SMT
-Passives
-Components
-Connectors

Passives/IPD
-Integrated Passive
Devices

Photonics Layer
PIC Chip- optical bus

Embedded Technology
-Passive component
-Active device

Mechanical Assy
-Laser welding
-Flex bending

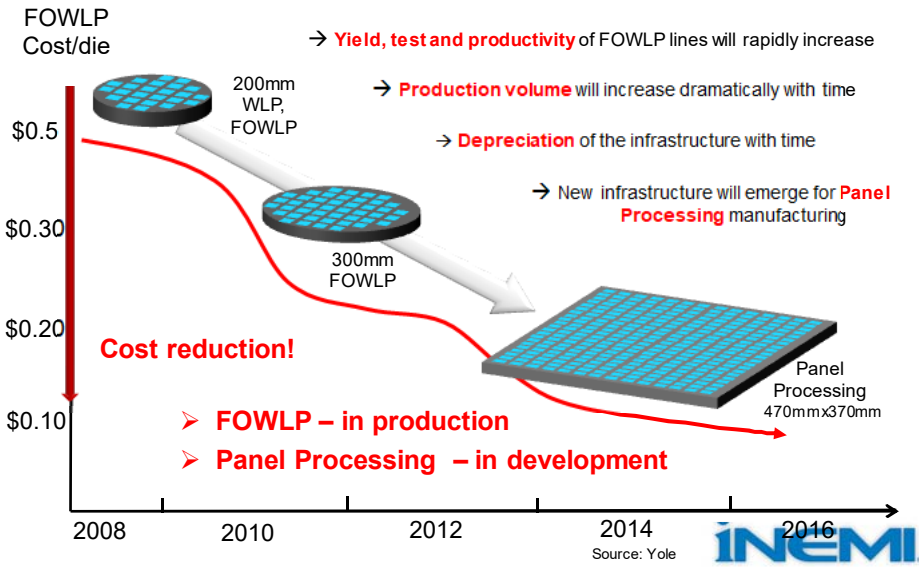
Wafer Bumping/WLP
-Leadfree / Cu Pillar
-Bare die package

Die/Pkg Stacking
-Die thinning
-Die interconnect

Source: ASE with additions

Find out more at https://www.imaps.org.uk/

WLP, FOWLP and Panel Processing Increase Parallelism and Reduce Cost



Grand Challenges

- Supply Chain Structure
  - Complex
  - Fabless
  - Integrity
  - Security
  - Short NPI required
  - Readiness
  - Very competitive
  - Cost effective

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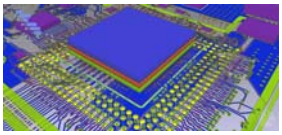
Grand Challenges



- Design
  - Coherent chip-package-system co-design, modelling and simulation
- **Power**
  - Decrease operating voltages
  - Better inductor/capacitor design
- **Thermal Management**
  - More complex structures
  - More functionality in smaller volume

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Grand Challenges

- **Manufacturing**
  - Placement accuracy (sub-micron)
  - Processes with maximum temperature below 250° C
  - Low cost handling of thinner die and wafers
  - Handling panels
- **Test**
  - KGD / KGW
  - Test access

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Grand Challenges

New Materials Will Be Required

Many deployed today

- Cu interconnect
- Ultra Low k dielectrics
- High k dielectrics
- Organic semiconductors
- Green Materials

100% of the packaging materials changed during the last decade

Many are in development

- Nanotubes
- Nano Wires
- Macromolecules
- Nano Particles
- Composite materials

50% will change again during this decade

Source: Bill Bottoms

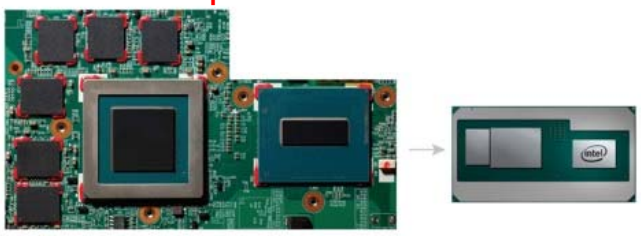
iNEMI

Benefits

These Driving Forces Lead Intel And AMD To Partner Evidence Of Fundamental Changes & Heterogeneous Integration

Integration of Intel's Core processor, AMD's Radeon graphics chip with High Bandwidth Memory

Decreased size, Decreased weight and improved performance



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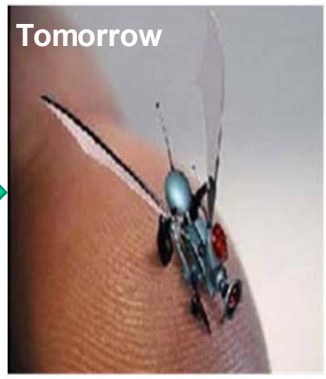
Enabling New Applications

GPS navigation, sensors, camera, memory
Radio, remote control



iNEMI

www.inemi.org

Grace O'Malley
gomalley@inemi.org

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Advanced Packaging: Where Have We Been and Where Are We Going?

E. Jan Vardaman

- TRACK INNOVATION
- IDENTIFY TRENDS
- ANALYZE GROWTH
- INFLUENCE DECISIONS

RELEVANT. ACCURATE. TIMELY

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A Lot Happened in the Last ~10 Years…….

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WLPs Increase Count in iPhone….

- **First iPhone contained 2 WLPs, and it was a big deal**
- **The iPhone 7 contained 44 WLPs, and it is a bigger deal**
  - One is FO-WLP (TSMC's InFO)
  - Additional 43 on main board plus WLPs in lightning cable, earbud, etc.
- **The iPhone 8 contains ~43 fan-in WLPs and one FO-WLP for the AP**
- **The iPhone X reduced the number of components but still ~40 WLPs with on FO-WLP**
  - New board design

Source: TSMC.

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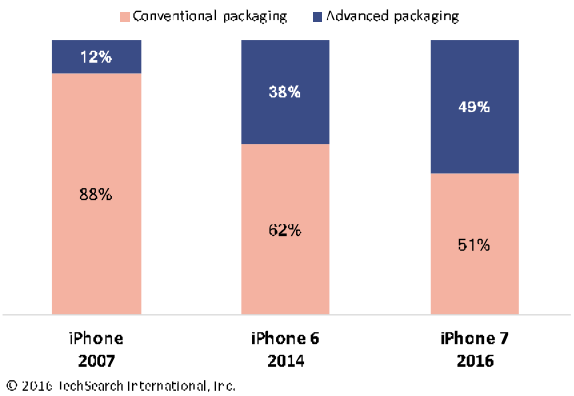
Advanced Packaging Share of iPhone's Total Die Area



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- **Increasing use of advanced packaging (FC and WLP)**
- **In iPhone 7, ~49% is assembled and packaged using WLP and flip chip packaging technologies**
- **Remaining 51% uses wire bond-type packages**

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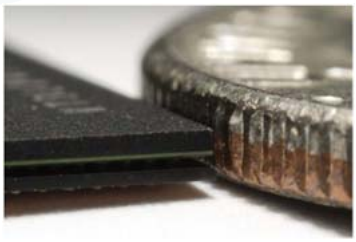
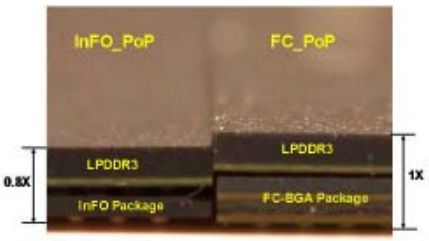
TSMC's InFO for Apple's A10 and A11 Processors



Source: TSMC.



Source: TSMC.

Source: TechInsights.

- **Die-first, face-up process, RDL formed on top of Cu pillars on die**
- **Improved electrical and thermal performance of InFO vs. FC-CSP**
- **Thinner than flip chip package (no substrate)**
  - InFO-PoP is 20% thinner than FC-PoP
  - Can enable a low-profile PoP solution as large as 15mm x 15mm body or greater
  - But thin is not the only driver…..

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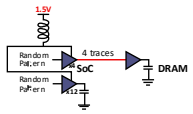
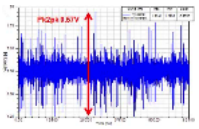
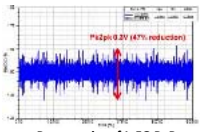
InFO PoP Power Noise Reduction and Signal Integrity Improvement



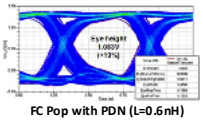
Equivalent PDN Network Circuit



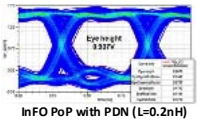
Power noise of FC PoP



Power noise of InFO PoP



FC Pop with PDN (L=0.6nH)



InFO PoP with PDN (L=0.2nH)

Source: TSMC.

- **Powerful demonstration of improvement in electrical performance compared to a FC on laminate substrate for bottom PoP**
  - Power noise reduction
  - Signal integrity improvement
- **Thermal performance improvement because no substrate**
  - Direct thermal path to PCB

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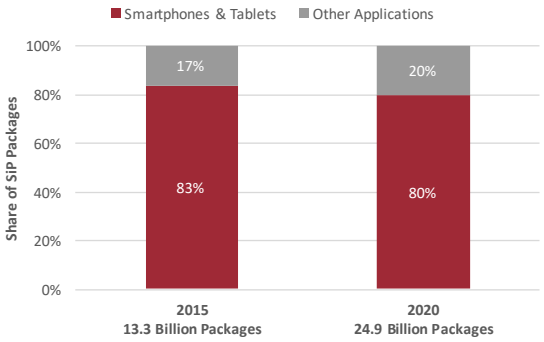
Smartphones & Tablets: Major Share of SiP Applications



- Smartphones and tablets will continue to account for the major share of the SiP market in number of packages
- High growth is expected in emerging applications such as automotive, medical, wearables, and high-performance computing/networking

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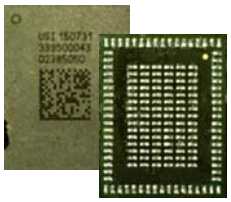
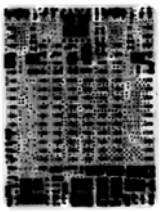
WiFi/Bluetooth/FM Connectivity Modules

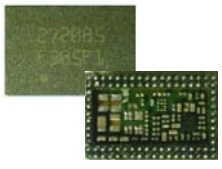
WiFi/BT/FM Module (Manufactured by USI)





9.0 mm x 11.7 mm x 0.8 mm
FLGA with 72 lands

WiFi/BT/FM Module (Manufactured by Murata)



9.3 mm x 6.3 mm x 1.1 mm
FBGA with 84 balls

Source: TPSS.

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Industry Trends

- **Traditional unit growth markets slowing….**
  - PC sales declining
  - Smartphone sales low growth
  - Impacts BGA and CSP growth
- **Shift in interconnect from WB to FC for DRAM, but low unit volume growth because of weakness in PC and mobile sectors**
- **Cryptocurrency driving unit volume growth end of 2017 and first of 2018, but will it continue?**
- **Connectivity trends**
- **Big data analytics drives high-performance packaging**
- **Increased electronic content in automobiles with ADAS**

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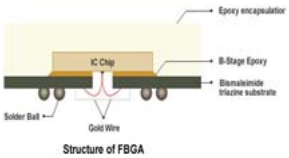
Shift in Memory Packaging and Interconnect

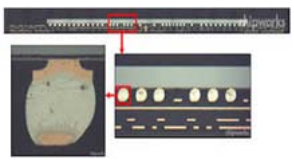
TSOP

FBGA



Structure of FBGA

Wire Bond



Flip Chip

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Find out more at https://www.imaps.org.uk/

Cryptocurrency Impacts ASIC, GPU Business

- **Creates Demand for chips with high-performance processing capability with power efficiency**
- **ASICs based on 16nm semiconductor node in mass production**
  - Designs for 10nm and 7nm semiconductor nodes in development
  - 40% of ASICs obsolete in one year = big replacement cycle and no need for long term reliability
- **CPU replaced by GPUs and ASICs also designed for cryptocurrency**
  - AMD and NVIDIA increased GPU (FC-BGA, up to 40mm x 40mm body size)
  - Increased use of ASICs (FC-CSP, 8mm x 8mm body size) not as many expected to ship in 2018
- **Major players**
  - Foundries: TSMC and GLOBALFOUNDRIES, SMIC future target
  - Major OSATs including China OSATs (Huatian, TFME, and JCET/STATSChipPAC)

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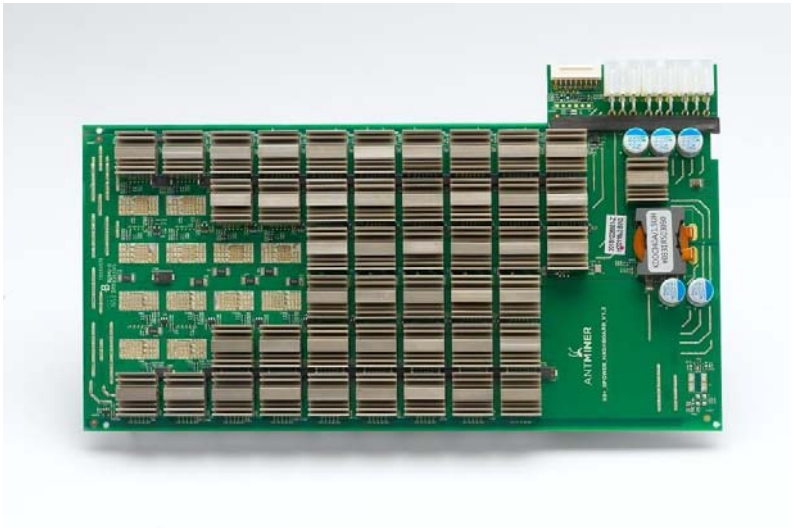
Antminer T9 Hashboard



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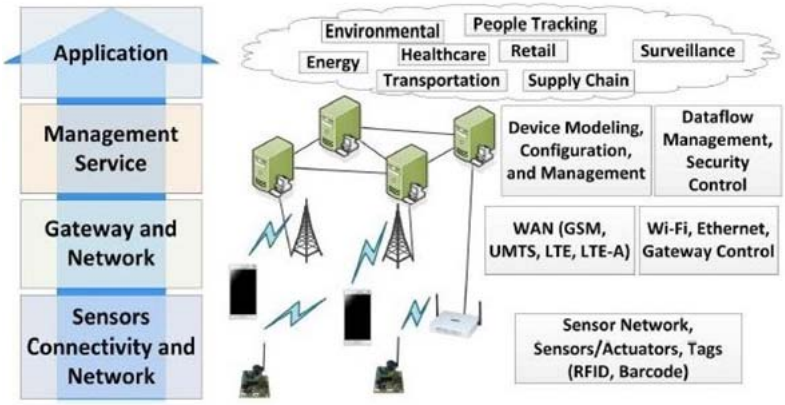
Smart Factory Trends



- **Sensors to detect**
  - Color, rotation, speed, tensile, compression, strain, roughness, warpage, sound, pressure, vibration, humidity…
- **Increased collection of data and analysis**
  - Predict downtimes (predictive maintenance), decrease waste, lower power cost, prevent accidents
  - Ultimately to increase productivity

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Future Trends for RF Modules: 5G

- **5G New Radio offers high bandwidth, low latency, and massive scalability of 5G**
  - High-performance baseband processors
  - Broadband, steerable, and high gain mmWave antennas
  - Efficient and broadband mmWave front-end ICs
  - RF components for co-design of mmWave antennas and front-end ICs with high-Q inductors, filters, power dividers, phase shifters, and attenuators
- **5G potentially means new radios, new modems, new PA, and new FEM**
  - Greater modularization expected
  - System-in-package designs with fully integrated antenna (so antenna design capabilities are important)
  - Thermal and electrical modeling become more critical
  - Electromagnetic compatibility and EMI shielding become more important
- **New dielectric materials may be required for IC package substrate and board (laminate form of module expected to be dominant)**

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Big Data Processing

- Many sources of information
- Key is analysis

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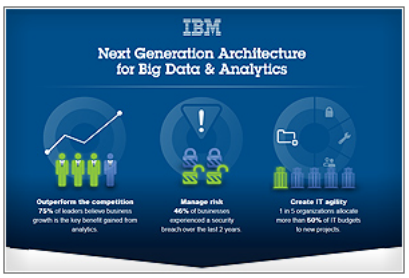
Data Analysis and Hardware

Source: HP.



- Data analysis
- Systems different package configurations
  - Si interposers and HBM packaging solutions
  - FO on substrate
  - Multichip modules (MCMs) with laminate substrates
  - Alternatives such as EMIB

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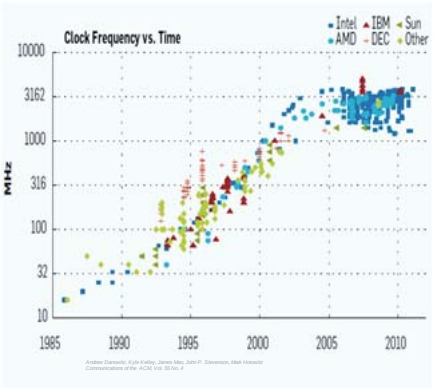
Trends Driving Heterogeneous Integration

- **With the move to each new silicon node, Moore's law (observation) has fulfilled the economic and technology promises of**
  - Density scaling
  - Speed scaling
  - Power scaling
  - Cost scaling
- **CPU architectures are not scaling**
  - Processor frequency scaling ended in 2007
  - Multicore architecture scaling has flattened
- **As the industry moves to the next silicon nodes (10nm, 7nm, etc.) new packaging solutions are need to achieve the economic advantages that were previously met with silicon scaling**
- **Large body size laminate substrates FC-BGA**
  - Drives development in new materials
- **Heterogeneous integration is considered the answer and is taking various forms**
  - Silicon interposers
  - Alternatives such as Intel's EMIB or Fan-out on Substrate
  - Future organic interposers



Source: Xilinx.

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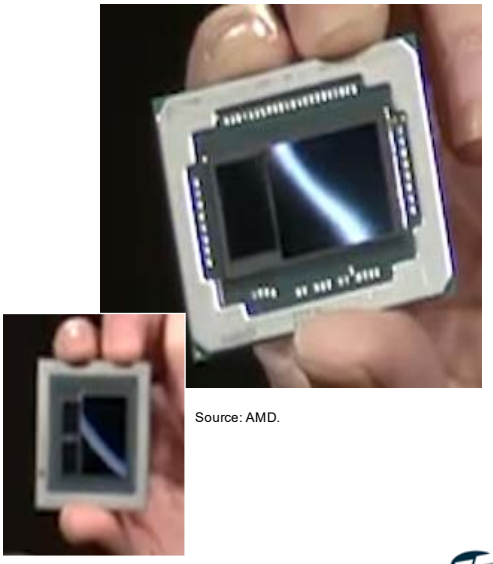
AMD's Radeon RX Vega Mobile with Interposer and HBM2

- **Launched at CES 2018**
  - Uses a silicon interposer and HBM2
  - 4 GB or 8 GB options
  - GPU z-height 1.7 mm slim



Source: AMD.

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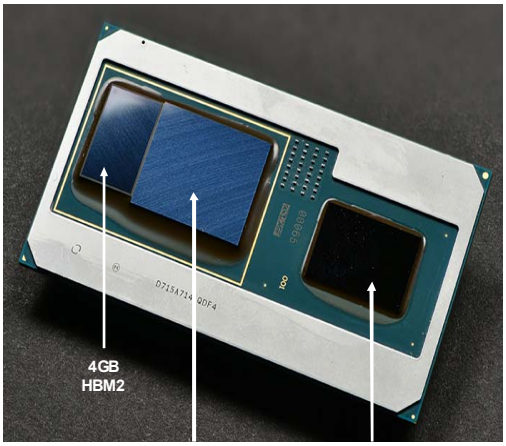
Find out more at https://www.imaps.org.uk/

8th Gen Intel® Core™ with Radeon™ RX Vega M Using EMIB Technology

- **First consumer solution to use Intel EMIB & HBM2**
  - Reduced silicon footprint over 50%
  - Keeps CPU and GPU z-height 1.7 mm slim
  - 4GB of HBM2 memory
  - Up to 80% less power than GDDR5



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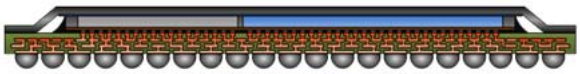
FO-WLP for Networking and Data Centers



FOCoS – Fan Out Chip on Substrate (FO FCBGA)

Source: ASE.

- **Hi-Silicon started FO-WLP shipments with ASE's Fan Out Chip on Substrate (FOCoS) for a networking system application in 2016**
  - Multiple die
- **MediaTek's shipping its network processor TSMC's InFO on Substrate (InFO_oS)**
- **Amkor is developing a version of its SWIFT® as a fan-out on substrate**

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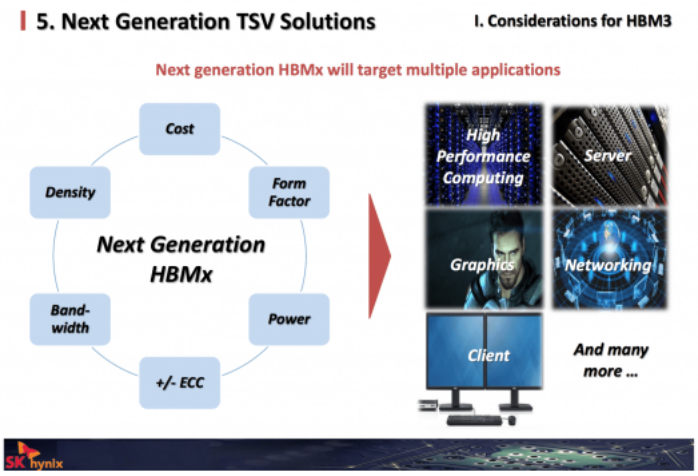
Next Generation HBM Solutions



- **Multiple applications for HBM market**

Source: SK Hynix.

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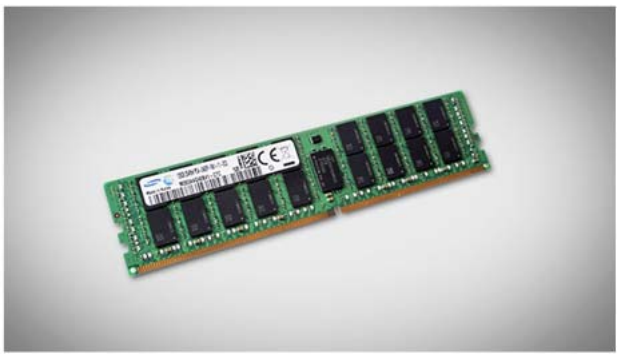
Samsung's DDR4 with TSV



- **Samsung's 128GB RDIMM uses DDR4 memory with TSVs**
  - DDR4 DRAMs fabricated on 20nm silicon node technology
- **Targeted for Datacenters and Servers**
  - Lower power
  - Double capacity of originally 64GB LRDIMM developed for Enterprise servers

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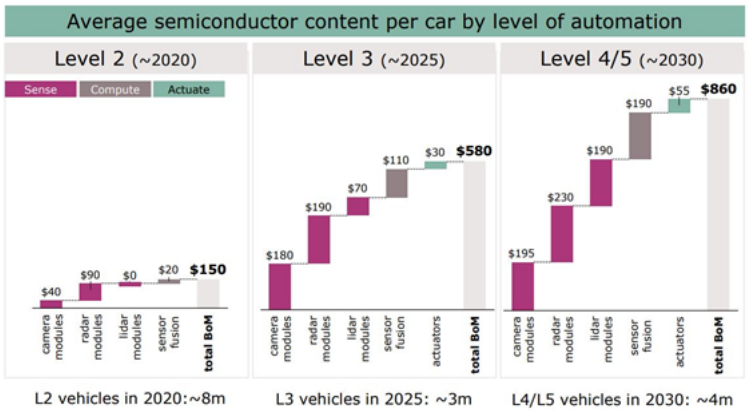
Increased Semiconductor Content in Automotive

ADAS/AD semi growth driven by radar and camera sensor modules over the next 5 years



L2 vehicles in 2020:~8m | L3 vehicles in 2025: ~3m | L4/L5 vehicles in 2030: ~4m

Source: Strategy Analytics; IHS Markit, Technology Group; Infineon.
Bill of material contains all type of semiconductors (e.g. radar modules include µC).

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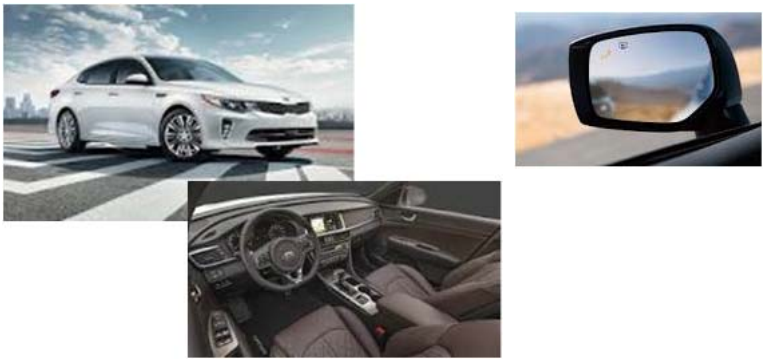
What's Here Now



- **Autonomous Emergency Braking (AEB)/Forward Collision Warning System (FCWS)**
- **Lane Departure Warning System (LDWS)**
- **Blind Spot Detection (BSD) System/Lane Change Assist**
  - Uses radar sensors

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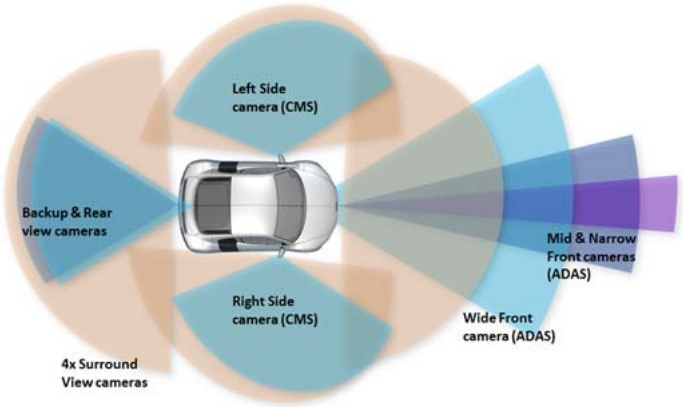
Multiple Cameras



- **Key Features for camera can't be degraded by package**
- **Challenges compared to cameras for mobile phone**
  - Day vs. night
  - Affected by bad weather conditions
  - LED flicker from traffic lights

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Processor for Camera Sensors

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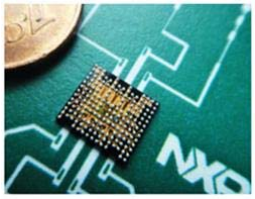
Automotive mmWave Radar Sensors

- **Shifting from 24 GHz to 79-81 GHz for SRR/MRR applications**
  - 24 GHz to be phased out in EU by 2022 (many in QFNs)
  - Some FC-CSP
  - Some bare die
- **FO-WLP prevalent for 79-81 GHz mmWave applications providing a**
  - Volumetric shrink of current and future systems (40 to 90%)
  - Increased functionality with heterogeneous integration
  - Improved in system performance
    - Low parasitics
    - Low inductance
  - Less expensive relative to other solutions

NXP radar module in FO-WLP



Source: NXP.

Source: TI.

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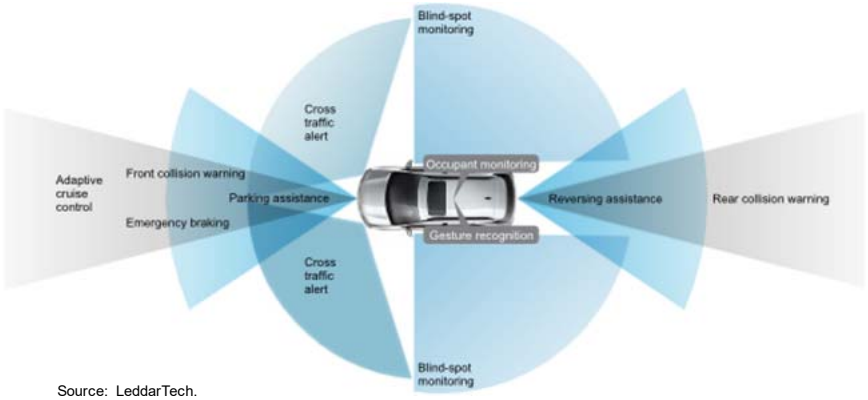
Application of LIDAR Sensors



Source: LeddarTech.

- **Sensors can be integrated into headlights, rear lights, or sideview mirrors for use in mainstream LIDAR applications**
- **Systems need to be smaller**
- **Systems need to be less expensive**

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Autonomous Driving: We're Not Quite There Yet……

- **Tesla Model S traveling at highway speeds crashed into a parked fire truck in Culver City, California (January 2018)**
  - Tesla traveling at 65 mph on Interstate 405
  - Fire truck was parked on side of the road after being deployed to an earlier accident
- **Allegedly happened while the car was on Autopilot…..**
  - Tesla says the Autopilot (AP) is intended only to be used by an attentive driver
  - Driver says Tesla was behind a pick up truck with AP engaged, truck swerved suddenly and he did not have enough time to react (pick up truck too high to see over)

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Autonomous Driving Needs Much More Work

- **On March 19 in Tempe, Arizona, a bicyclist was struck and killed by a self-driving Uber vehicle.**

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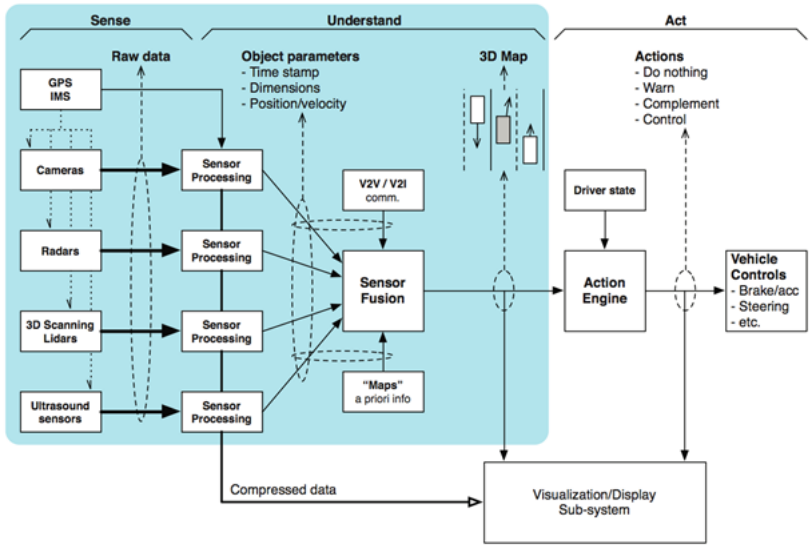
Autonomous Vehicle Platform

Autonomous vehicle platform: a functional diagram



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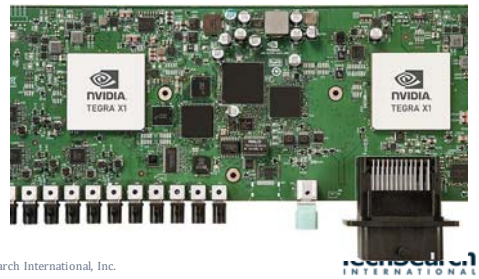
NVIDIA's Graphics Processors in FC-PBGA

- **First applications for Infotainment**
  - Packaged in FC-BGA
  - Single chip solution in package
- **GPU for sensor fusion/AI**
  - 2 Tegra chips each in FC-BGA mounted on board
  - Provides inputs for up to 12 cameras each packaged in FC-PBGA
- **Continental announced partnership with NVIDIA to enable production of AI computer systems that scale from Level 2 to Level 5**
  - NVIDIA DRIVE Xavier™

Source: NVIDIA.



Source: NVIDIA.

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NVIDIA GPU for Automotive

- **Thermal challenges….**

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Automotive Packaging Reliability Creates New Material Requirements

DIS	Chassis & Safety	ADAS	Body	Powertrain
Grade 3 & 2	Grade 1	Grade 1	Grade 1	Grade 1 & 0
-40°C to +105°C	-40°C to +125°C	-40°C to +125°C	-40°C to +125°C	-40°C to +150°C

Package STRESS	ABV	TEST METHOD			Duration			
		Standard	Condition	Unit	Grade 3	Grade 2	Grade 1	Grade 0
Temperature Cycling	TC	AEC-Q100, JESD22-A104	-50 ~ +175C	cycles				1000
			-50 ~ +150C		500	500	1000	2000
High Temperature Storage Life	HTSL	AEC-Q100, JESD22-A103	+175C	hours			500	1000
			+150C		500	500	1000	2000

Source: NXP formerly Freescale.

- **Automotive harsh environment testing for zero defect quality and 15+ year reliability at the ECU level**
- **Ambient temperature ranges for grades shown**
- **Increasing number of semiconductors are being used in automotive that are not designed for automotive**
- **Substrates and assembly methods require change**

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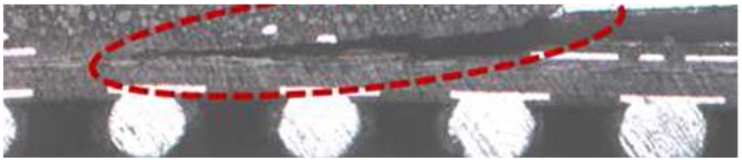
Flip Chip BGA Challenges

- Improved substrate performance is required to meet automotive reliability (no failures)
- AEC-Q100 Grade 0 requires BGA packages to pass high heat resistance and storage temperature of 175°C (normal would be 150°C)
- Trace cracking has been reported on FC-BGA packages when qualified for automotive applications
- Degrading of adhesion between the solder resist and base material or Cu layers has been report
- Underfill cracking observed resulting from package design induced stress
- New thermal interface materials may be required to handle high heat dissipation



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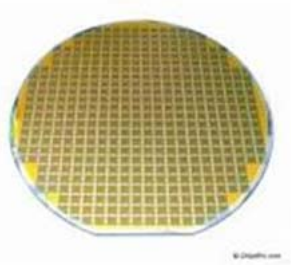
Changing Assembly Model: Processing at the Wafer Level

- **Traditional model:**
  - Wafer is processed in fab
  - Wafer sent to assembly facility for singulation, assembly, and test
- **New model:**
  - Some wafers stay at the foundry for packaging and assembly
  - Some OSATs install wafer processing equipment to create package on the wafer



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2018 Equipment CAPEX Budgets

- **CAPEX spending for 2018 for top 4 OSATs is projected to be ~$2.2 billion**
  - Spending on buildings is excluded
- **Greater level of investment required for advanced packaging with fab-like equipment and processes**
  - Increased revenue growth required to sustain CAPEX
  - Sustained revenue growth remains a challenge and drives M&A activity

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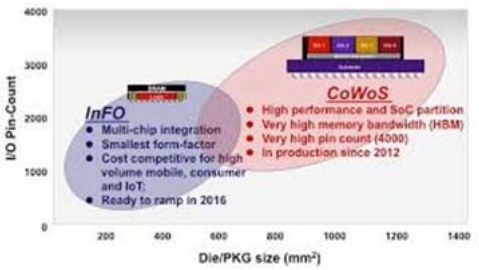
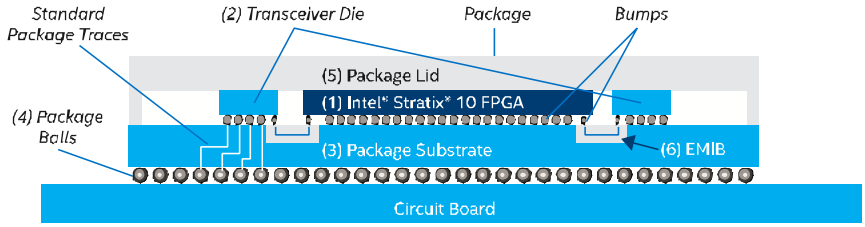
Competition: Foundries Offer Assembly Options

- **TSMC**
  - Fan-in WLP
  - InFO FO-WLP
  - CoWoS for Si Interposer
- **Intel**
  - EMIB
- **Samsung**
  - Si interposer + HBM
  - FO-WLP



Source: TSMC.



Source: Intel.

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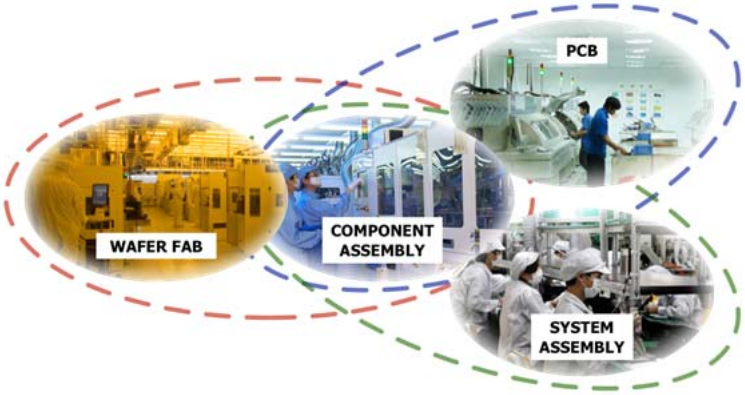
Everybody Wants a Piece of the Pie!



- **Competition from EMS companies in SiP, etc.**
- **PCB and substrate makers compete with embedded components**

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China: The Largest IC Market in the World

- **Consumes more than half the world's semiconductors**
  - But imported>$260 billion of chip-related products in 2017
  - No mainland Chinese firms in world's top 20 semiconductor
- **Foundry expansion in Mainland China**
  - TSMC, UMC, GLOBALFOUNDRIES, SMIC aggressive capacity expansion plans
  - Government offers incentives to non-native foundries and IDMs to build fabs
  - Semiconductor fab equipment spending will double from $3.6 billion in 2017 to $7.1 billion in 2018
- **China's strategy "Made in China 2025"**
  - Goal to become self-sufficient in semiconductors
  - Targeting 20% revenue CAGR 2016-2020 for ICs (from $57 billion to $145 billion)
- **National fund of $21.9 billion (government + 16 investors including local governments, private enterprises, and financial institutions—Citi Research estimates)**
  - 10% for IC design
  - 50% in manufacturing
  - 30% in OSAT, material, and equipment segments

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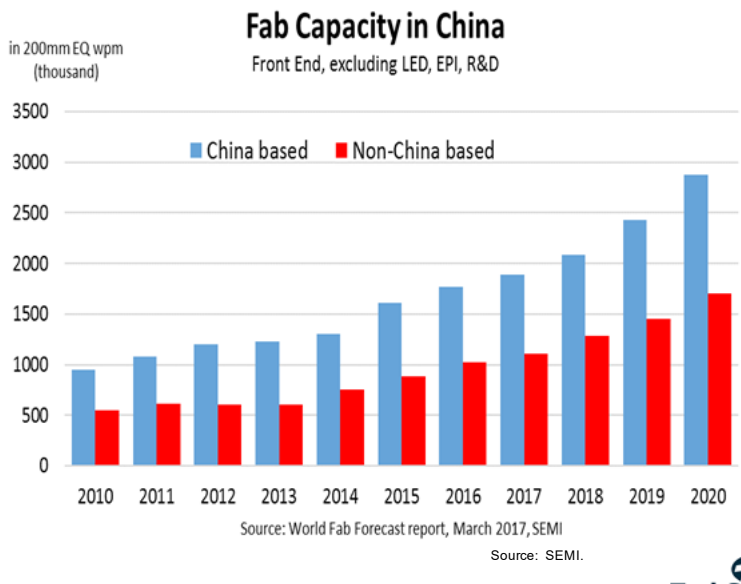
China Fab Growth



Source: SEMI.

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What Does the Future Hold for Packaging and Assembly?

- **Wire bond is not dead**
  - Majority of packages today still use wire bond, but growth is in flip chip
- **Industry evolving to increased packaging and assembly at the wafer level**
  - Flip chip continues to grow
  - Mobile products increasingly using wafer level packaging including fan-in WLP and FO-WLP
  - FO-WLP on Substrate, Si interposer, and alternatives for high performance computing
- **Next semiconductor nodes challenging**
  - Heterogeneous integration increasingly key to success
  - Co-design of semiconductor is essential
- **Look to the future where the action is happening!**

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The Next Webinar:

"Free"….

IMAPS – UK

Advanced Circuit Boards

1st November

PCB - Polymer Substrates - Jim Francey – Optiprint
The future for substrates - Piers Tremlett – Microsemi

Highlights from the IMAPS Advanced Circuit Board Workshop
Recording download will be available to members

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Forthcoming Event Programme:

pOp II 2018

The 2nd International Conference
on
Photonics and Opto Packaging

"Linking Optoelectronics Designers & Manufacturers"
Tuesday 23 October 2018
The University Centre, South Devon College, Paignton, TQ4 7EJ

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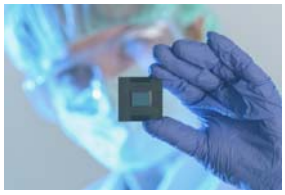
Forthcoming Event Programme:

DIE ATTACH WORKSHOP
The MTC, Coventry, UK
November 22, 2018



- An IMAPS-UK Educational Workshop
- Sessions on: Processes, Manufacturing Know How & Optimisation, Reliability and Test, Plus presentations on Materials and a Short Surgery
- Counts towards Continuing Professional Development "CPD"
- Training for those involved with die bonding processes, those new to the microelectronics industry, or for people wanting to expand their knowledge

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Future Events are being planned for 2019 :

- IoT Packaging Workshop - Feb 2019
- Basic Packaging Workshop – June 2019
- Thermal Design Workshop – September 2019
- Aerospace & Space Packaging – Oct/Nov 2019

AGM

MicroTech 2019

The Annual Conference and Exhibition

Will be held in Cambridge – late March/early April 2018

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