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Adoption of IC Packaging, Test and Reliability Advances for MEMS Devices

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Fairchild Semiconductor

Solutions for Your Success™

Brand Name Products with MEMS

Gyros & accels…

A lot more than iDevices

Source: K. Yang, ADI presentation at COMS2008

Adding Sensor Degrees of Freedom Enables New Apps

3DOF Accelerometer

Orientation
Sports
User Interface

\+

3DOF Gyroscope

Image Stabilization
Smoother gaming
Complex gestures

\+

3DOF Magnetometer

Compassing
Directional Heading
Navigation

\+

Altimeter

Location applications
Indoor navigation
Parking lots/Tall buildings
Sports (Skiing, Gliding)

\+

Temperature

Activity aware devices
Medical Monitoring
Sports Performance

3DOF

6DOF

9DOF

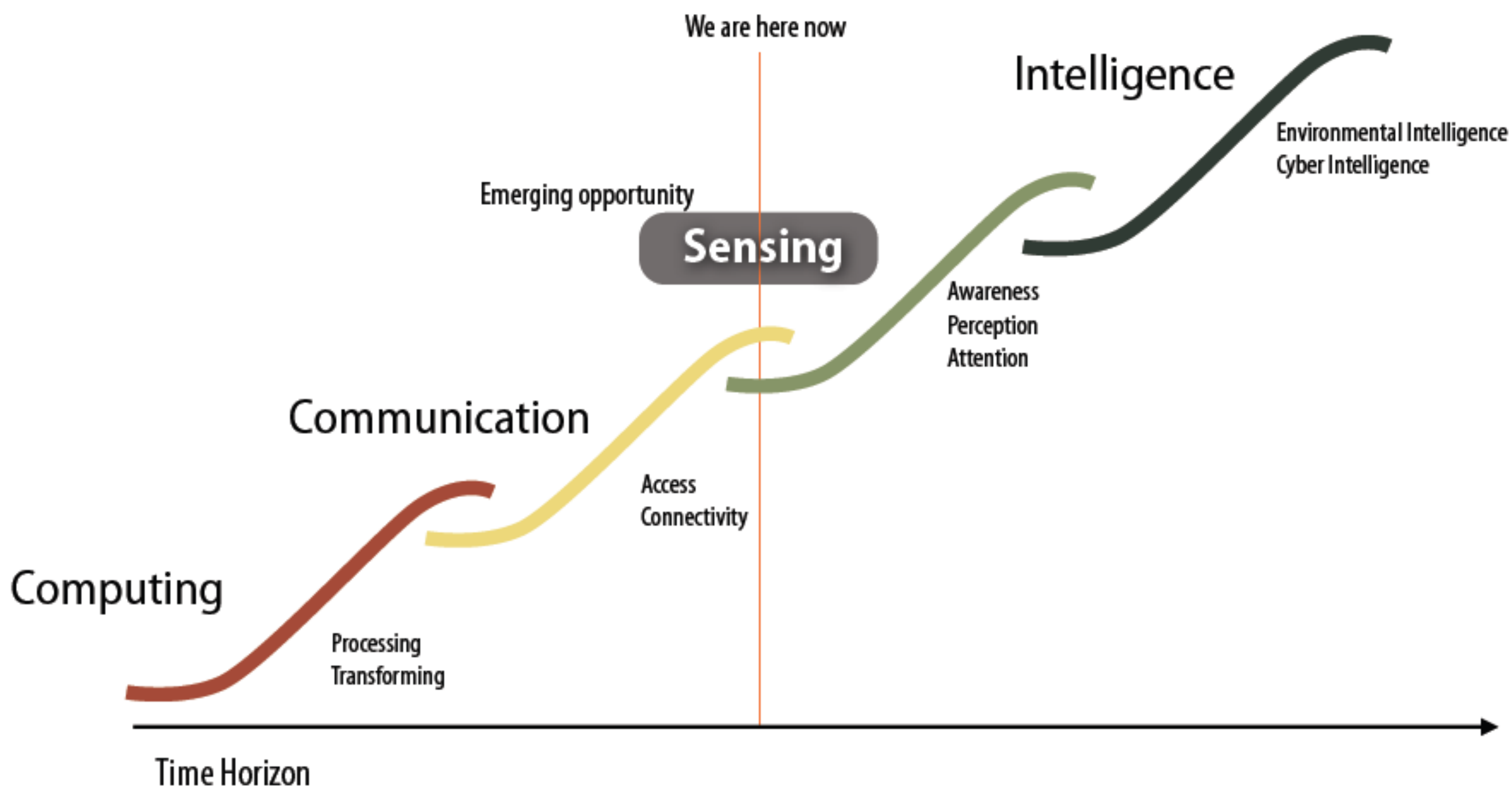
10DOF

11DOF

Outline

- Market drivers
  - Drivers for test and reliability standardization
- Packaging trends
- Reliability and testing
- Conclusions

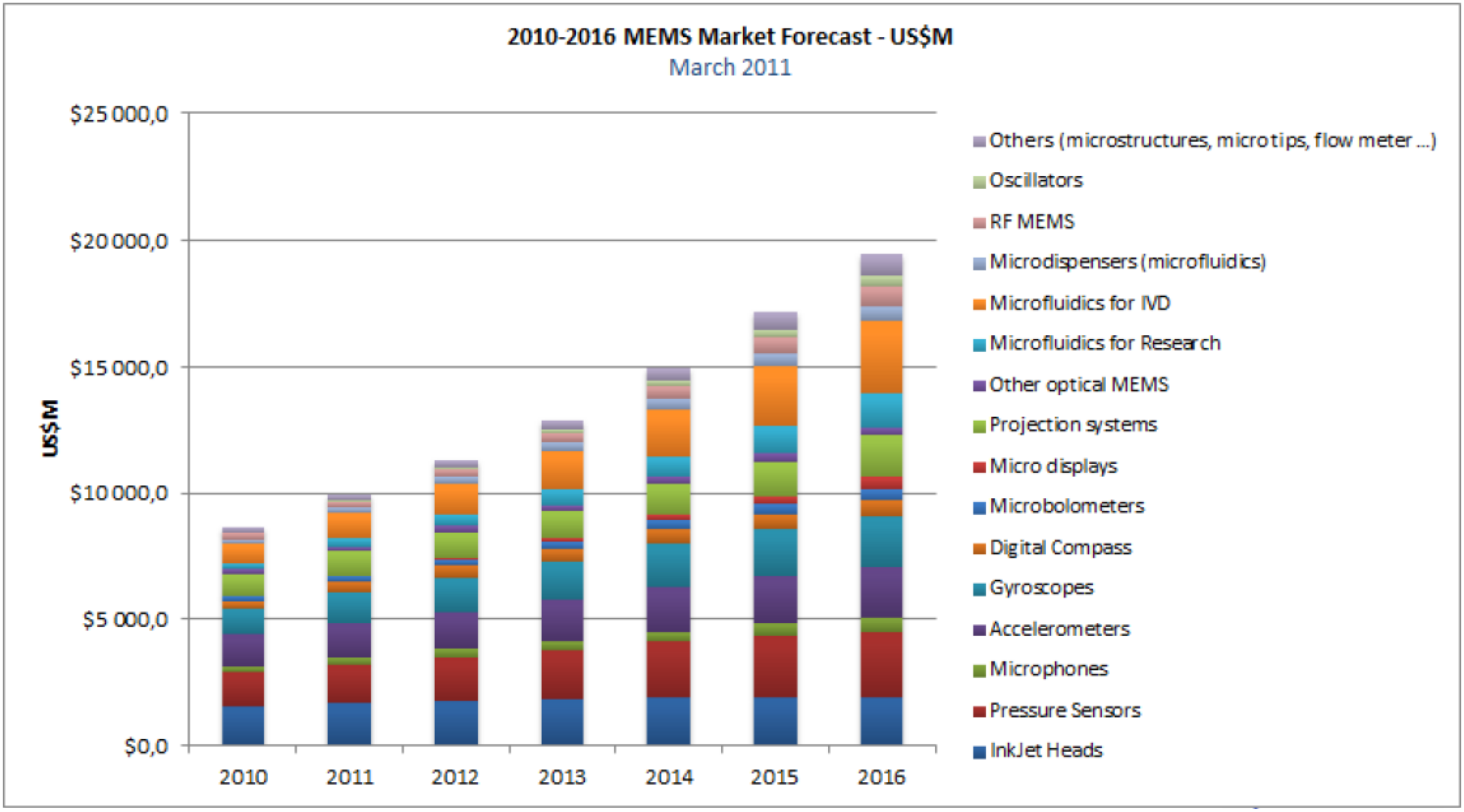
Market Shift to Sense Based Intelligence



∗ Paul Saffo — Institute of the future; Stanford U

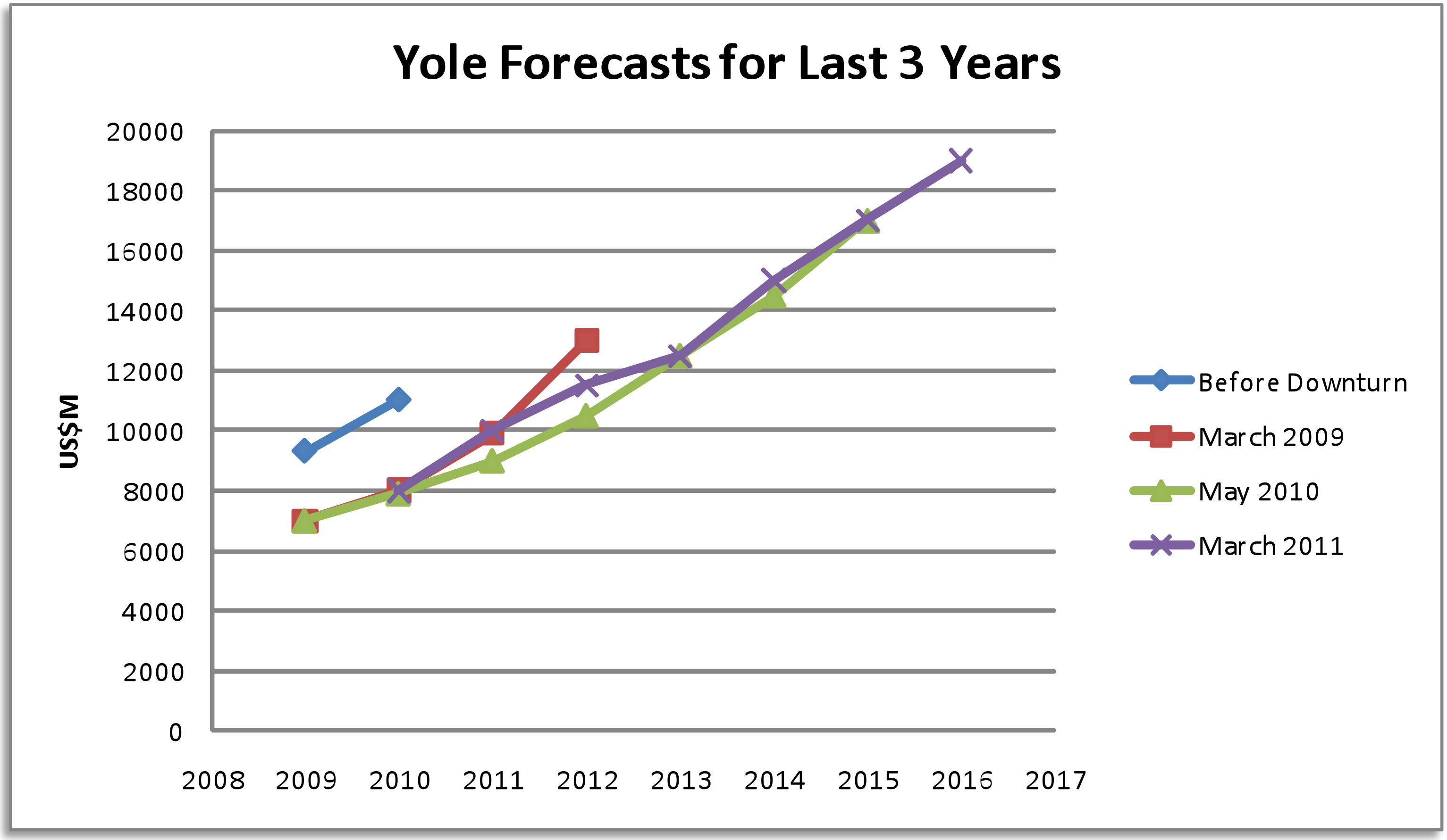
2011 Yole MEMS Forecast

- **Reaching $10B… flirting with $20B by 2016…. 25% in 2010 14% CAGR thru 2016**



Source: Yole Development

Stability of Market Forecasts



Emerged Mobile MEMS Applications

- Augmented reality
- Point of Interest
- Enhanced user interface
- On line gaming
- Location based services
- 3D tagging
- Indoor/outdoor navigation

How much is that shirt?

Point of Interest

POI

No compass

POI_Filtering

With compass

Source: Sekai Camera

Source: Layar and Wikitude

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MEMS for Personalized Healthcare

- Almost 7B people on earth.
    - Aging population.
    - Increasing lifespan.
- Increasing health cost.
    - $2.5 trillion in 2009 in the US alone.
        - 18% of the GDP.
- Remote home care emerges as Tornado in making to reduce health care cost.
    - Initial focus: monitoring chronic conditions.
- Wearable devices market (ABI Research):
    - 2010: 12M devices (almost all of them for sports and fitness)
    - 2014: 420 million wearable health monitors
      59 million used at home.

Trillion Sensors in this Decade?

A Central Nervous System for the Earth (CeNSE)

- Awareness of planet
- Measurement of impact

- Taste/Smell/Touch/Sound/Sight

- Safety
- Sustainability
- Security

~1 trillion sensor nodes

Source: Hewlett Packard Development Co, Peter Hartwell, HP Labs

2011 MEMS – Current State

- Several applications exceeded $200M.

- MEMS law still in effect – "one product - one process – one package – one test procedure"
  - Cracks in the law are visible
  - LGA package dominates gyro and acceleration packaging from most vendors.
  - Test systems from selected vendors enable high speed testing of multiple sensor categories (pressure, magnetic, acceleration, rate).

- Commercialization cycle is shrinking, but it is still:
  - At least 4 years.
  - 3-4 CEOs
  - $45M investment

- Potential for market to grow much larger (~$300B by some estimates), but several developments needed
  - Faster learning cycles, 15 R&D cycles of learning per year
  - Develop 3D packaging
  - Develop platform processes
  - Form development and manufacturing super groups
  - Open-mindedness and curiosity

PACKAGING TRENDS

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Historical MEMS Products

- 1960’s – 1970’s
  - Defense and avionics applications
  - Low volumes
  - Fully custom packages
  - Unique reliability and qualification requirements
- 1980’s – 1990’s
  - MAP sensors (starting in late 1970s)
  - Medical disposable blood pressure sensors
  - High customized packages determined by application
- 1990’s
  - Airbag sensors in 1990s
  - Ink jet printers
  - DLP
- 2000’s
  - Further growth of optical MEMS
    - Custom packages
  - Tire Pressure Monitoring
    - Custom packages but using fairly standard IC industry capability and technology
- 2010’s
  - Consumer MEMS
  - Wide adoption of standard IC packages
    - But still contain MEMS specific requirements
  - Emerging adoption of wafer level packages

Kulite

Ford

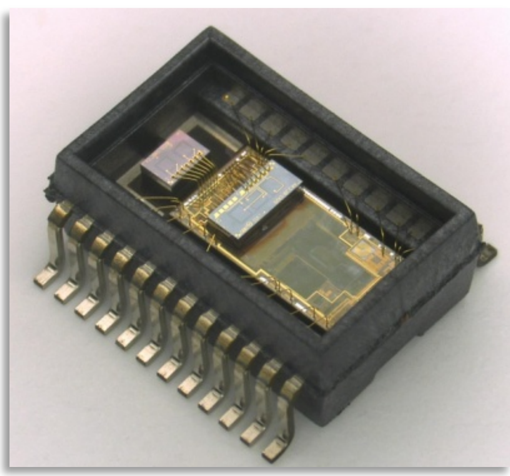
NovaSensor

Custom Package Examples

Source: Holst Center, IMEC

VTI’s watch pressure sensor

Rosemont



LVSI’s TPMS part

TPMS module from Beru AG

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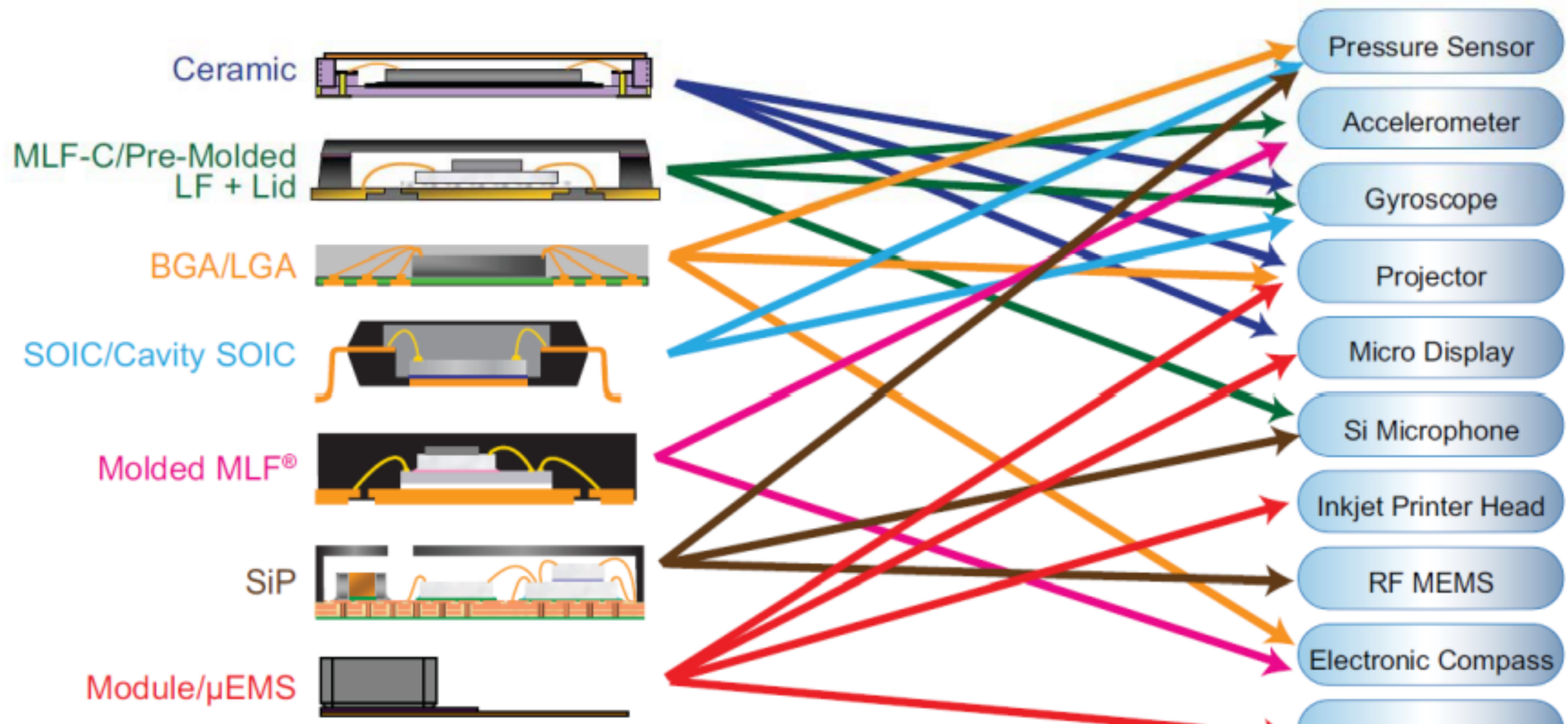
Amkor MEMS Packaging Matrix



Source: Amkor

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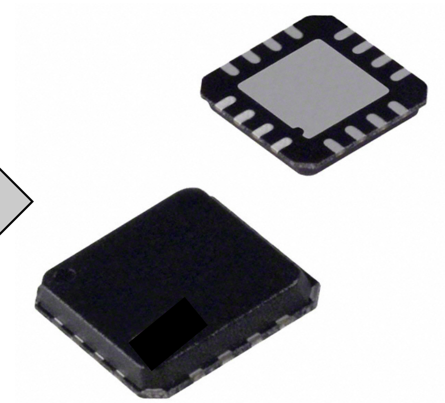
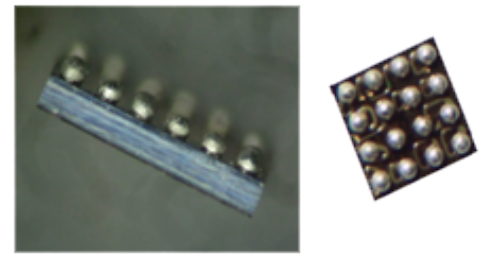
Packaging Progression – Towards WLP or (WSP)





LCC

- Ceramic Leadless Chip Carrier
- ~ 2 mm thick
- Hermetic package seal
- Expensive

LFCSP

- Lead Frame Chip Scale Package
- 1.0 – 1.5 mm thick
- Capped die in plastic package
- Most similar to std IC packages
- Least expensive option

WSP

- Wafer Scale Package
- < 1.0 mm thick
- Smallest footprint
- Potential to be least expensive

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Enabling Technologies for Wafer Level MEMS Packaging

- Wafer Bonding
  - Eutectic Bonding
  - Silicon Fusion Bonding
- Zero kerf wafer dicing
- Thin wafer handling
  - More difficult for MEMS because of internal cavities and stresses
  - Need to handle different thicknesses
- Through Silicon VIAs (TSV)
  - Vertical TSVs for MEMS
  - Vertical TSVs through ASIC
  - Silicon interposers
    - Blank silicon with VIA
  - Lateral VIAs

Packaging Requirements

- Small percentage of devices will use non-IC type packaging
  - E.g., process control transmitters
- Majority will have to use IC-derived packaging as it offers the best cost
- Major categories of MEMS packaging:
  - Optical, enabling light transmission
    - Display, spectrometers
  - Open to the silicon chip for air/fluid access
    - Pressure sensors, microphones, Lab-on-Chip, gas chromatographs chemical sensors, ink-jet nozzles,
  - IC-like with some stress control
    - Acceleration sensors, gyros, RF switches and filters, resonators
  - Specialty
    - Scavengers, etc.

State of MEMS Packaging 2011

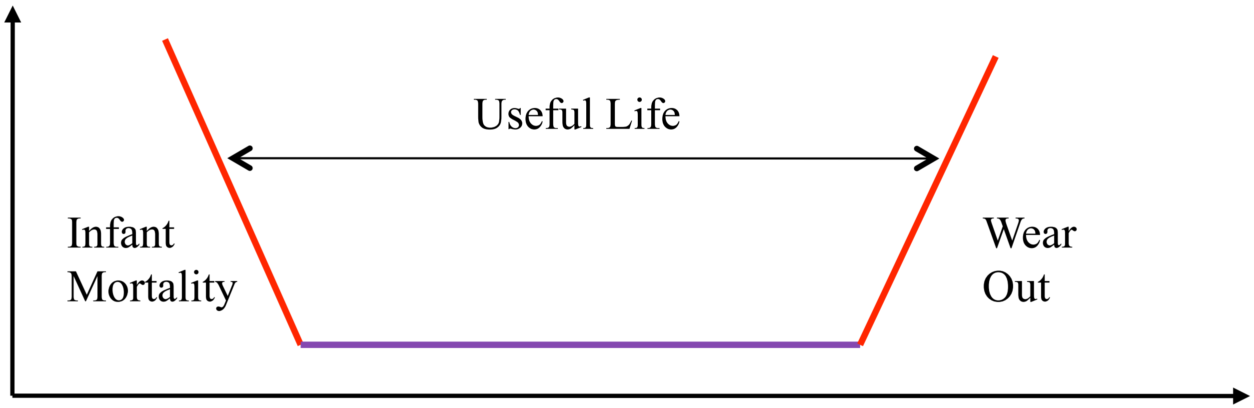
- Drive toward Standard IC Packages
  - Currently most MEMS use some form of modified IC package
  - Inertial sensors especially look more and more like standard IC packages
- Move to all silicon (wafer level package)
  - Reliability issues associated with MEMS
    - Shock for example
  - Testing issues
    - Fixtures and infrastructure
    - Some packaging solutions do not allow MEMS to be tested without ASIC
      - Puts higher priority on design for test

RELIABILITY AND TEST

Reliability Standards for MEMS

- Standard IC reliability tests used
- AEC-Q100 also widely used
- Many device specific reliability issues for which there aren't good standards
  - Stiction is an excellent example
- Universal MEMS standards do not exist
  - Standards could help reduce test cost and time to market
  - Diversity of products makes this more difficult
  - Where to start?
    - Device level
    - Inertial sensors

MEMS Reliability Tests



- Microelectronics and ICs
  - Accelerated life tests
    - Thermal cycle, thermal shock, HAST, etc.
    - The goal of accelerated life tests is to determine the probability of “wear out”
  - Burn in tests (temperature and humidity)
    - The goal of burn in tests is to have “infant mortality” occur in the factory, not in the field
- MEMS devices
  - All of the above!
  - Failure by mechanical causes - shock, vibration
  - Shipping / handling and in service performance
  - Media contact
    - Pressure diaphragm for example

Adapted from “Overview of the Current State of MEMS Reliability and Test”
Mehran Mehregany, Case Western Reserve University

Failure Mechanisms in MEMS and Microsystems

Failure Mode	Causes	Probability
Mechanical	Local stress concentration due to surface roughness	Low
	Improper assembly tolerances	Moderate
	Vibration-induced high cycle fatigue failure.	Low in silicon Moderate in plastic
	Delamination of thin layers.	Moderate to high
	Thermal stresses by mismatch of CTE	High
Electromechanical break-down	Collapse of electrodes due to excessive deformation	High
Deterioration of materials	Aging and degassing of plastic and polymers. Corrosion and erosion of materials.	Moderate
Excessive intrinsic stresses	Residual stresses and molecular forces inherent from microfabrication	High
Packaging	Improper bonding and sealing, poor die protection and isolation	High
Environmental effects	Temperature, humidity, dusts and toxic gas	High

“Overview of the Current State of MEMS Reliability and Test”
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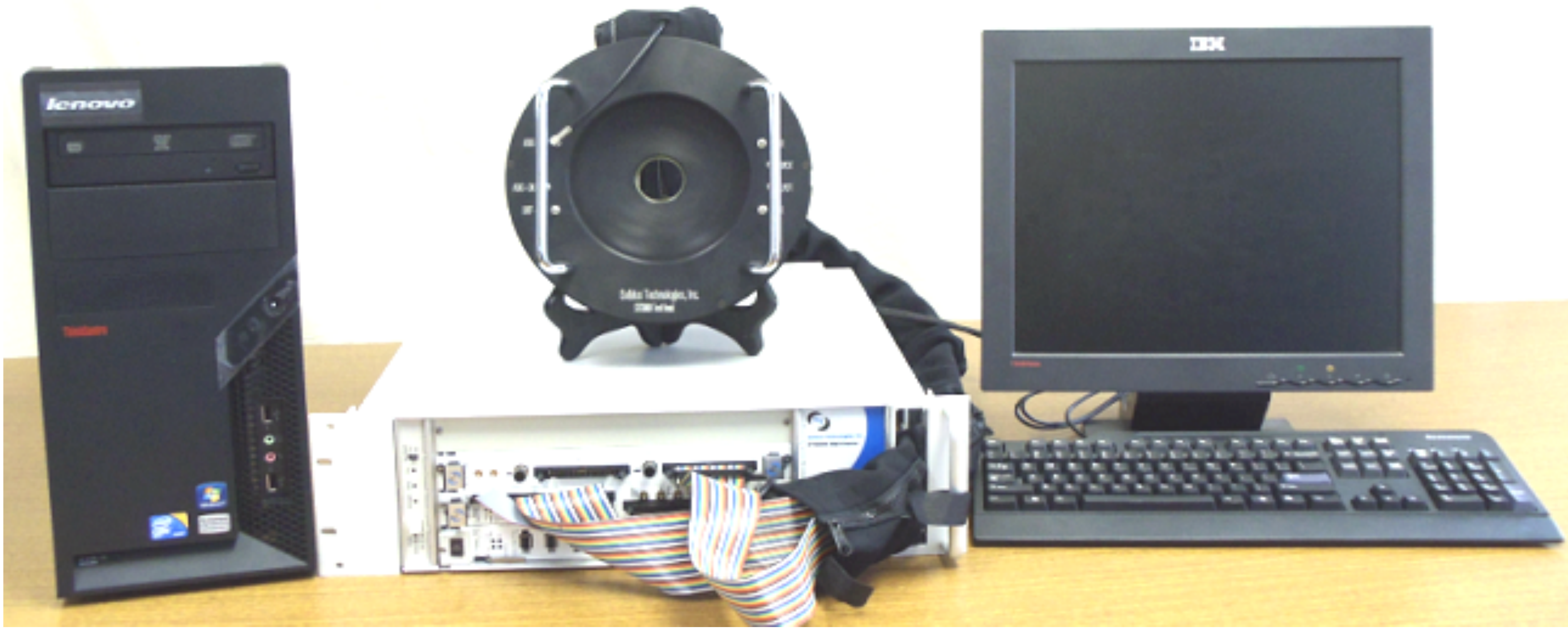
MIG Testing Standards Workshop

- When we began our journey in the summer of 2010, we asked you to "imagine a world" with MEMS standards. Working with our members and partners, MEMS Industry Group (MIG) worked to identify and document device level qualification and testing needs. We also set out to document the results as a guide to where to focus R&D and standards development for device testing on inertial devices. The ultimate goal is to help reduce MEMS manufacturing costs by up to 60%; a number often attributed to the cost of MEMS testing.

- In collaboration with our members and partners, MIG is pleased to announce the first step in this journey - the release of **MEMS Testing Standards: A Path to Continued Innovation - Report on MEMS Testing Standards Workshop**. We encourage you to view/download the document, join the discussion, and contact MIG to be a part of the next steps that are outlined in the report.

Solidus Dynamic Wafer Level Testing

Tests the "Dynamic" Mechanical Performance of MEMS Capacitive Elements at Wafer-Level, including Natural Frequency, Damping, Quality Factor, Stiction, Gyro Quadrature Error, Frequency, Phase, Amplitude and others.



STI3000 Wafer Probe Test System

Solidus Technologies
Leveraging Engineering for the Future

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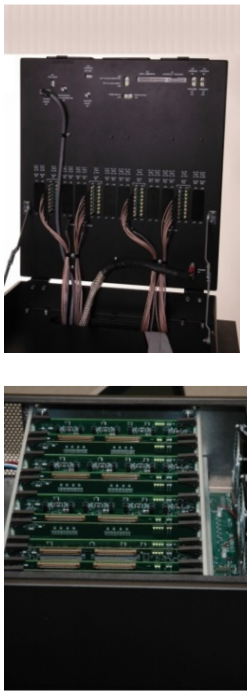
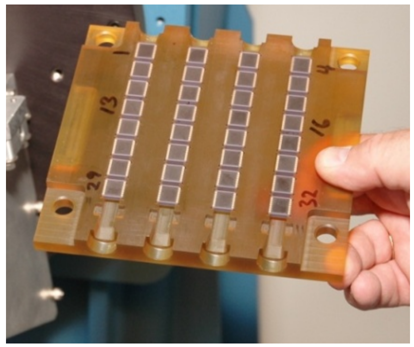
Focus Test: MEMS Test Cell

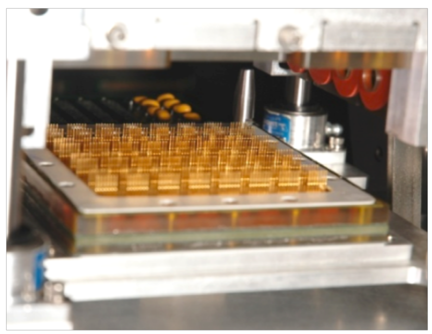
After development of over 30 different MEMS test systems shipped to U.S., Europe and Asia, FocusTest introduces a 3rd Generation MEMS Test Cell.



MPX-2 Test Head



32 DUT Test Carrier

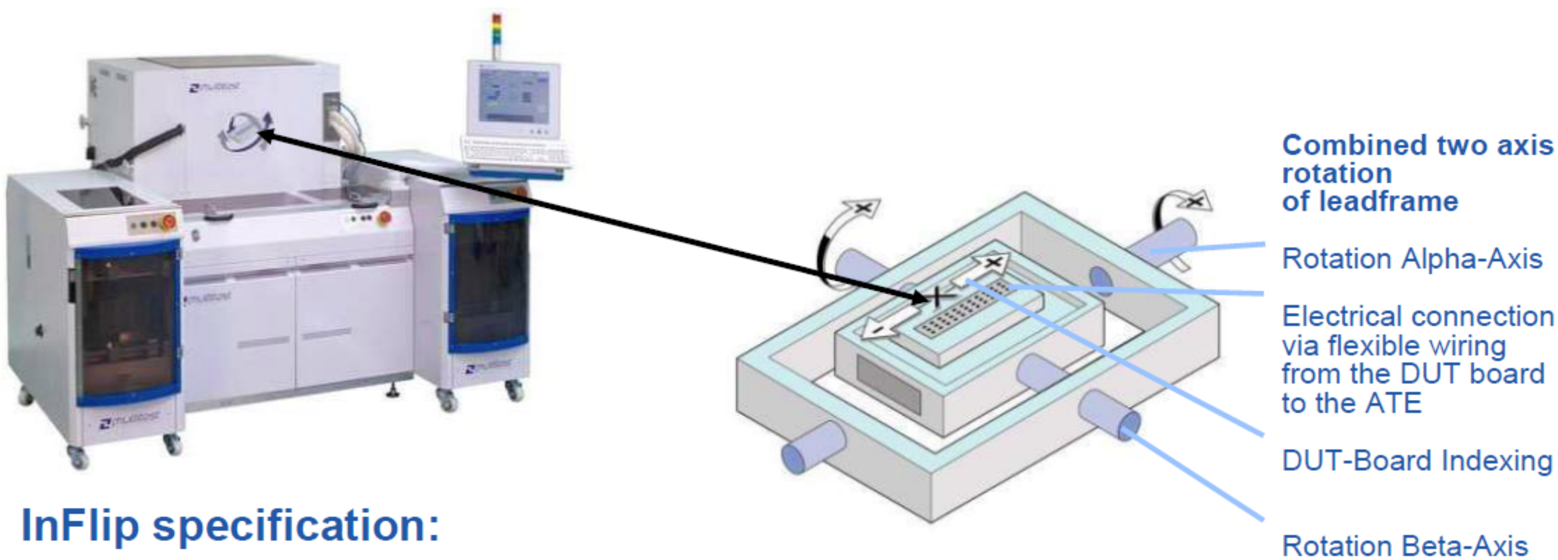


32 DUT Test Contactor

Accelerometer / Gyroscope Test System

InFlip test module

InFlip test = 3axis accelerometer test, low g



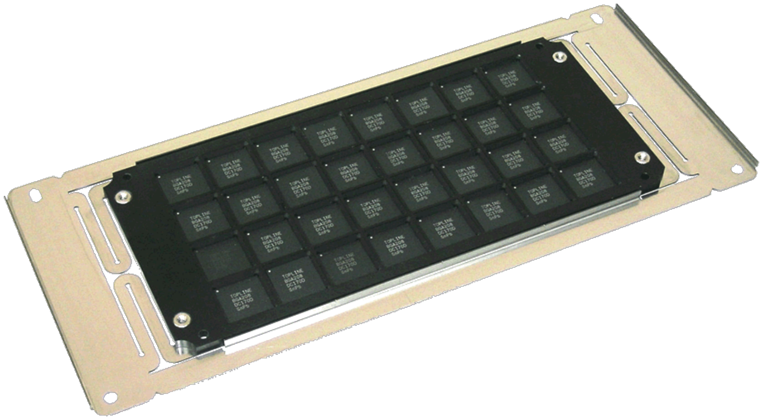
InFlip specification:

- 2 Axis, +/- 185° rotation angle both
- 600 / 1200 contact pins parallel from DUT to ATE (soft docking)
- Rotation speed: 180°/s
- Rotation accuracy: +/- 0,1°
- Temperature range: -40°C .. +125°C (at 600 contacts)
- Sub-indexing of strip in one direction (test complete rows)
- Full angle and Index control from ATE via GPIB (IEEE 488.2)

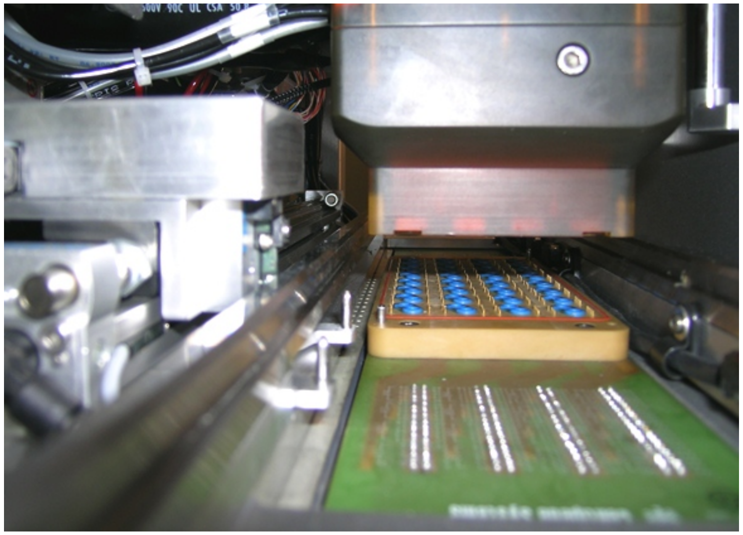
SEMICON Taiwan 2010

Source: Semicon Taiwan 2010

Centipede Test Systems



32 DUT Flex Frame Carrier



Pressure Sensor Test Head

Automated Test-in-Tray System

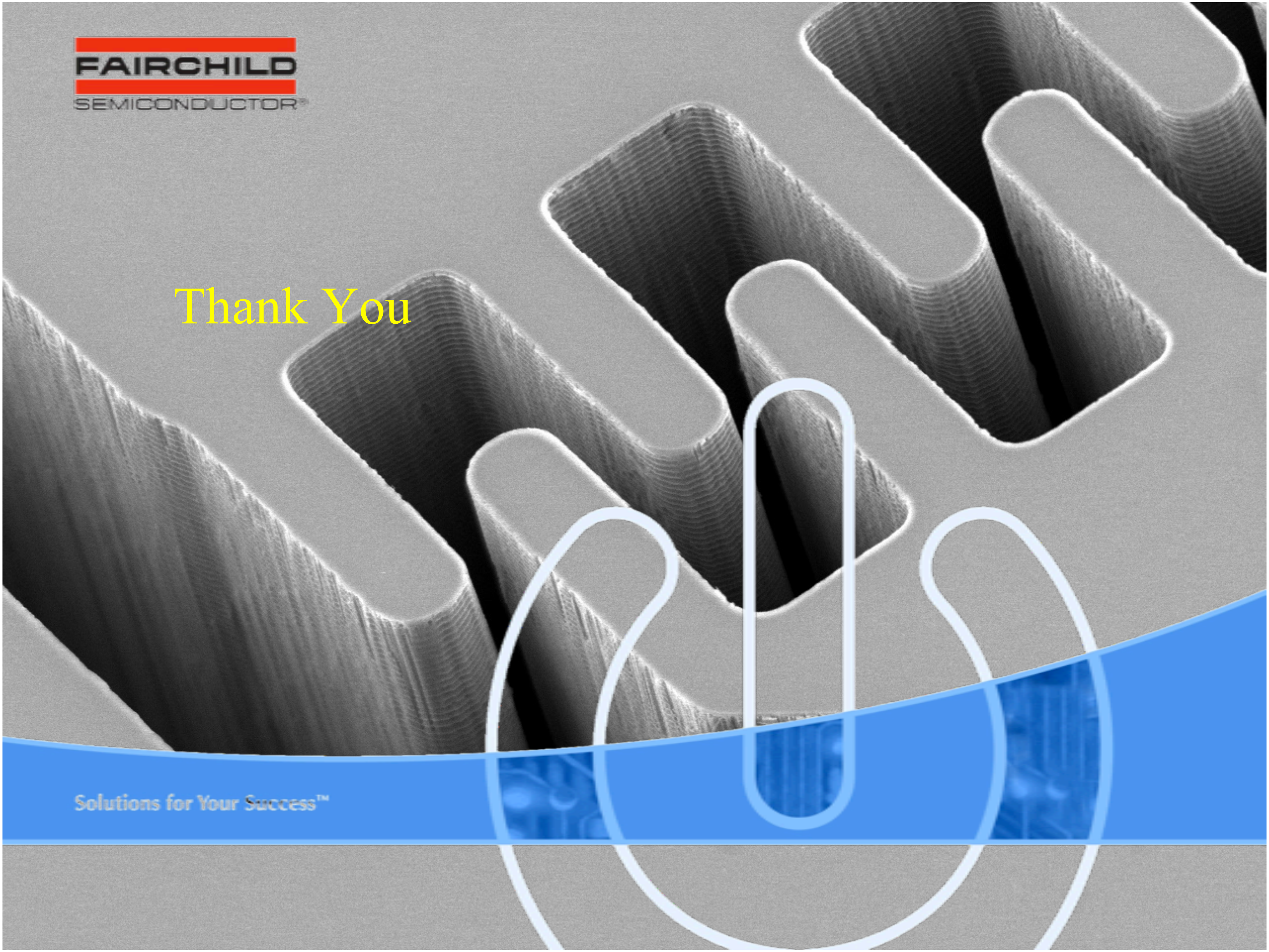
Source: T. H. Di Stefano

Test Summary

- Standards are lacking, but progress is being made
- Diversity of MEMS will always require a certain amount of custom test procedures and test systems
- Test systems infrastructure is now quite well developed for inertial, pressure, and magnetic sensors

Conclusions

- MEMS continues to have very strong growth
  - Current consumer MEMS Tornado
  - Potential future Tornados in area of personal health monitoring and wearable devices
- Current consumer MEMS focus is pushing packaging towards more standardization with IC packages
- High volumes in inertial, pressure, and magnetic are driving a more mature production test infrastructure
- Both of these developments are reducing development time and costs
- MEMS does, and will continue to have, unique reliability and test requirements
- New high volume MEMS developments rely almost exclusively on large packaging vendors, no start-up companies are visible yet
  - Big companies need to expand coverage of MEMS applications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