MEMS
Technology Roadmapping

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Chair, iNEMI and ITRS MEMS Technology Working Groups

Nano-Tec Workshop 3
31 May 2012

ITRS

iNEMI

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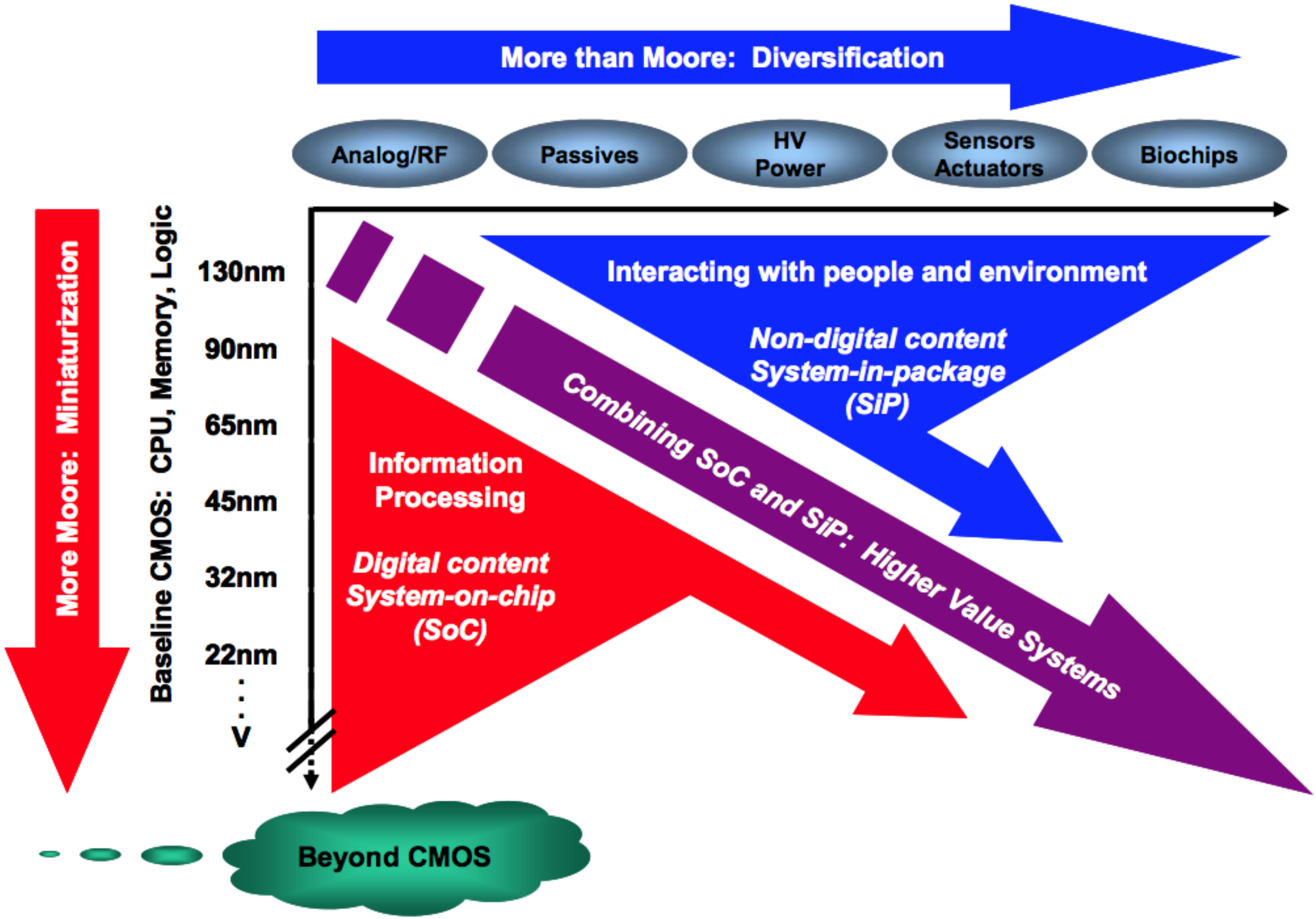
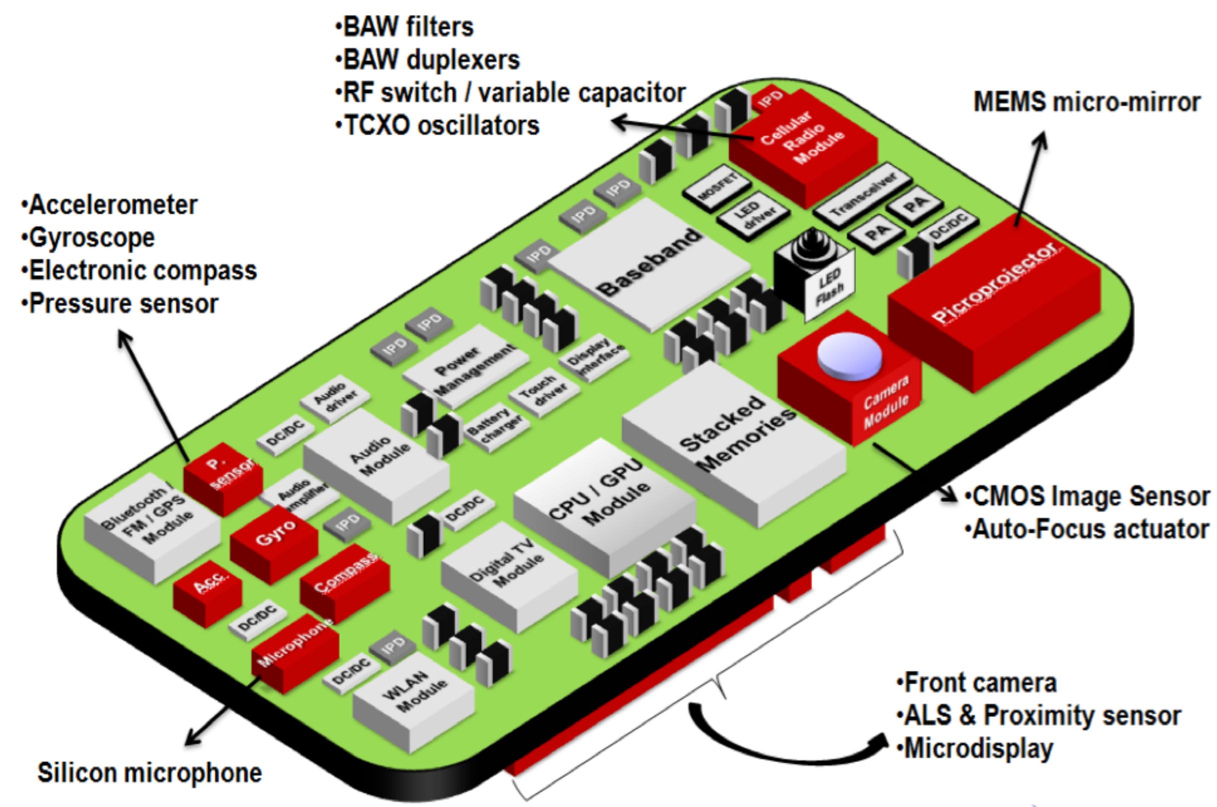


“More than Moore” White Paper, http://www.itrs.net

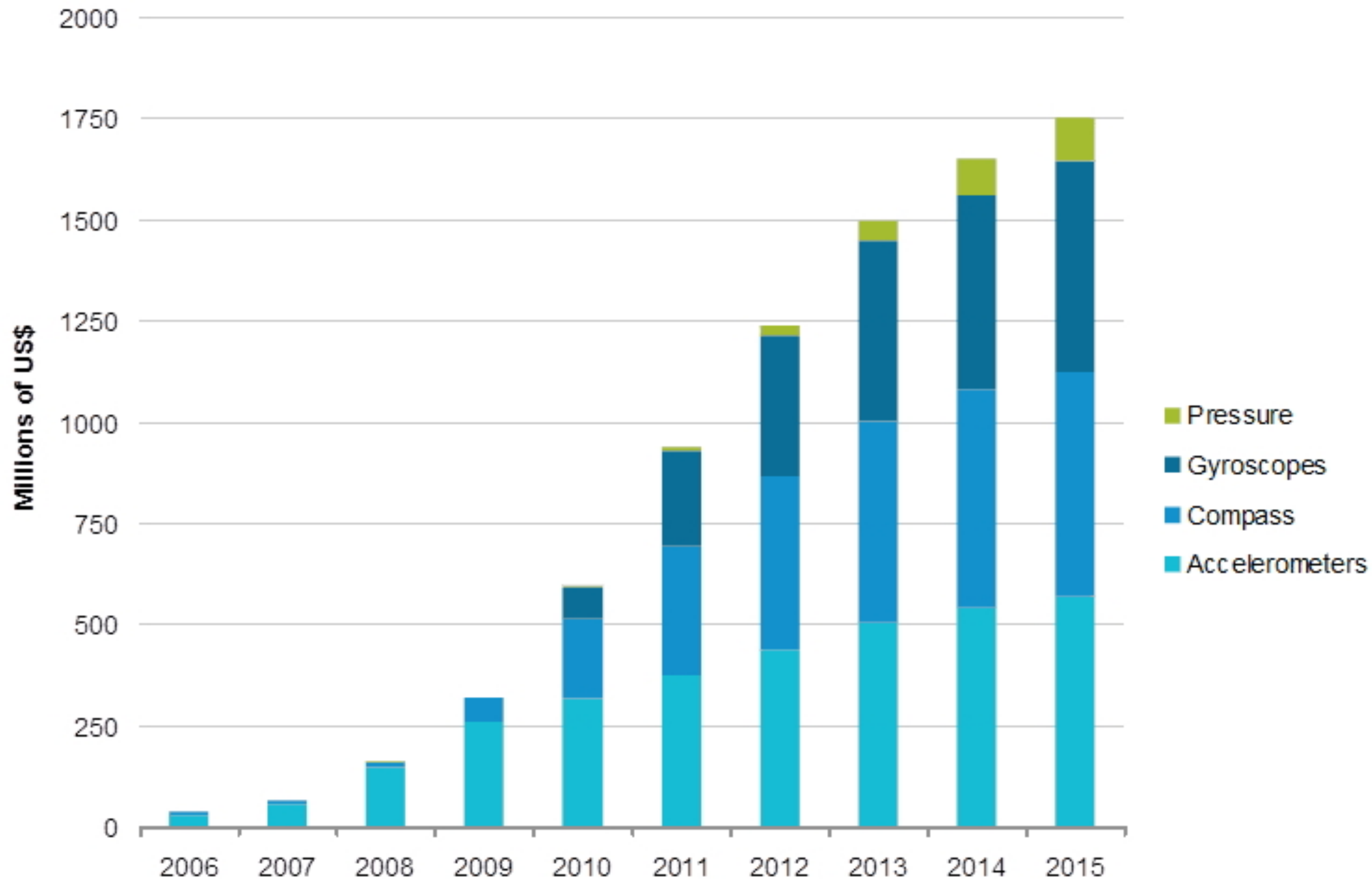
MEMS in Smart Phones

- Accelerometers
- Gyroscopes
- Electronic Compass
- Pressure Sensors
- Microphones
- Micro speakers
- Auto focus
- (Pico) Projectors
- RF MEMS



Source: Yole Development

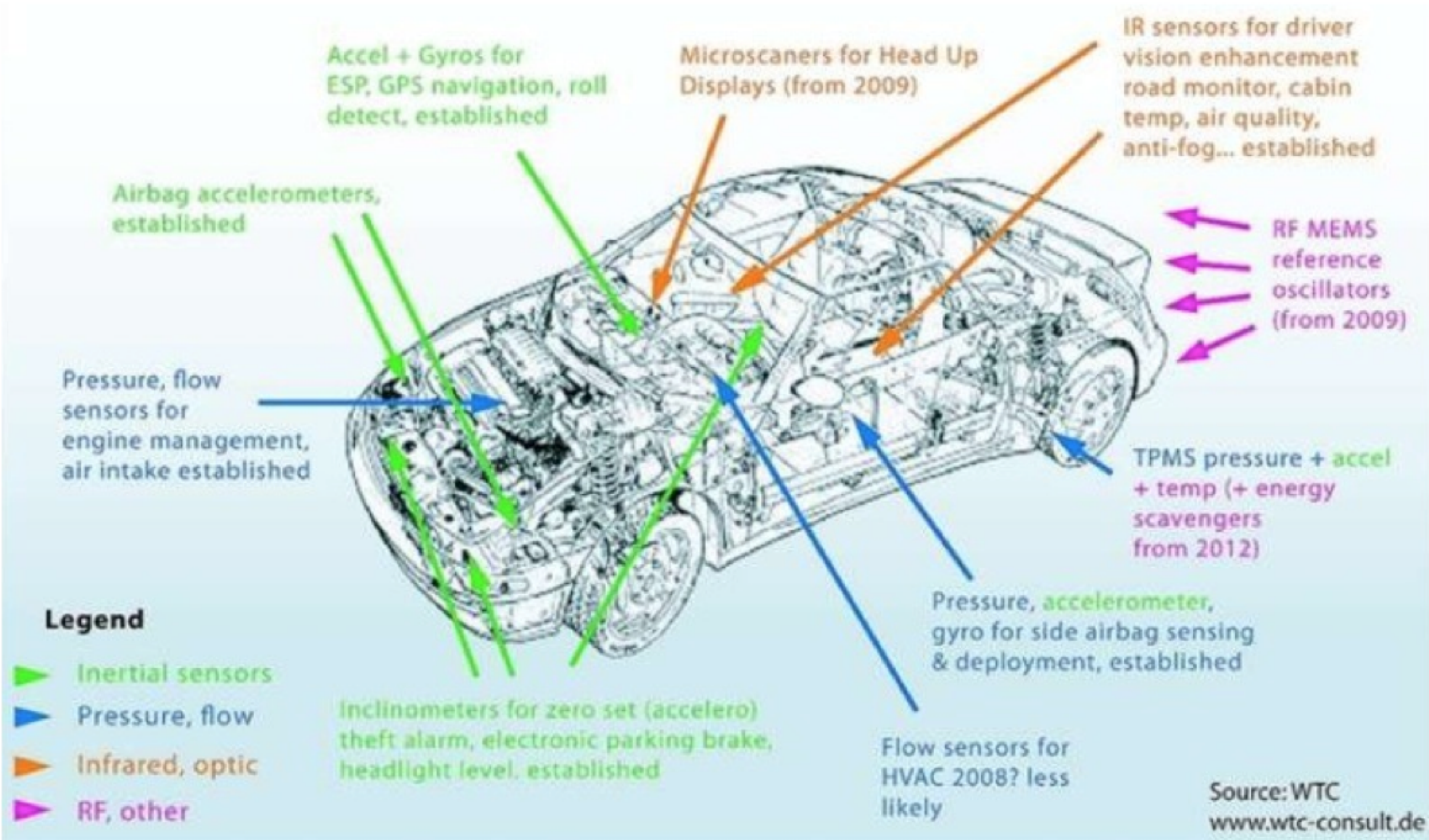
Hottest of the hottest!!!
Motion sensors in Handsets and Tablets
(accelero, gyro, pressure + compass)



Source: IHS iSuppli Special Report
"Motion Sensors in Handsets and Tablets", H1 2011

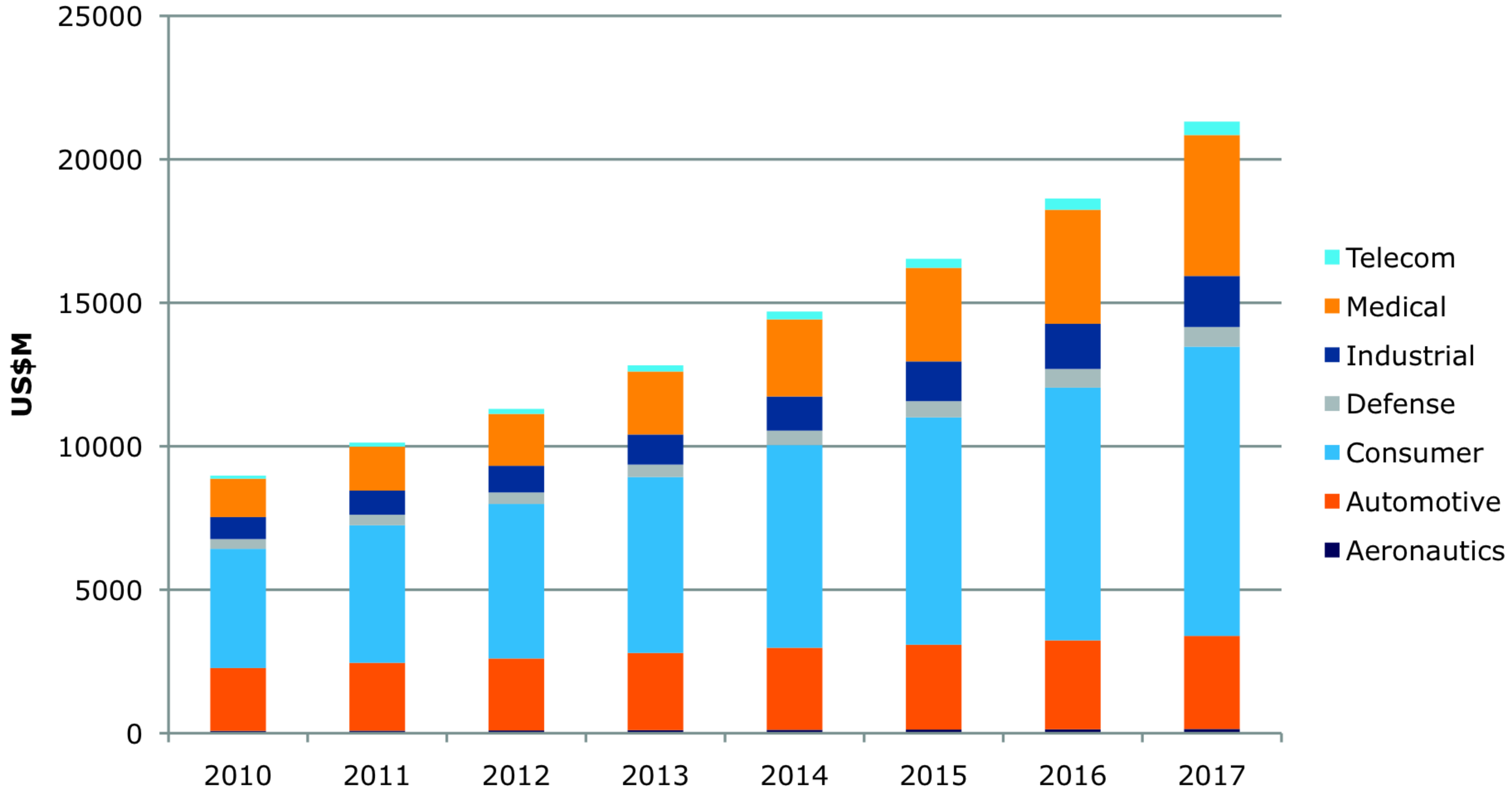
From Jérémie Bouchaud's MIG Webinar "A Global Analysis of the Current MEMS Market" on July 27, 2011

Automotive MEMS



MEMS market forecast 2010 - 2017 (US$M)

(Source: Status of the MEMS industry report, to be released mid 2012, Yole Développement, March 2012)

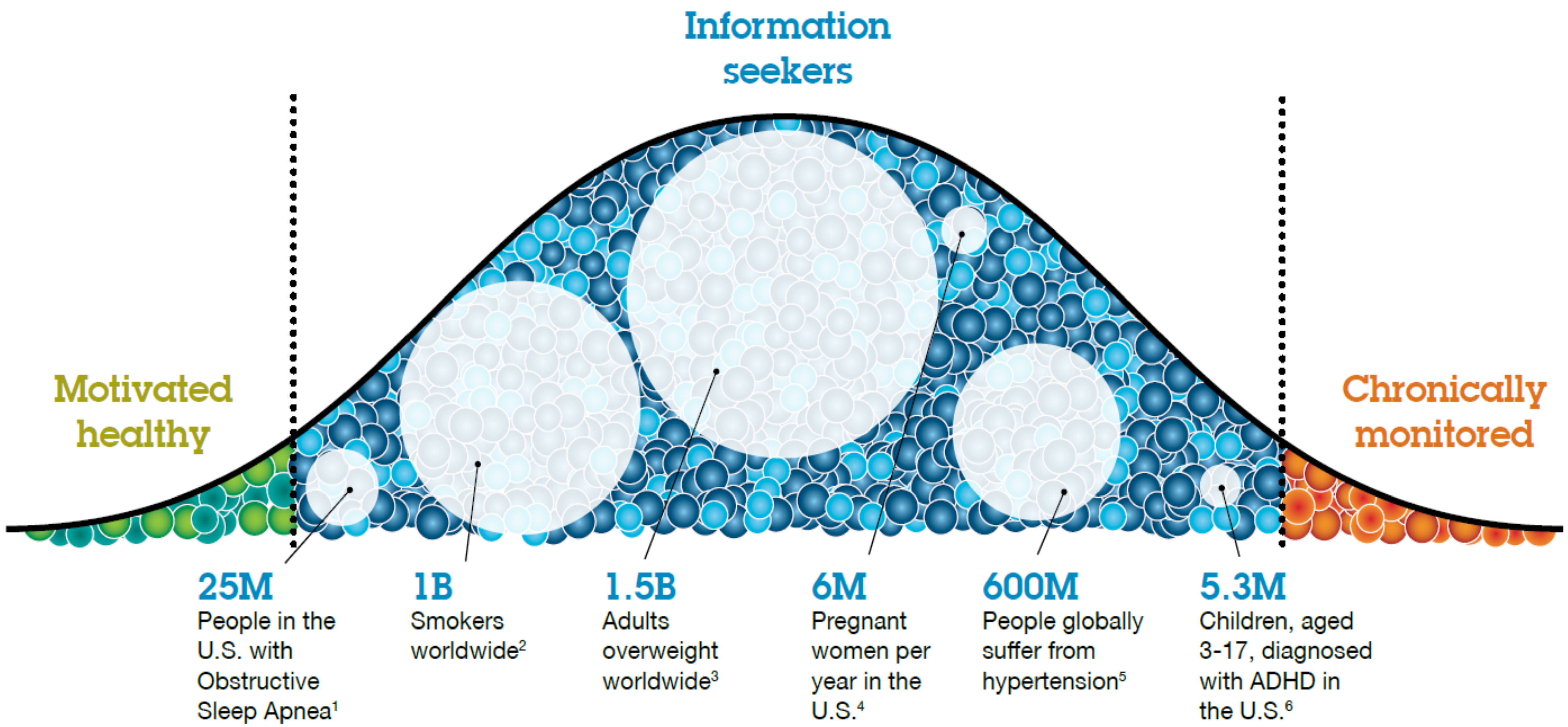


From Yole Development at the MEMS Industry Group's M2M Workshop, May 2012

Medical MEMS
The Worried Well

Lab On A Chip Technologies

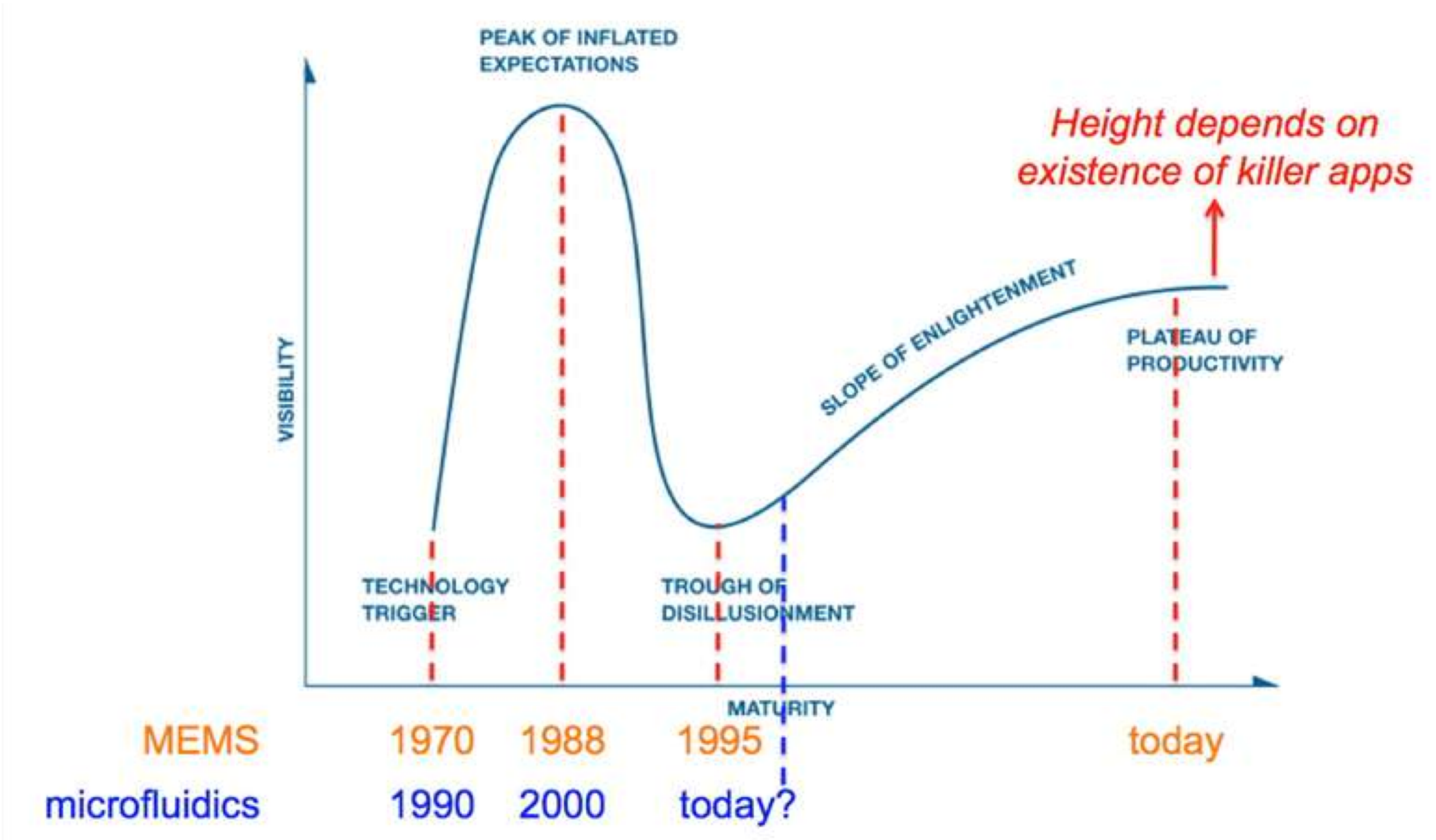
MEDICAL MARKET- High Potential



Bubble Chart Ref: IBM Institute for Business Value," The future of connected health devices"

- **3 BILLION POTENTIAL CUSTOMERS FOR CONNECTED HEALTH DEVICES**

Gartner Hype Cycle Model



Holger Becker, Lab Chip, 2009, 9, 2119-2122

MEMS COMMERCIALIZATION TIME TABLE

Product	Discovery	Product Evolution	Cost Reduction	Full Commer-cialization	Elapsed Time years
Pressure Sensors	1954-1960	1960-1975	1975-1990	1990	36
Accelerometers	1974-1985	1985-1990	1990-1998	1998	24
Gas Sensors	1986-1994	1994-1998	1998-2005	2005	29
Valves	1980-1988	1988-1996	1996-2002	2002	22
Nozzles	1972-1984	1984-1990	1990-2002	2002	24
Photonics/Displays	1980-1986	1986-1998	1998-2005	2005	25
Bio/Chemical Sensors	1980-1994	1994-2000	2000-2010	2015	35
Radio Frequency (R.F.)	1994-1998	1998-2001	2001-2008	2014	20
Rate Sensors	1982-1990	1990-1996	1996-2006	2008	26
Micro Relays	1977-1993	1993-1998	1998-2008	2014	37
Oscillators	1965-1980	1980-1995	1995-2009	2013	48
Median	10 yrs.	8 yrs.	12 yrs.		30 yrs.

ROGER GRACE ASSOCIATES
MARKETING COUNSEL

Critical Success Factors for the Commercialization of MEMS: The 2011 MEMS Industry Report Card, Roger Grace, Roger Grace Associates, MIG's M2M Workshop, May 2012.

MEMS Technology Roadmapping

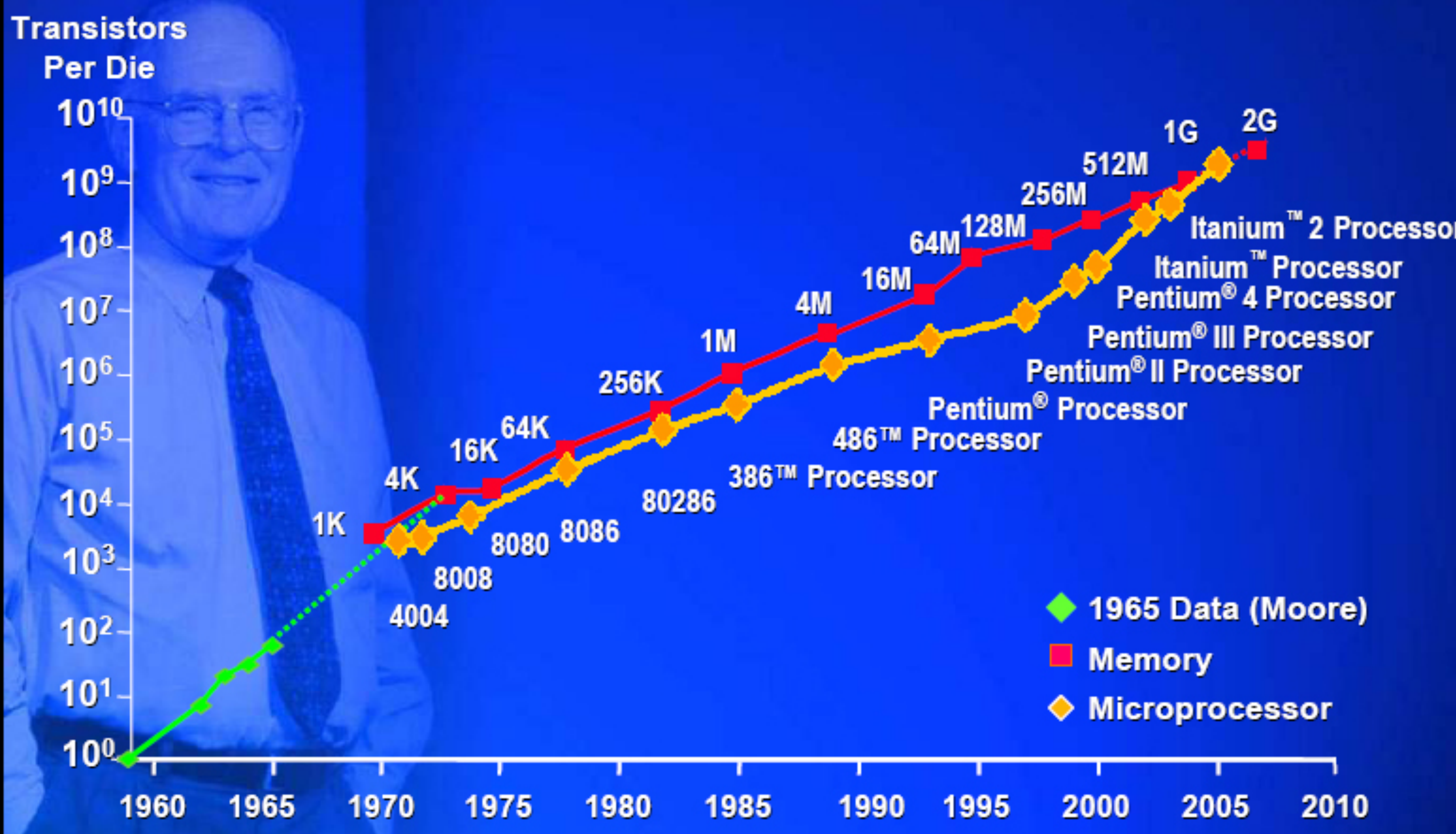
- A technology roadmap is a plan that matches goals with specific technology solutions to meet those goals.*
  - A consensus about a set of needs and the technologies required to satisfy those needs
  - A mechanism to help experts forecast technology developments in targeted areas
  - A framework to help plan and coordinate technology developments both within a company or an entire industry

*Garcia, M.L. and Bray, O.H. (1997), Fundamentals of Technology Roadmapping. Strategic Business Development Department. Sandia National Laboratories.

What are Required Conditions?

1. (FOM) restricted set of figures of merit.
2. (ECO) existence of a community of players.
3. (SHR) willingness to share information.
4. (WAT) potential market of significant size indicating a wide applicability of the roadmap.
5. (LEP) convergence of opinion among a majority of the key players on the progress of trends.

Moore's Law - 2005



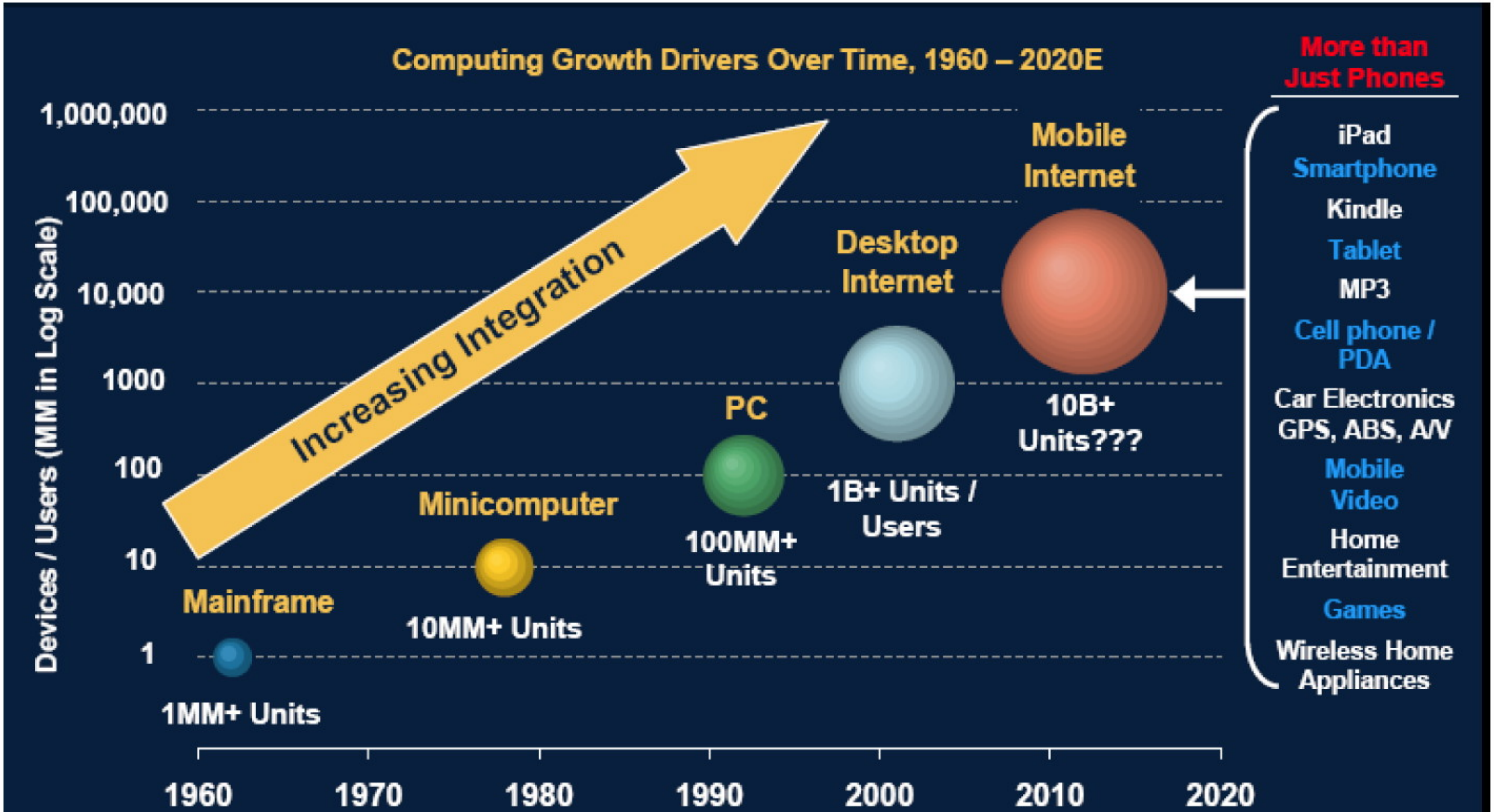
Source: Intel

But … How Can We Roadmap MEMS?

- MEMS are too diverse
- We don’t need/want any standards
- MEMS are one process, one device
- Every product/company has a “secret sauce”
- There is no common ground
- MEMS companies are fiercely competitive, how will they cooperate?
- What is the scope for the ITRS roadmap of More than Moore?

Ease of use Improvements Drive Growth

User Interface + Smaller Form Factor + Lower Prices + New Services



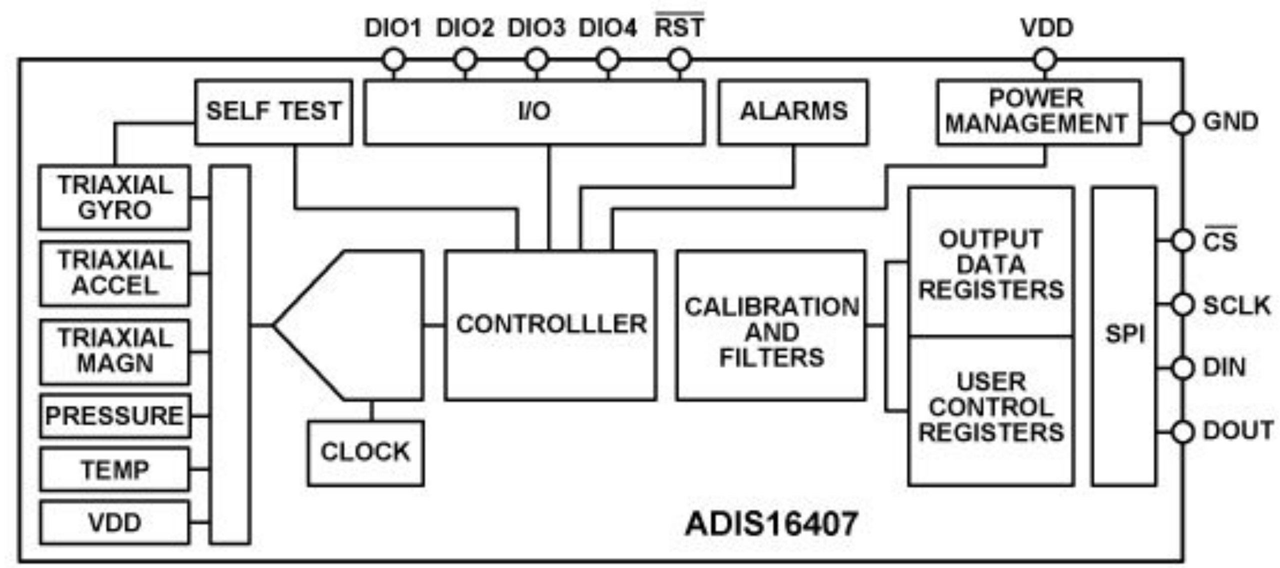
Source: 2009 Estimates Morgan Stanley

Inertial Measurements

STMicroelectronics

May 18, 2011 STMicroelectronics' Three MEMS Sensors Provide 10 DoF. The three ST MEMS sensors include a geo-magnetic module, a gyroscope, and a pressure sensor.

Analog Devices



June 16, 2011 Analog Devices ADIS16407 iSensor MEMS-based inertial measurement unit combines a tri-axis accelerometer, a tri-axis gyroscope, a tri-axis magnetometer, and a pressure sensor in a single unit.

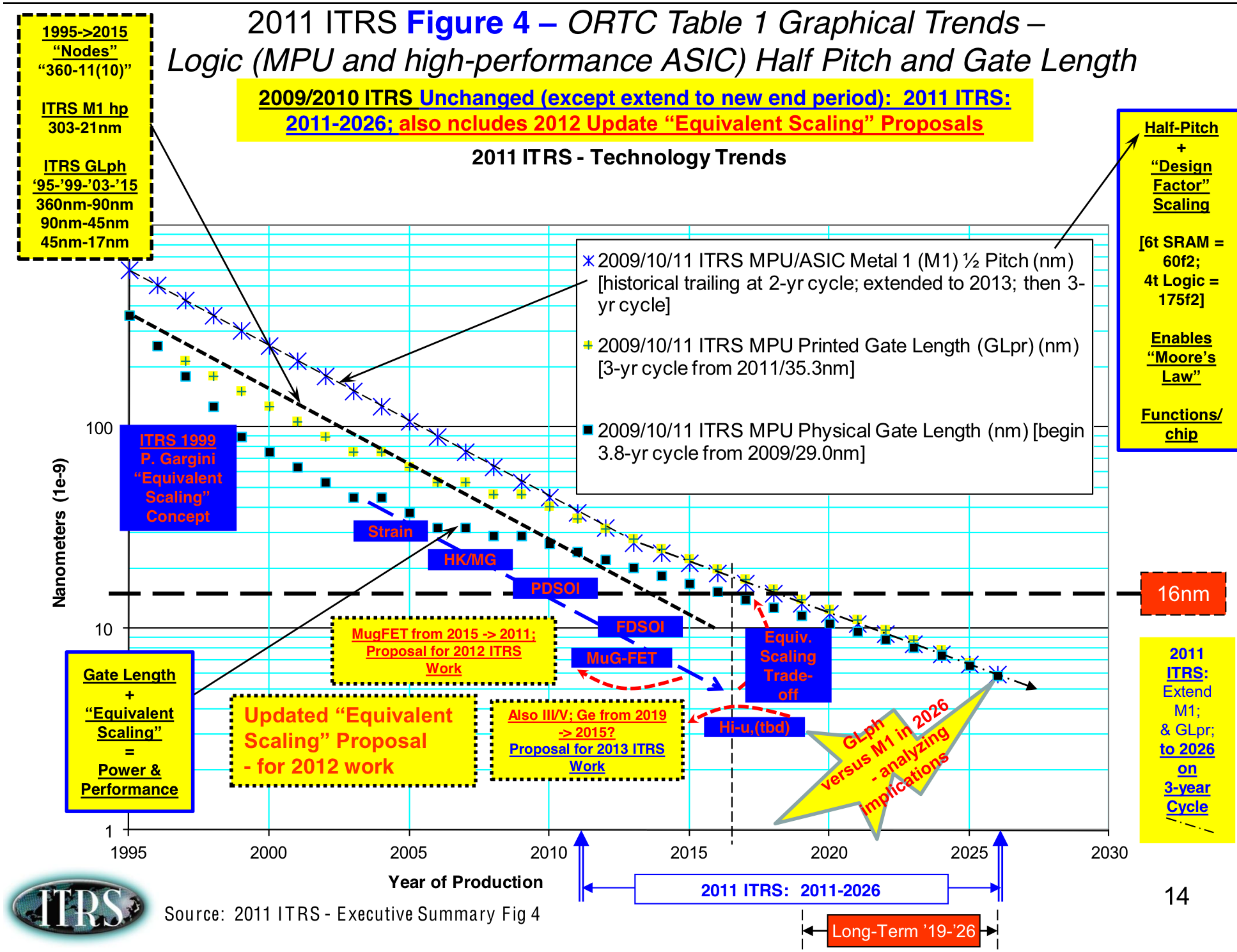
Technology Requirements

Accelerometers

Table MEMS1 Accelerometers

Year of Production	*2011*	*2012*	*2013*	*2014*	*2015*	*2016*	*2017*
ORTC Driver line item [copy from the ORTC tables]							
Performance							
Range [+/- g]	±16		±16		±16		±16
Resolution [µg]	1000		750		500		500
Zero g level (biais) [mg]	±40		±35		±30		±25
Zero g level drift over temperatrure [mg/°C]	±0.5		±0.5		±0.4		±0.4
Package Size [mm²]	3x3x1		2x2x1		2x1x1		1x1x1
Power consumption [uW]	30		25		20		15
Cost [$]	0.60		0.35		0.25		0.20
Integration path at the package level	6-DOF (accelero + magneto or accelero + gyro)		9-DOF (accelero + magneto or accelero + gyro)		10-DOF (accelero + gyro + magneto + pressure)		
Integration path at the chip level	Stand- Alone 3-Axis Accelero		Integrated in 6+ DOF Product		Integrated in 9+ DOF Product		Integrated in 10+ DOF Product
Design and Simulation							
Design for testability							
Reliability simulation							
Simulation of package to predict device perfromance from wafer-level tests							
Cost modeling for packaging and integration							
Design verification, optimization, DRC, LVS							
Power consumption							
Simulation of drift, noise, Q							
Cross axis sensitivity and coupling effects							
Simulatuon of shock tests							
Packaging and Integration							
MEMS Packaging Standardization							
Advancement of Integration methods such as 3D stacking with TSV for MEMS							

Technology Nodes (ITRS)

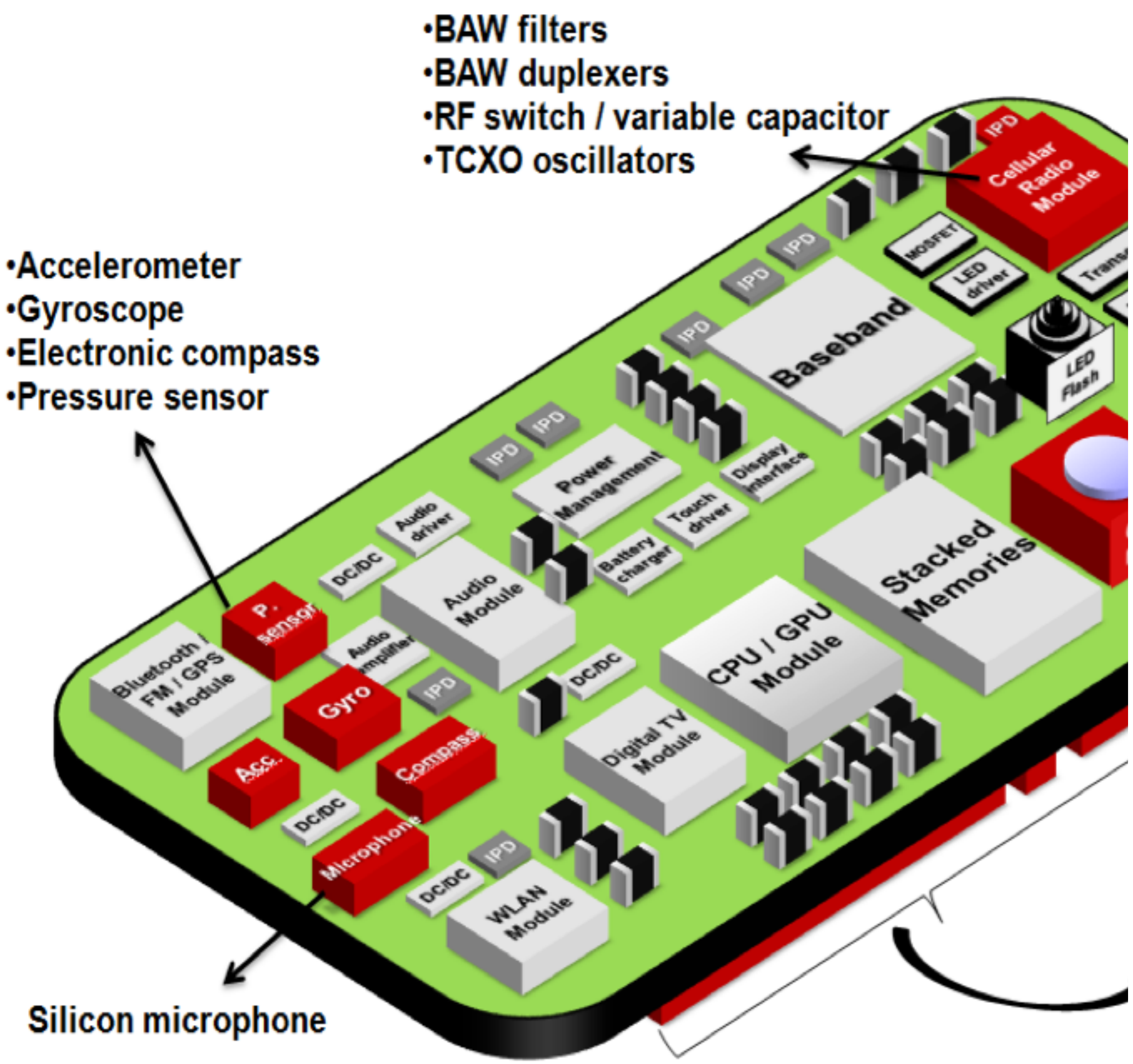


Integration Path for Inertial Sensors

Year of Production	2011	2013	2015	2017
Integration path at the package level	**6 DOF** (accelero + magneto or accelero + gyro)	**9 DOF** (3 axis accelero + gyro + magneto)	**10 DOF** (accelero + gyro + magneto + pressure)	
Integration path at the chip level	3-axis accelero and gyros	Integrated 6 DOF Product	Integrated 9 DOF Product	Integrated 10 DOF Product

DOF = Degrees of freedom. For example, a 10 DOF product is a 3-axis accelerometer, 3-axis gyroscope, 3-axis magnetometer, and a pressure sensor.

Integration Nodes



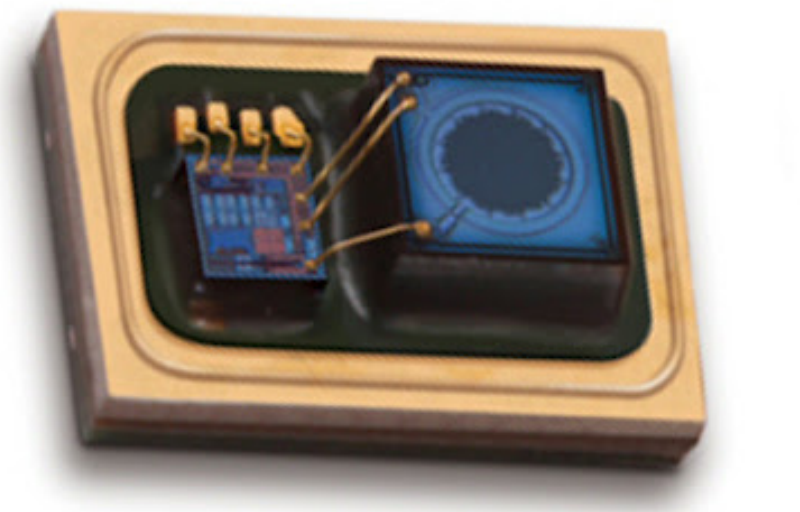
- As we begin to roadmap MEMS, we see two trends:
  1. Continuous improvement in performance.
  2. Integration of functions.
- Can we roadmap an integration path for MEMS applications?

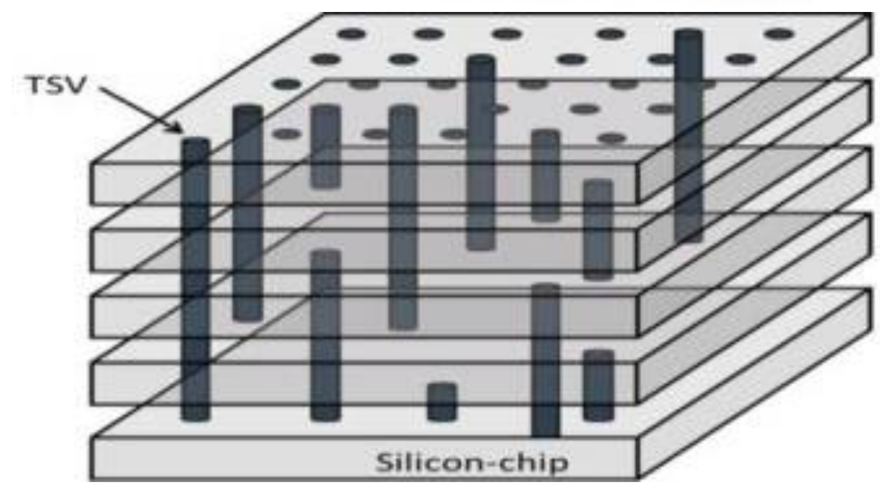
Integration Nodes

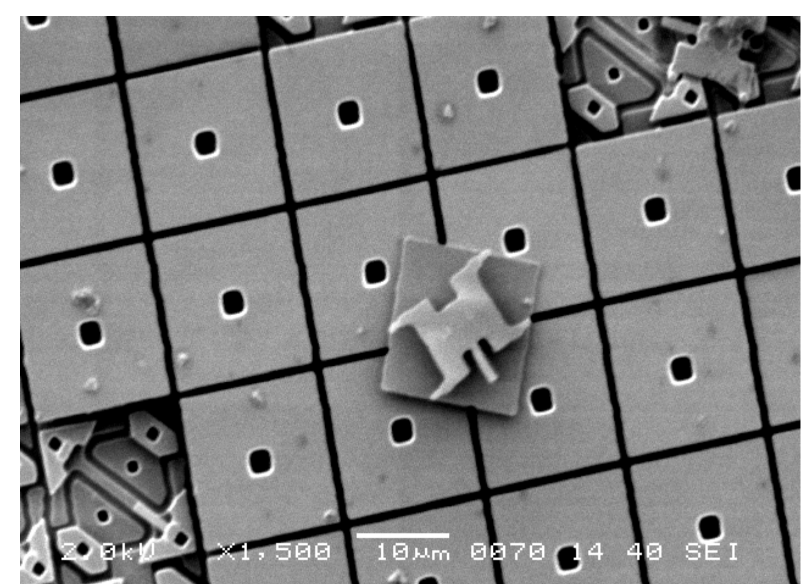
We will roadmap MEMS device performance metrics and the associated requirements for advances in the manufacturing technologies required

- *as discrete MEMS devices advance in performance evolve towards multimode sensors (e.g., inertial with electronic compass)*
- *which will require advances in packaging and integration technologies*
- *towards the goal of a "smart phone on a chip"*

Can we also roadmap the integradtion nodes for multimode sensor integration?



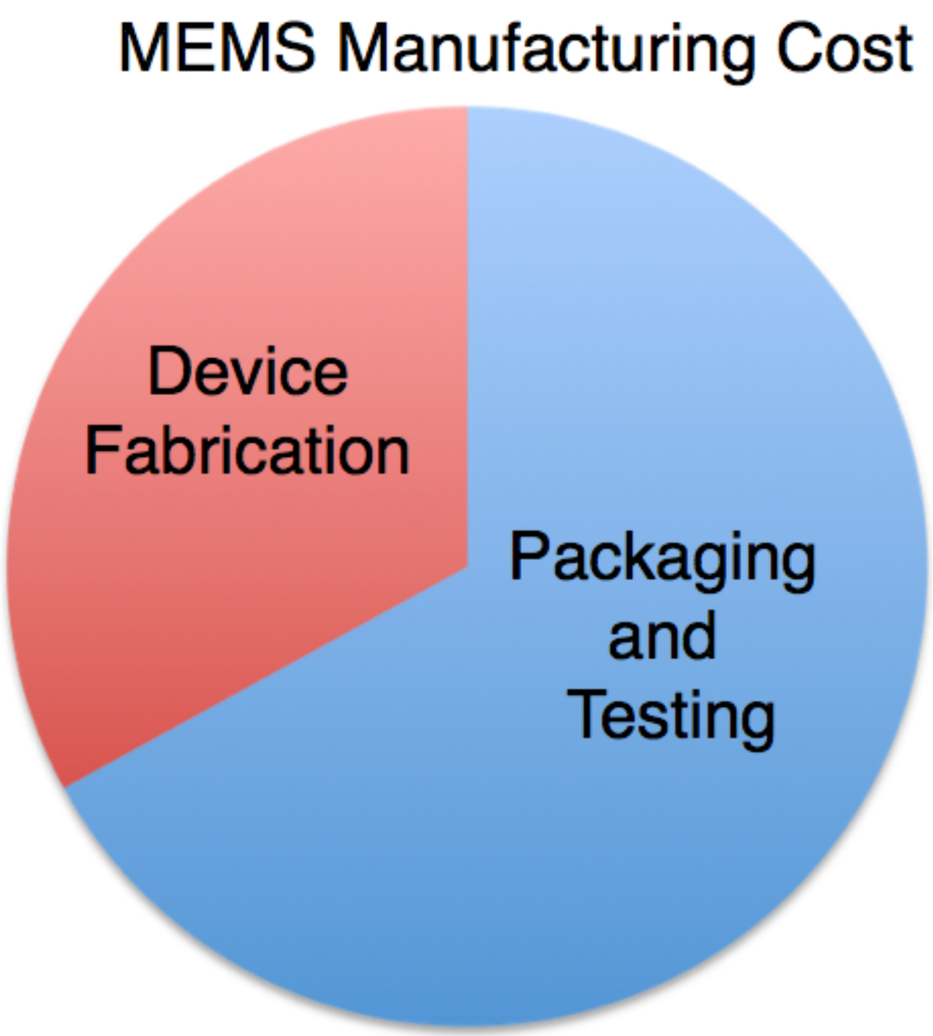


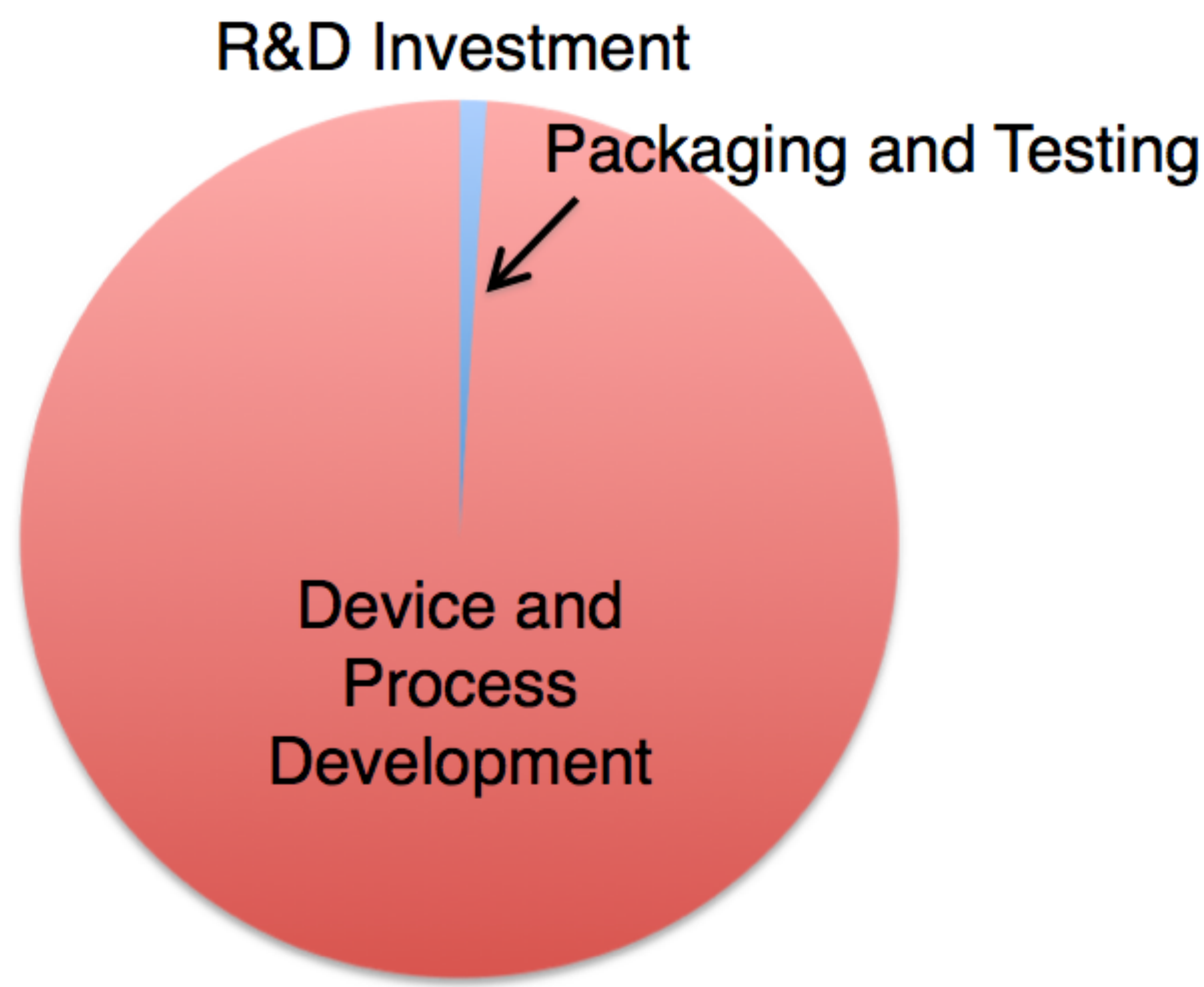


Grand Challenges

Difficult Challenges	Potential Solutions
Integration of MEMS in the Package	Standardization for MEMS packaging to support integration. Packages are needed that reduce or eliminate mechanical stress and enhancing hermeticity. Package data that can be used to accurately predict the effect of the package on device performance.
Testing of MEMS	More testing towards the wafer level. Validated tools to predict device device performance from wafer tests. Methodologies for "Design for Test" or "Design for NO Test."
Validated accelerated life testing for MEMS	More knowledge of the physics of failure is required to develop accelerated life tests. Need to share information. Individual solutions exist but are not being generalized across the industry.

Manufacturing Cost vs. R&D Investment





Comparison to IC Design

	Digital	Analog	MEMS
Process	Fixed	Fixed	Not Fixed
Design Flow	Top Down	Bottom Up	Bottom Up
Primitives	Gates	Transistors	Application dependent
Integration	Extremely high	Low/Medium	Low (except arrays)
Synthesis	Yes	No	No

MEMS Design can be compared to Analog Design in Multiple Physical Domains

Co-design Strategies for MEMS-based Products, Mary Ann Maher, CEO, SoftMEMS, M2M Workshop, May 2012.

SWOT

Strengths	Weaknesses
1. MEMS are in production 2. MEMS are in the ITRS Roadmap 3. New applications appear often 4. MEMS can be (co)integrated with the IC 5. MEMS enabled Nano	1. The complexity and cost of testing is increasing 2. Each MEMS device requires its own packaging technology 3. Need to co-design tools
Opportunities	**Threats**
1. New testing paradigms: design for test, design for no test, new test methodologies 2. New packaging and integration technologies, including TSV, and standardization 3. New co-design tools	1. High cost of assembly, packaging and testing (back end) 2. Disagreement about the need for standards 3. The industry needs a common voice