Lecture 01
Introduction to MEMS

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Outline

What is MEMS?

MEMS = MicroElectroMechanical System

Micro-Electro-Mechanical Systems (MEMS) is the integration of mechanical elements, sensors, actuators, and electronics on a common substrate through the utilization of microfabrication technology ($1\mu m$ = 1/10 of human hair)

Micro ⇒ Small size 10^{-6} m
Electro ⇒ Controllable by electrical signals
Mechanical ⇒ Movable for sensing and actuation
System ⇒ Integration of many devices

- MicroSystems Technology (MST) - Europe, Micromachines - Japan
- Made using microfabrication technology
- MEMS size can be of a rice grain, or smaller!
- Available MEMS products include: Micro sensors, Micro actuators, Read/write heads in computer storage systems, Inkjet printer heads, Micro device components

Miniaturization Makes Engineering Sense!!!

- Small systems tend to move or stop more quickly due to low mechanical inertia and hence ideal for precision movements and for rapid actuation
- Miniaturized systems encounter less thermal distortion and mechanical vibration due to low mass
- Miniaturized devices are particularly suited for biomedical and aerospace applications due to their minute sizes and weight
- Small systems have higher dimensional stability at high temperature due to low thermal expansion.
- Smaller size of the systems $\Rightarrow$ less space requirements.
- Less material requirements $\Rightarrow$ low cost of production and transportation
- Ready mass production in batches

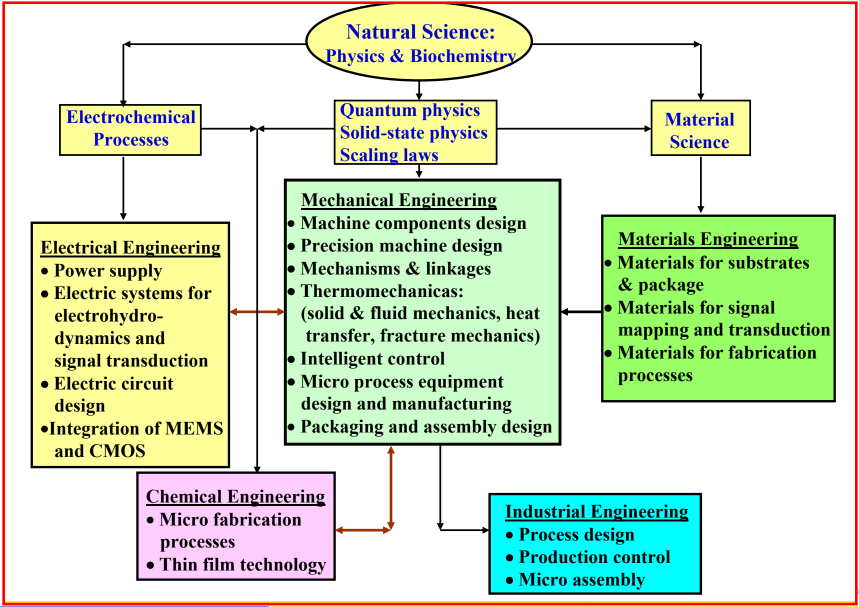
Why Micromachine?

- Minimize energy and materials use in manufacturing
- Integration with electronics
- Reduction of power budget
- Faster devices
- Exploitation of new effects through the breakdown of continuum theory in the micro-domain
- Cost/performance advantages
- Improved reproducibility (batch fabrication)
- Improved accuracy and reliability
- Minimally invasive (e.g. pill camera)

Comparison of Microelectronics and MEMS

Microelectronics	MEMS
Primarily 2-D structures	Complex 3-D structures
Stationary structures	May involve moving components
Specific electric functions	Perform electrical, optical, mechanical, biological functions
Si, Si compounds, plastic	Si, Si compounds, plastic + polymer, metals, quartz,ceramics
Non-contact with Media	Sensor is interfacing with contact media
Mature IC design methodology & standards	Lack of engineering design rule and standards
Mass production	Custom-needs basis
Well established packaging technology	Infant stage
Fewer components to be assembled	Many more components to be assembled
Complex patterns with high density of electrical circuitry over substrates	Simpler patterns over substrates with simpler electrical circuitry
Primarily involves electrical and chemical engineering	Involves all disciplines of science and engineering

The Multi-disciplinary Nature of MEMS



MEMS Energy Domains

Thermal	temperature, heat and heat flow
Mechanical	force, pressure, velocity, acceleration, position
Chemical	concentration, pH, reaction rate
Magnetic	field intensity, flux density, magnetization
Radiant	intensity, wavelength, polarization, phase
Electrical	voltage, charge, current

Scale of MEMS

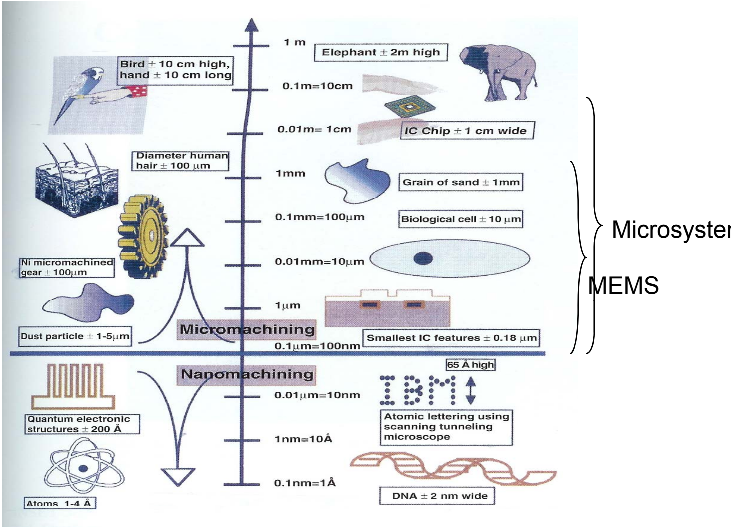
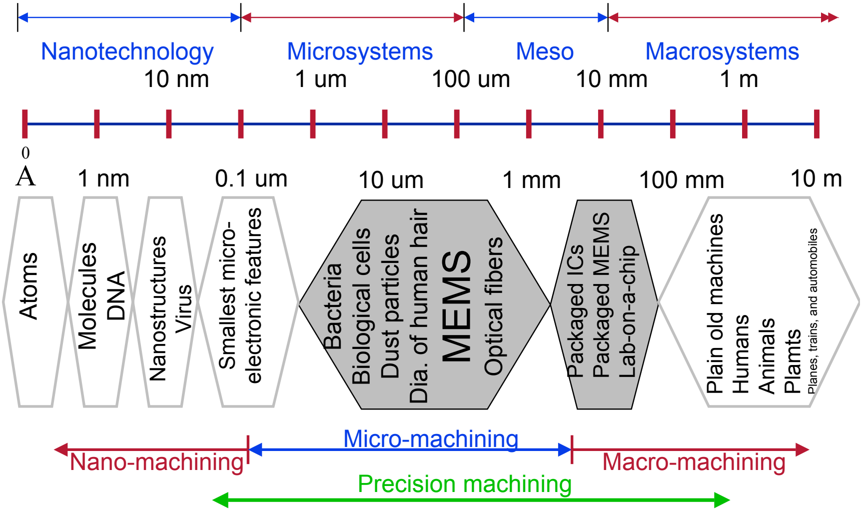


FIGURE 1.5 Various objects and their linear size.

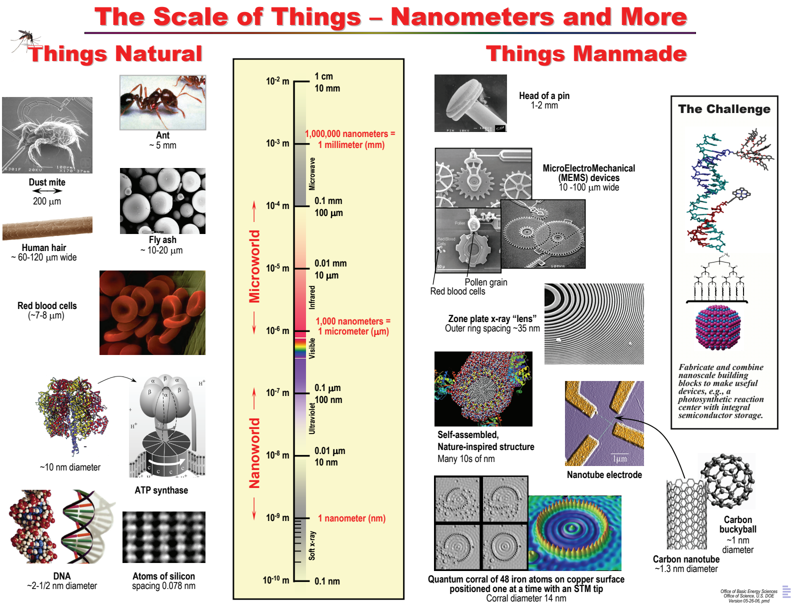
Ant with MEMS Gear

Gear: 100um

Scale of MEMS



Scale of Things



Why use Silicon?

- Advantage of extensive experience from IC production
- Readily available in very pure form
- Si strength-to-weight ratio is higher than many materials
- Material properties are very well known
- Can integrate electronics
- Exceptional properties
  - Very strong
  - Relatively light
  - Semiconductor (low resistivity)

MEMS Timeline

Dec 29,1959	Richard Feynman's Talk:There's Plenty of Room at the Bottom
1962	Chapman and Long demonstrate silicon integrated piezo actuation
1965	Nathason and Wickstrom produce Surface micromachined FET accelerometer
1967	Anisotropic wet etching of silicon demonstrated by Wagganer
1977	Silicon electrostatic accelerometer developed at Stanford
1979	Terry, Jerman, and Angell produce the first integrated gas chromatograph
1982	Kevin Peterson publishes "Silicon as a Mechanical Material"
1983	Integrated pressure sensor developed by Honeywell
1984	Draper Labs begins silicon MEMS development
1985	LIGA developed by Ehrfeld et al. at Karlsruche
1986	Shimbo demonstrates silicon wafer bonding
1987	First inertial MEMS gyro measured by Draper
1987-1988	Integrated fabrication of mechanical mechanisms appears using microfabrication processes in silicon
1989	The term MEMS coined at the IEEE MicroTeleOperated Robotics Workshop
1991	Guckel publishes paper on the possible applications of polySi MEMS
1992	SCREAM process developed by MacDonalds group at Cornell
1992	Multi-User MEMS Process MUMPS - First Foundry Service

MEMS Timeline

1994 Analog Devices manufactures the first commercial surface micromachined accelerometer

1996 Sandia institutes a 3 layer surface micromachining process

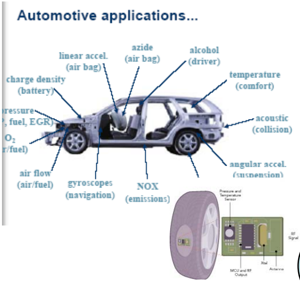
1997 Sandias SUMMiT V Foundry Process

1997 Bosch DRIE Etching

1999 Optical network switch (Lucent)

2004 Massively parallel micro self assembly

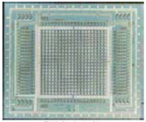
Applications of MEMS



Biomedical...

- Biochips, blood pressure sensing, genetic analysis, proteomics, diagnostics, drug delivery ...

Disposable lab on a chip (Caliper Technologies Inc.)



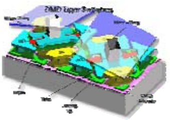
DNA Analysis chip (Fabricated at Standard MEMS, Inc.)

Microneedles (Fabricated at Standard MEMS, Inc.)

MEMS/ Microsystems

Communications...

- Optical switching and routing, relays, wireless communication, information systems ...

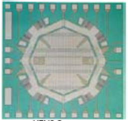


Digital Mirror Device (DMD) Light Switch (Texas Instruments)

Micro-Fresnel Lens (Fabricated at Standard MEMS, Inc.)

Aerospace...

- Aircraft, micro-satellites, space exploration ...

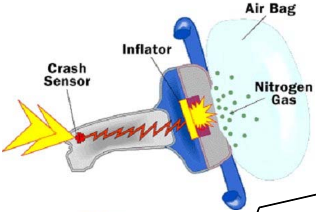


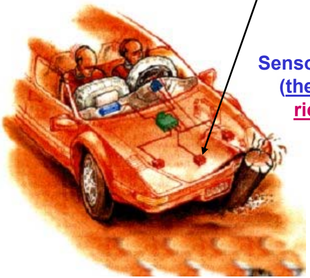
MEMS Gyroscope (Fabricated at Standard MEMS, Inc.)

MEMS Applications

Automotive	Electronics	Medical	Communications	Defence
Internal navigation sensors	Disk drive heads	Blood pressure sensor	Fibre-optic network components	Munitions guidance
Air conditioning compressor sensor	Inkjet printer heads	Muscle stimulators & drug delivery systems	RF Relays, switches and filters	Surveillance
Brake force sensors & suspension control accelerometers	Projection screen televisions	Implanted pressure sensors	Projection displays in portable communications devices and instrumentation	Arming systems
Fuel level and vapour pressure sensors	Earthquake sensors	Prosthetics	Voltage controlled oscillators (VCOs)	Embedded sensors
Airbag sensors	Avionics pressure sensors	Miniature analytical instruments	Splitters and couplers	Data storage
"Intelligent" tyres	Mass data storage systems	Pacemakers	Tuneable lasers	Aircraft control

Inertia Sensor for “Air Bag” Deployment System



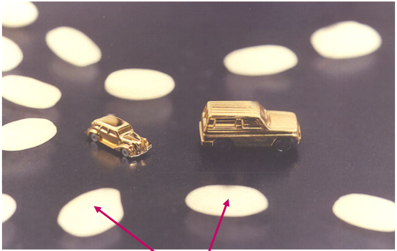


Micro inertia sensor (accelerometer) in place:

Sensor-on-a-chip:
(the size of a rice grain)

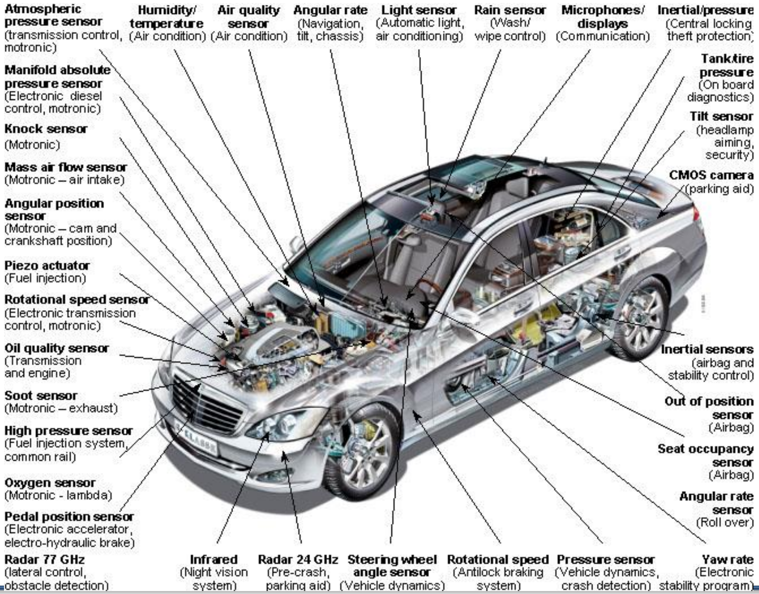
(Courtesy of Analog Devices, Inc)

Micro Cars

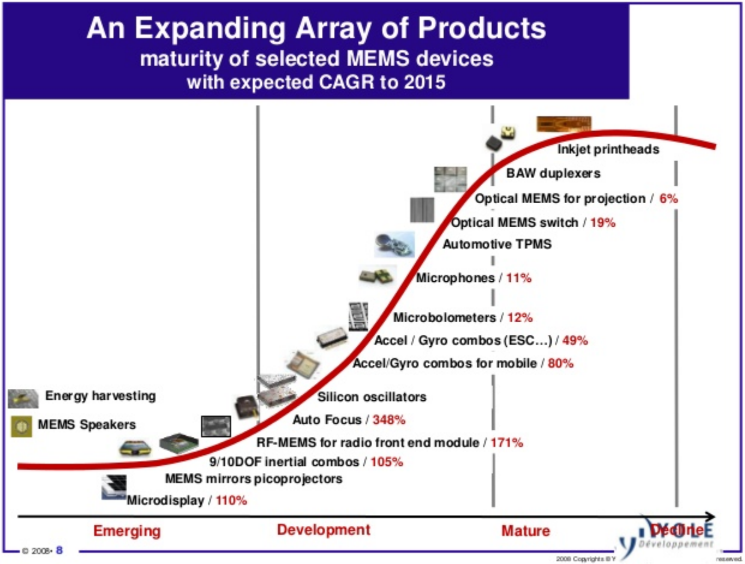


Rice grains

MEMS in Today's Vehicles

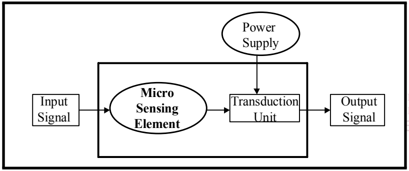


MEMS Product Evolution

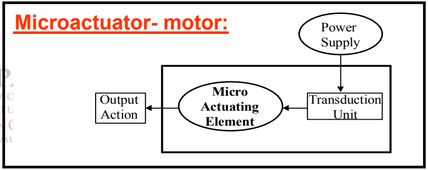


MEMS Microsensor and Microactuator

Accelerometers and gyros are sensors because the convert the non-electrical input “acceleration” or “angular velocity” into electrical signals



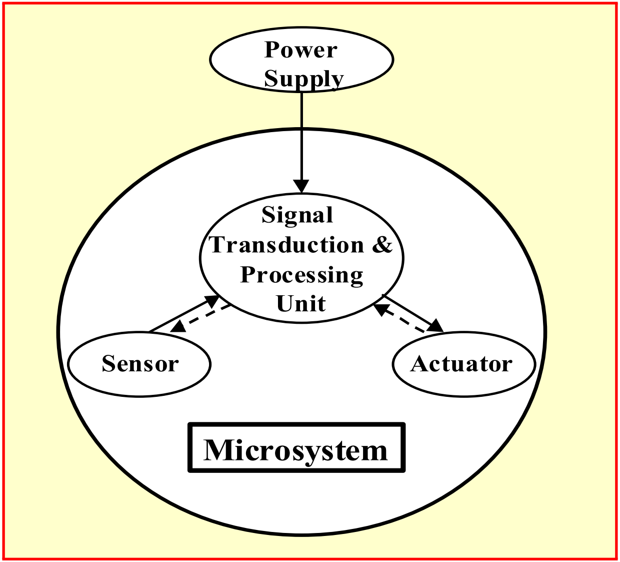
MEMS as Microsensor



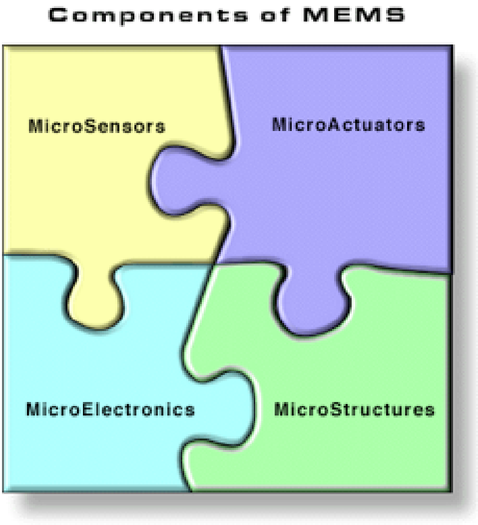
MEMS as a Microactuator

The DLP Chip is an actuator because it converts electrical signals to mechanical displacements of mirrors

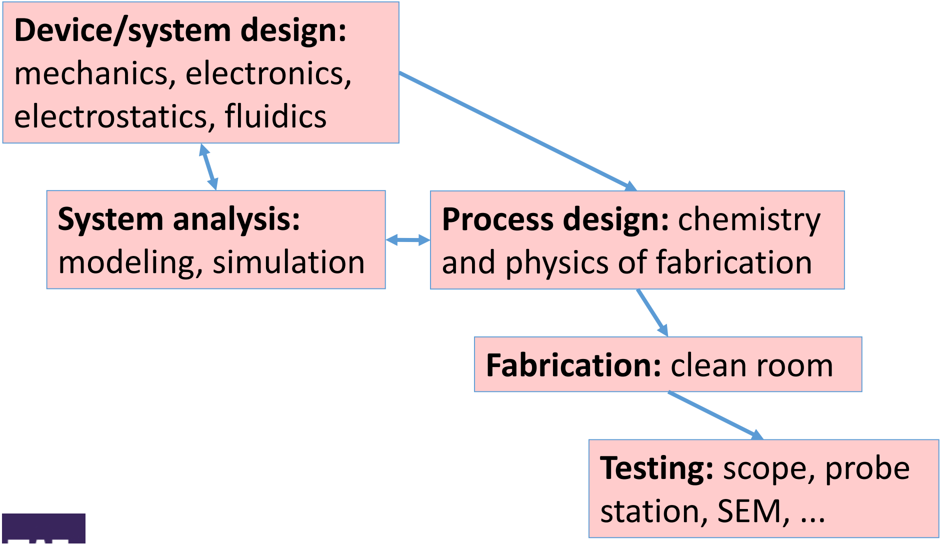
Components of MEMS



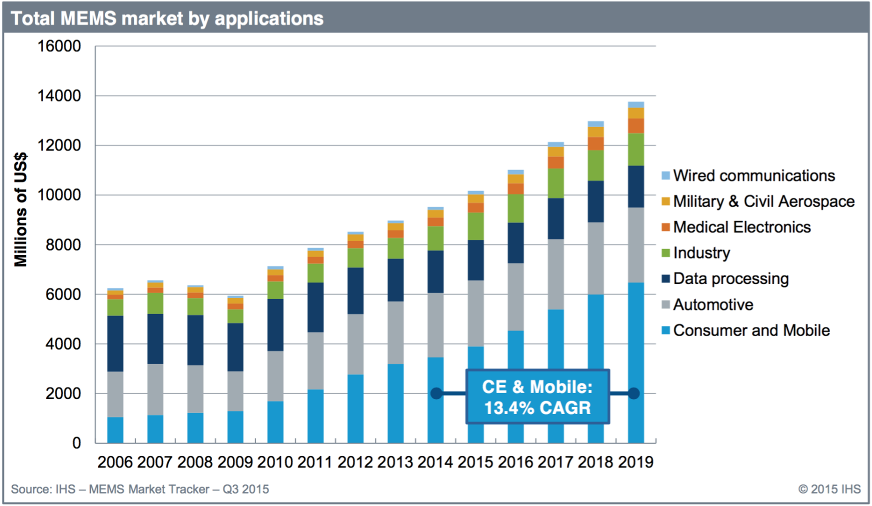
Components of MEMS



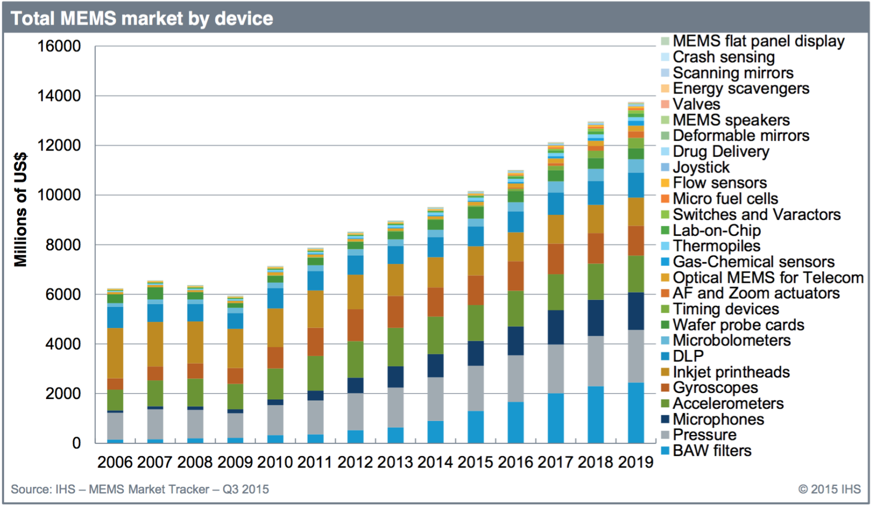
How Do We Make MEMS?



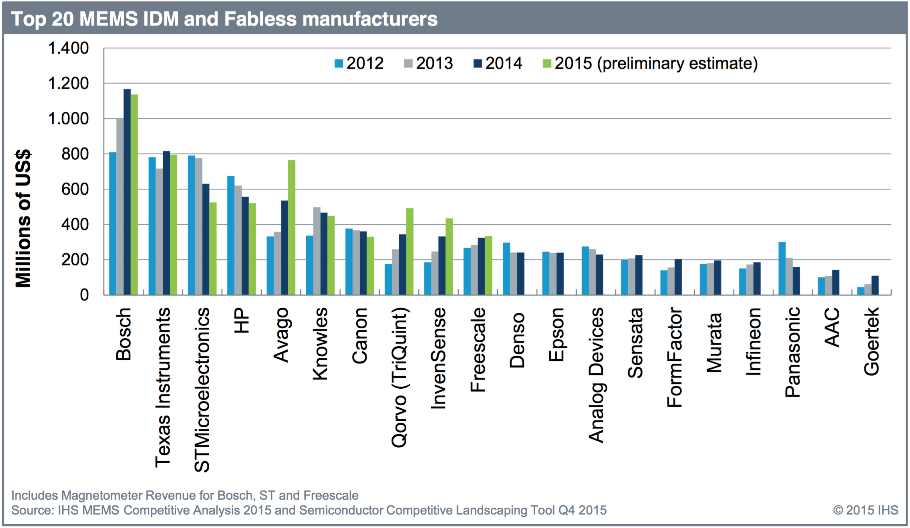
MEMS Market by Applications



MEMS Market by Device



Top 20 MEMS Manufacturer



References

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