



TECHNOLOGY DRIVEN. WARFIGHTER FOCUSED.

MEMS, Nanotechnology and Spintronics for Sensor Enhanced Armor, NDE and Army Applications

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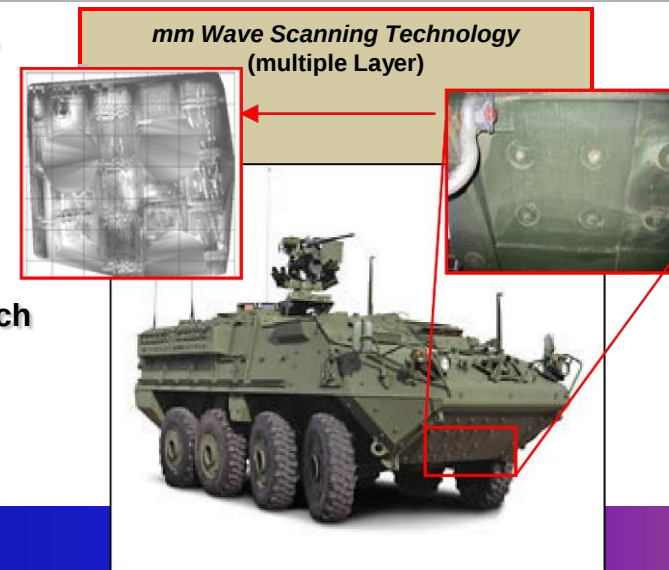
- Project is looking at a variety of ways to assess health of armor over life of vehicle (including prior to installation).
- Making vehicle more intelligent, increase survivability for vehicle and soldier, cost effective, more real time status, health of armor and vehicle.
- Portray capability to scan all types of armor with some type of wave/sound/light – data shows cracks/no cracks.

TARDEC groups involved: Survivability, Intelligent Ground Vehicle Systems, Condition Based Maintenance

Industry: General Dynamics / BAE

Academia: Michigan State University, University of Michigan, Wayne State University, Oakland University (supporting background research ways to measure health of armor)

Audience: future customers, other government labs, contractors, not so much universities

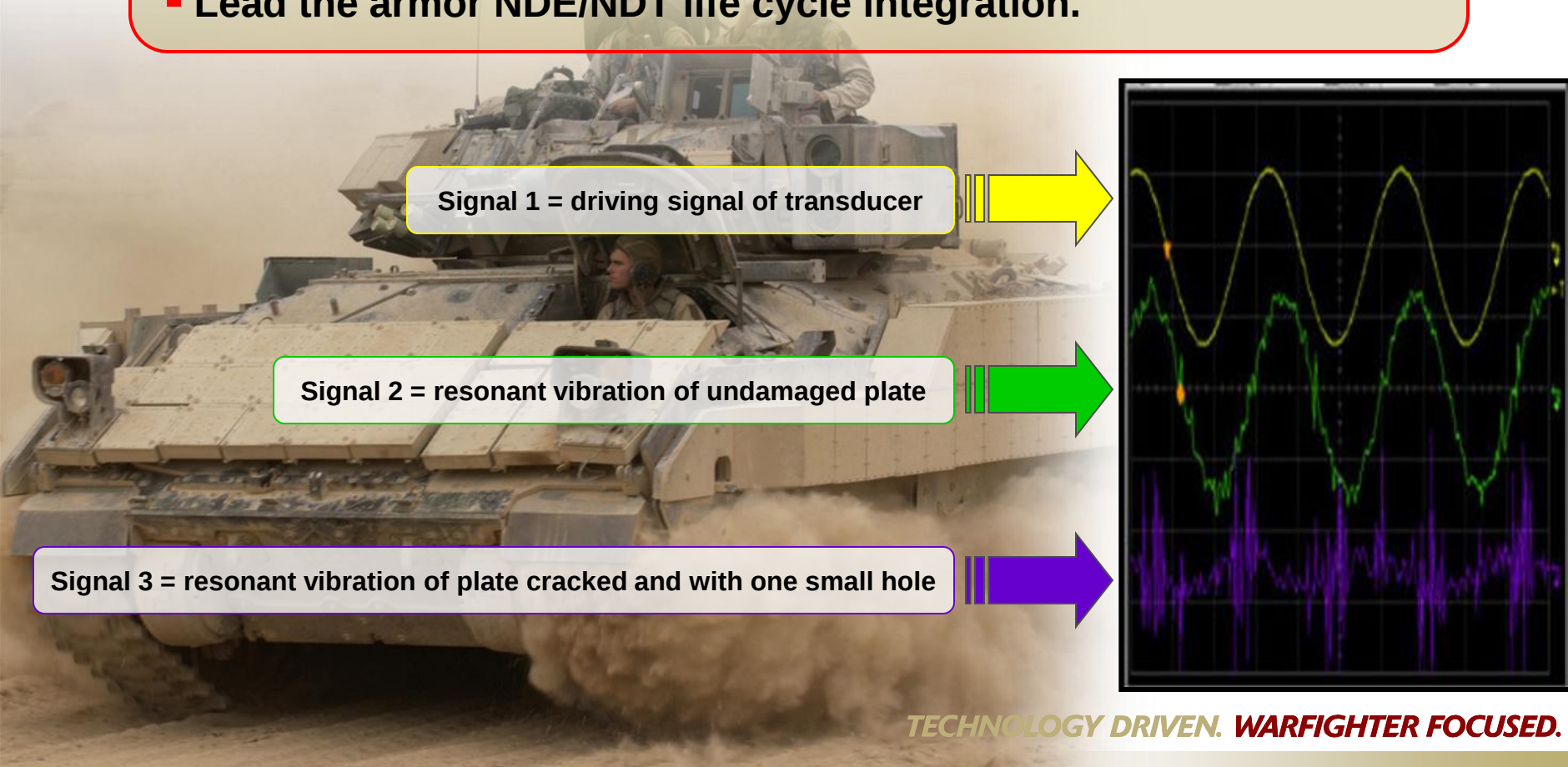


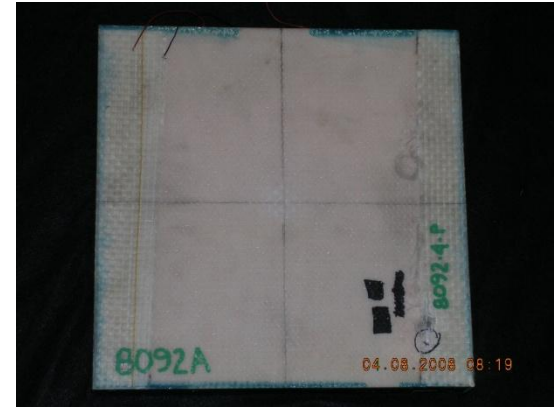
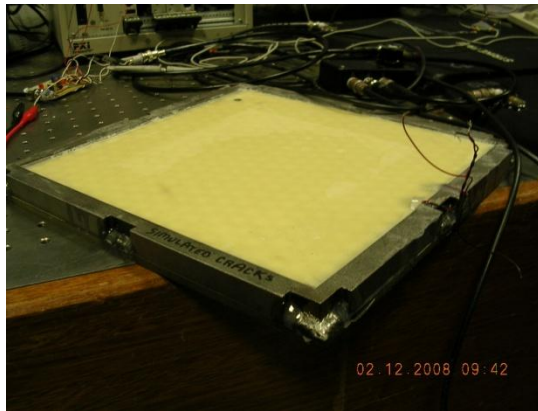
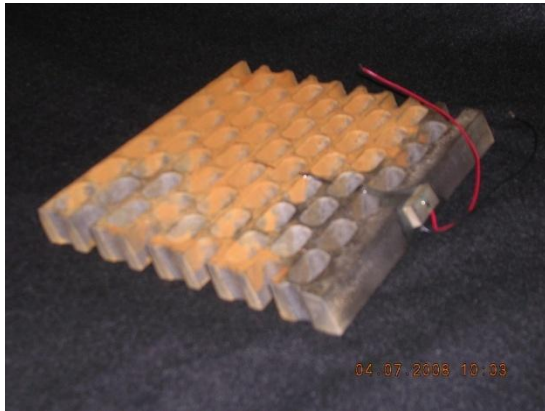
PARTNERS



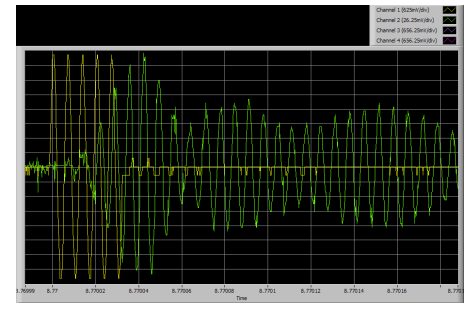
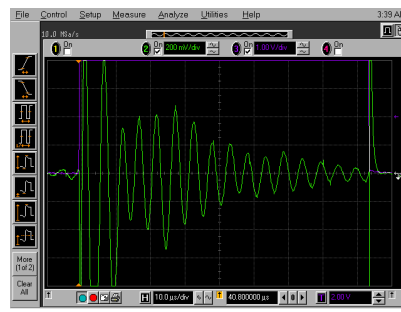
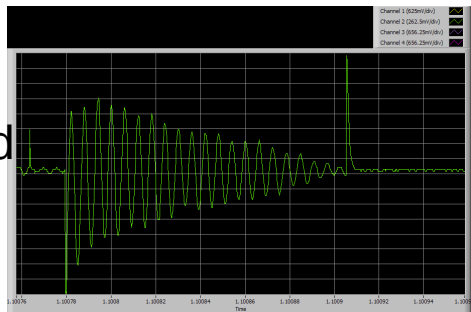
Ground Vehicle Survivability NDT/NDE and Sensor Enhanced Armor

- Survivability role – develop sensors and technologies for various armor recipes.
- Prototype different sensor enhanced armor on demonstrators.
- Lead the armor NDE/NDT life cycle integration.

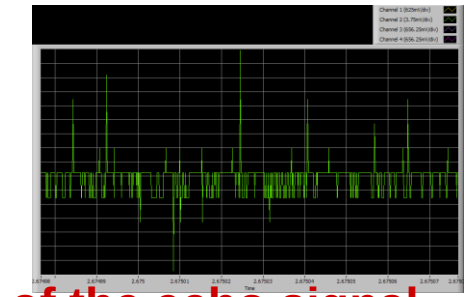
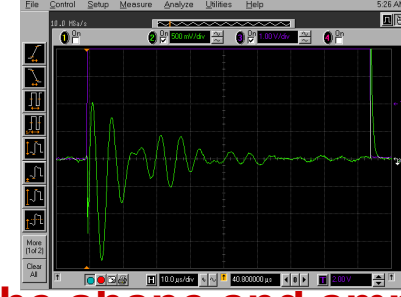
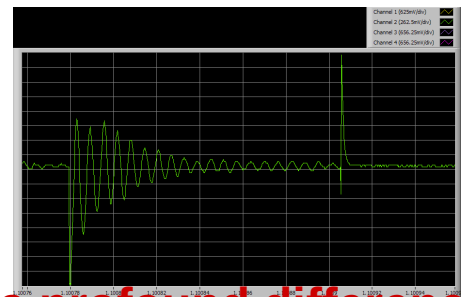




Undamaged



Damaged



There is a profound difference in the shape and amplitude of the echo signal between the damaged and undamaged plates. Tests are underway using embedded transducers for real-time armor integrity monitoring.



GROUND VEHICLE POWER & MOBILITY

- Hybrid Electric
- Pulse Power
- Engines
- Fuel Cells
- Suspension
- Tracks

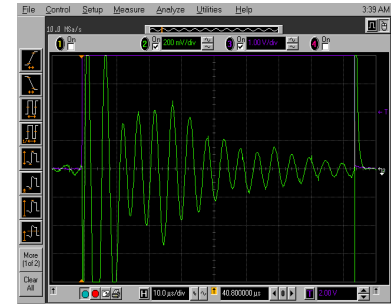


Battery Pack w/ Integrated Heat Exchanger

SMART ARMOR

INTEGRATED SURVIVABILITY

- Active Defense
- Signature Management
- Laser Vision Protection
- Ballistic Protection



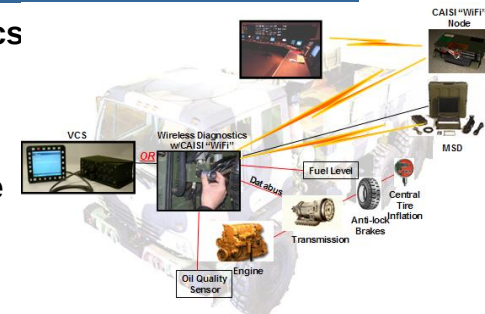
INTELLIGENT GROUND SYSTEMS

- Robotic Systems Technology
- Human-Robot Interaction
- Crew Interface and Automation
- Robotic Follower ATD
- ARV Robotic Technologies Program

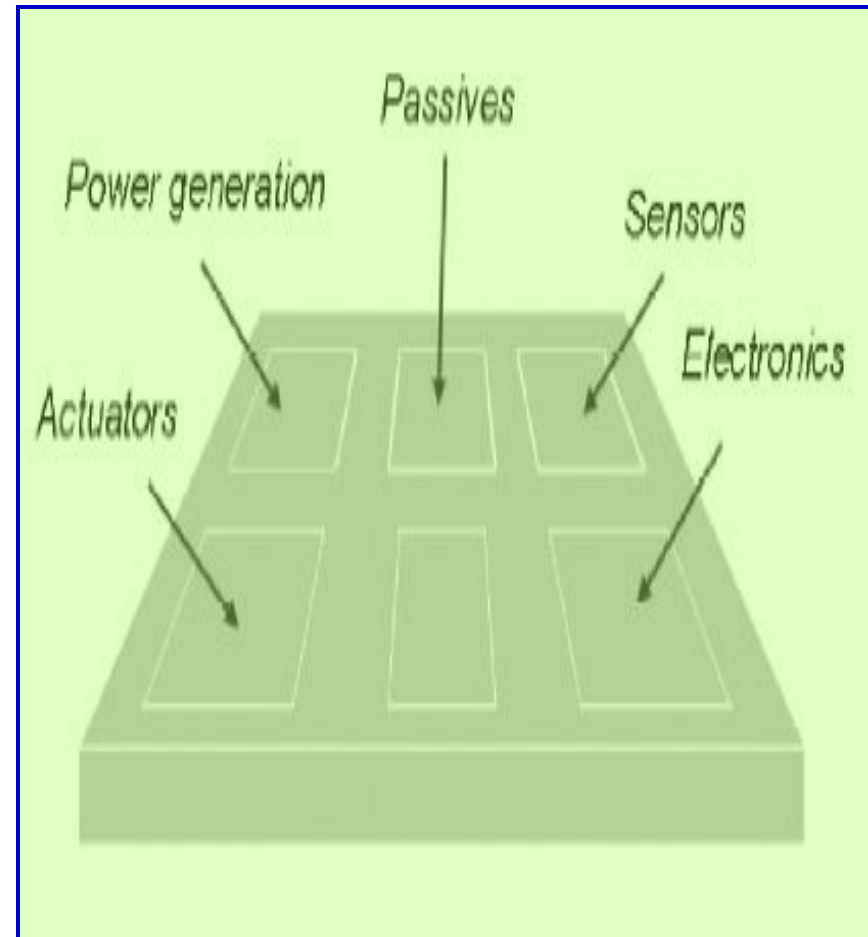


CONDITION BASED MAINTENANCE

- Diagnostics/Prognostics
- Data Analytics
- Sensor Integration
- Network Architectures
- Predictive Maintenance



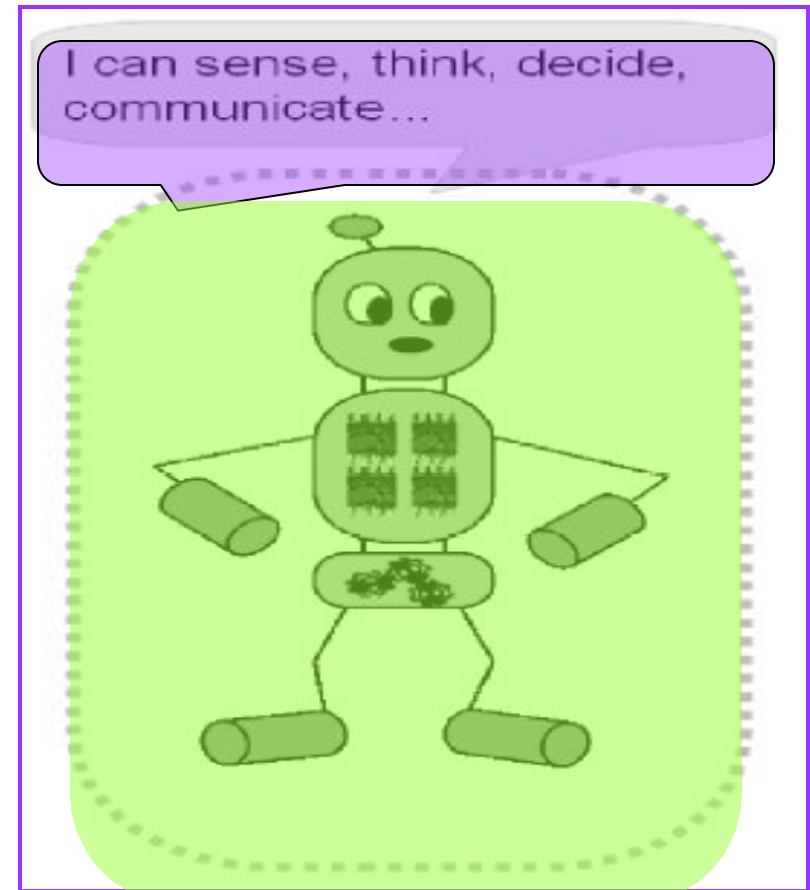
- **Micro-Electro-Mechanical-Systems**
- **MEMS integrate silicon-based microelectronics with micromachining technology to produce a system of miniature dimension**



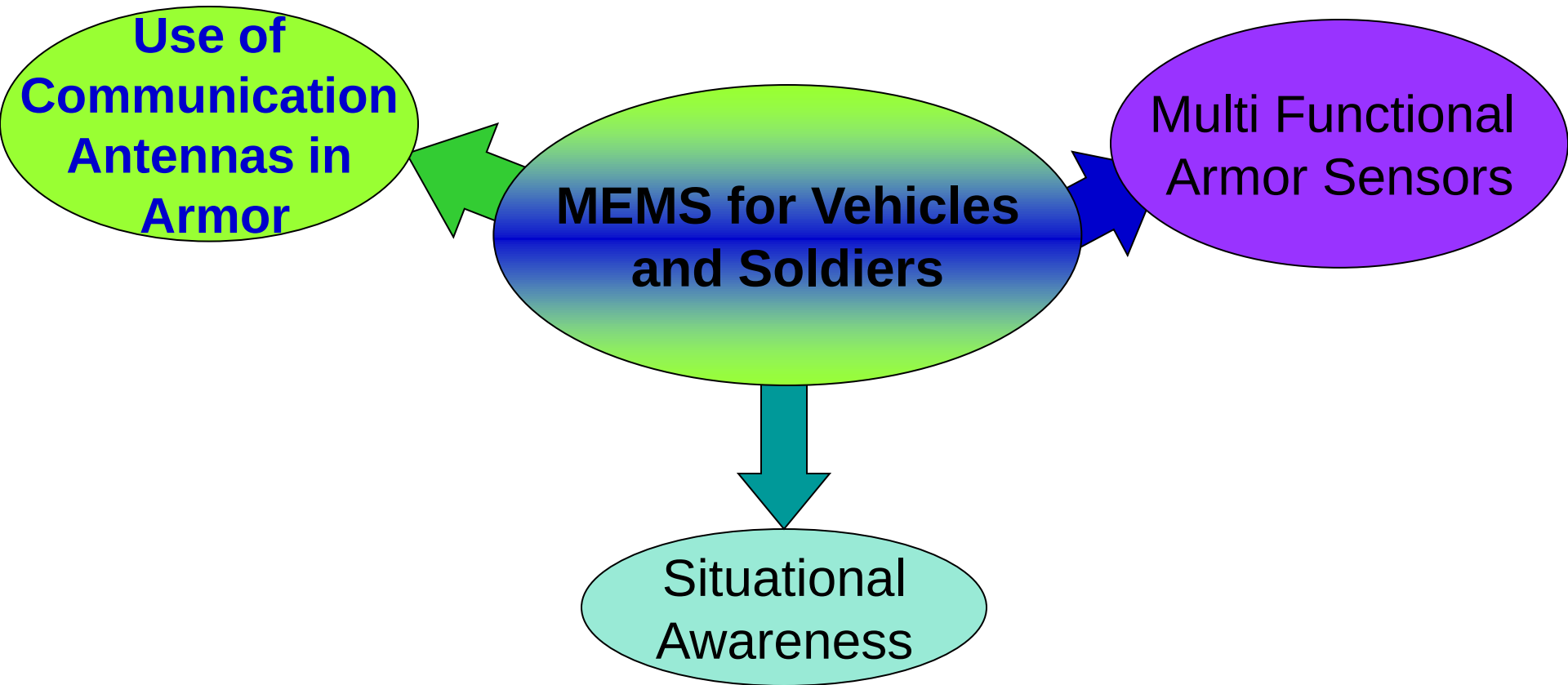
- **Miniaturization**
 - ❖ Low Power Consumption
 - ❖ Low Mass
 - ❖ Low size
 - ❖ Ease of deployment and maintenance
 - ❖ Portability
- **Batch Fabrication**
 - ❖ Low cost of manufacturing
 - ❖ Bulk production
- **Precision and accuracy**
- **Integration**

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- Using microsensors and microactuators, MEMS augment the computational ability of microelectronics with
 - System and Material Health Assessment
 - Control abilities
- Allows development of smart products
- Makes realization of complete Systems-on-a-Chip possible



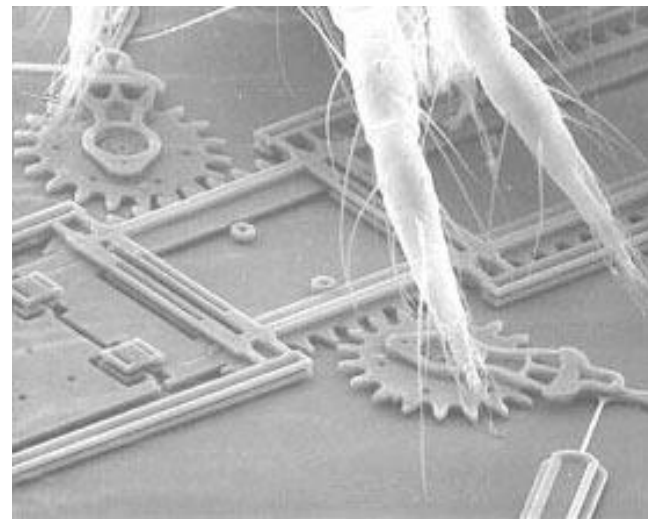
Artist impression of integrated
microsystem



- Thin film deposition and etching techniques used to make miniature devices on the order of 100 μm or less



Courtesy Sandia National Labs

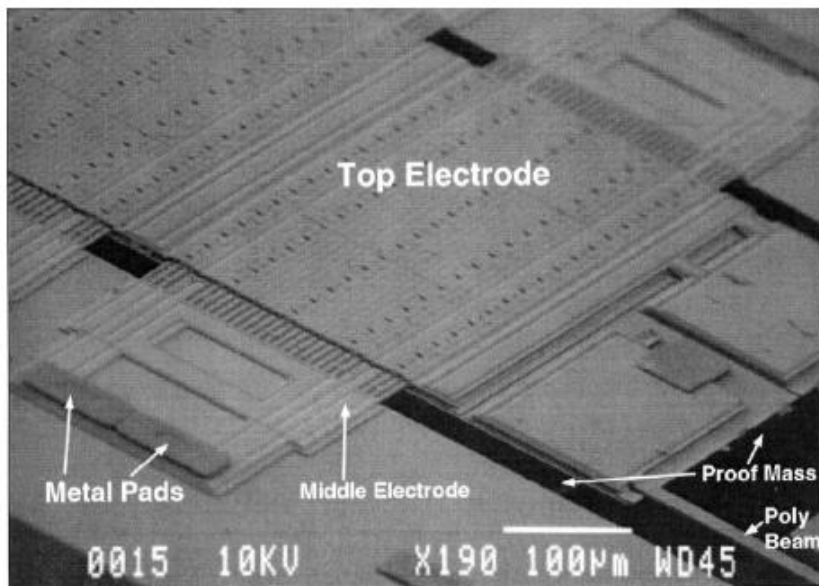


TECHNOLOGY DRIVEN. WARFIGHTER FOCUSED.

- **Signal processing**
- **Wireless Communication**
- **Mass data storage**
- **Sensors for maintenance and structural monitoring**
- **Unattended sensors for tracking and surveillance**
- **Biomedical sensors**
- **Inertial measurements**
- **Aerodynamic and hydrodynamic systems**
- **Optical Fiber components and networks**

Source: Calahan, S., Nanotechnology in a New Era of Strategic Competition, Essay Competition on Military Innovation, 1999-2000.

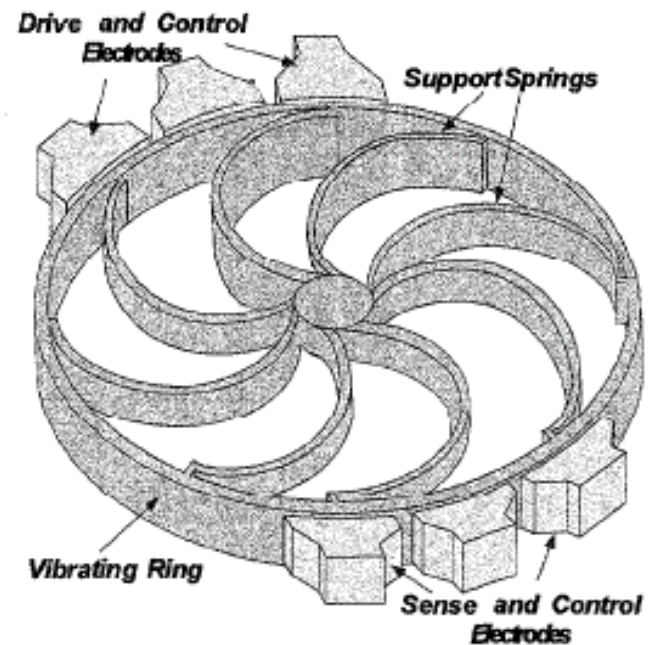
- Accelerometers



Source: K. Najafi et al, JMEMS 2003

- 2.6 mm x 1 mm proof mass, 1.4 μm air gap
- 11 pF/g per electrode.
- Noise floor: 0.18 g/ $\sqrt{\text{Hz}}$ at atmosphere.

- Gyroscopes



Source: Vibrating Ring Gyroscope, F. Ayazi et al.

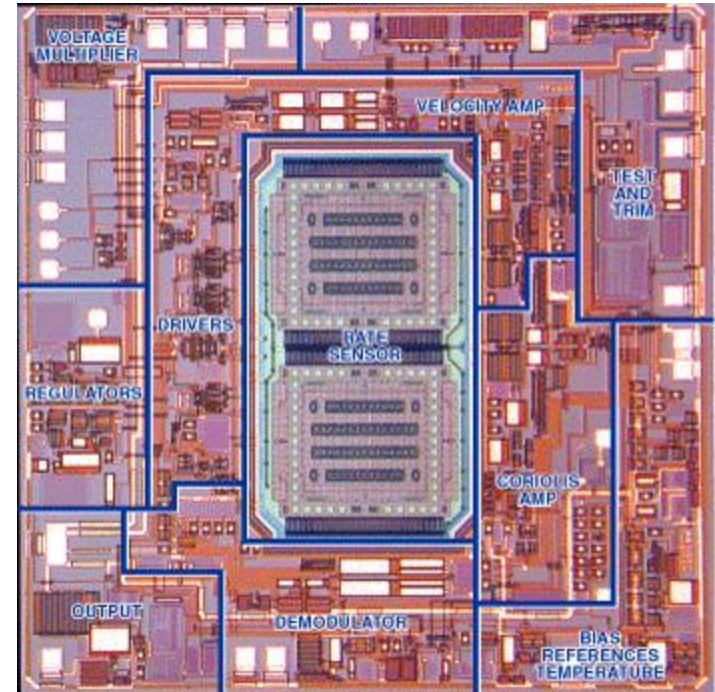
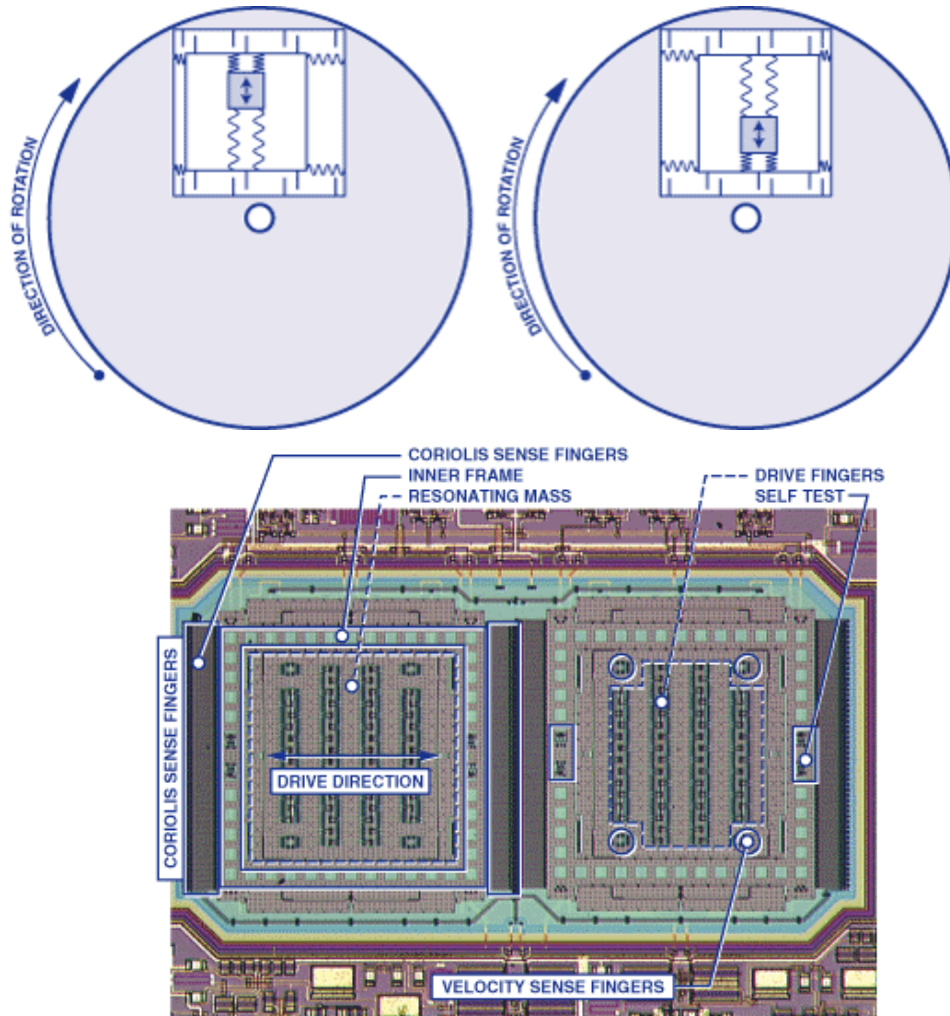
- 200 V/deg/s in a dynamic range of ± 250 deg/s
- Noise floor: 0.01 $^{\circ}/\sqrt{\text{Hz}}$ at atmosphere.



MEMS based IMUs are displacing other technologies



- **MEMS gyros are making great strides in displacing ring laser gyroscopes (RLG) and fiber optic gyroscopes (FOG).**
- **Conventional systems typically \$7-8,000 each. The new MEMS systems will be considerably lighter and should cost \$1,200 to \$1,500 each.**
- **10 of the top 12 IMU suppliers are either currently offering or actively developing MEMS gyro-based IMUs.**
- **Of the 60 IMUs available, or known to be in development, nearly 50% use (or will use) both MEMS gyros and MEMS accelerometers.**
- **Total market for MEMS gyros to grow from \$279 million in 2002, to \$396 million in 2007 (annual growth rate of 24.2%)**



- Differential design rejects shocks up to 1000g
- 5mV/ /s

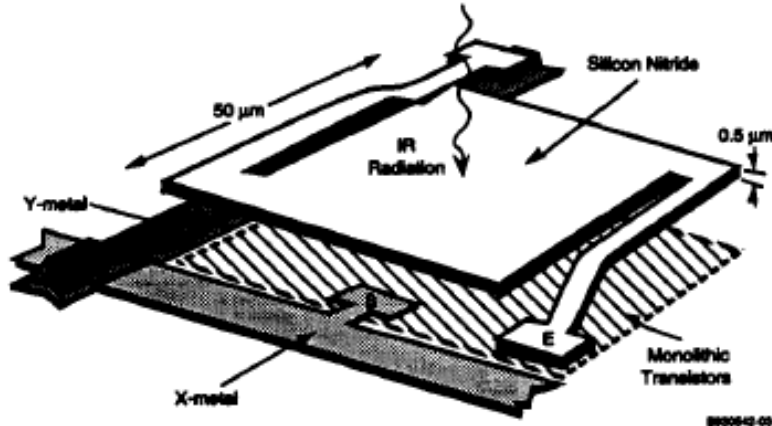
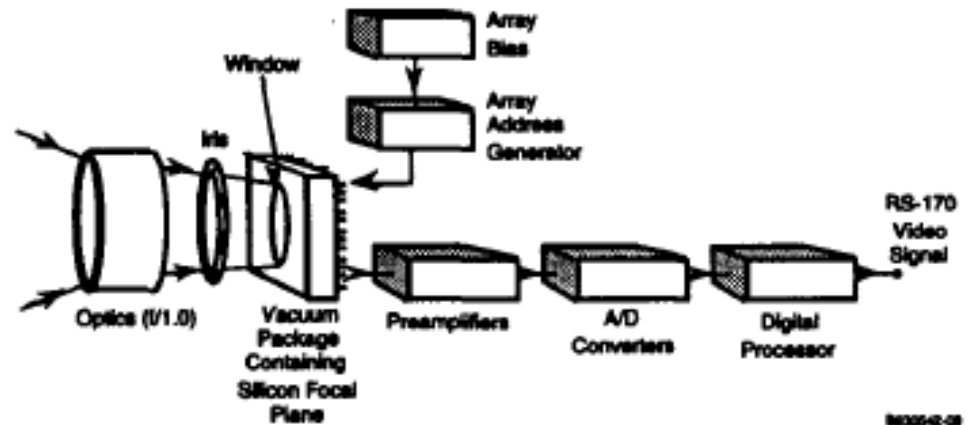


Figure 1. Microbolometer Pixel Structure

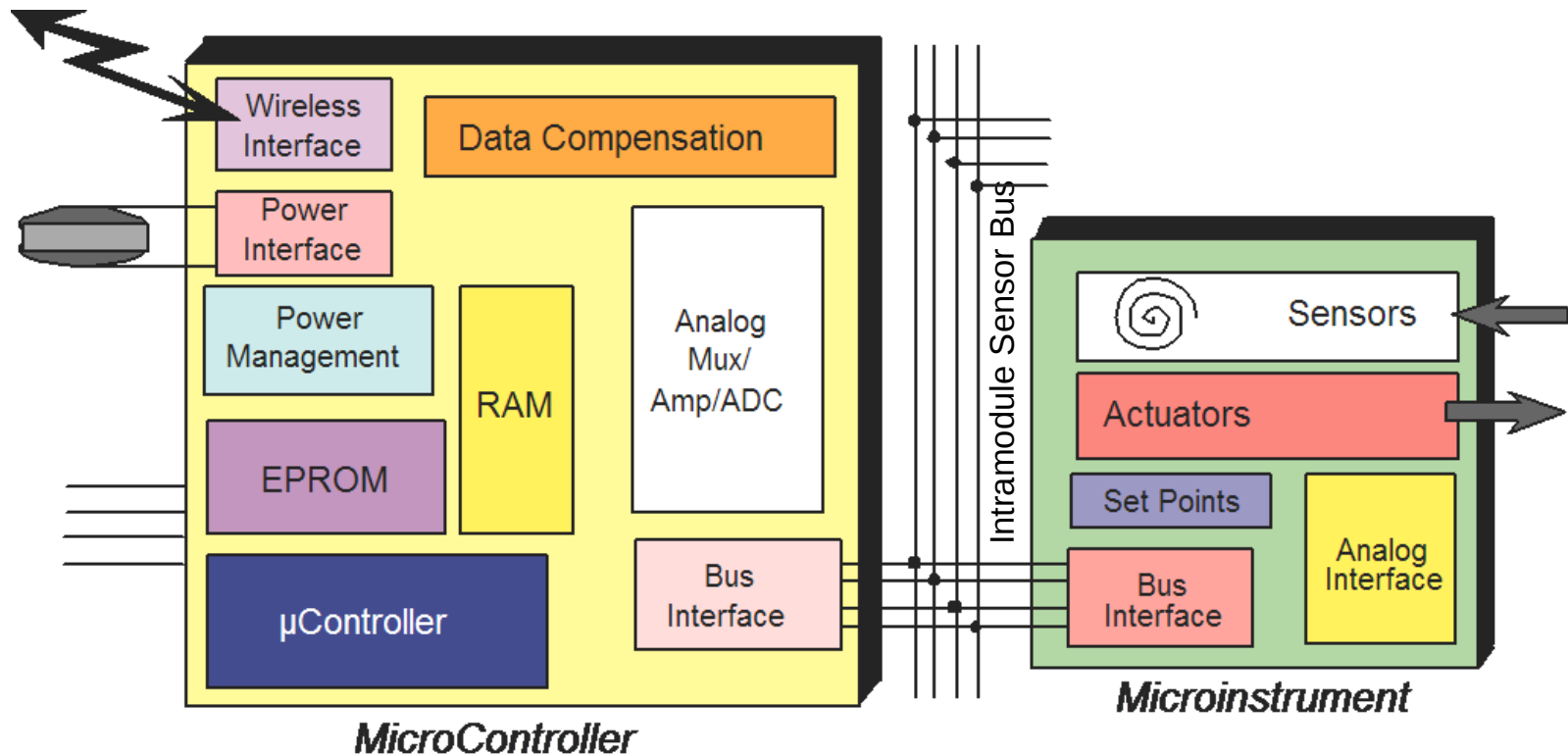


- 240x336 array of bolometers,
- NETD of .039°C, limited by Johnson noise of sense resistor
- 30 Hz operation
- Originally developed by Honeywell



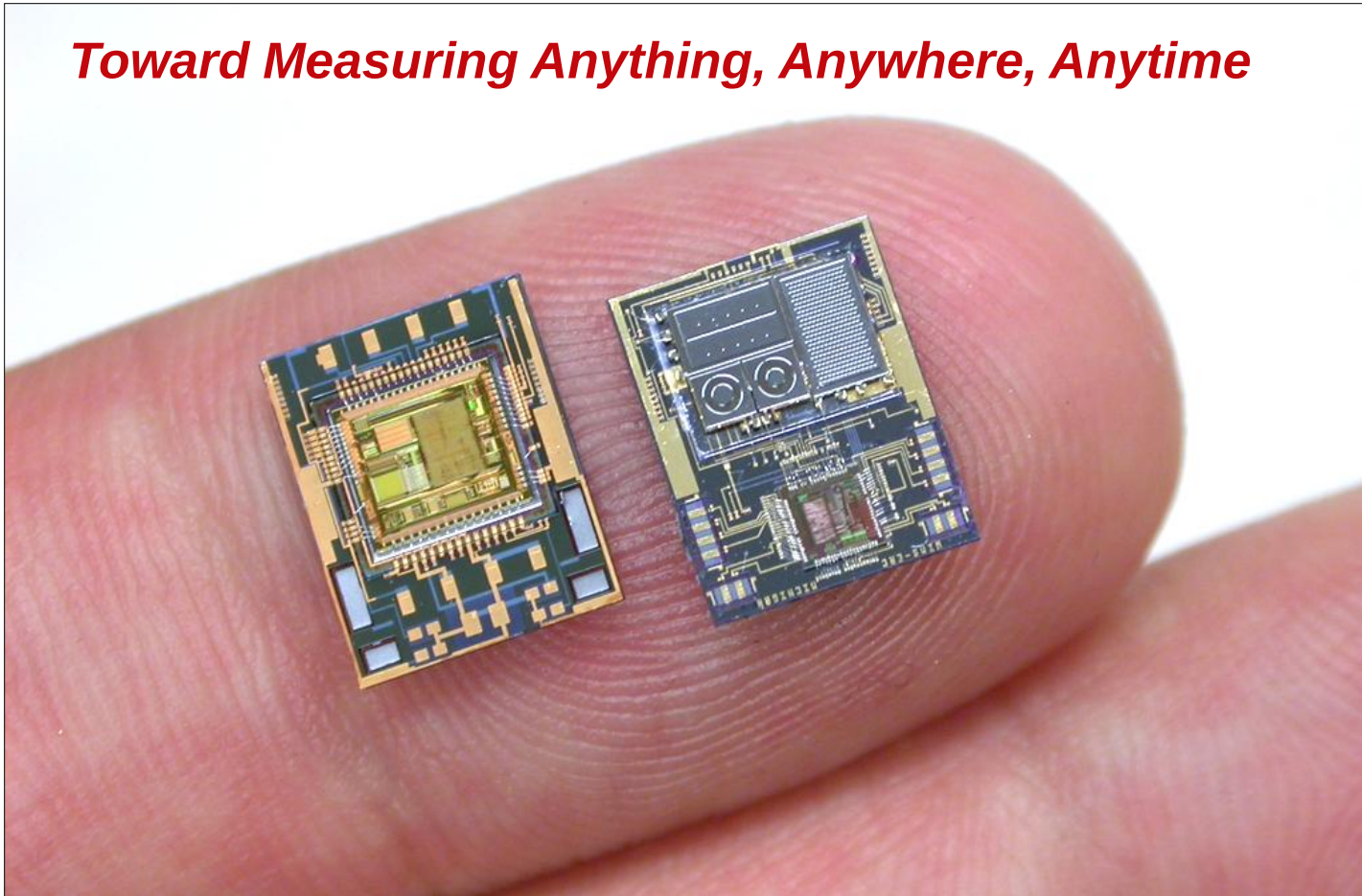
Daytime Parking Lot (white is hot)

Source: Wood, IEDM 1993

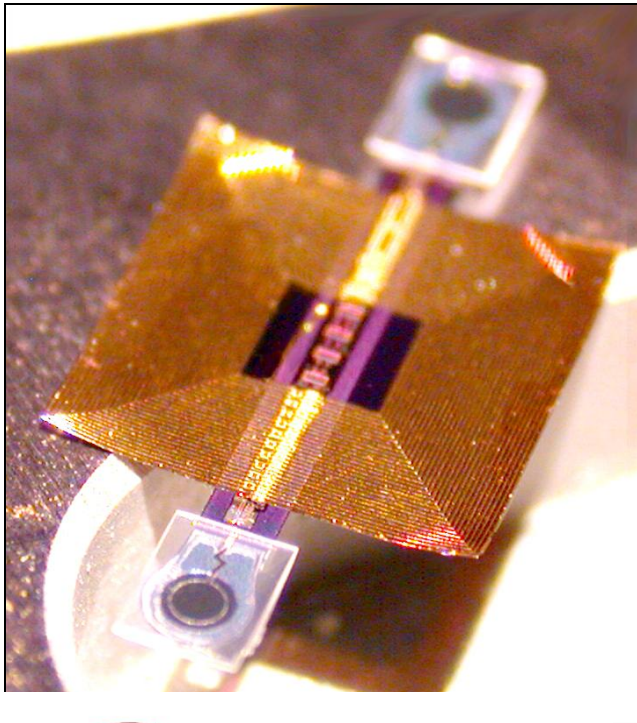


Key Components: Power Source, Embedded Micropower Controller with Power Management and Data Compensation, Software, Wireless I/O, Integrated Programmable Transducers with a Standard Bus Interface, Hermetic Packaging

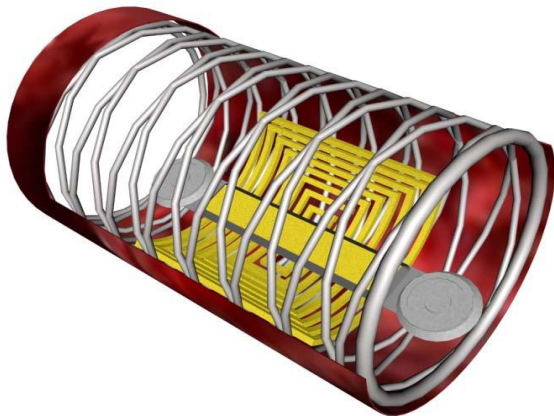
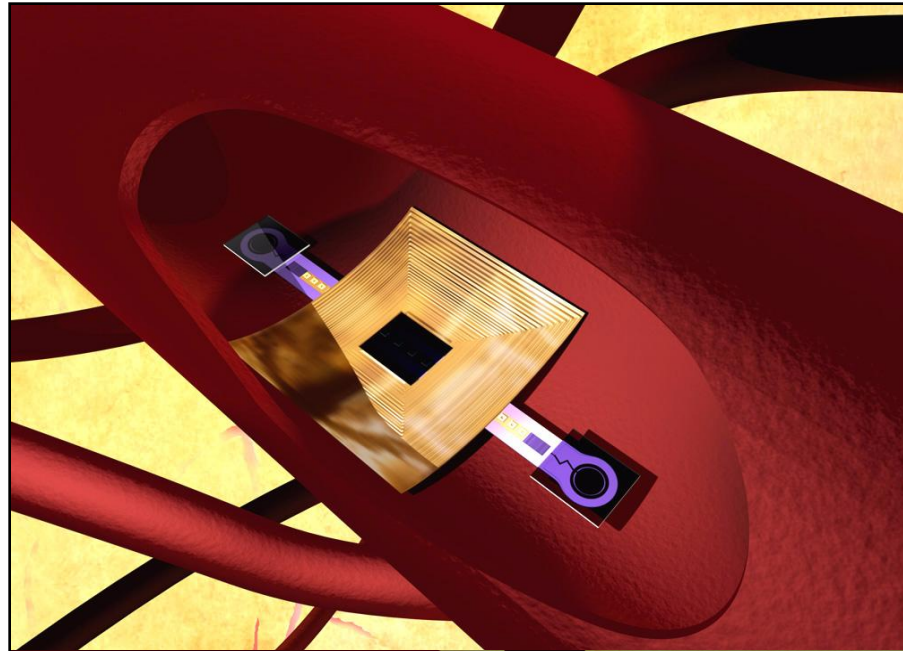
Toward Measuring Anything, Anywhere, Anytime

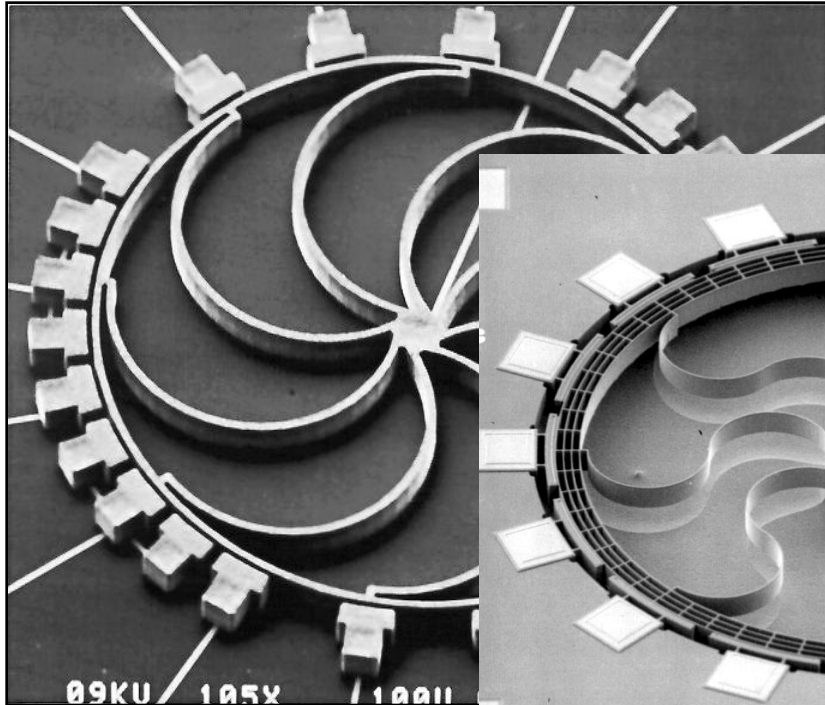
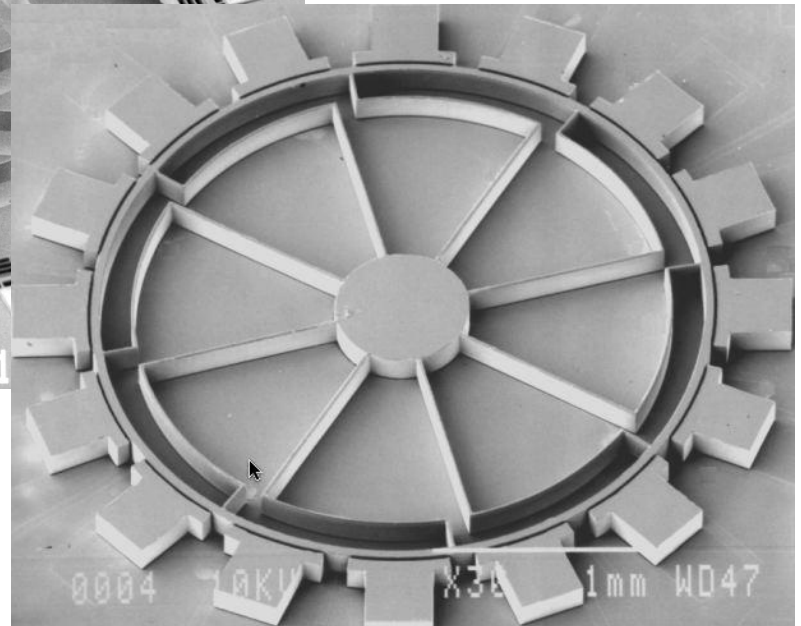
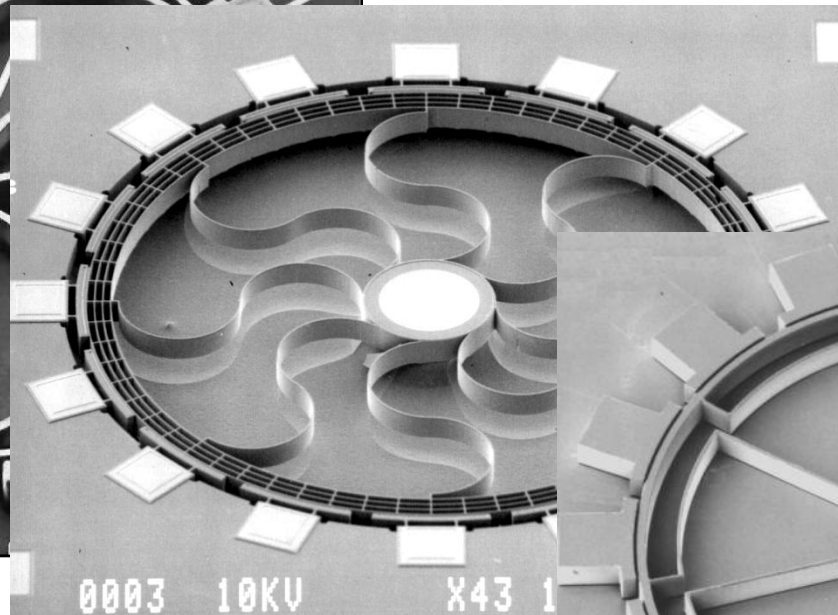


- Embedded μ Controller, 16Mb Flash Memory, Fully Programmable
 - Sensors for Pressure, Temperature, Humidity, and Biosignals



Suitable for the carotid arteries; not yet small enough for the coronaries.

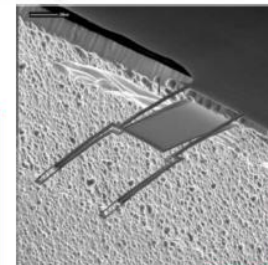
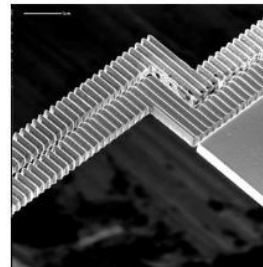
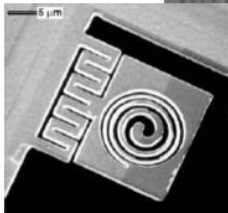
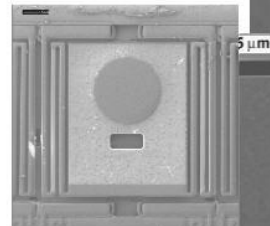
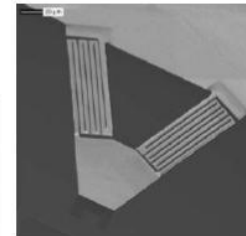
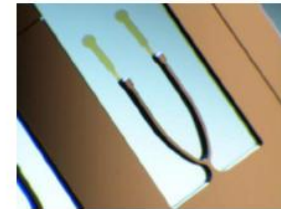
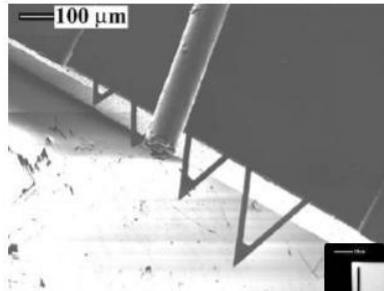
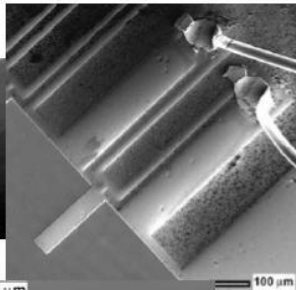
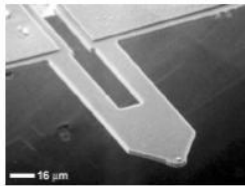
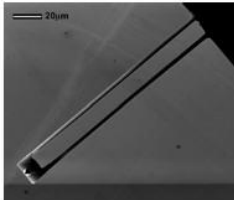


Nickel Vibrating Ring Gyroscope, 1994***Resolution: 0.5°/sec, Q: 4000******Polysilicon Vibrating Ring Gyroscope, 1999******Resolution: 20°/Hour, Q: 10000******Single-Crystal Si Vibrating Ring Gyroscope, 2002******Resolution: 7.5°/Hour, Q: 14000***



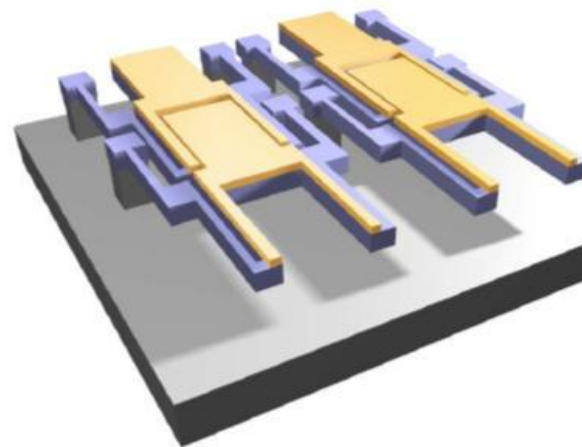
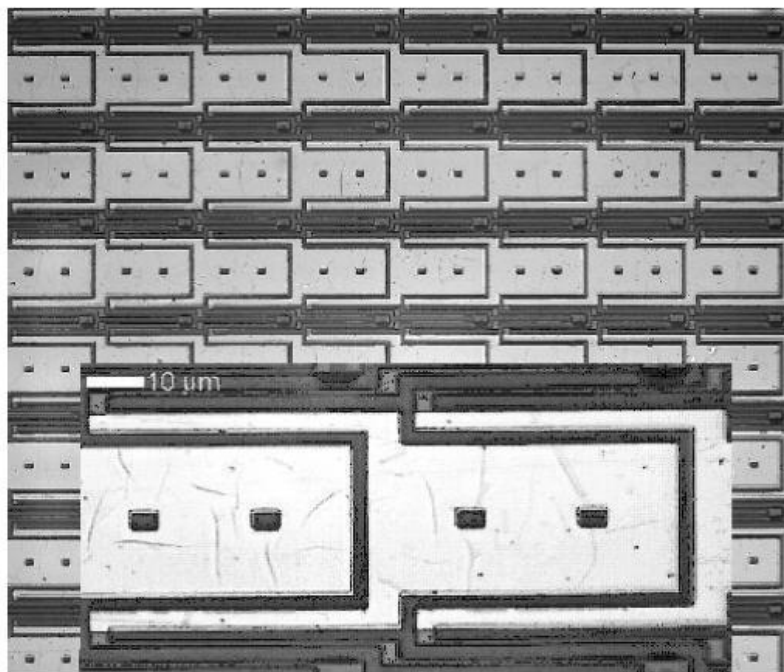
- **MEMS Magnetometers can detect presence of equipment up to 100 feet below ground.**
- **Magnetometers can be scattered by air drop or individually positioned to provide tactical information.**
- **These Magnetometers sense changes in earth's magnetic field to detect metallic objects anytime they move.**

Microcantilevers



Length	: 50- 500 μm
Width	: 10-50 μm
Thickness	: 0.1-4 μm

Example of MEMS IR array



Source: Oak Ridge Labs



MEMS SOFTWARE

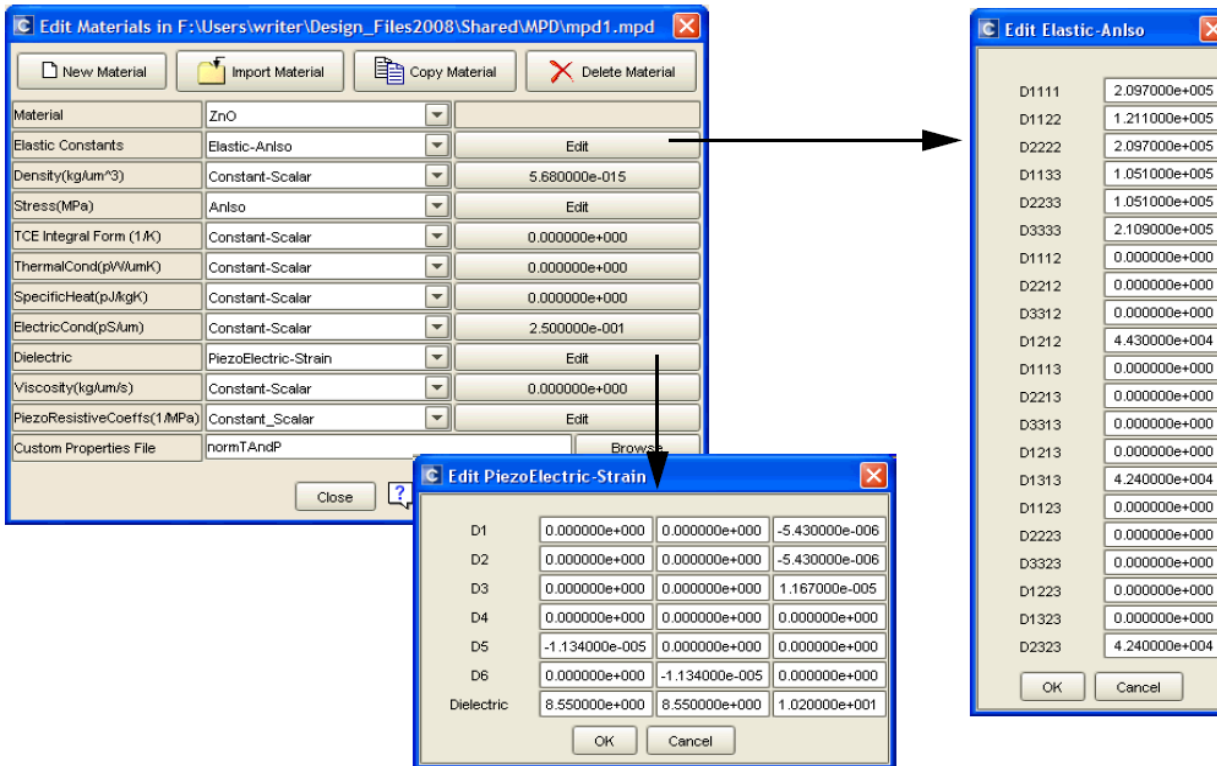


Designing and Modeling Using MEMS Simulation Software

- **We will demonstrate how to create and simulate a MEMS device using a simulation software.**
 - * An FBAR (film bulk acoustic resonator) MEMS device will be created in this presentation.

- **Steps:**
- **I) Materials**
- **II) Fabrication Process**
- **III) Creating a 2D Layout**
- **IV) The 3D Model**
- **V) Meshing**
- **VI) Simulations**
- **VII) Conclusion**

- Step 1: Check for correct materials and material values.



- (LEFT) values for the material ZnO which include stress, density, dielectric and more.

- (RIGHT) Some values for various materials that may be used.

Property	Data Type	Sub prop	Aluminum (film)	Silicon	SIN	Units
Elastic Constants	Elastic-Iso	E	7.70e+04	1.69e+05	2.22e+05	MPa
		Poisson	3.00e-01	3.00e-01	2.7e-01	
Density	Constant-Scalar		2.30e-15	2.50e-15	2.7e-15	kg/μm ³
Stress	AnIso	S _x	0	0	0	MPa
		S _y	0	0	0	
		S _z	0	0	0	
Dielectric			0	1.19e01	8.0e+00	

- **Step 2: Create the process we want to follow in the “Process Editor”.**
 - * Your process may require you to stack, straight cut, partition, etc. the MEMS device you are creating.

Process Editor - [F:/Users/writer/Design_Files2008/FBAR/Devices/FBAR.proc]

File Edit View Tools Windows Help

Number	Step Name	Layer Name	Material Name	Thickness	Mask Name	Photoresist	Depth	Mask Offset	Sidewall Angle
0	Substrate	Substrate	SILICON	10	SubstrateMask				
1	Stack Material	NitrideBottom	SIN	0.25					
2	Straight Cut				Nitride	-	0	0	
3	Stack Material	Silicon	SILICON	20					
4	Straight Cut				KOH_Etch	-	0		35.3
5	Stack Material	Membrane	SIN	0.25					
6	Straight Cut				KOH_Etch	-	0	0	
7	Stack Material	ElectrodeBottom	ALUMINUM(FILM)	0.4					
8	Straight Cut				ElectrodeBot	+	20.9	0	0
9	Stack Material	PZE	ZnO	1.24					
10	Straight Cut				PZE	+	0	0	
11	Stack Material	ElectrodeTop	ALUMINUM(FILM)	0.32					
12	Straight Cut				ElectrodeTop	+	0	0	

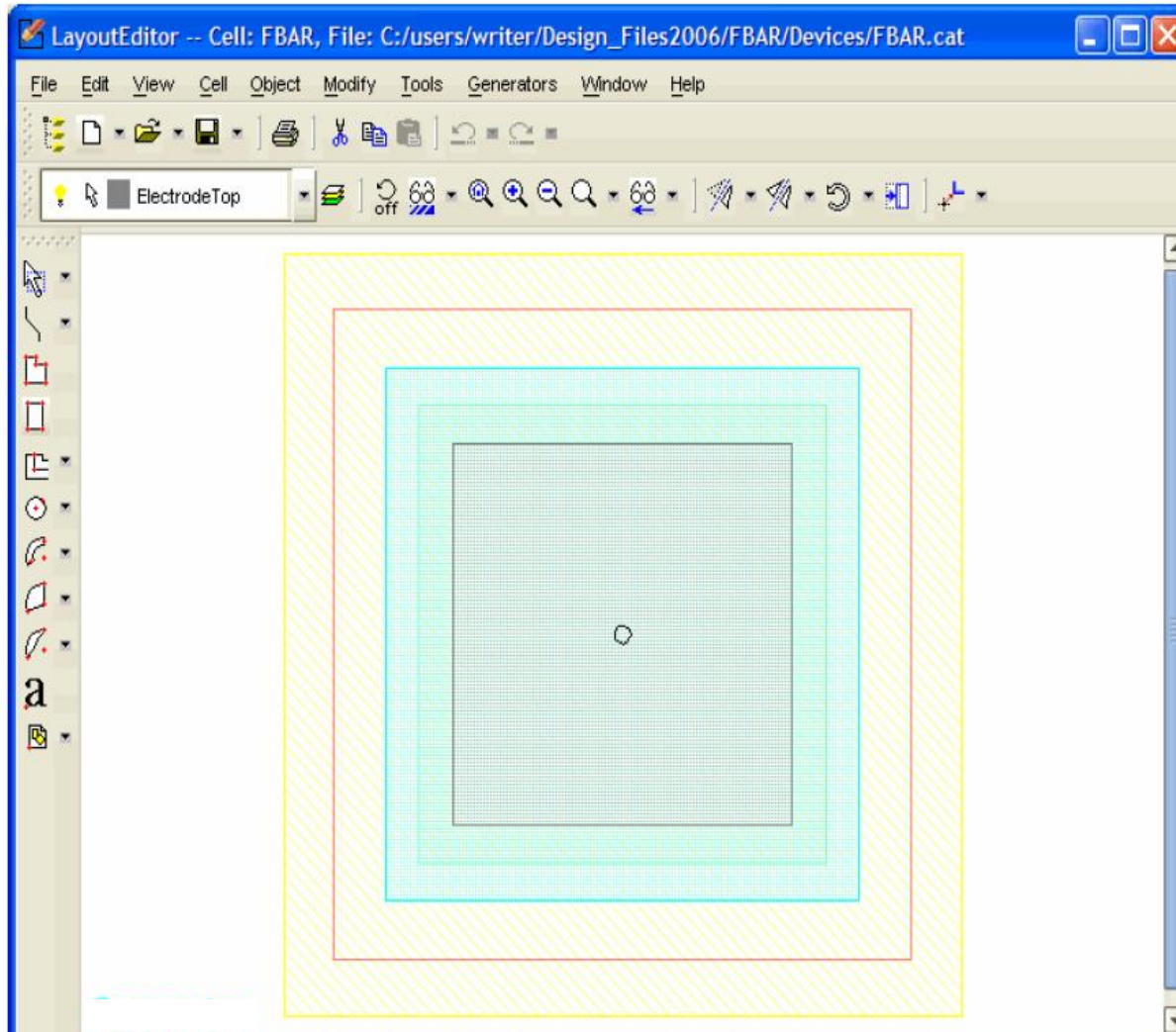
Process Library

- Modeling Ac
- User-Define
 - Anisotrop
 - Anisotrop
 - Generic
 - Generic
 - Deep R
 - Release
 - Release
 - Strippin
 - Therma

- This is the fabrication process we intend to use for our FBAR device. There are 12 steps which include straight cutting and stacking of the various materials.

- **Step 3: Create a 2D layout of our FBAR device.**

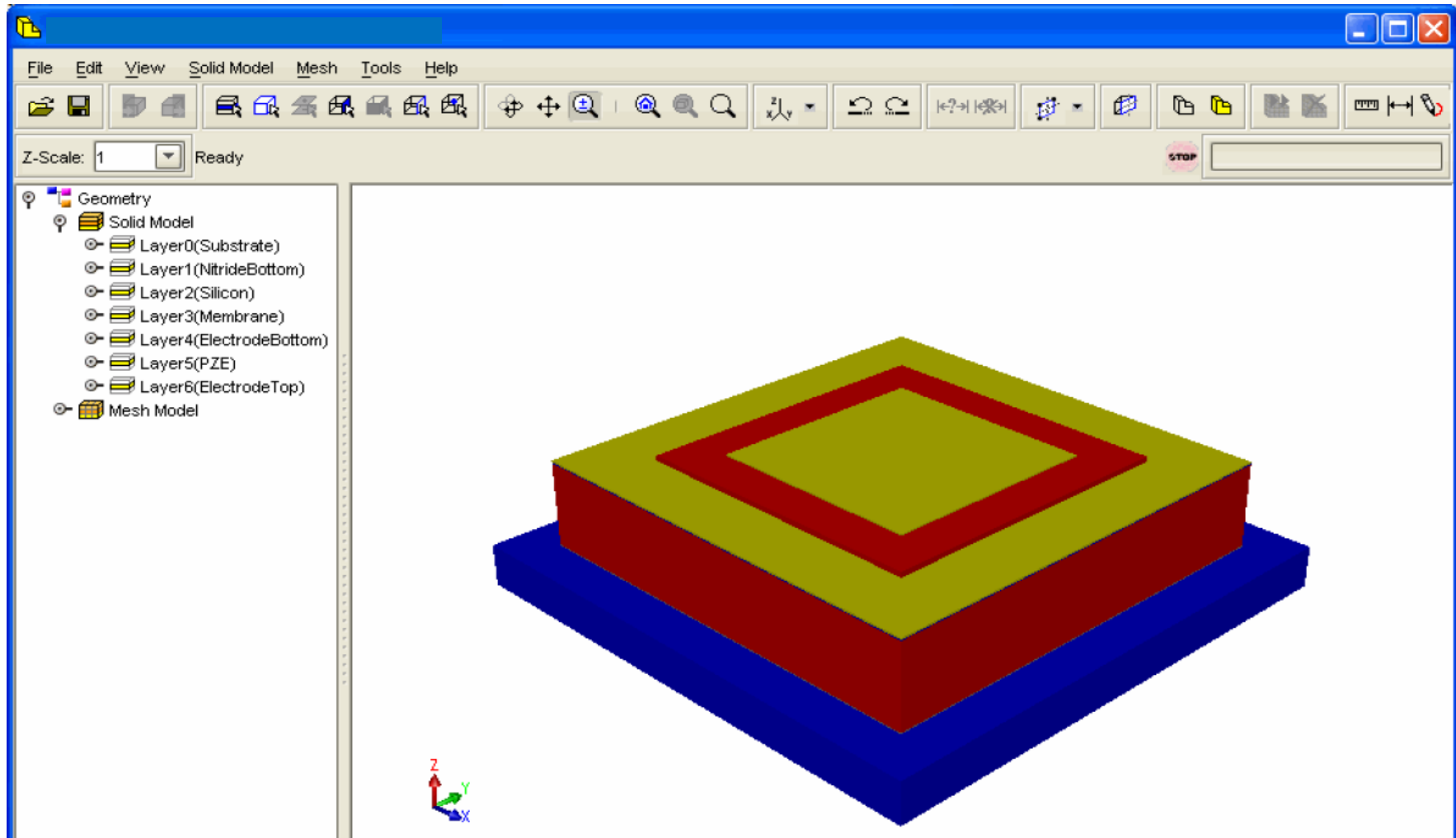
- * This 2D layout will later be used to create the 3D layout which is needed for simulation.



- You can see 5 different layers in this layout.
- You can draw rectangles, circles, triangles, and many other shapes in this layout editor.

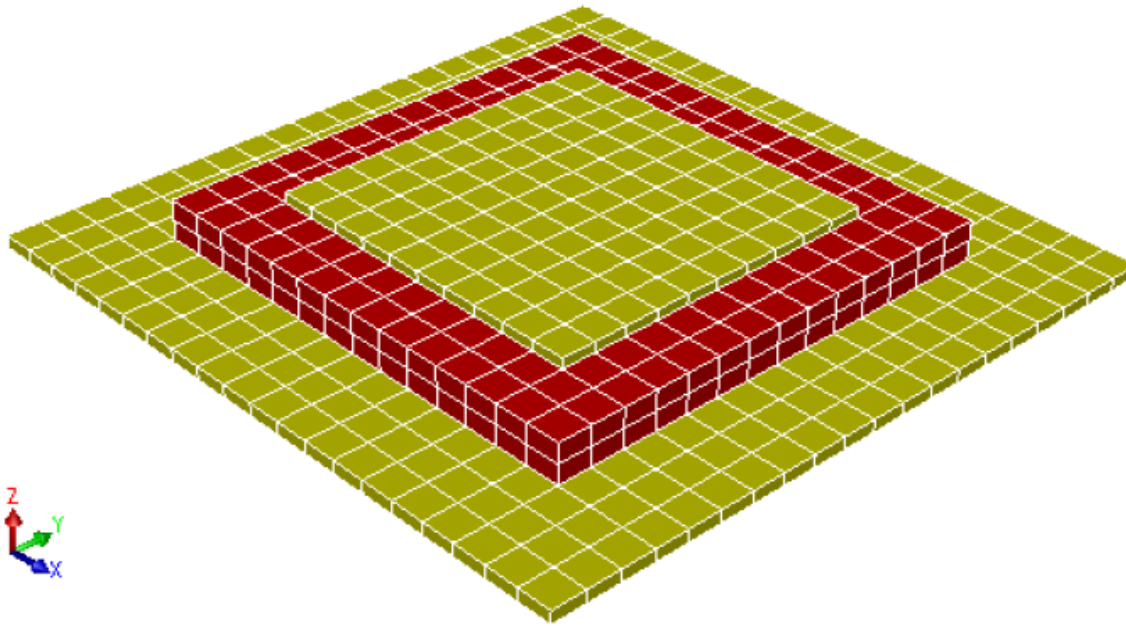
- **Step 4: Generate the 3D model.**

- * The MEMS simulation software automatically creates the 3D model using all of the information you have provided it with.



- Our data has been used to create the above 3D model.

- **Step 5: The device we have created thus far is too large an object to be analyzed. Thus we must 'mesh' the device. This means to separate it into many small pieces.**



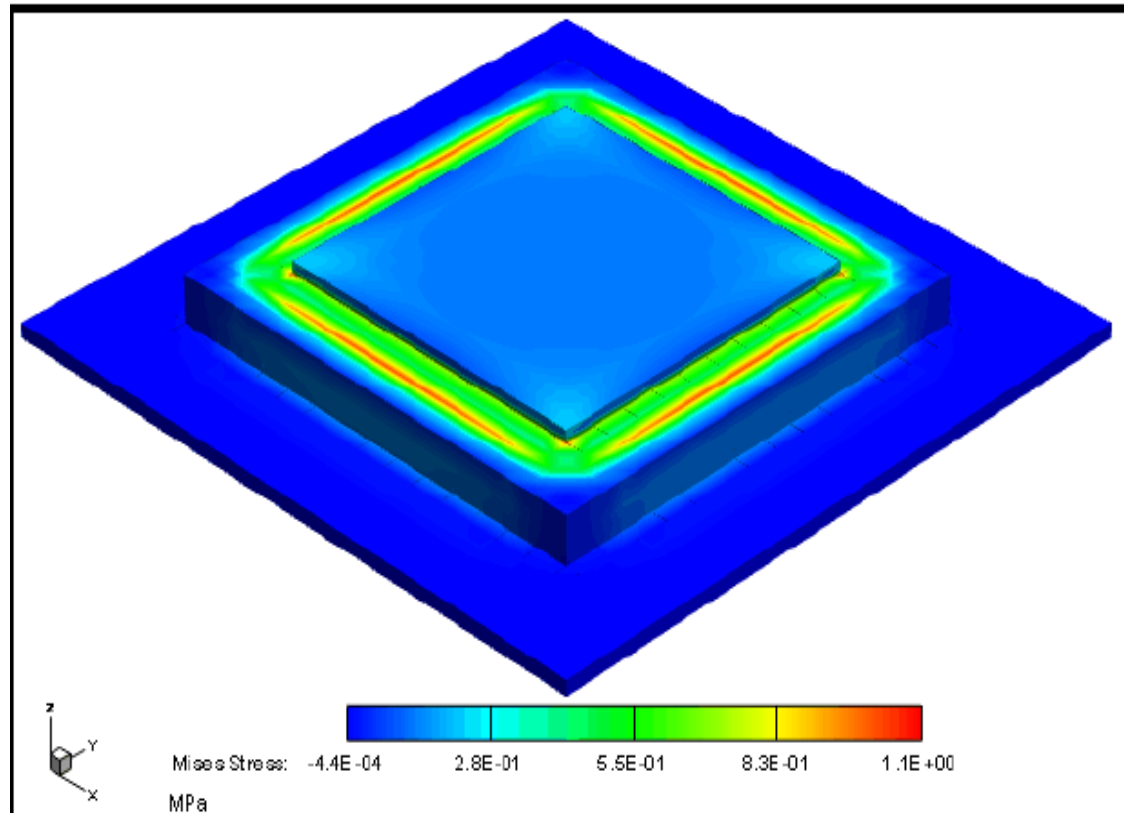
- After meshing, the FBAR has been separated into many small rectangles which together form a single device.

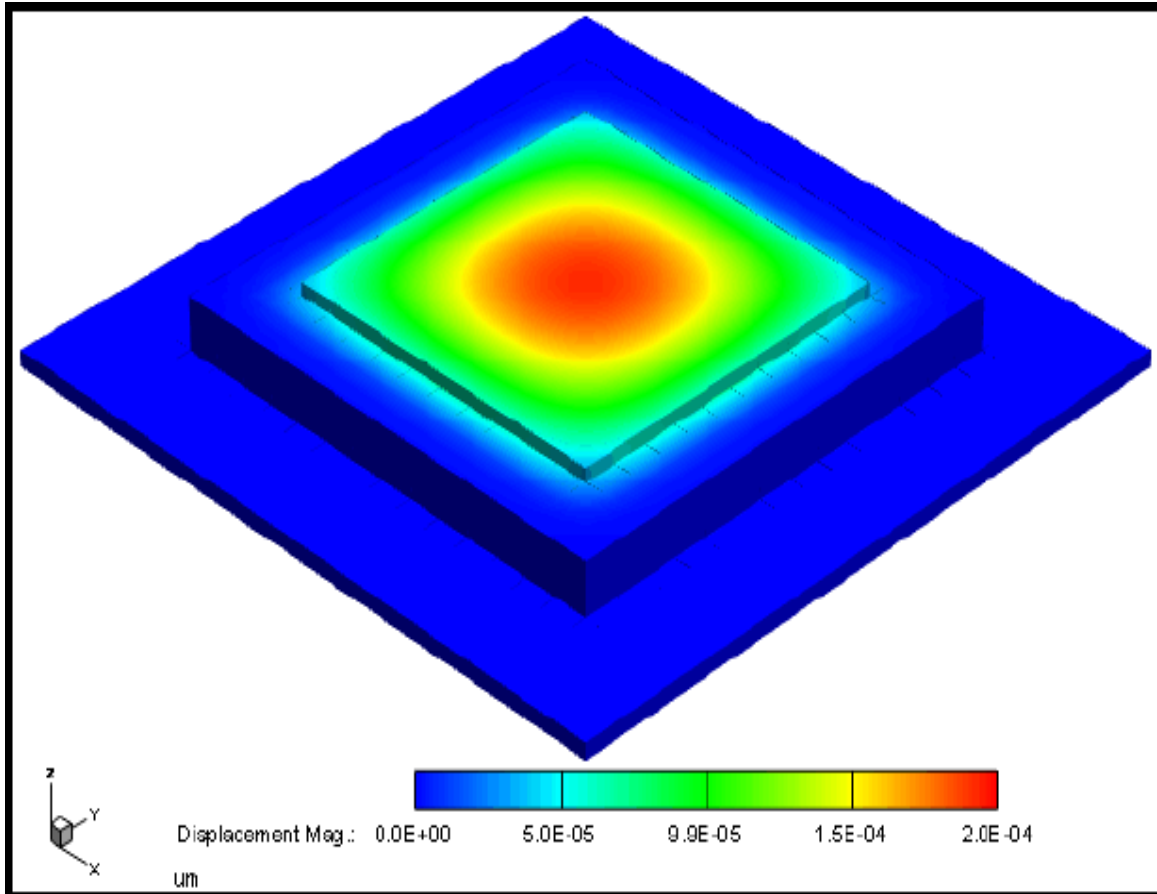
- **Step 6: Begin various simulations on device.**

- * It is possible to simulate many physical phenomenon using this MEMS simulation packages such as pressure, conductivity, motion, DC analysis, and more.

- For our FBAR, we apply a 1V charge to the top and notice various aspects of change that occur.

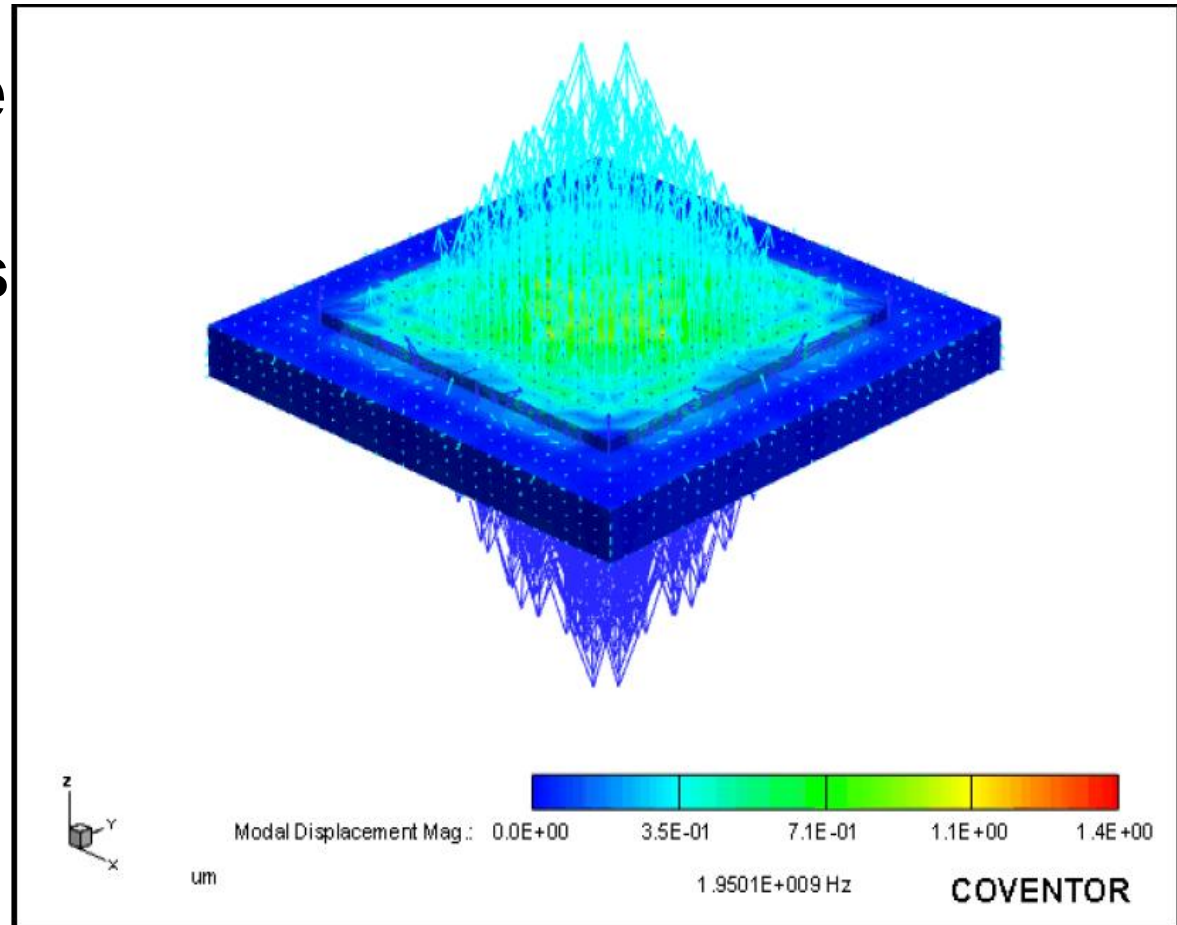
- We notice the stress on the device around the edges. (The red area indicates greater stress)





- We see the displacement that has taken place due to the input voltage. (The red area indicates greater displacement)

- Here we see the resonance the 1V input causes our FBAR.

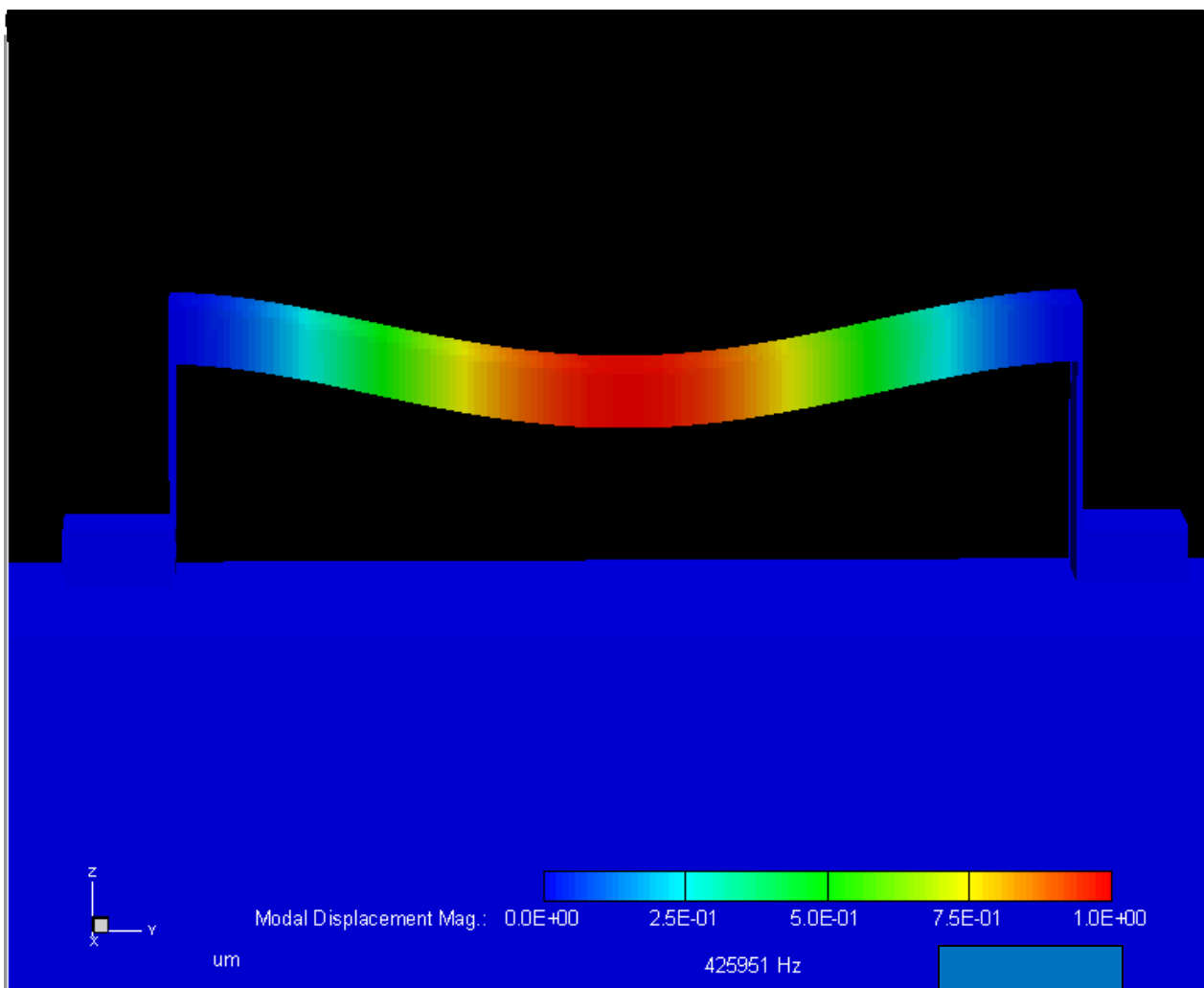




Other Examples: Beam Vibrations



- The following slide shows a beam vibrating due to pressure application at its top.



- **MEMS based devices currently in use for**
 - Inertial measurement units, IR imagers, explosive detection.
 - NDE real time sensors
- **Many future possibilities, including the following**
 - Biochemical sensors for gas and explosives detection
 - Neural implants for robotic insects
 - Smart skins
 - Biosensors for Soldiers
 - Many others

Emerging Technologies [one list...]

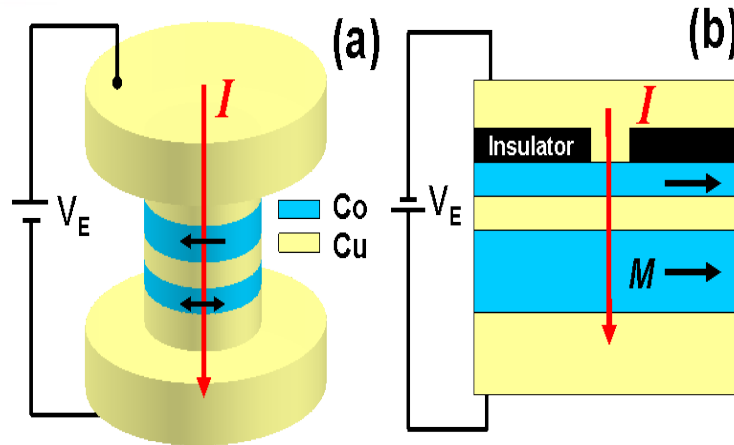
- **Technotronics**—from microelectronics to nanotronics, quantum-spintronics and biotronics
- **MEMs**
- **Nano Tech**—nanomachines, self assembly, nanotubes
- **Mobile telecommunications networks**
- **Sensors and Sensing systems**—smart sensors, distributed sensing, RFID, sensor nets and swarms, biosensors
- **Info tech**—virtual reality, ubiquitous computing, grid computing
- **Robotics**—intelligent systems, robot teams, nanobots, human augmentation
- **Autonomous Systems**—unmanned combat air vehicles, organic air vehicles, micro air vehicles, UGS, UUVs/USVs
- **Biotech**—genetic engineering, bio-diagnostics, bio-remediation, bio-weapons
- **Energy & Propulsion**—fuel cells, directed energy, superconductors

A technology has emerged called spintronics (spin transport electronics or spin-based electronics), where it is not the electron charge but the ***electron spin*** that carries information.

The discovery in 1988 of the giant magnetoresistive effect (GMR) is considered the beginning of the new, spin-based electronics. *GMR is observed in artificial thin-film* materials composed of alternate ferromagnetic and nonmagnetic layers.

A new generation of devices combining standard microelectronics with spin-dependent effects that arise from the interaction between spin of the carrier and the magnetic properties of the material is being developed.

Source: Wolfe, 2001, Science



Geometry of (a) nano-pillar and (b) nano-contact magnetic nanostructures used to study the spin-transfer torque effect.

The structures consist of two magnetic layers (thin “free” layer and thicker “fixed” layer shown in blue) and a non-magnetic spacer between them (shown in yellow). The spacer can be made of a non-magnetic metal (usually Cu) (spin-valve), or of a non-magnetic insulator (usually MgO) (magnetic tunnel junction).