The Road Ahead: Outlook for the Industry

E. Jan Vardaman, Founder and President

TRACK INNOVATION

IDENTIFY TRENDS

ANALYZE GROWTH

INFLUENCE DECISIONS

RELEVANT, ACCURATE, TIMELY

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Industry Trends

- **Traditional unit growth markets slowing….**
  - PC sales declining (additional sales gated by Intel's inability to fab parts)
  - Smartphones low growth, but slight improvement for year end totals
  - Shift in interconnect from WB to FC for DRAM, especially in server market continues
  - DRAM expansion slowing but transition to FC continues
- **Cryptocurrency drove unit volume growth end of 2017, but lower growth this year**
- **AI and HPC drives high-performance packaging**
  - Driving Si interposer and FO on substrate
  - Drives HBM
  - High $ value, but low unit volumes
- **Increased electronic content in automobiles with ADAS and growth in EV**

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CAPEX Spending Will Be Lower than Projected

Worldwide Semiconductor Capital Spending Trends (2000-2022F)

Source: IC Insights

*22% growth in '17 when excl. Samsung
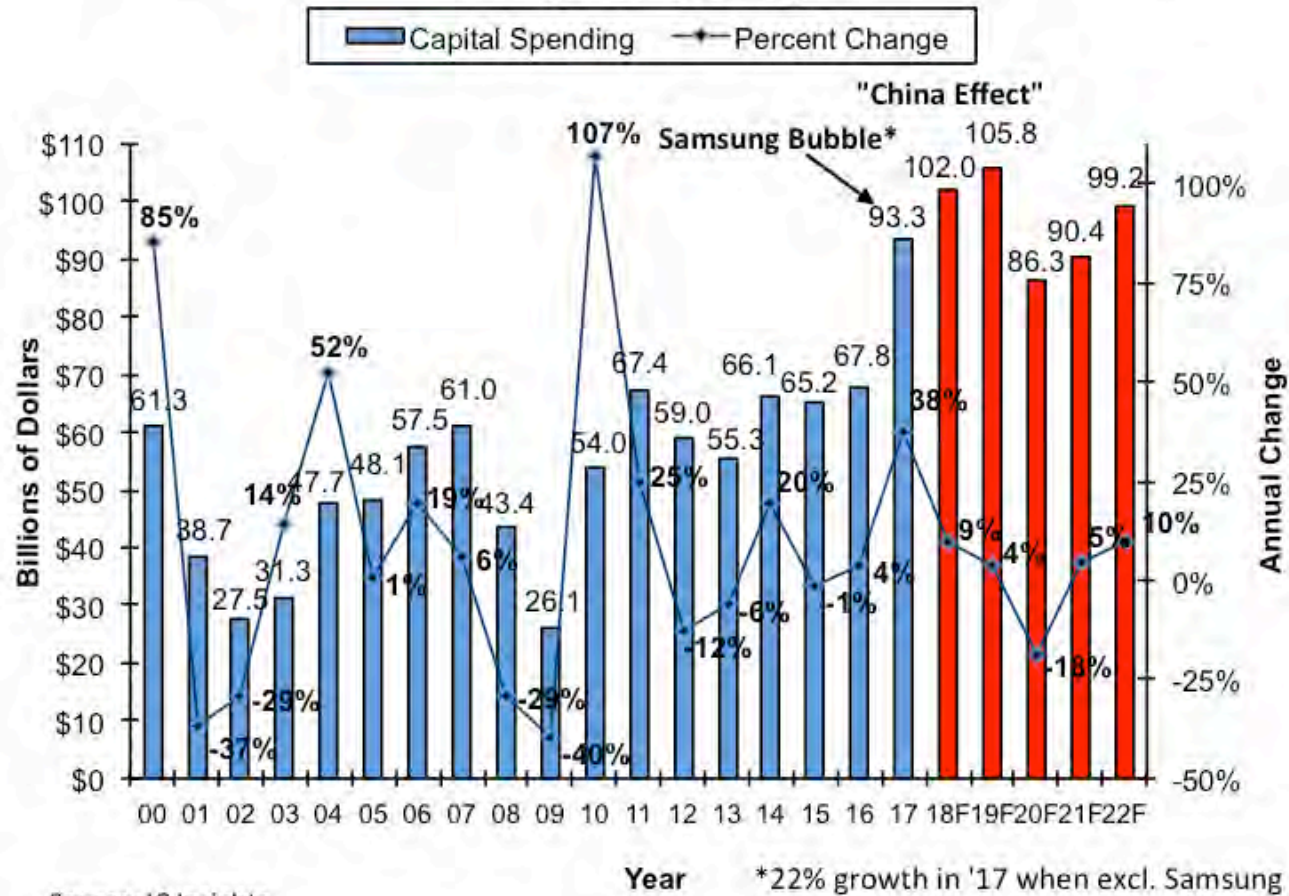
- **Global growth projections lower from 3.9% to 3.7% for next year**
- **CAPEX spending will slow to lower than projected**
  - Samsung has announced it will reduce spending for DRAM, considers DRAM at peak

DRAM CAPEX Spending Will Slow

DRAM Capital Spending vs. DRAM ASP (2009-2018F)
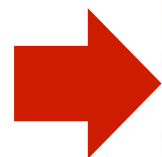

Legend: DRAM Capital Spending, DRAM ASP
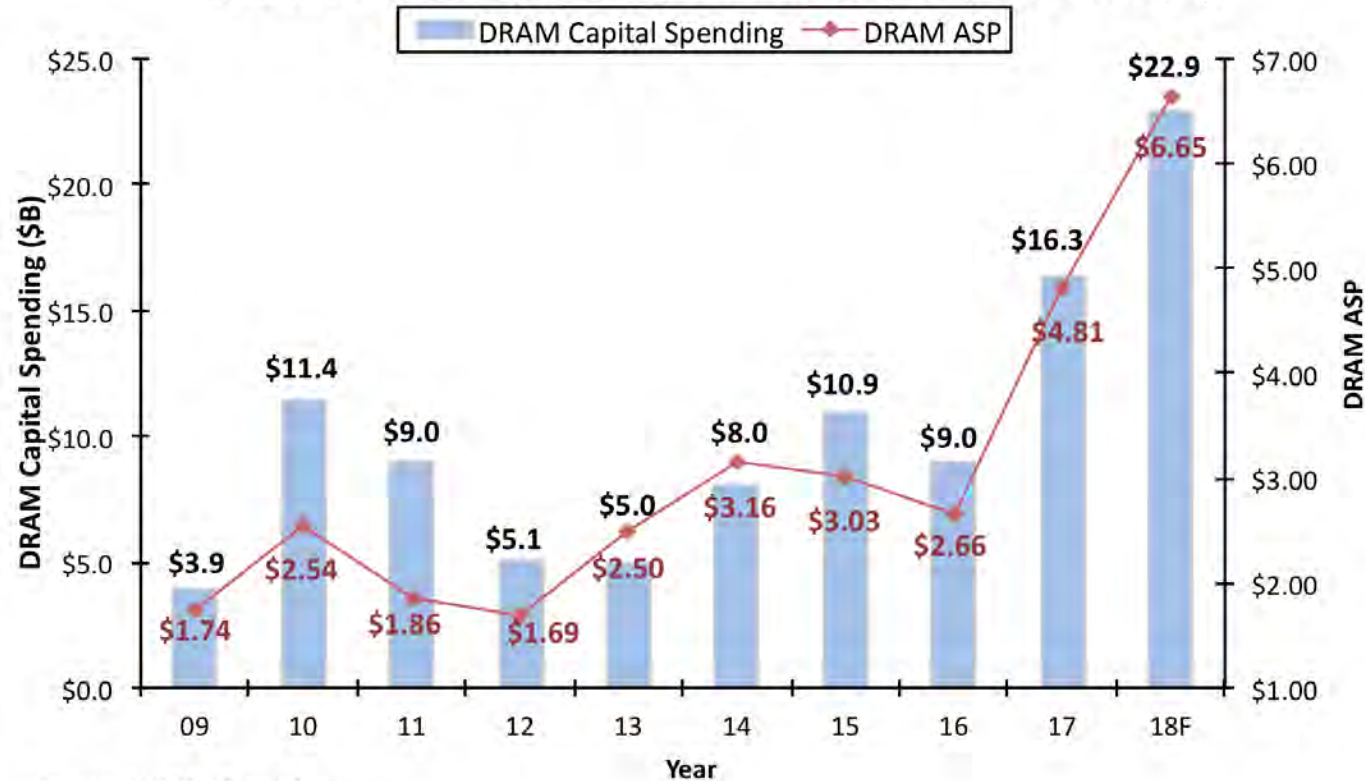
Source: WSTS, IC Insights

- **DRAM CAPEX spending will slow (will be lower than $22.9 projection), but transition from WB to FC will continue**
  - Samsung has announced plans to lower spending (maybe 20% lower)

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Shift in Memory Packaging and Interconnect Changes

TSOP

FBGA

Epoxy encapsulation

B-Stage Epoxy

IC Chip

Bismaleimide triazine substrate

Solder Ball

Gold Wire
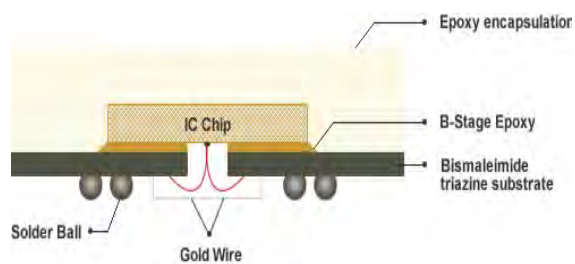
Structure of FBGA

Wire Bond

Flip Chip

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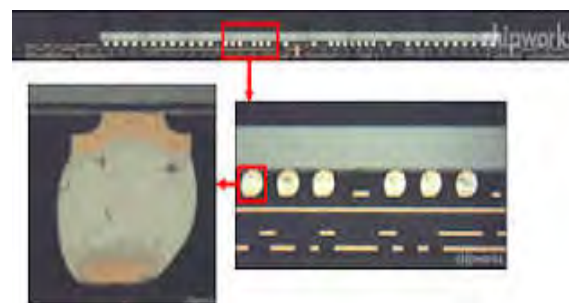
Global Smartphone Shipment Forecast

Source: IDC

- **IDC expects global smartphone shipments to decline 0.7% from 2017 to 2018**
  – Positive growth for second half of 2018
- **Growth increasing in 2019**
  – Drives SiP volumes

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Cryptocurrency: Is it a Windfall???

- **Need high-performance processing capability with power efficiency**
- **ASICs based on 10nm semiconductor node moving into production**
  - Smaller body size, drives FC-CSP volumes
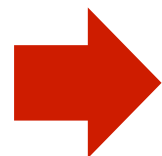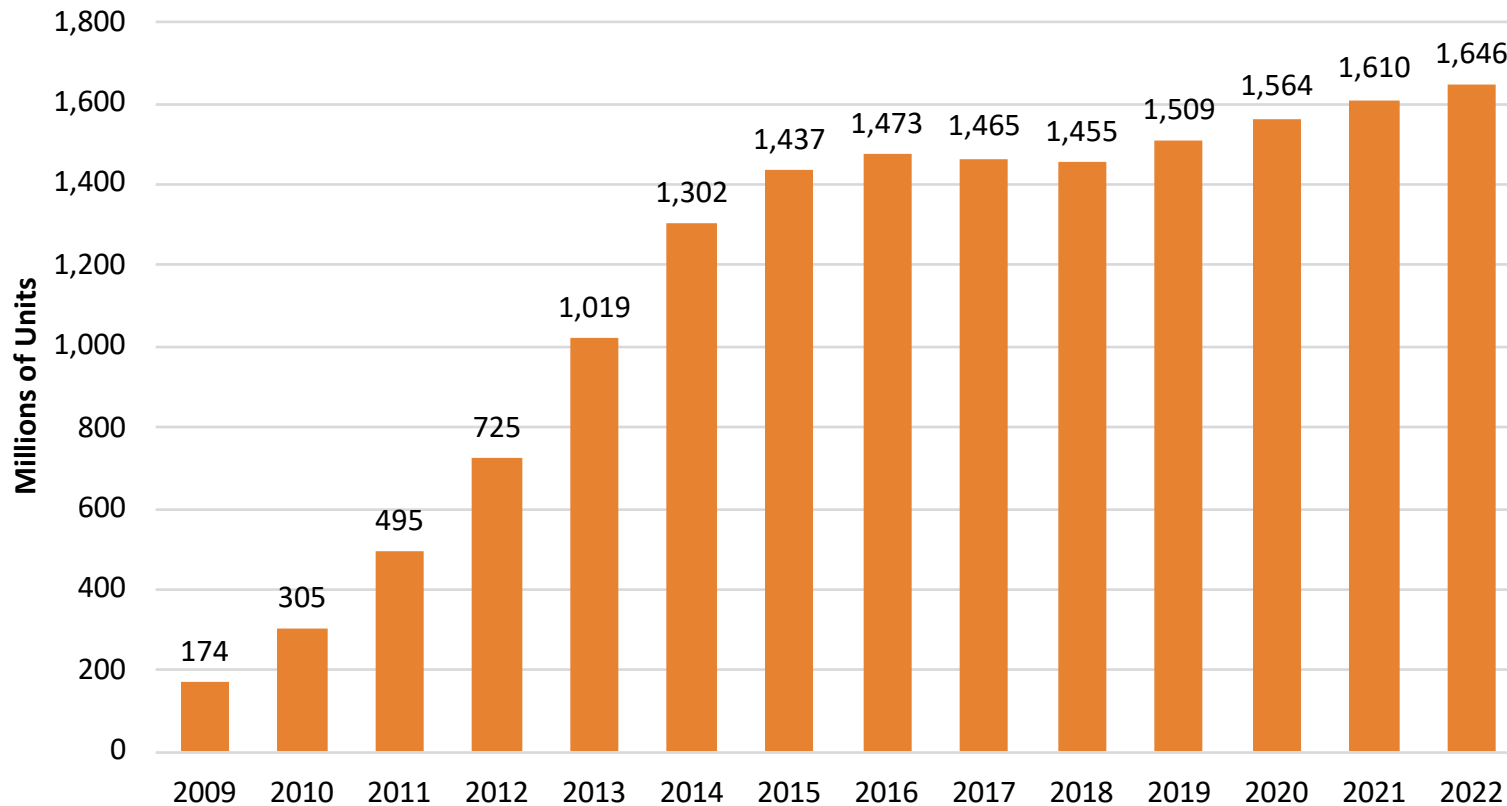 - 40% of ASICs obsolete in one year = big replacement cycle and no need for long term reliability
- **Contributed to strong industry growth in 2017**
  - Last year ~750 million units (flip chip BGA and CSP), contributed to capacitor shortage
  - Not as strong this year
- **Major players**
  - Major OSATs including China OSATs (Huatian, TFME, and JCET)
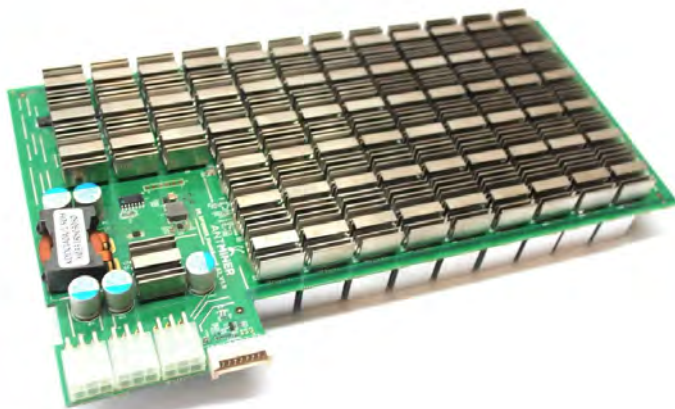
Growth in Server Market

- **Demand for datacenters from Alibaba Group Holding (China), Amazon, Apple, Google, Microsoft, Facebook, and Tencent Holdings (China) to run retail operations, search engines, cloud services, and social networks over the Internet**
- **Demand for high-performance chips for data crunching drives demand for advanced packaging (flip chip packages)**
  - Intel Xeon server processors for example (high dollar value)
  - Intel accounts for ~95% of server market, but AMD is gaining ground!
- **Demand for data storage driving growth in Flash memory (SSD)**
- **Demand for DRAM in DIMMs**

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Datacenter Impact on Semiconductor Industry

31% CAGR

Legend:
- **Enterprise SSD**
- **Server DRAM**
- **NVDA DC**
- **Intel DCG**

Years: 2015, 2016, 2017, 2018E

Y-axis: $00, $10, $20, $30, $40, $50, $60, $70
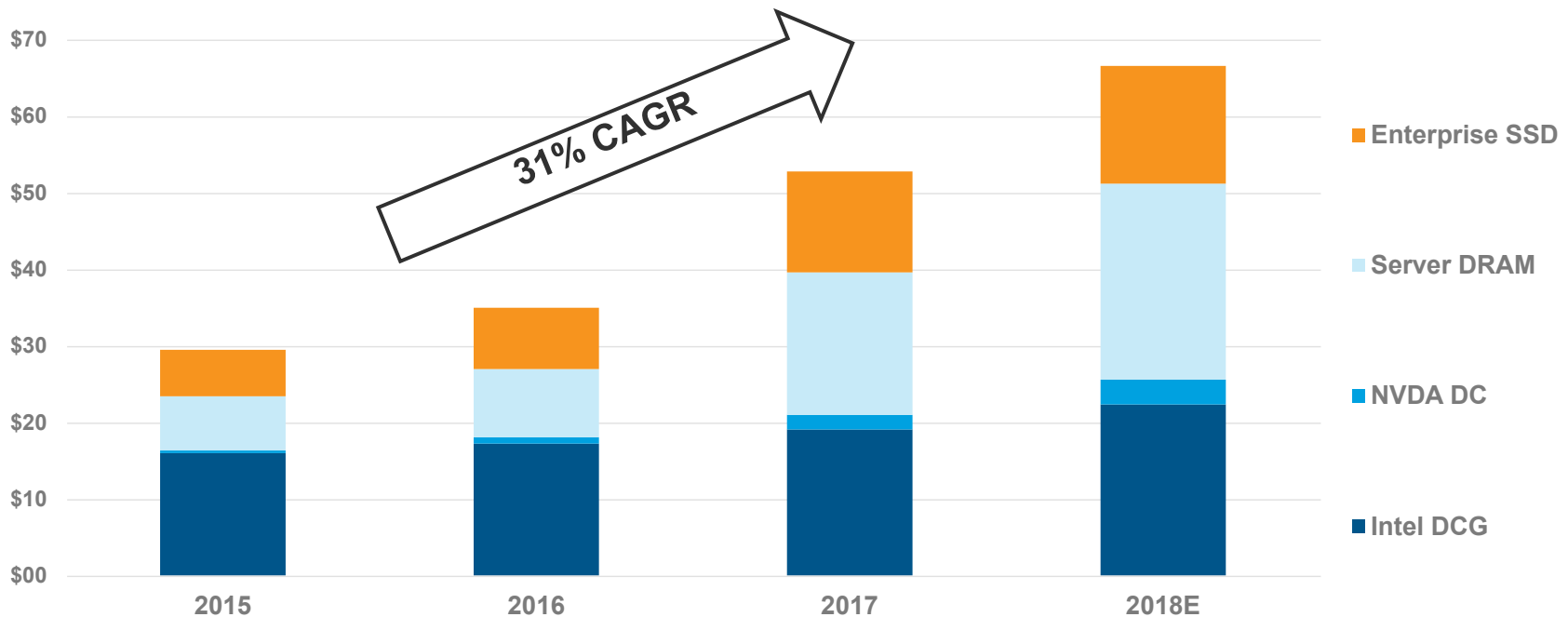
Source: Macquarie Capital.

- **Datacenter growth continues**
  - Last year Amazon, Google, Facebook, and Microsoft spent $40 billion on new plants and equipment
- **Drives demand for fast DRAM for servers and flash memory for storage**
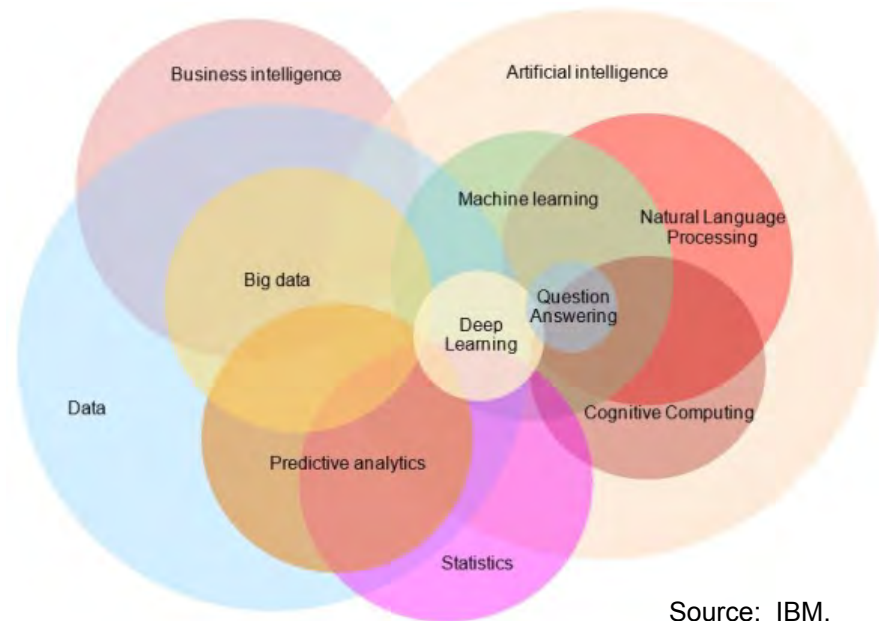
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Samsung's DDR4 with TSV

- **Samsung's 128GB RDIMM uses DDR4 memory with TSVs**
- **Targeted for datacenters**
  - Lower power
  - Double capacity of originally 64GB LRDIMM developed for Enterprise servers

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What is Artificial Intelligence (AI)?

- **Artificial Intelligence: Theory and development of computer systems able to perform tasks that normally require human intelligence**
  - Visual perception and pattern recognition
  - Speech recognition
  - Decision-making
  - Natural language processing and translation

- **Machine Learning: Branch of AI in which computers learn from data without human assistance**

- **Deep Learning: Type of machine learning that trains a computer to perform human-like tasks**
  - Recognizing speech, identifying images, or making predictions
  - Sets up the parameters about the data and trains the computer to learn on its own by recognizing patterns using many layers of processing

Business intelligence

Artificial intelligence

Machine learning

Natural Language Processing

Big data

Deep Learning

Question Answering

Data

Cognitive Computing

Predictive analytics

Statistics
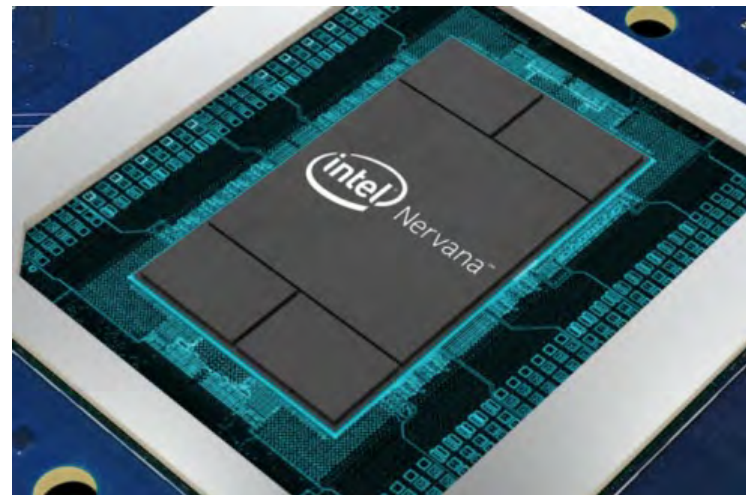
Source: IBM.

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AI Chips See Increased Demand

- **TSMC reports that more than 300 million smartphones shipped with built-in AI (refers to speech recognition etc.)**

- **Silicon content in smartphones expanding with adoption of facial recognition and new applications such as AR, VR, and 3D video**

- **Increased computing for automotive ADAS will use AI in future**

- **AI accelerators in datacenters to increase from 15% today to 50% by 2020**
    - TSMC reports a 4X growth in AI accelerators since 2016 to 800,000 units in 2018


Source: NVIDIA.
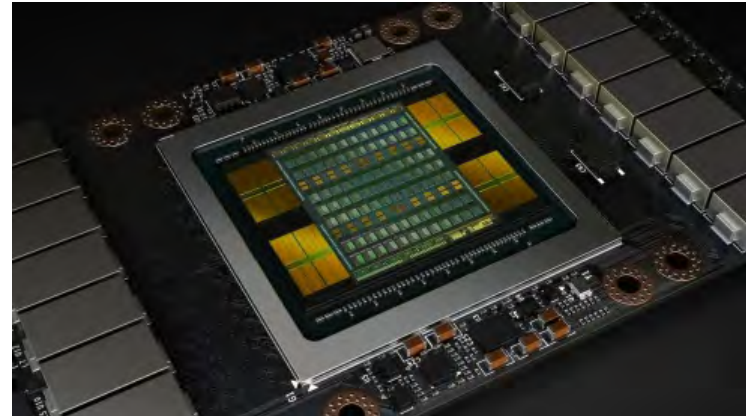
Source: Intel.

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Where Do We Find AI and What Package Types are Required?

- **Accelerators for datacenters**
  - Google (ASIC + HBM2 on Si interposer)
  - NVIDIA (GPU + HBM2 on Si interposer)
  - Intel Nervana (ASIC + HBM2 on Si interposer)
  - Intel Stratix 10 (FPGA + HBM2 on EMIB)
  - Xilinx UltraScale+ (FPGA slices + HBM2 on Si interposer)
  - Baidu (ASIC + HBM2 on Si interposer)
- **Automotive autonomous driving**
  - NVIDIA DRIVE PX Pegasus (4 GPUs packaged in FC-BGAs on a board)
- **Smartphones processors with AI features**
  - Apple A11 Bionic (InFO FO-WLP)
  - Huawei Kirin 970 (flip chip in MCeP PoP)
  - Samsung Exynos 9810 (flip chip on 1-2-1 SLP substrate with embedded passives, PoP)
  - Qualcomm Snapdragon 845 (flip chip in MCeP PoP)

Source: NVIDIA.

Source: Qualcomm.

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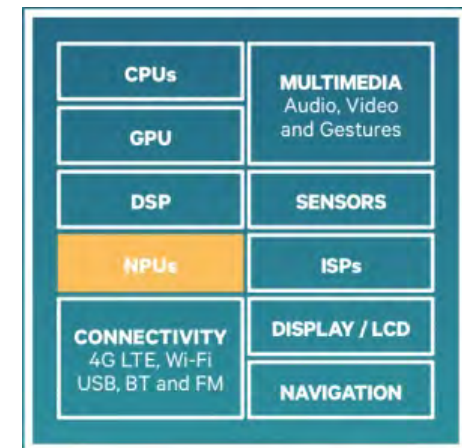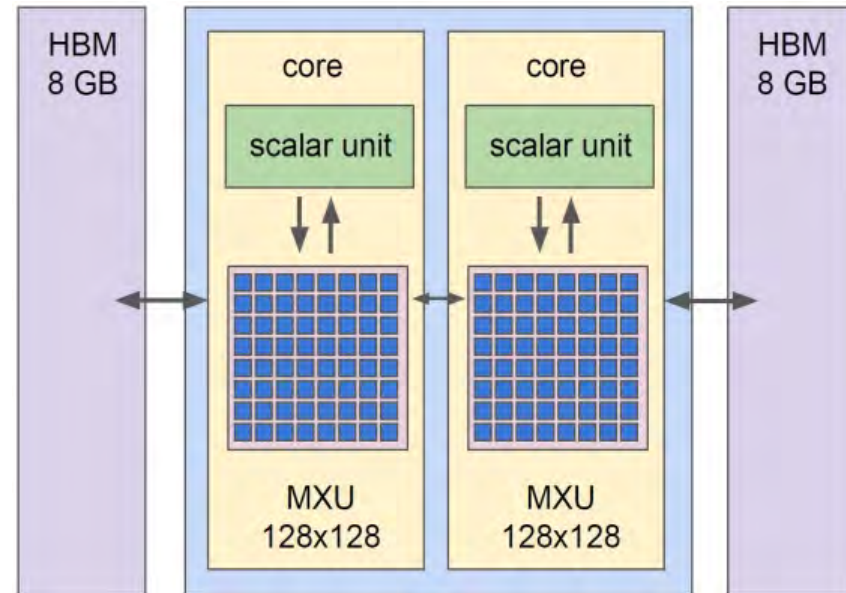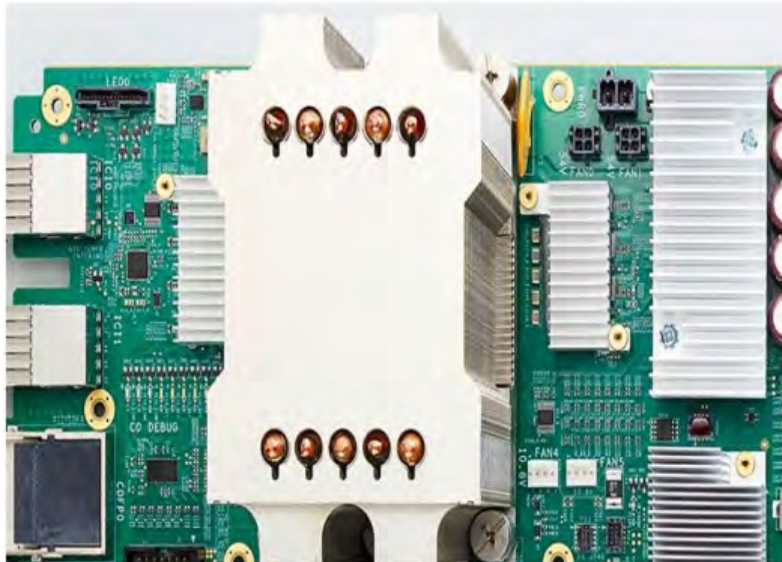
Google Tensor Processing Unit v2 with Interposer and HBM

- **Google-designed device for neural net training and inference**
  - 16 GB of HBM
  - 600 GB/s memory bandwidth
- **ASIC + HBM on Si interposer using TSMC's CoWoS**

- **Version 3, introduced in May 2018, doubles the HBM**

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Xilinx VIRTEX UltraScale+™

- **VIRTEX UltraScale+™ silicon interposer with TSVs using TSMC's CoWoS**
  - Interposer as large as 30 mm x 36 mm
  - Metal line stitching used for larger than reticle interposer products
  - 3 Cu metal layers plus 1 Al layer
  - <1μm lines and spaces
  - Thickness of 100 μm
- **Approximately 660,000 interconnects in the module**

Source: Xilinx.

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Samsung Foundry Business Seeing AI Customers from China
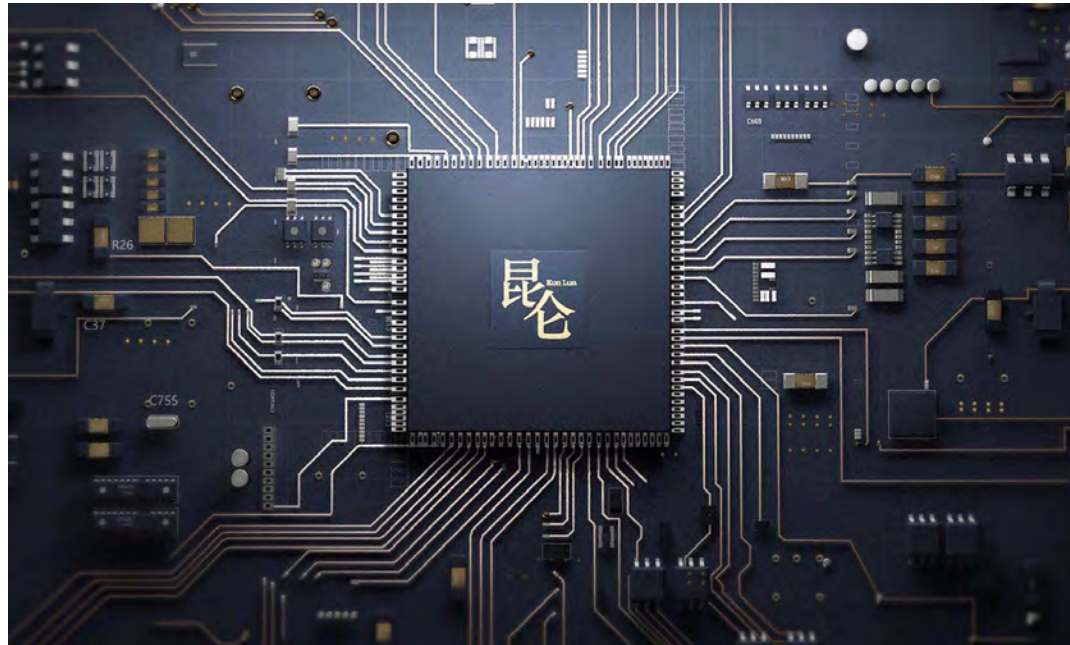
Source: Baidu.

- **Samsung picks up AI chip design business from China design houses**
  - Baidu's Kunlun AI accelerator for datacenters
  - Fabricated at Samsung on 14nm semiconductor node
- **ASIC and HBM2 on a Si interposer**
  - Driving Si interposer and HBM expansion
  - Driving interposer assembly

Intel's Silicon Bridge
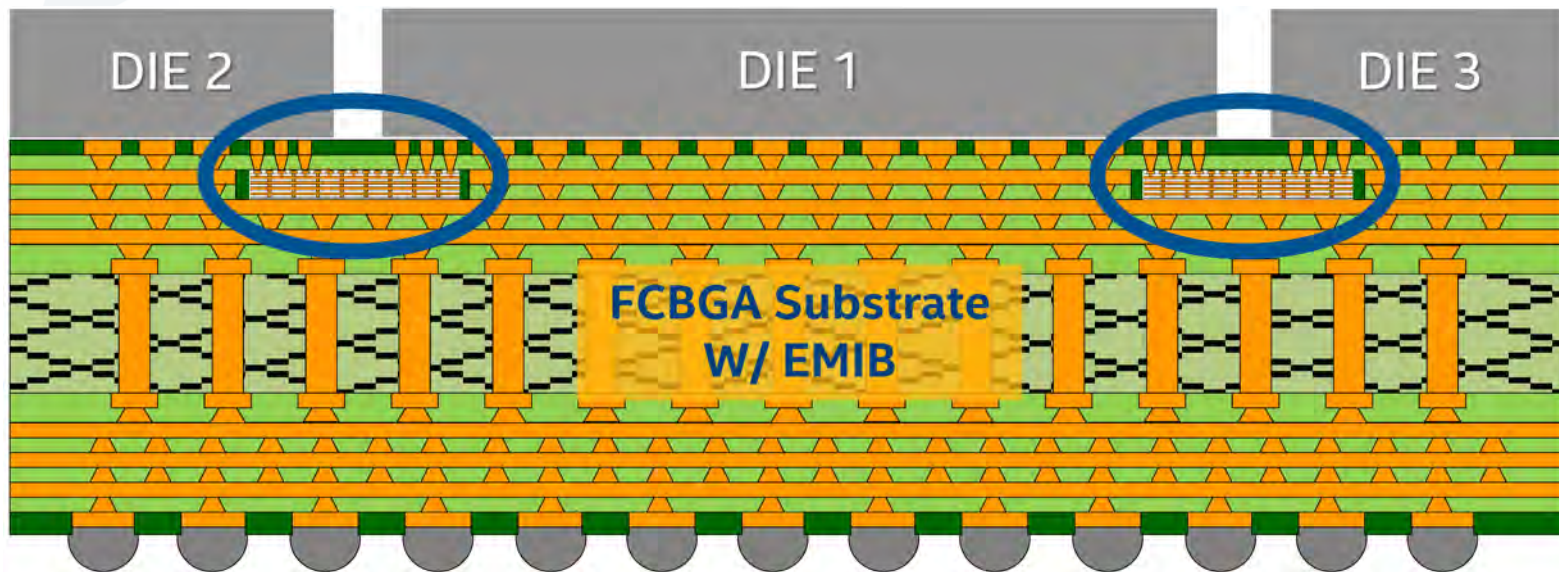
Source: Intel.

- **Embedded Multi-die Interconnect Bridge (EMIB) A small silicon bridge chip is embedded into the package (no TSVs)**
  - Package substrate provided by substrate supplier (does Si bridge embedding)
- **Considered less expensive because only small area for high-density silicon and no TSVs**
- **EMIB allows the die I/O or bumps to be placed as close as possible to the edge of the die because fewer I/O or bumps are required**
  - Micro bumps on chips, communication between chips through interposer
- **Good electrical performance is reported due to the short interconnects**

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Automotive Semiconductor Content Growth due to ADAS

Average ADAS* semiconductor content per level of automation

Partial automation — Level 2
- Camera 40%
- Radar 60%
- Lidar
- Sensor Fusion
- Total BOM $100

High automation — Level 3
- Camera 45%
- Radar 35%
- Lidar
- Sensor Fusion 12%
- Actuators 8%
- Total BOM $400

Full automation — Level 4
- Camera 40%
- Radar 25%
- Lidar 5%
- Sensor Fusion 20%
- Actuators 10%
- Total BOM $550

In addition to current $300/car average)
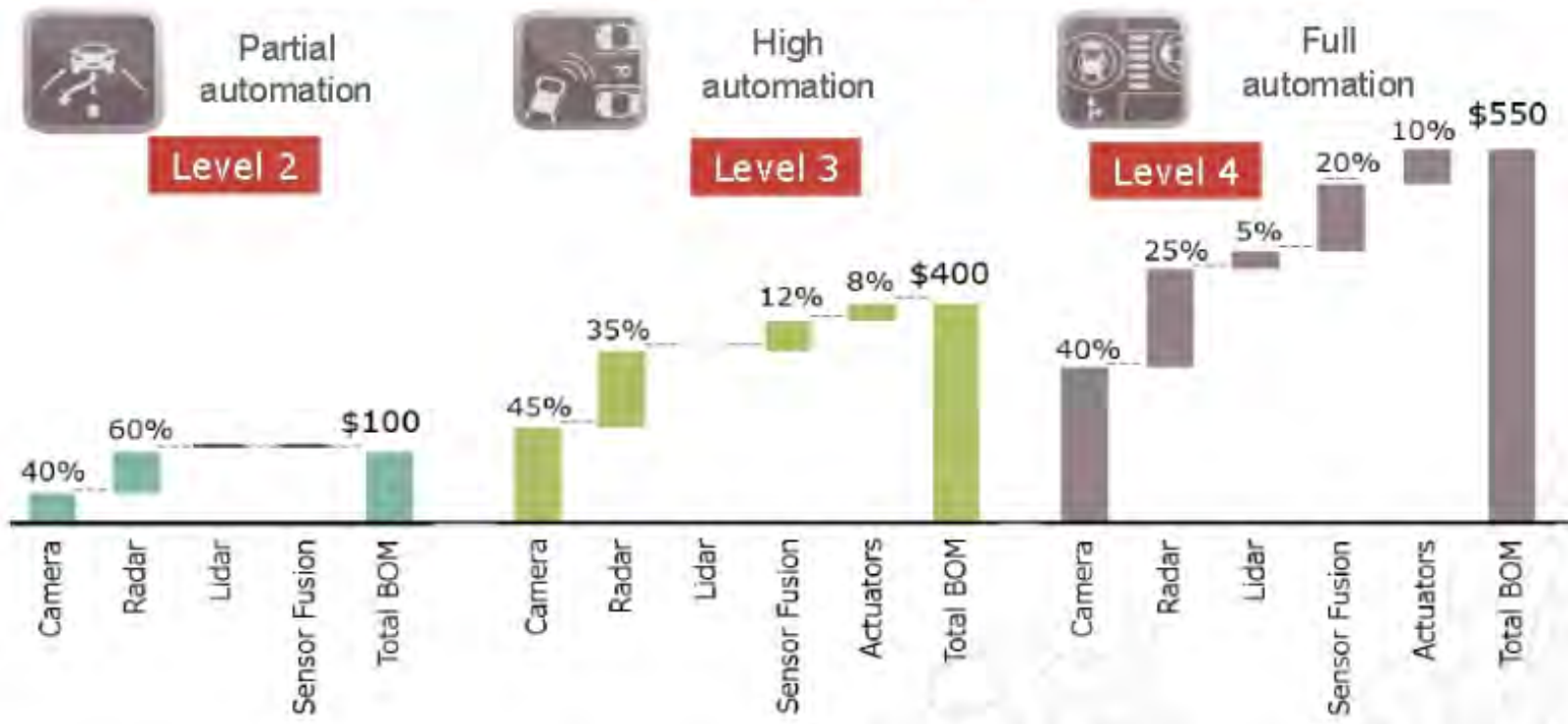
Level 2: 2015-2020 (up to 30 million vehicles per year

Level 3: 2020-2025 (up to 10 million vehicles per year)

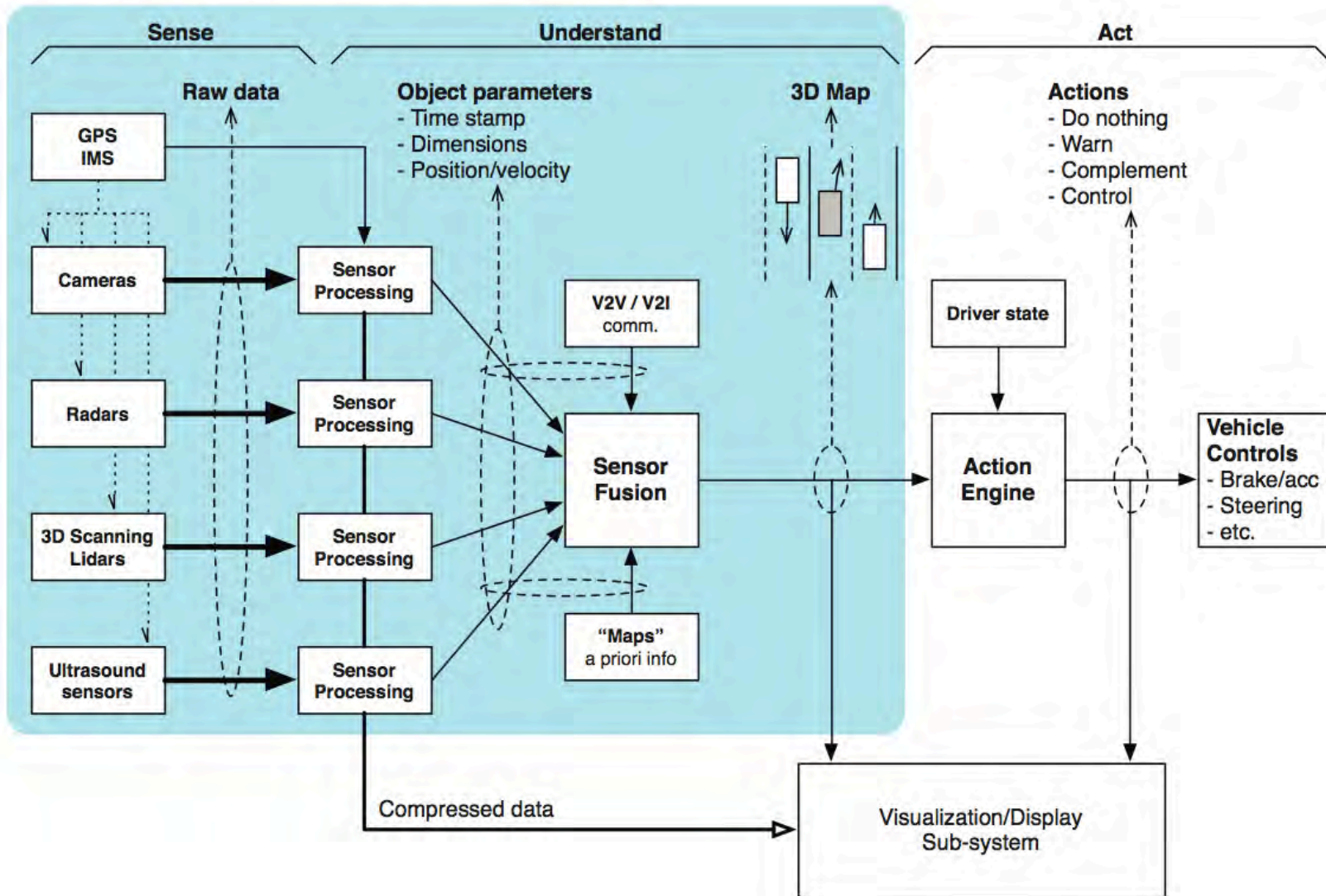Level 4: 2025-2030 up to 5 million vehicles per year

Source: Infineon.

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Autonomous Vehicle Platform

Autonomous vehicle platform: a functional diagram

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NVIDIA's AI Platform for Autonomous Driving

- **NVIDIA's AI solutions for autonomous driving include "Pegasus"**
  - GPU packaged in FC-PBGAs
  - Package size up to 42.5 mm x 42.5 mm
- **NVIDIA® HGX-2™ fuses AI and high-performance computing into a single platform**
- **Thermal performance important**

DRIVE PX "Pegasus" AI Computer for Autonomous Driving
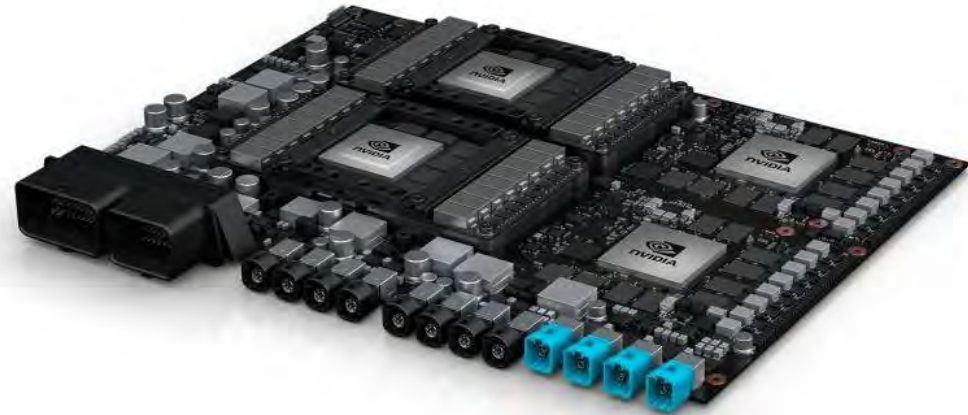
Source: NVIDIA.

FO-WLP on Substrate: Network Switch, Potential AI

- **Amkor's Silicon Wafer Integrated Fan-out Technology (SWIFT®)**
  - RDL with 2/2µm L/S
  - Up to 3 RDLs plus UBM

- **ASE's Fan-Out Chip on Substrate (FOCoS)**
  - RDL with 2µm/2.5 L/S
  - Up to 3 RDLs plus UBM
  - High I/O (>1,000)
  - In production for Hi-Silicon since 2016

- **TSMC Integrated Fan-Out WLP on Substrate (InFO_oS)**
  - RDL with 2µm L/S
  - Up to 3 RDLs plus UBM
  - In production for MediaTek switch (split die)

SWIFT™ on Substrate with Heatspreader
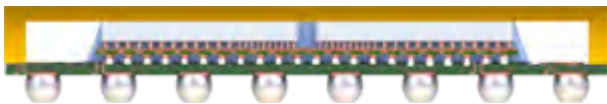
Source: Amkor.

FOCoS – Fan Out Chip on Substrate (FO FCBGA)

Source: ASE.

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WLP Growth

- **Number of fan-in WLPs in many phones continues to increase**
  - Apple, Samsung, and China handset makers
- **Fan-in WLP for many products**
  - Wearables such as smartwatches

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Market for Wearables

- **IDC expects increase of 6.2% for wearables market this year to 122.6 million units**
  - CAGR of 11.6% for 5-year forecast
- **Wearables include**
  - Watch (largest segment)
  - Wristband (second largest segment)
  - Earwear
  - Clothing
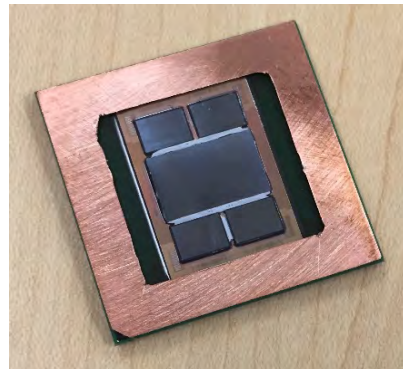- **Small market compared to smartphones, but growing market**
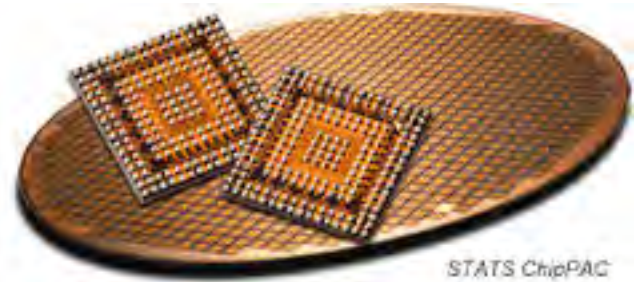
Migration to FO-WLP

FC-CSP

FO-WLP (many versions)

STATS ChipPAC
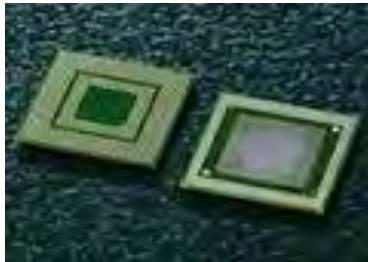
Fan-in WLP

Silicon Interposer (Data center, networking)

Fan Out Chip on Substrate Package

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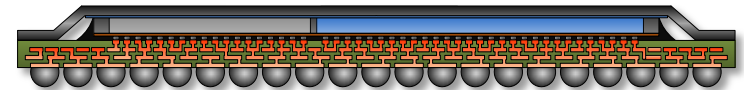
Growing Number of FO-WLP Applications (Red is Panel)

- **Baseband processors**
- **Application processors**
- **RF transceivers, switches, etc.**
- **Power management integrated circuits (PMIC)**
- **Connectivity modules (IoT)**
- **Radar modules (77GHz) for automotive**
- **Audio CODECs**
- **Microcontrollers**
- **Logic + memory**
  - Data center servers, networking, AI etc. (Fan-out on substrate)
  - Future AP + DRAM for mobile
- **Sensors (fingerprint, image, etc.)**
- **LED**
- **Many multi-die configurations**

Multidie FO-WLP
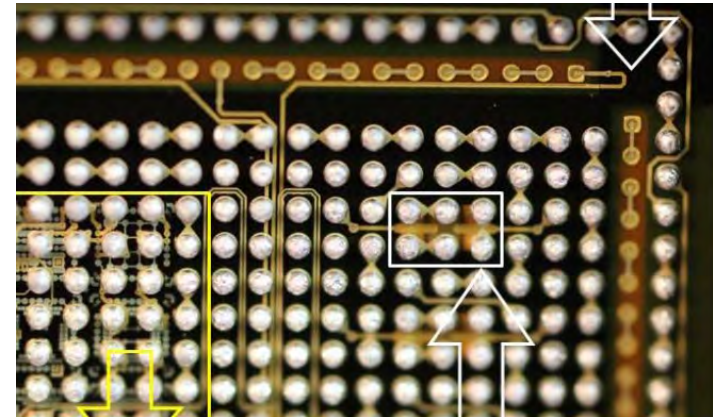
Source: Nanium.

IoT Module

Source: Nepes.

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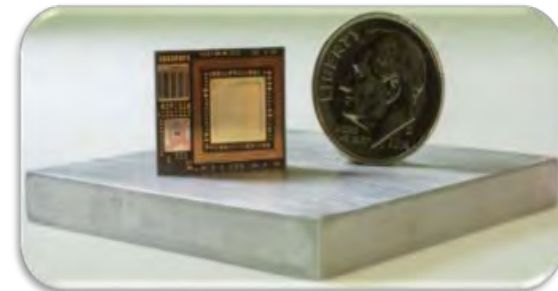
Consortia and Companies Working on Panel FO-WLP

- **Companies**
  - SEMCO in Korea
  - Nepes in Korea
  - Powertech Technology (PTI) in Taiwan
  - Unimicron in Taiwan
  - ASE/Deca in Taiwan
- **Consortia**
  - Fraunhofer IZM
  - FOPLP Consortium (ASMPT promoting) in Hong Kong
  - IME A*STAR in Singapore
  - ITRI in Taiwan
  - NCAP in China
  - Jisso Open Innovation of Tops in Japan (New)

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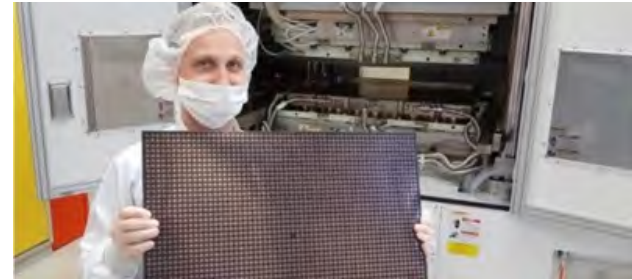
Panel-Level FO-WLP Activity

- **PTI is in production with its panel FO-WLP line**
  - PMIC from MediaTek

- **SEMCO in production with panel FO-WLP for Samsung Gear watch**
  - Application processor and PMIC with backside RDL
  - PoP
  - Thin solution

- **NEPES in production with panel FO-WLP for fingerprint sensors**

- **Unimicron continues R&D activity for panel**

- **YOUR NAME HERE**
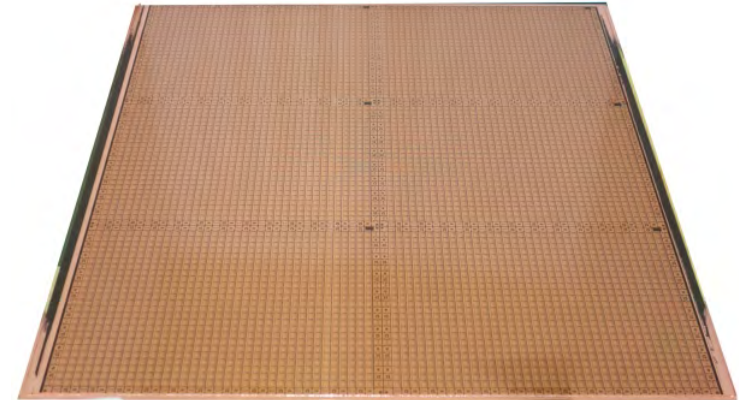
Source: PTI.

Images courtesy of Samsung.

Via-Frame Fan-Out WLP (VF-FOP) with Double-side RDL

Source: Nepes Corp.

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China and OSAT Growth

- **China's economy show signs of slower before Trade War**
  - 6.5% growth in Q3 vs. Q2 growth of 6.7%
- **Capacity expansion still underway**
- **Domestic OSAT capacity expansion not always driven by demand requirements**
  - Government continues to drive expansion of semiconductor industry and infrastructure
  - ZTE's experience confirms the need for China domestic industry expansion
- **Will we get overcapacity?**
- **JCET**
  - New CEO
  - Capacity addition for bumping with SMIC JV
- **Tongfu Microelectronics**
  - Adding capacity for bumping and WLP
- **Huatian**
  - Adding capacity for bumping and WLP

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Conclusions

- **Economic trends**
  - Some slowing next year
  - Will result in pull back on some expansion
  - Uncertainty created by trade-war, but China expansion continues
- **Smartphones still account for large unit volumes**
  - SiP
  - WLP and FO-WLP
- **DRAM transition from WB to FC**
  - Memory has large unit volumes
- **AI**
  - Watch datacenter growth
  - AI accelerators demand increasing, drives silicon interposer and HBM
- **Automotive electronics growth, but takes time**
  - Reliability is key
- **WLP growth continues for fan-in and FO-WLP**
- **Panel FO-WLP activity is increasing**
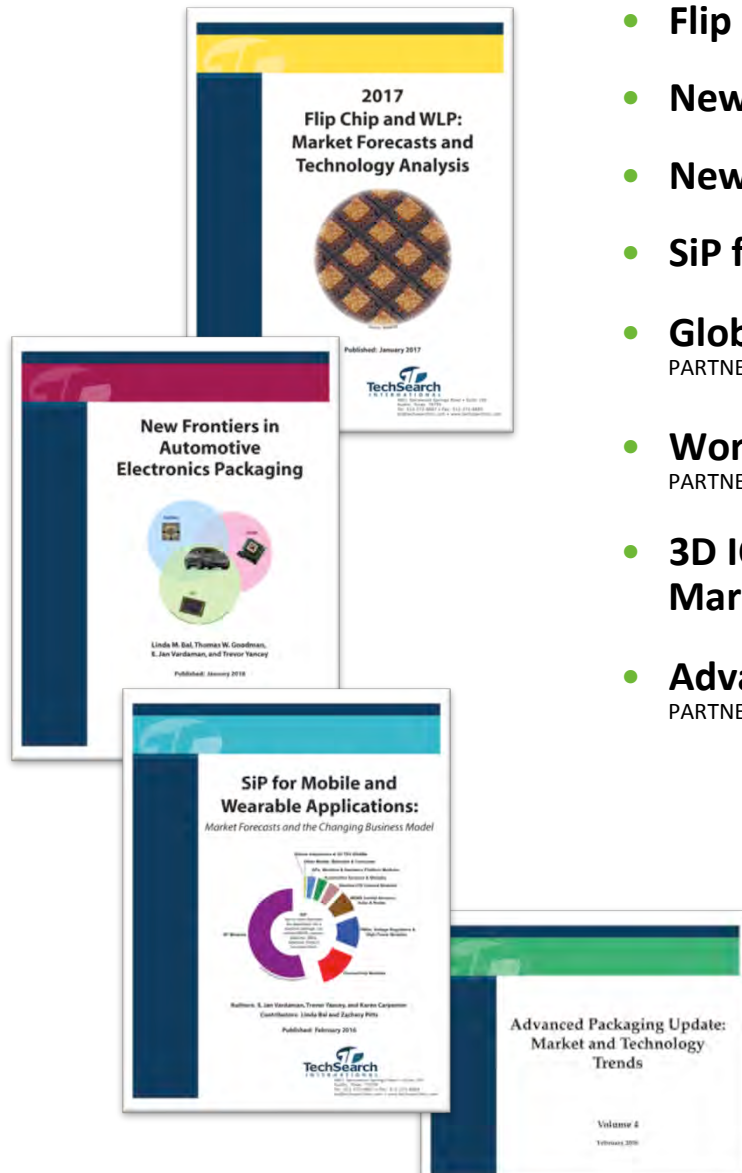 - Production examples
  - Additional plans

Thank you!

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Market analysis you can trust!...Multi-client reports

- **Flip Chip and WLP Market and Technology Analysis**

- **New Packages and Materials for Power Devices**

- **New Frontiers in Automotive Electronic Packaging**

- **SiP for Mobile and Wearable Applications**

- **Global Semiconductor Packaging Materials Outlook**
  PARTNERSHIP WITH SEMI

- **Worldwide OSAT Manufacturing Sites Database**
  PARTNERSHIP WITH SEMI

- **3D IC Gap Analysis: Remaining Issues, Solutions, Market Status**

- **Advanced Packaging Cost Models and Analysis**
  PARTNERSHIP WITH SAVANSYS

- **Advanced Packaging Update** (4 issues each year)

  – Economic and business developments in the semiconductor packaging and assembly industry including market forecast by package type (FBGA, FLGA, QFN, stacked die CSP, PoP, etc.)

  – New packages and materials including trends and drivers

  – Various market and technology analysis

At the forefront...Recognizing emerging trends

- **Automotive Electronics**

  First industry analysis of packages for automotive electronics with a focus on ADAS

- **Flip Chip Trends**

  Publishing reports on flip chip markets and technology trends since 1994 — We've done cutting edge analysis in recognition of the shift to Cu pillar

- **WLP Demand and Capacity**

  Tracking wafer bump and WLP capacity and demand trends since 2003 — We've been at the front in recognizing the shift to fan-out WLP (FO-WLP)

- **Ball Grid Arrays and Chip Size Packages**

  First industry analysis of the ball grid array market in 1994 — We've published annual forecasts of BGA and CSP demand ever since

- **3D IC with TSVs and Si Interposers**

  We are recognized as the provider of realistic market forecasts — We are unique in offering gap analysis, with indications of key areas requiring additional work

- **System-in-Package and Multichip Modules**

  Tracking markets and trends since 1990

Copper Pillar Demand on 300mm Wafers

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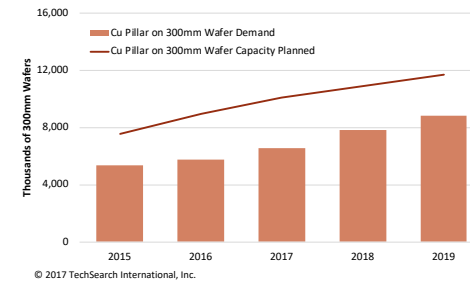
Fan-In WLP Demand in 200mm Equiv. Wafers

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SiP Market by Device Type

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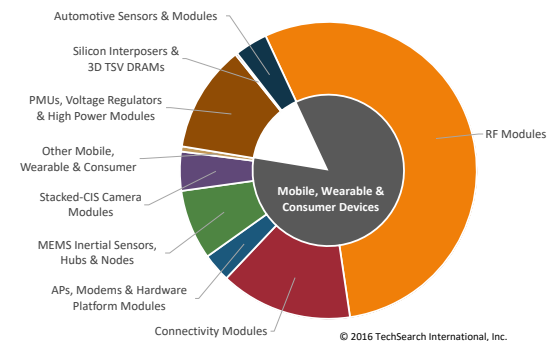
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Corporate Contributors (plus dozens of individuals)

Kulicke & Soffa

Promex — Microelectronics Assembly Technologies
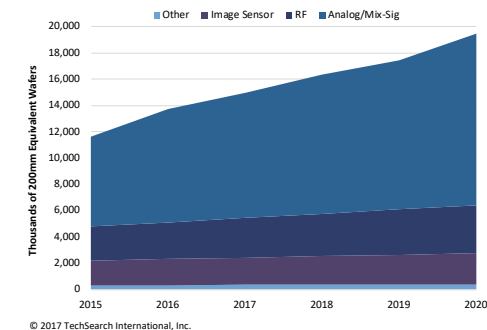
Quik-Pak — Microelectronic Packaging & Assembly Solutions

CPMT — IEEE COMPONENTS, PACKAGING AND MANUFACTURING TECHNOLOGY SOCIETY

Mühlbauer — High Tech International

NATIONAL INSTRUMENTS

tsmc

Los Alamos NATIONAL LABORATORY

Lam RESEARCH

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EAST BAY COMMUNITY FOUNDATION

TICER TECHNOLOGIES

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- **William Chen in tribute to his wife, Mary Voris Chen**

- **In memory of Lt. Colonel Arthur S. Metcalfe by his daughter, Kitty Pearsall**

- **In memory of Adriaan Anton Uijttenbroek, a life member of IEEE by his wife, Janet Clark**

- **M.S. Lin**