

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

Dr. Janusz Bryzek, Dr. Shad Roundy  
Fairchild Semiconductor

# Brand Name Products with MEMS

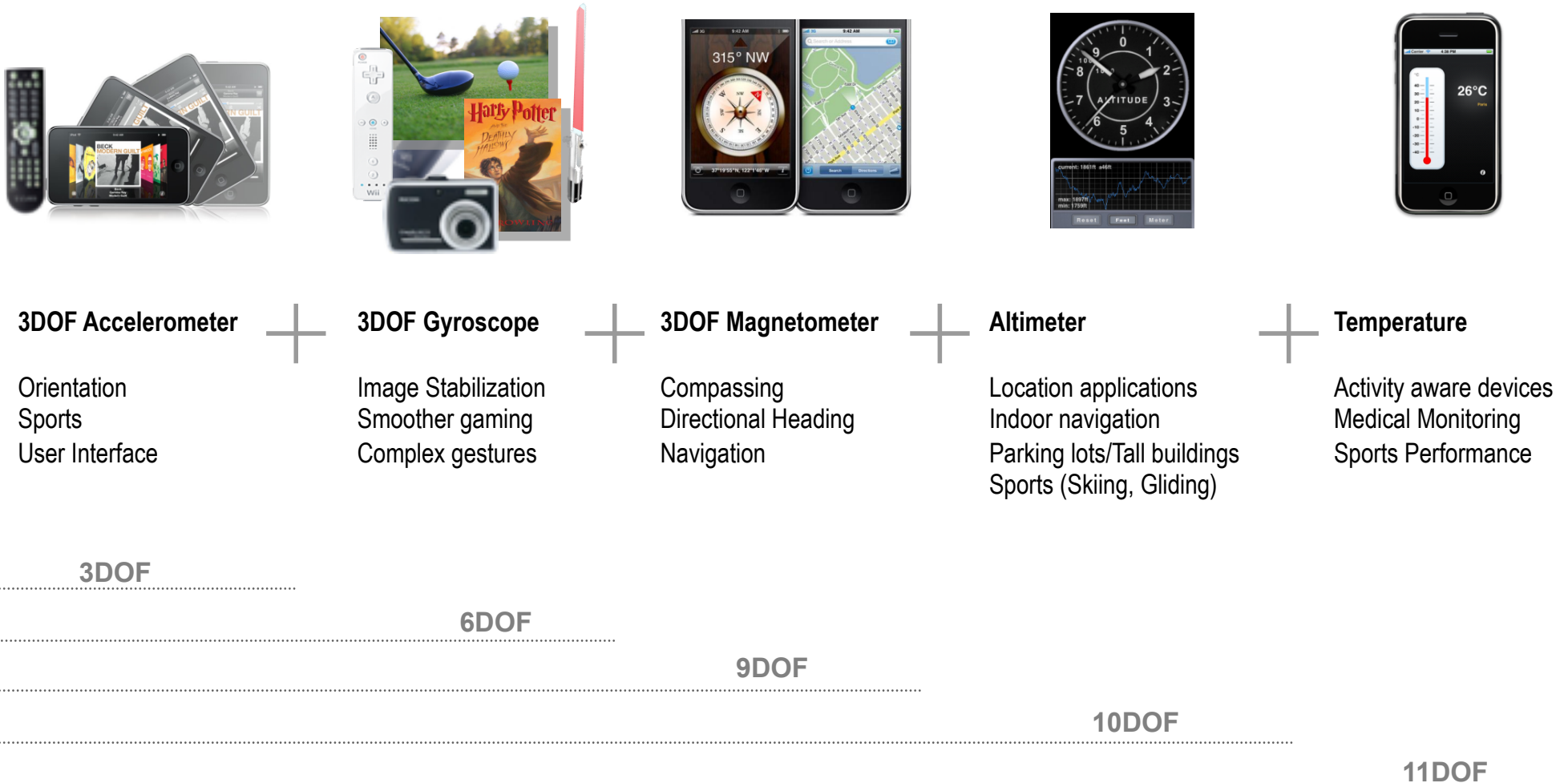


Gyros & accels...  
A lot more than iDevices

Source: K. Yang, ADI presentation at  
COMS2008

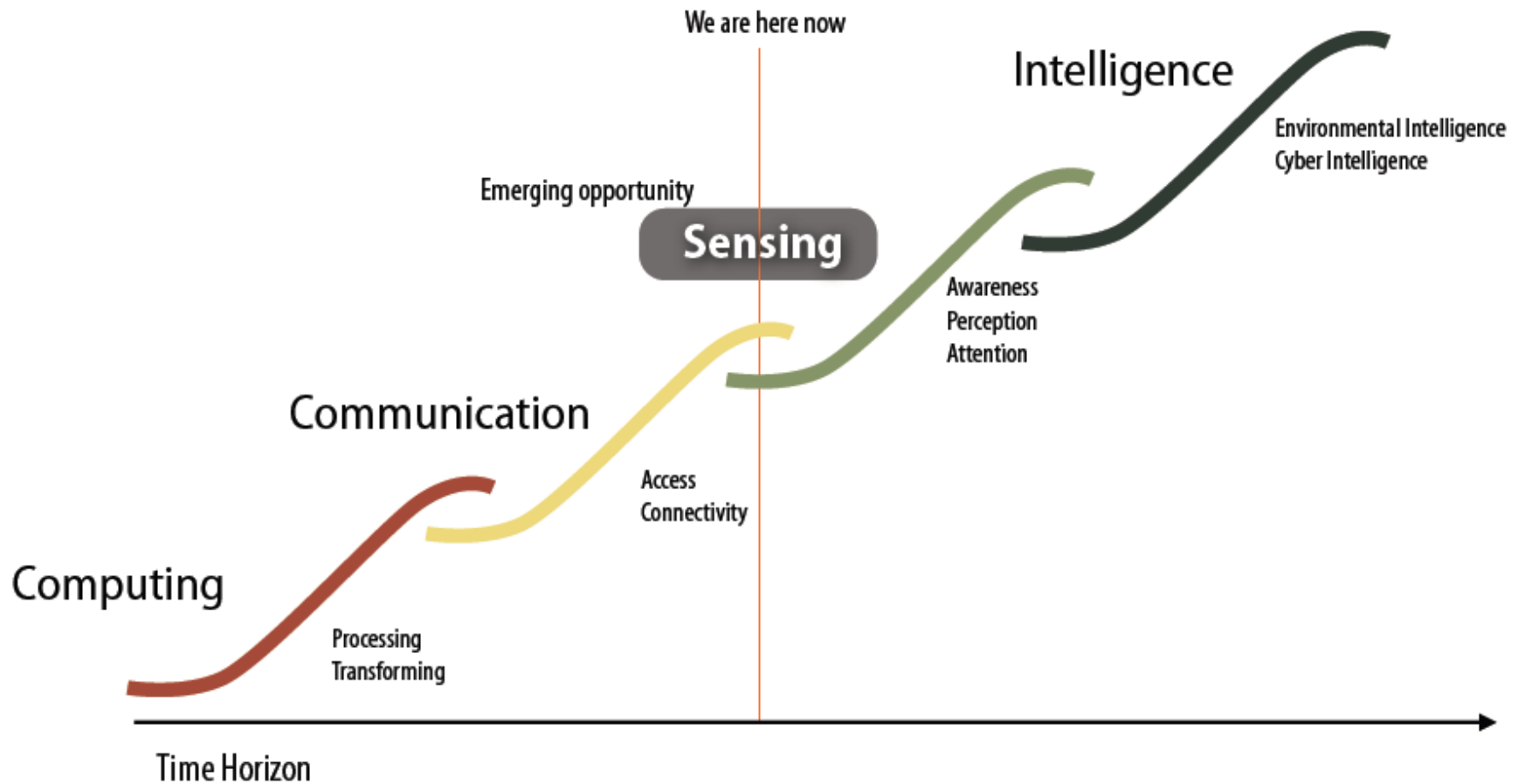


# Adding Sensor Degrees of Freedom Enables New Apps



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

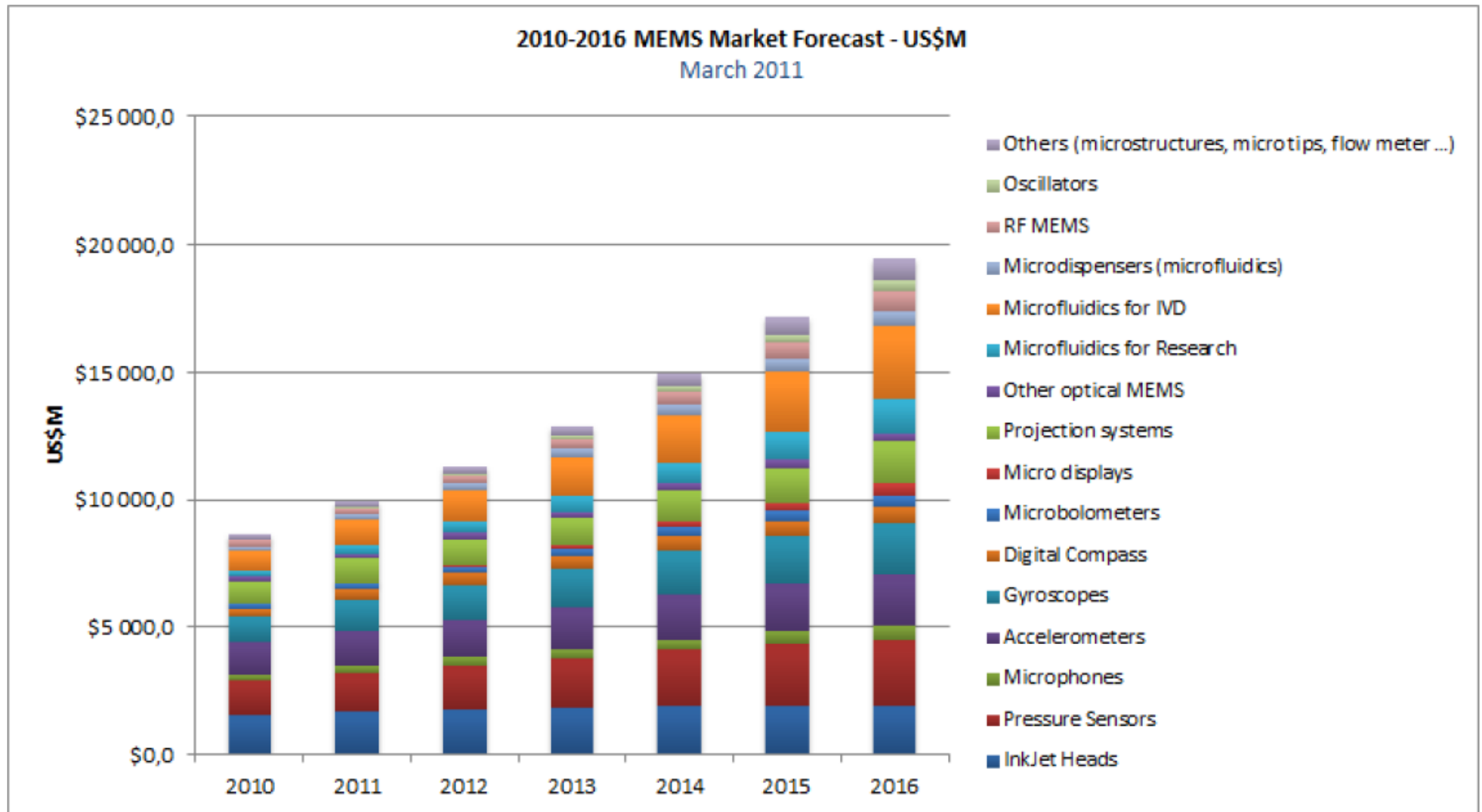
# Market Shift to Sense Based Intelligence



\* Paul Saffo — Institute of the future; Stanford U

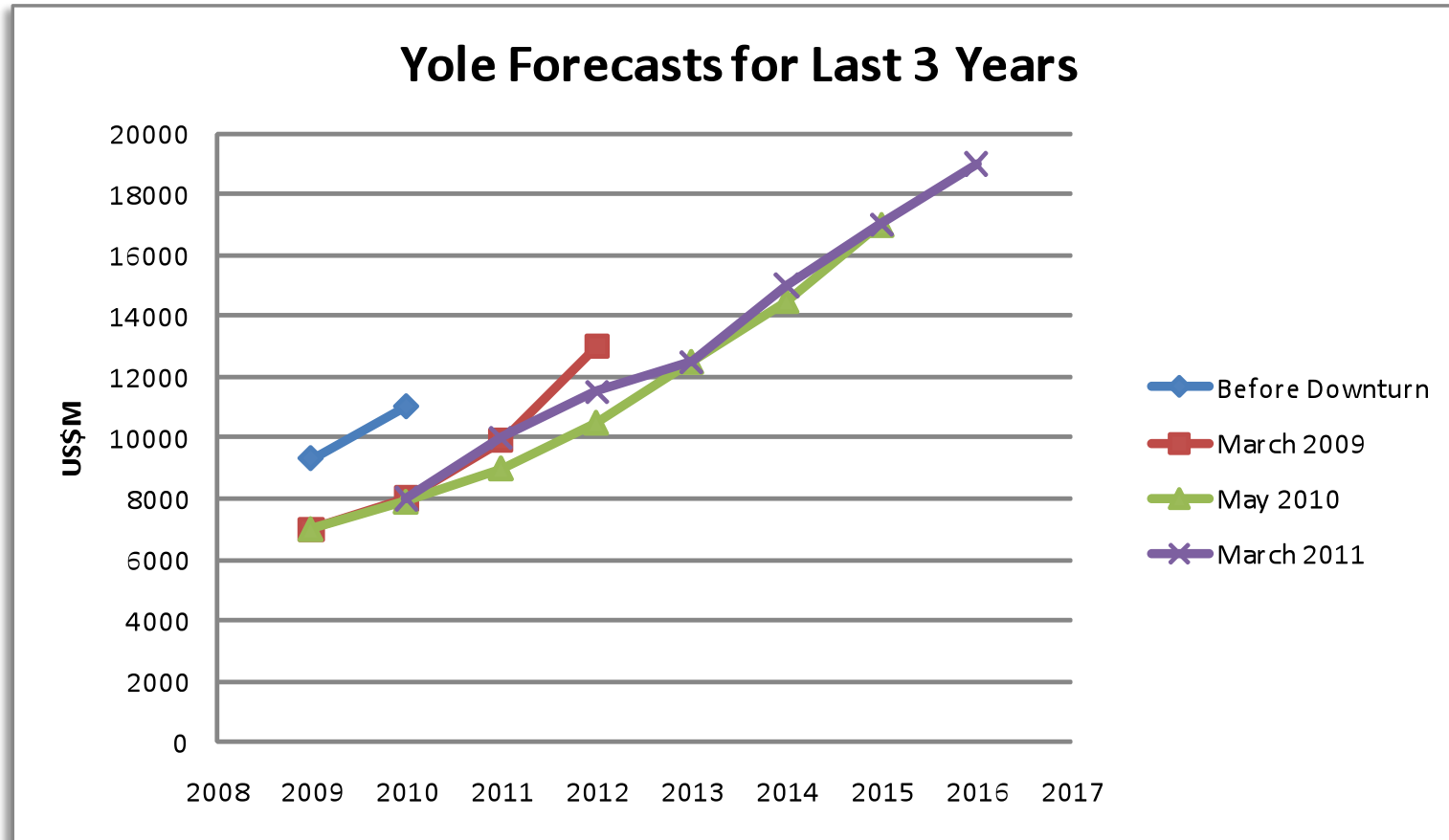
# 2011 Yole MEMS Forecast

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



Source: Yole Development

# Stability of Market Forecasts



# Emerging 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?



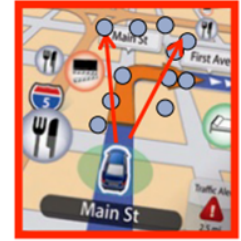
Point of Interest

POI



No compass

POI\_Filtering



With compass



Source: Sekai Camera



Source: Layar and Wikitude



- 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)



15 ©2010 Hewlett-Packard Development Co, Peter Hartwell, HP Labs

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



# 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



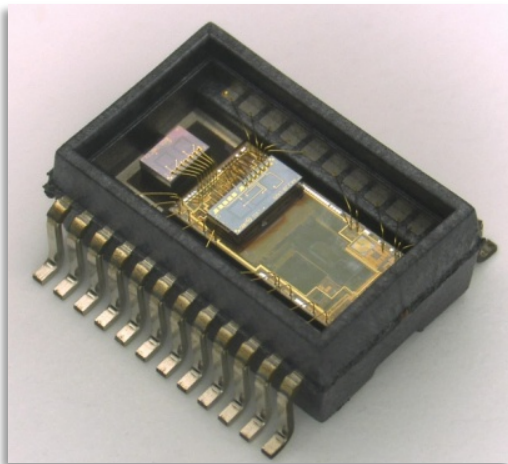
Source: Holst Center, IMEC



VTI's watch pressure sensor



Rosemont

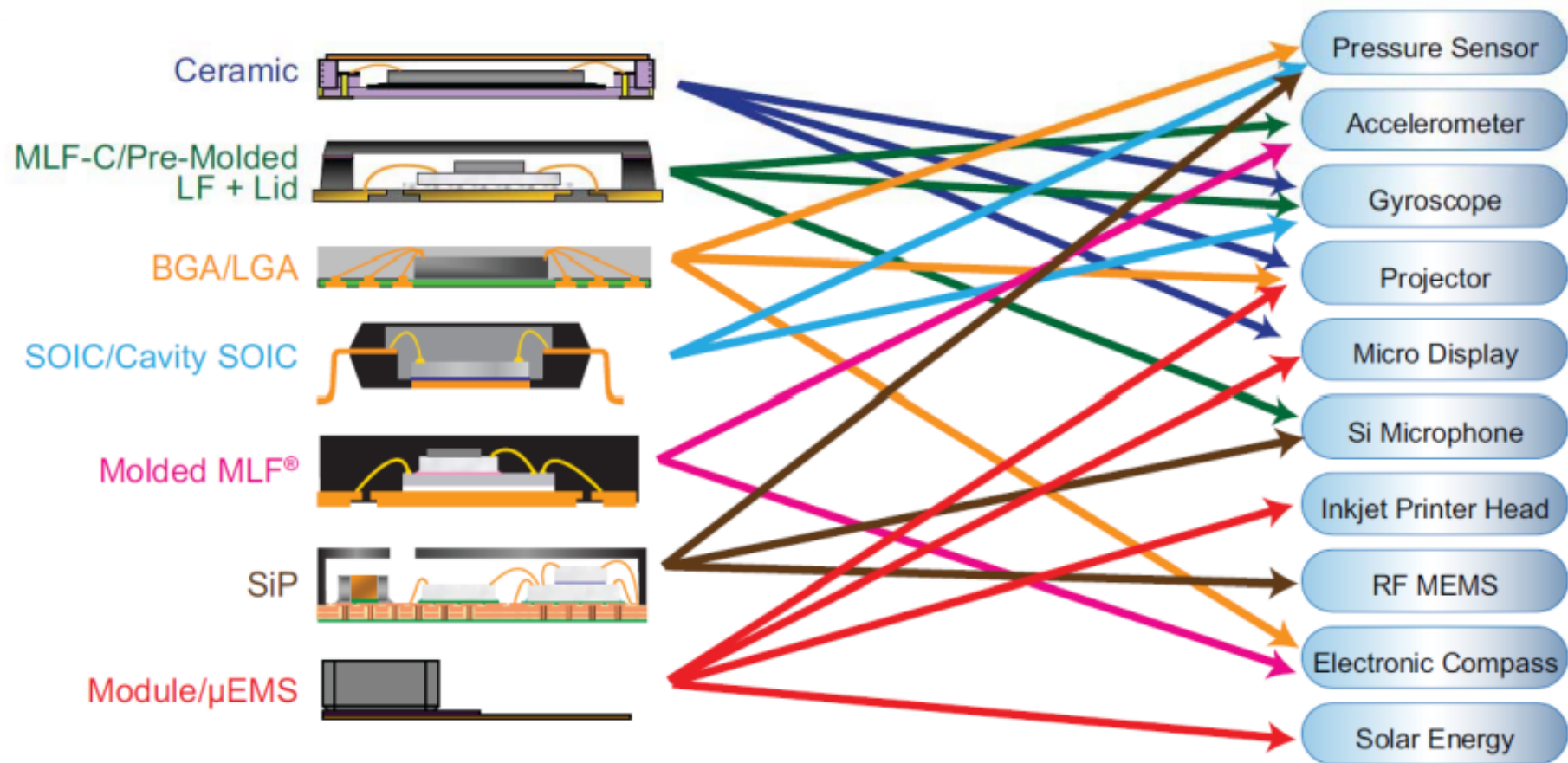


LVSI's TPMS part



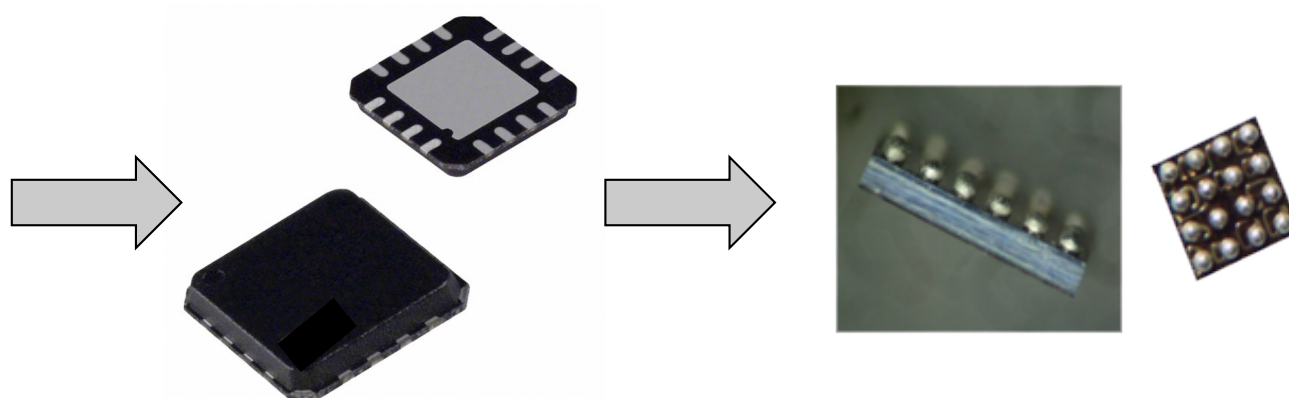
TPMS module from Beru AG

# Amkor MEMS Packaging Matrix



Source: Amkor

# 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

# 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.

- 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

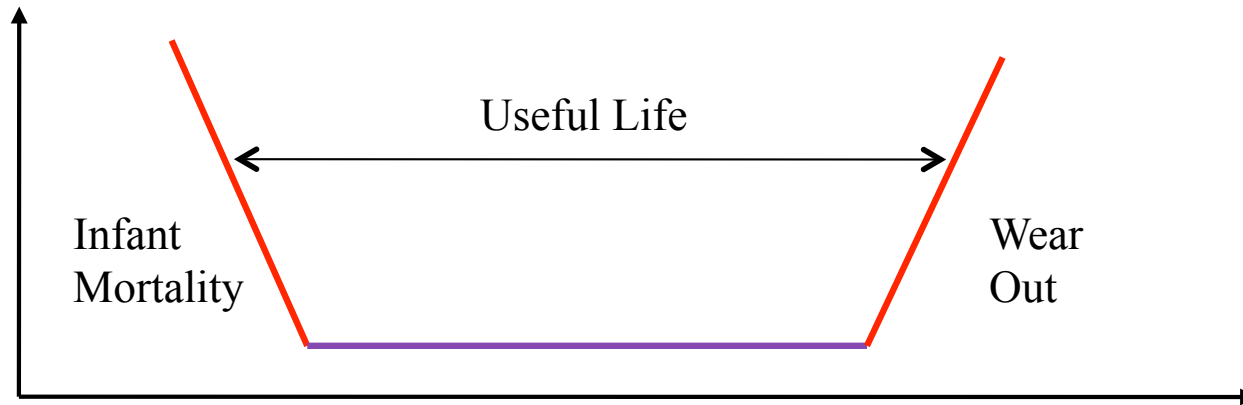
# RELIABILITY AND TEST

# 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<br>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.<br>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”  
 Mehran Mehregany, Case Western Reserve University

# 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

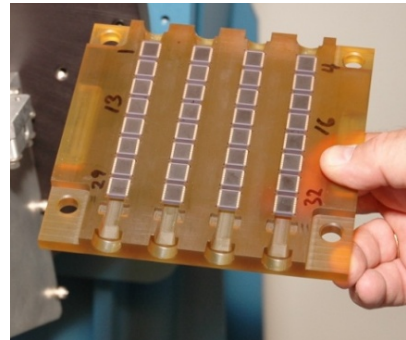
# Focus Test: MEMS Test Cell



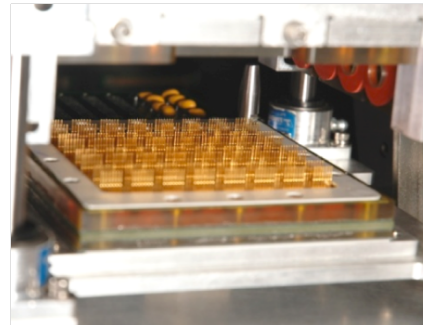
After development of over 30 different MEMS test systems shipped to U.S., Europe and Asia, FocusTest introduces a 3<sup>rd</sup> Generation MEMS Test Cell.



MPX-2 Test Head



32 DUT Test Carrier



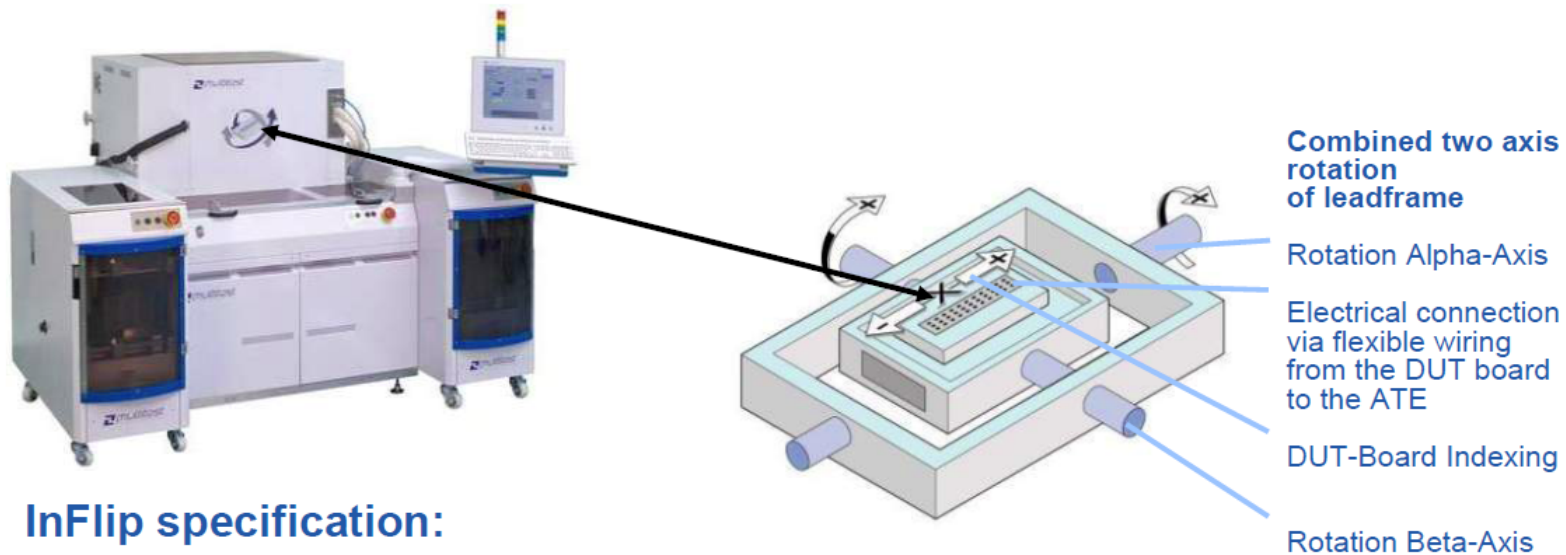
32 DUT Test Contactor



Accelerometer / Gyroscope  
Test System

## InFlip test module

**InFlip test = 3axis accelerometer test, low g**



### InFlip specification:

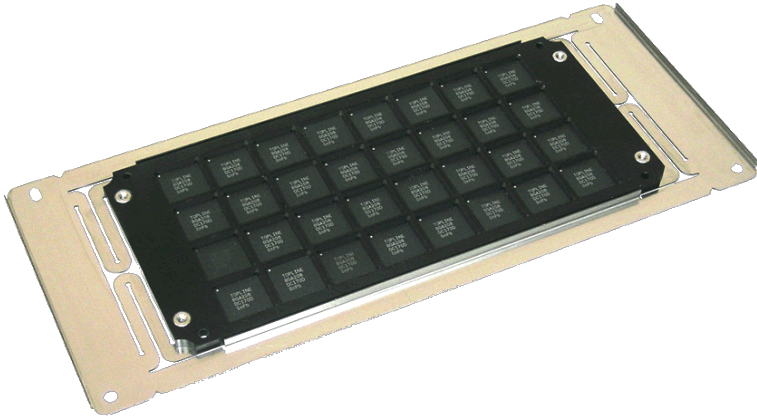
- 2 Axis, +/- 185° rotation angle both
- 600 / 1200 contact pins parallel from DUT to ATE (soft docking)
- Rotation speed: 180°/s
- Rotation accuracy: +/- 0,1°
- Temperature range: -40°C .. +125°C (at 600 contacts)
- Sub-indexing of strip in one direction (test complete rows)
- Full angle and Index control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

Thank You