RDECOM

TARDEC

TECHNOLOGY DRIVEN. WARFIGHTER FOCUSED.

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

Dr. Thomas Meitzler, Team Leader, Sensor Enhanced Armor – NDE Lab

Acting Deputy Associate Director, Survivability

June 16, 2009

Report Documentation Page

Form Approved
OMB No. 0704-0188

1. REPORT DATE **16 JUN 2009**	2. REPORT TYPE **N/A**	3. DATES COVERED **-**
4. TITLE AND SUBTITLE **MEMS, Nanotechnology and Spintronics for Sensor Enhanced Armor, NDE and Army Applications**		5a. CONTRACT NUMBER 5b. GRANT NUMBER 5c. PROGRAM ELEMENT NUMBER
6. AUTHOR(S) **Thomas Meitzler**		5d. PROJECT NUMBER 5e. TASK NUMBER 5f. WORK UNIT NUMBER
7. PERFORMING ORGANIZATION NAME(S) AND ADDRESS(ES) **US Army RDECOM-TARDEC 6501 E 11 Mile Rd Warren, MI 48397-5000**		8. PERFORMING ORGANIZATION REPORT NUMBER **19933RC**
9. SPONSORING/MONITORING AGENCY NAME(S) AND ADDRESS(ES)		10. SPONSOR/MONITOR'S ACRONYM(S) **TACOM/TARDEC** 11. SPONSOR/MONITOR'S REPORT NUMBER(S) **19933RC**
12. DISTRIBUTION/AVAILABILITY STATEMENT **Approved for public release, distribution unlimited**		
13. SUPPLEMENTARY NOTES **The original document contains color images.**		
14. ABSTRACT		
15. SUBJECT TERMS		

16. SECURITY CLASSIFICATION OF:			17. LIMITATION OF ABSTRACT	18. NUMBER OF PAGES	19a. NAME OF RESPONSIBLE PERSON
a. REPORT **unclassified**	b. ABSTRACT **unclassified**	c. THIS PAGE **unclassified**	**SAR**	**46**	

Standard Form 298 (Rev. 8-98)
Prescribed by ANSI Std Z39-18

TARDEC-wide Involvement
Sensor Enhanced Armor

- 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

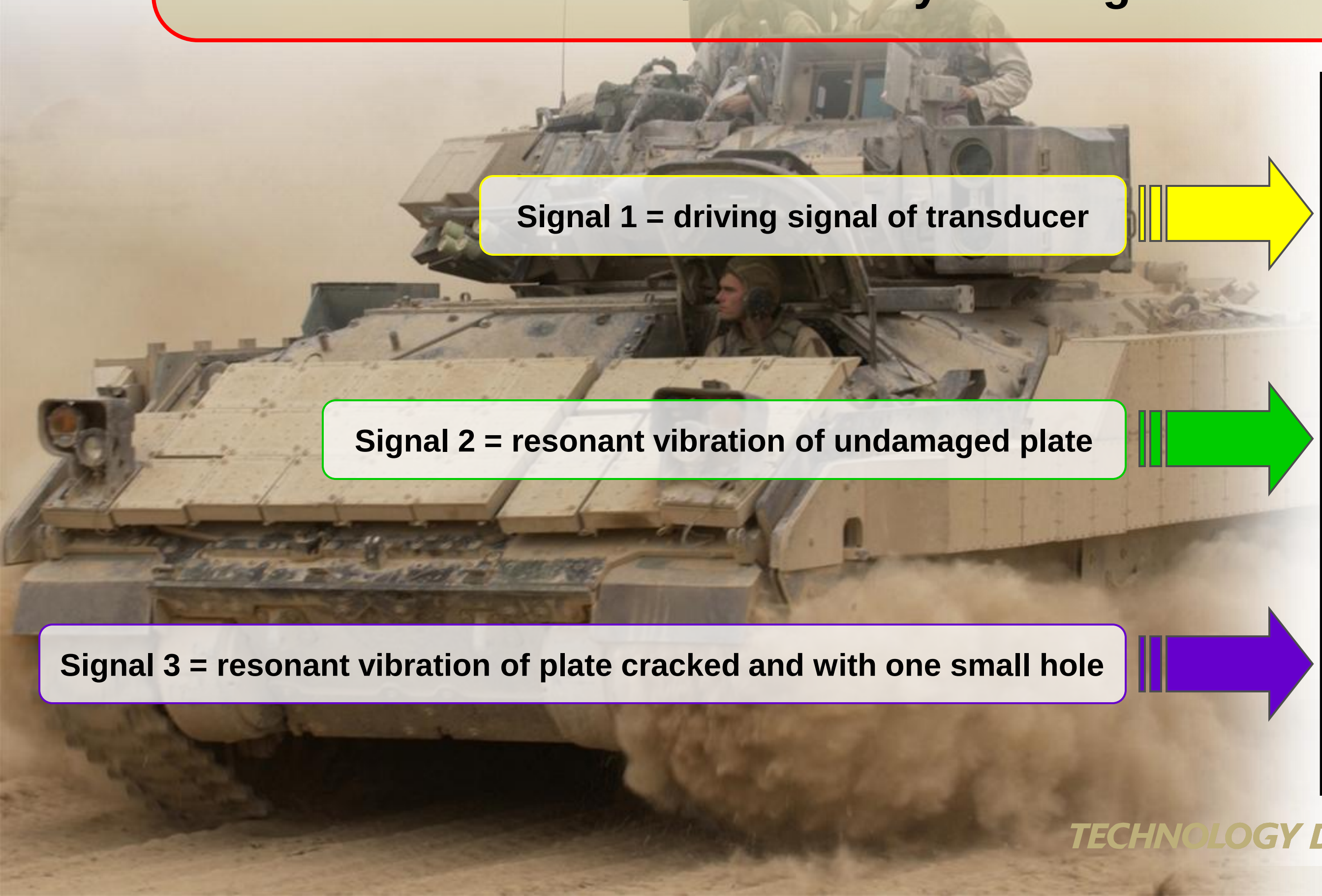
Argonne National Laboratory

Armament Research, Development & Engineering Center, Picatinny, NJ

ARL

Ground Vehicle Survivability NDT/NDE and Sensor Enhanced Armor

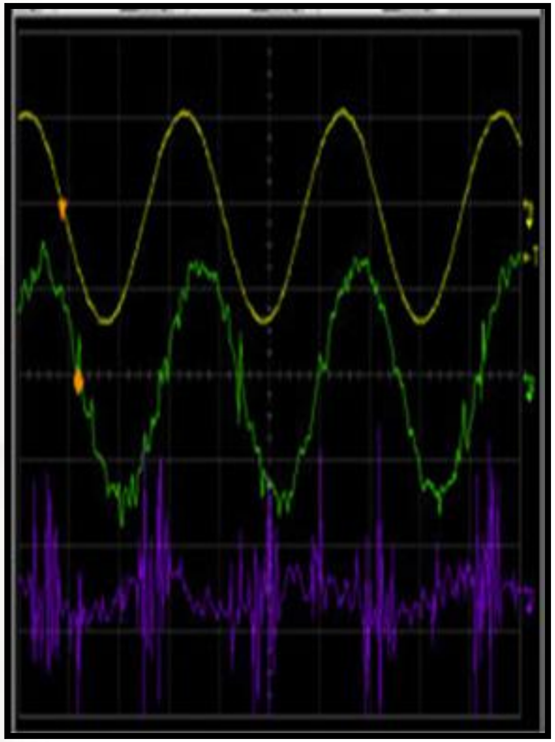
- Survivability role – develop sensors and technologies for various armor recipies.
- Prototype different sensor enhanced armor on demonstrators.
- Lead the armor NDE/NDT life cycle integration.



Signal 1 = driving signal of transducer

Signal 2 = resonant vibration of undamaged plate

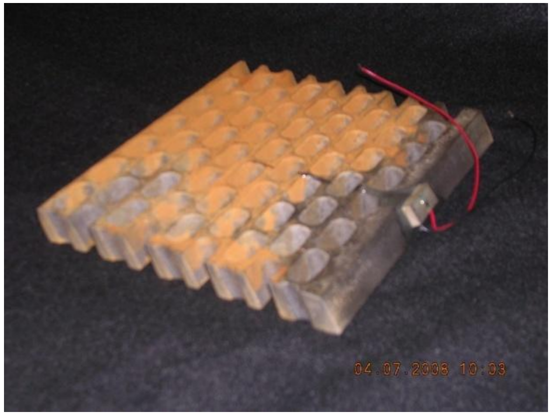
Signal 3 = resonant vibration of plate cracked and with one small hole

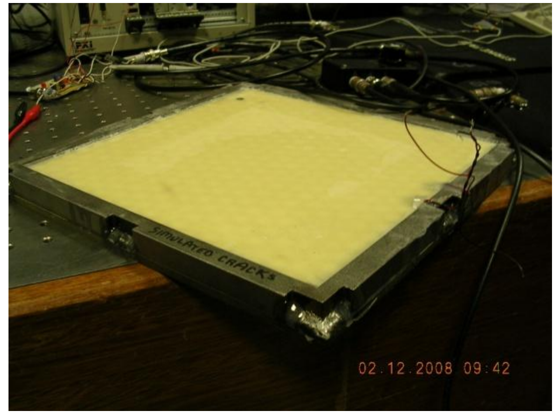


RDECOM

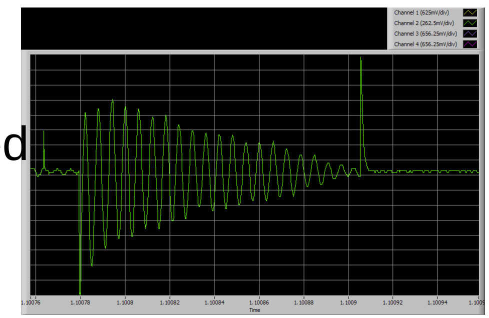
Armor Solutions Tested with Ultrasonics
NDT/E leading to Smart Armor

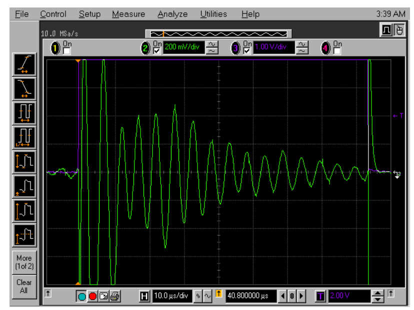
TARDEC

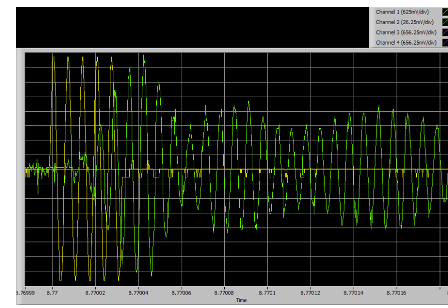




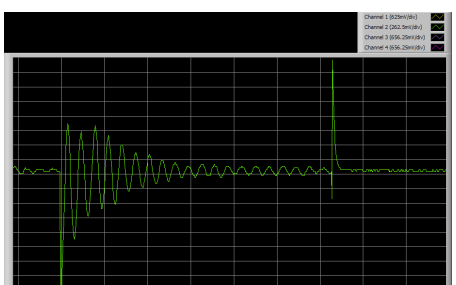
Undamaged

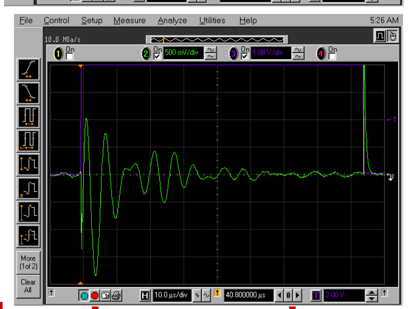


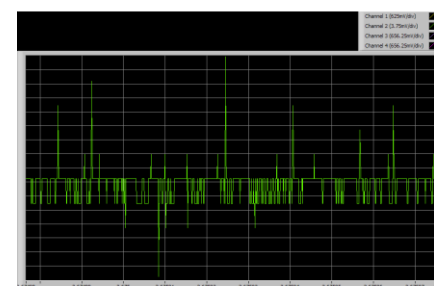




Damaged

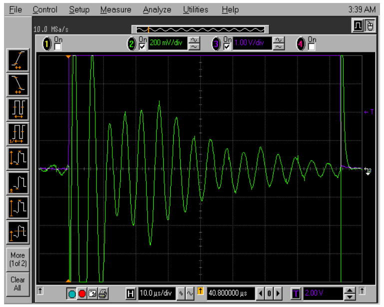






There is a profound difference in the shape and amplitude of the echo signal between the damaged and undamaged plates. Tests are underway using embedded transducers for real-time armor integrity monitoring.

TARDEC Integrated Systems



SMART ARMOR

GROUND VEHICLE POWER & MOBILITY

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

Battery Pack w/ Integrated Heat Exchanger

INTEGRATED SURVIVABILITY

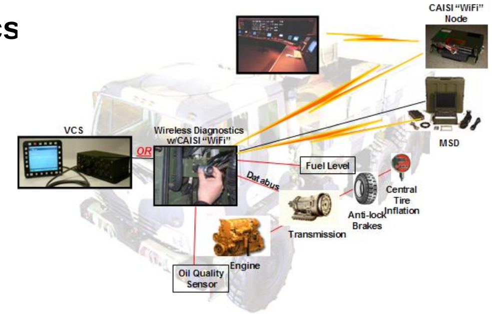
- Active Defense
- Signature Management
- Laser Vision Protection
- Ballistic Protection

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

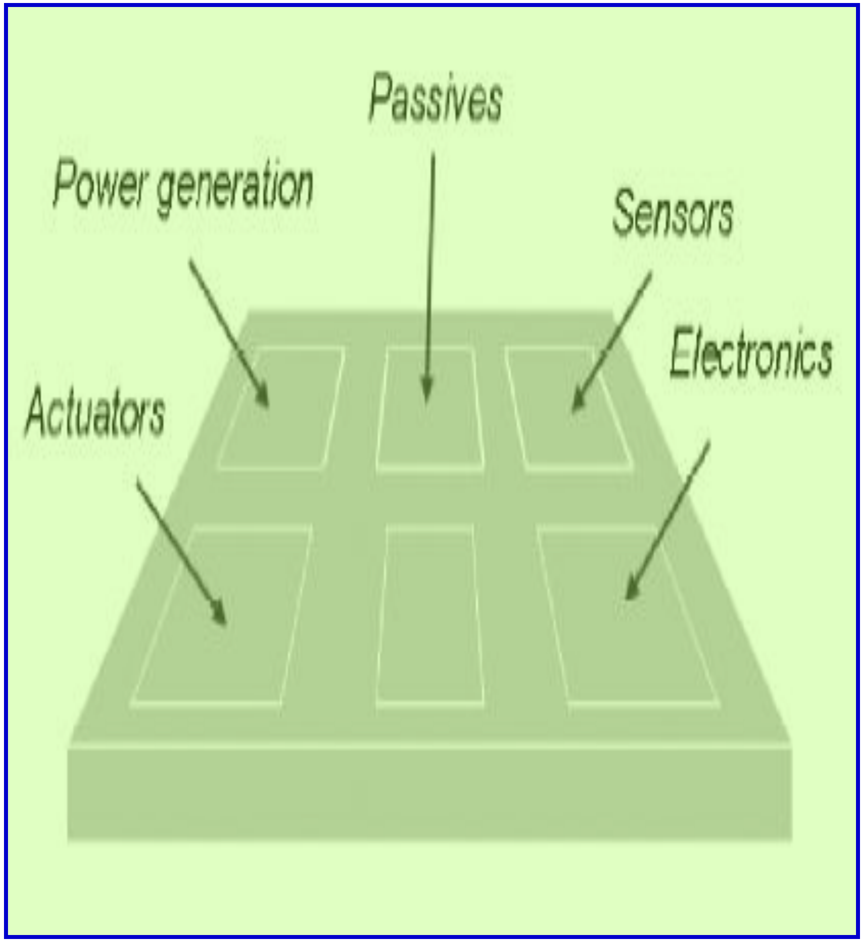


TECHNOLOGY DRIVEN. WARFIGHTER FOCUSED.

Introduction to MEMS

- Micro-Electro-Mechanical-Systems

- MEMS integrate silicon-based microelectronics with micromachining technology to produce a system of miniature dimension

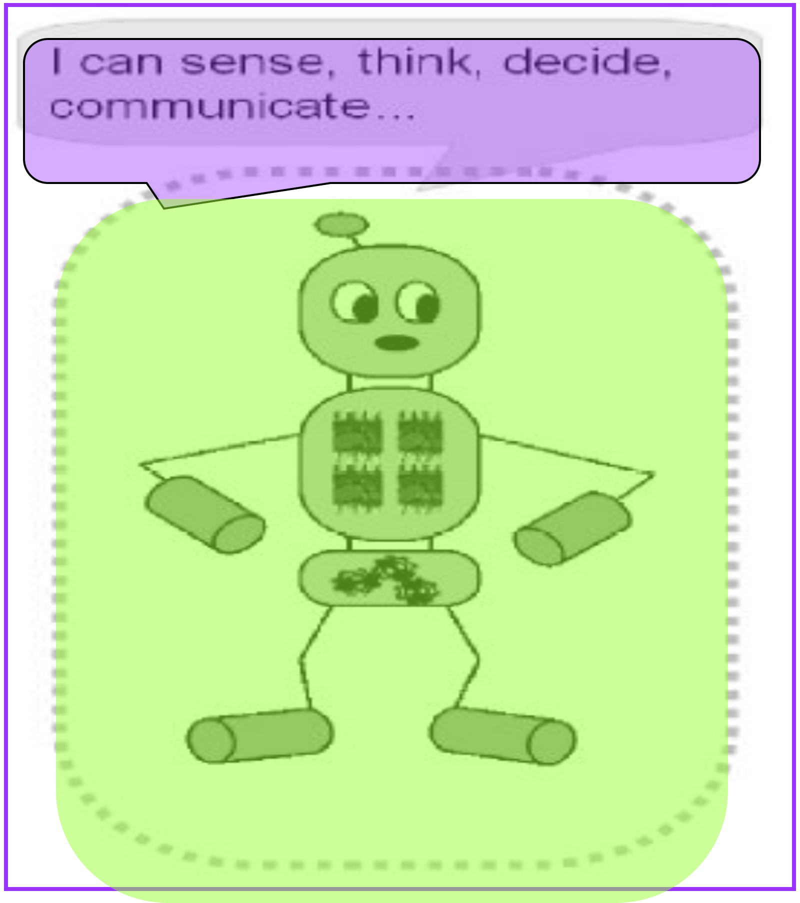


Technological Advances of MEMS

- **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**

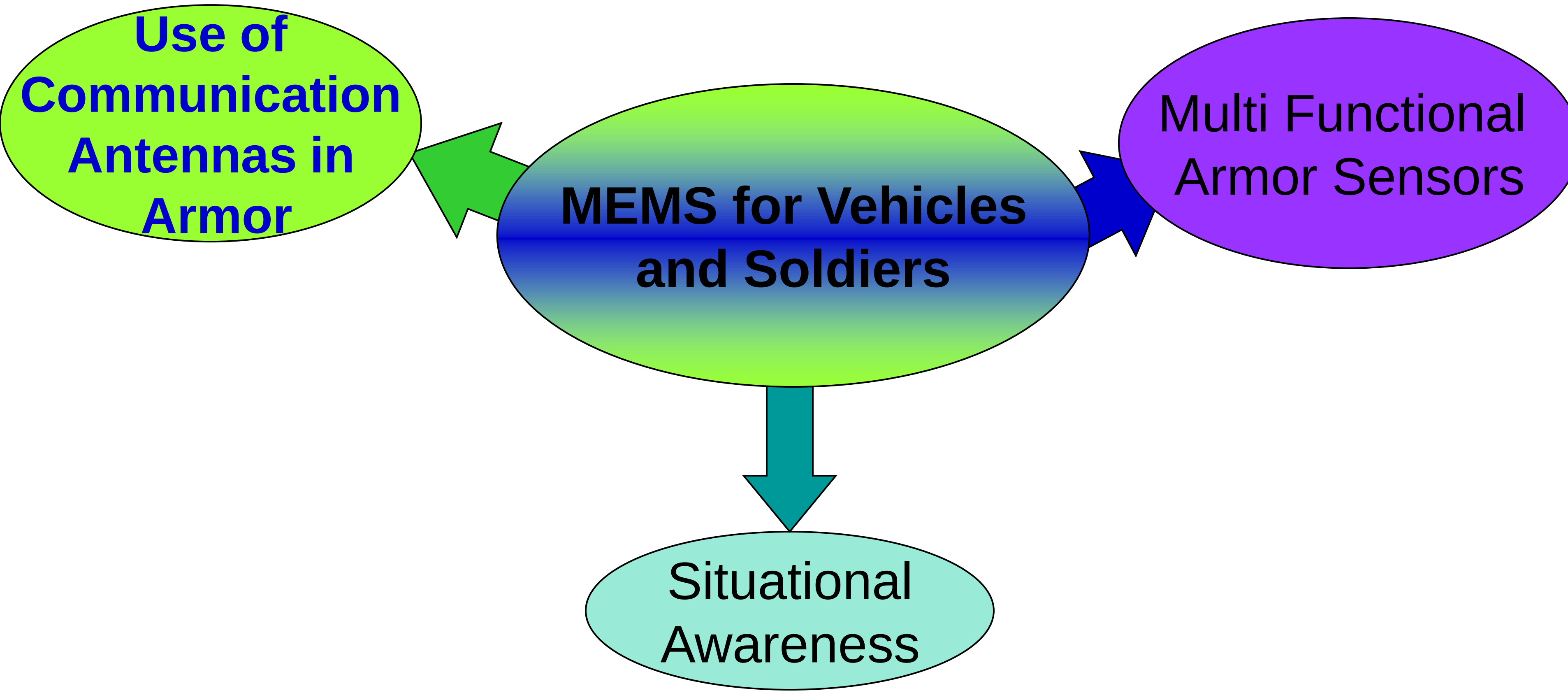
Impact of MEMS

- 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



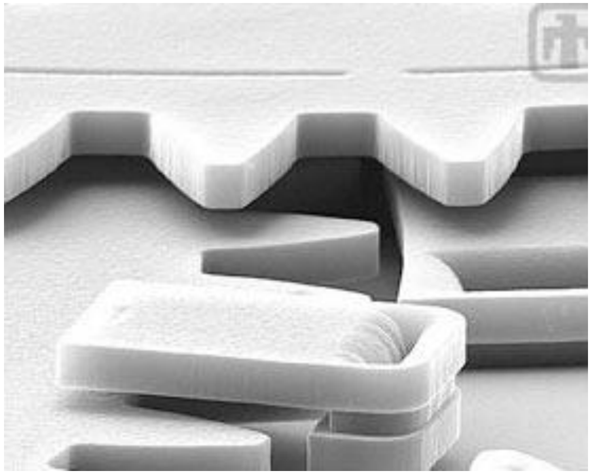
Artist impression of integrated microsystem

Classifying MEMS for Vehicles and Soldiers

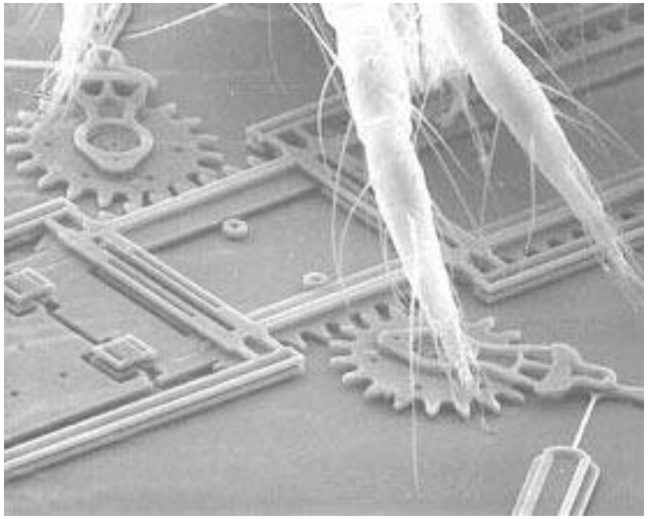


MEMS Technology

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



Courtesy Sandia National Labs



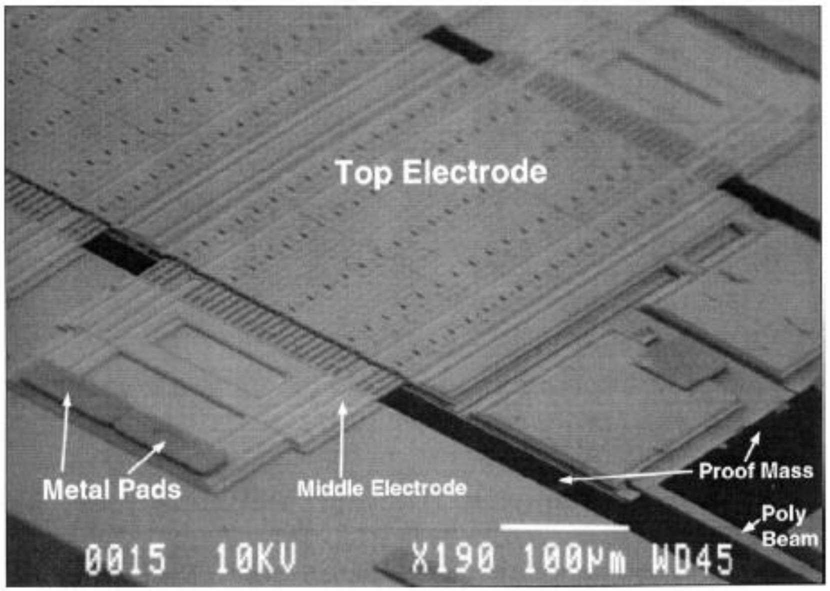
Military Applications of MEMS

- 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.

Detection technologies

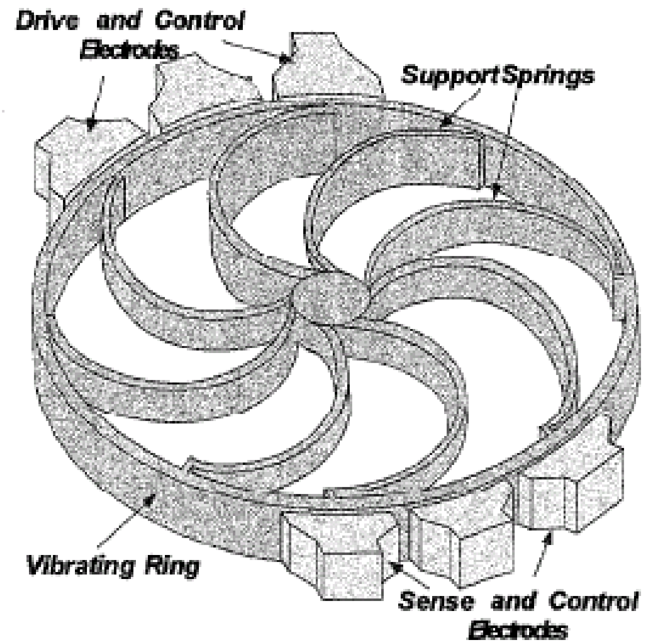
- Accelerometers



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/√Hz at atmosphere.

- Gyroscopes



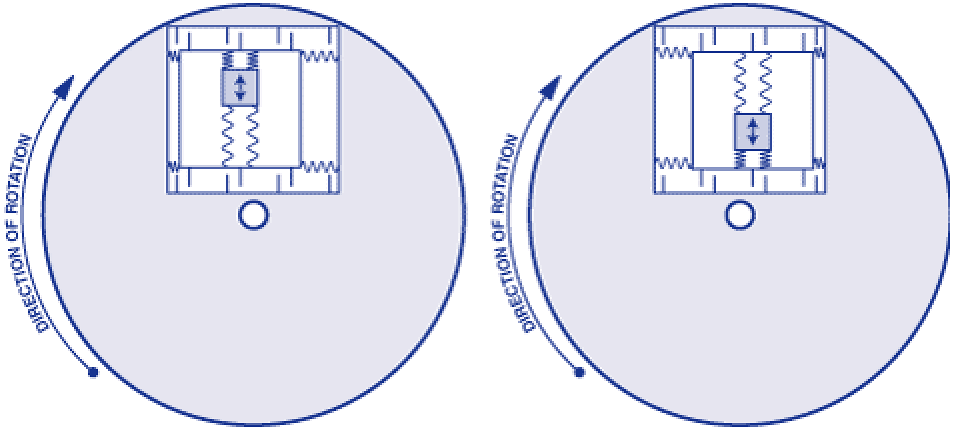
Source:Vibrating Ring Gyroscope, F. Ayazi et al.

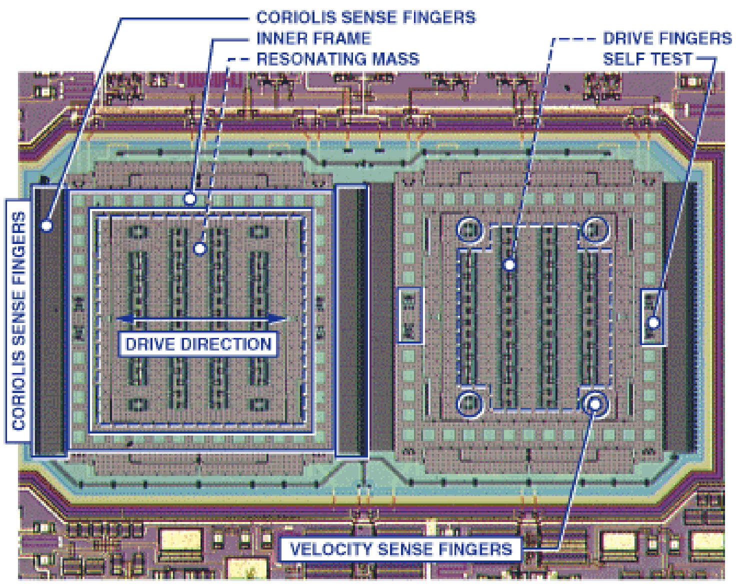
- 200 V/deg/s in a dynamic range of +/-250 deg/s
- Noise floor: 0.01 /s/√Hz at atmosphere.

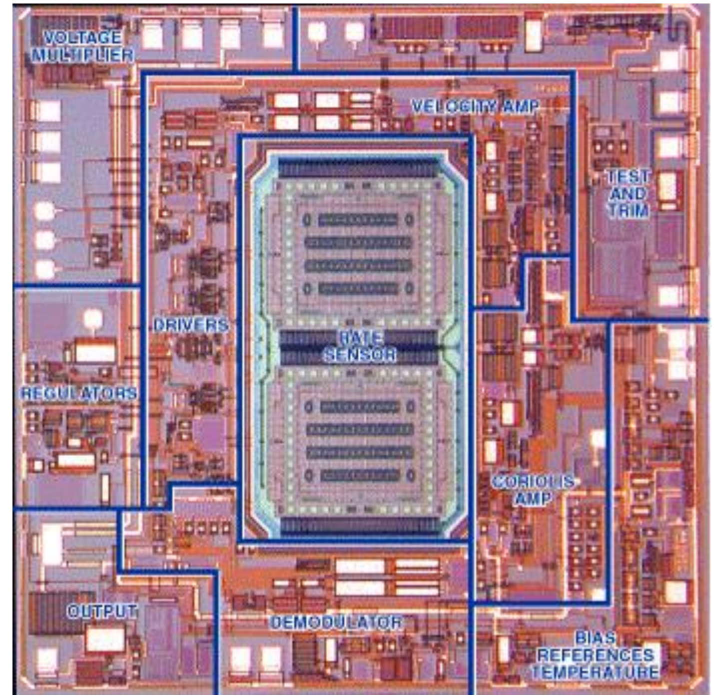
MEMS based IMUs are displacing other technologies

- 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%)

Analog Devices: MEMS Gyro







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

Night vision with MEMS Based Microbolometers

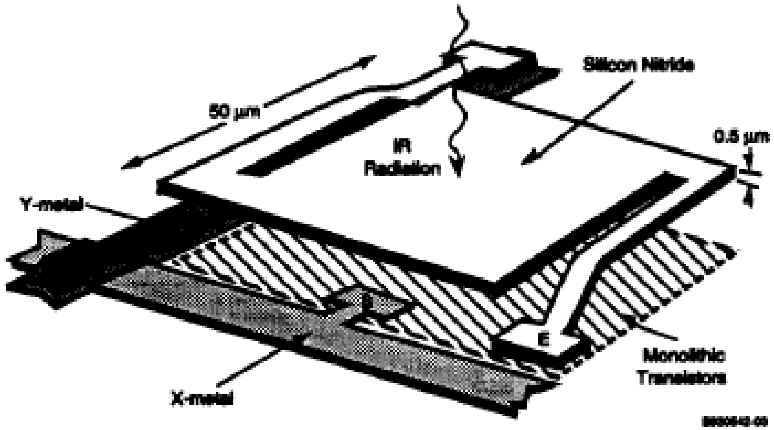
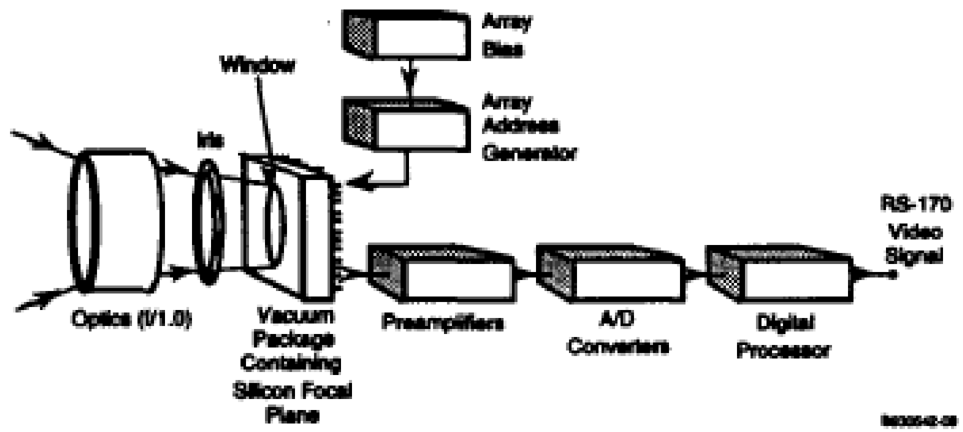


Figure 1. Microbolometer Pixel Structure

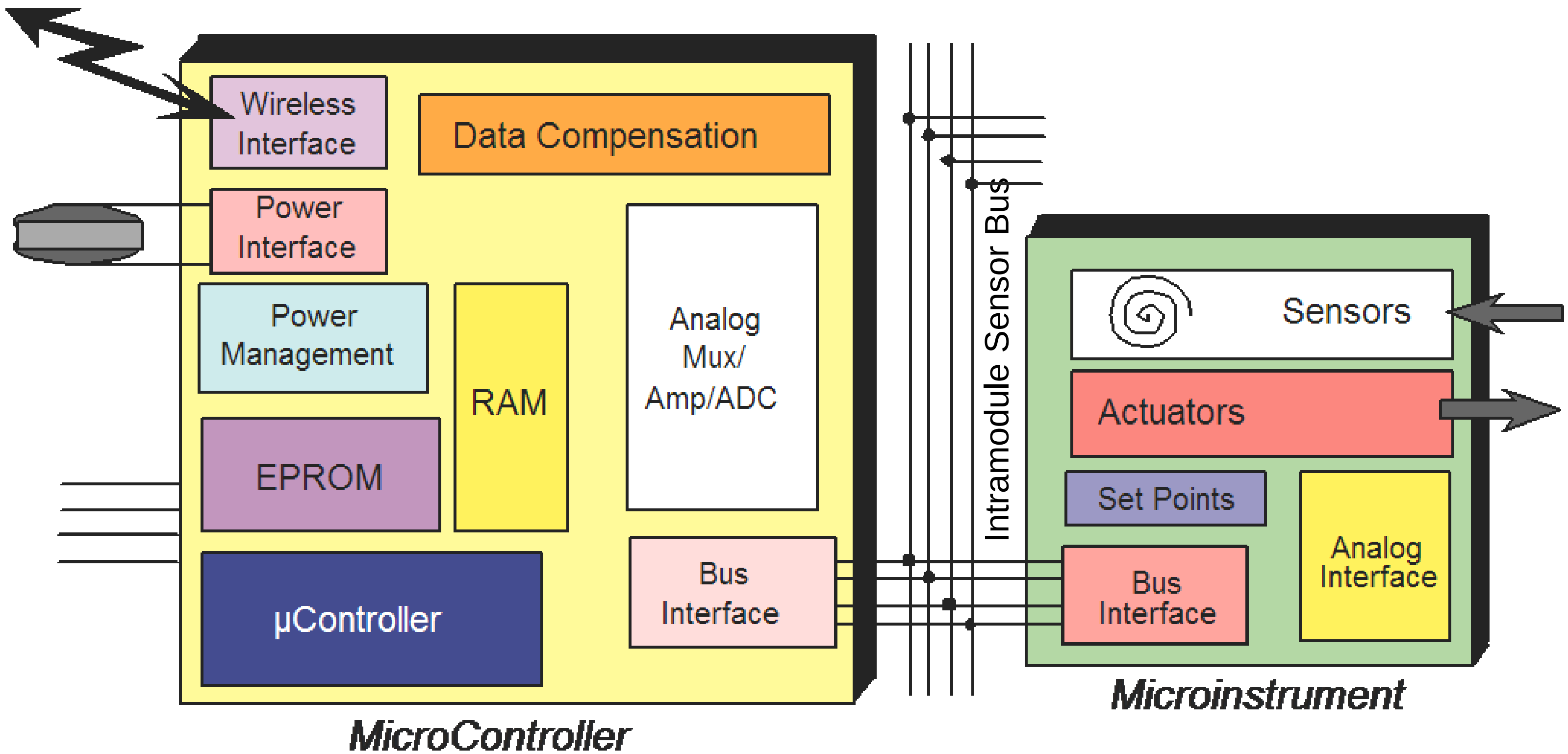


- 240x336 array of bolometers,
- NETD of .039°C, limited by Johnson noise of sense resistor
- 30 Hz operation
- Originally developed by Honeywell

Daytime Parking Lot (white is hot)

Source: Wood, IEDM 1993

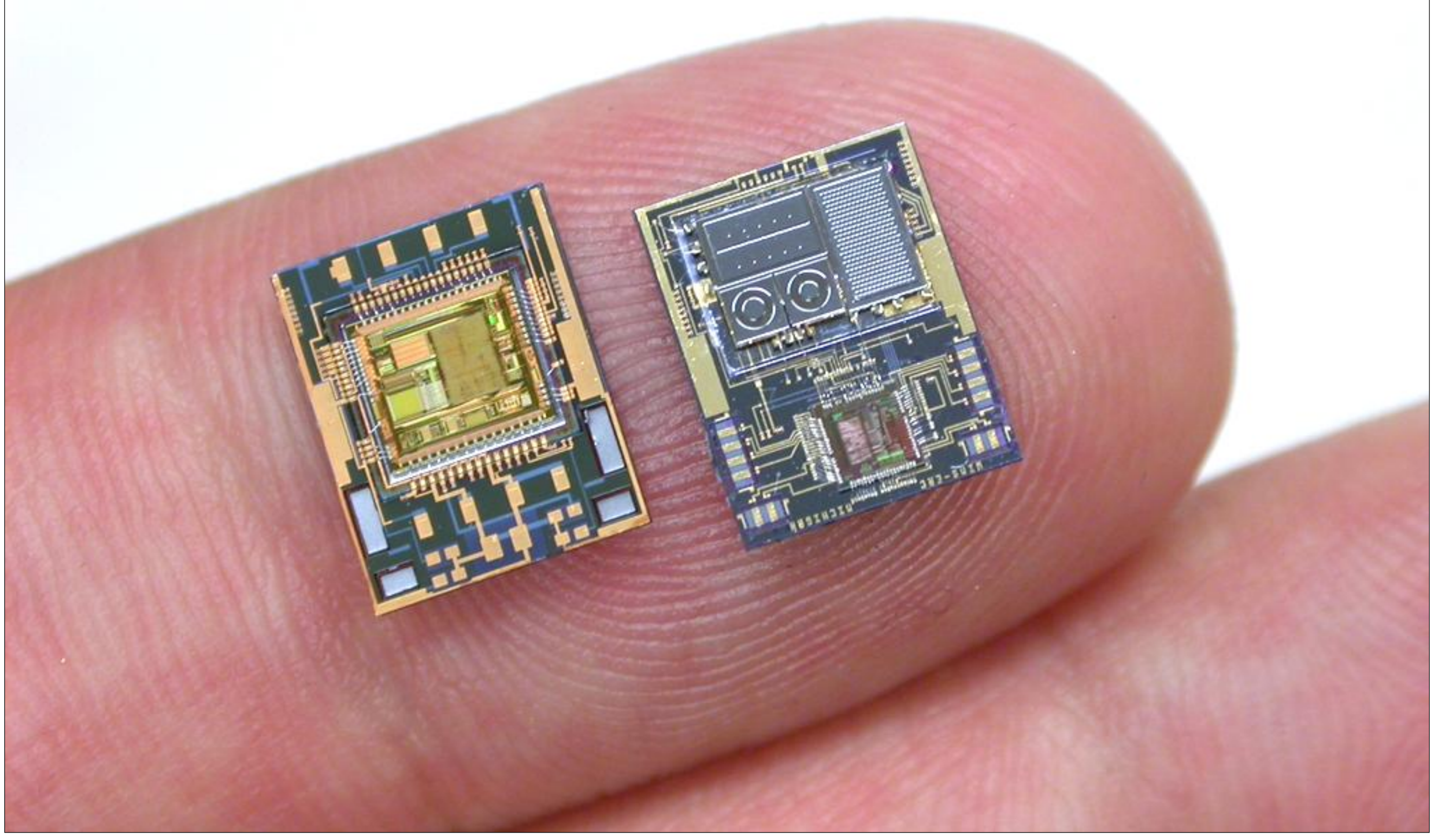
A GENERIC WIMS ARCHITECTURE



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

A FULLY-INTEGRATED MICROSYSTEM FOR AUTONOMOUS DATA GATHERING

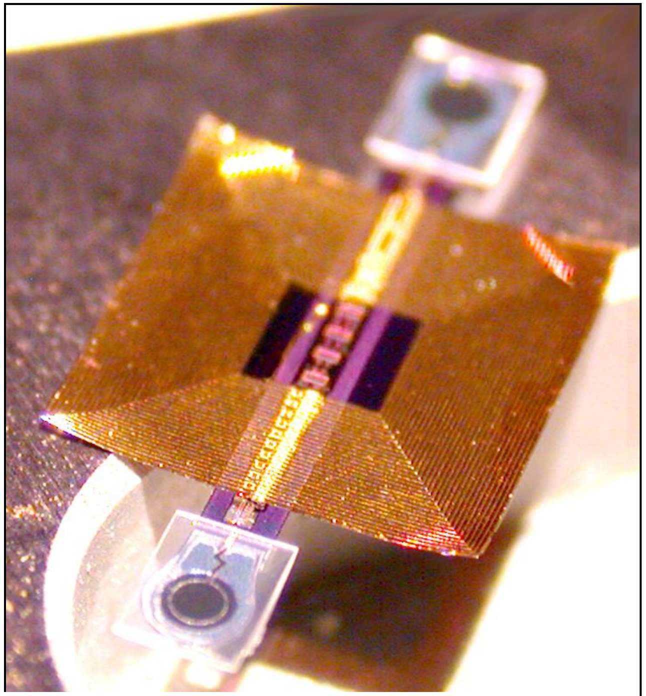
Toward Measuring Anything, Anywhere, Anytime



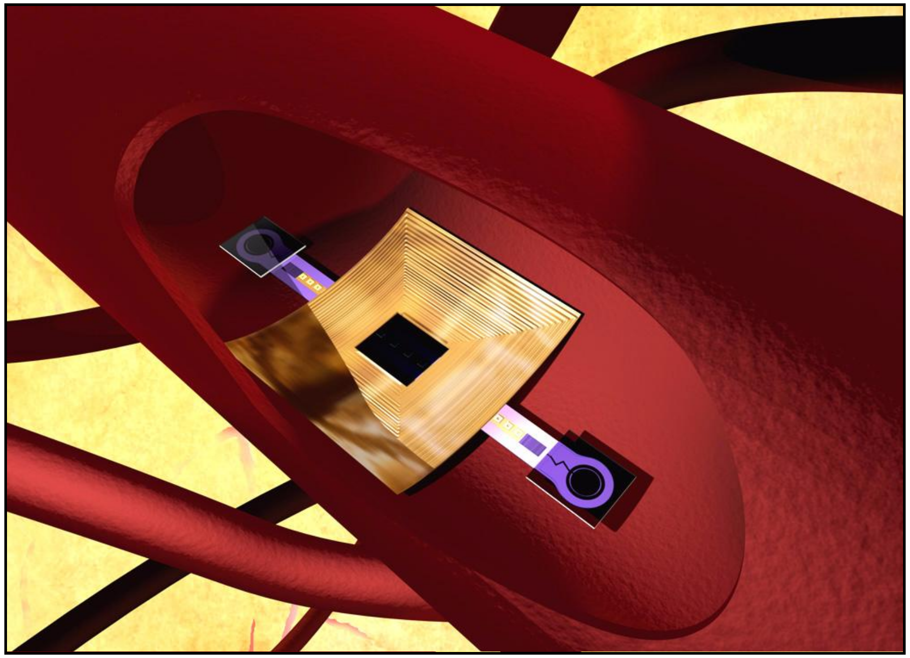
- Embedded µController, 16Mb Flash Memory, Fully Programmable
- Sensors for Pressure, Temperature, Humidity, and Biosignals

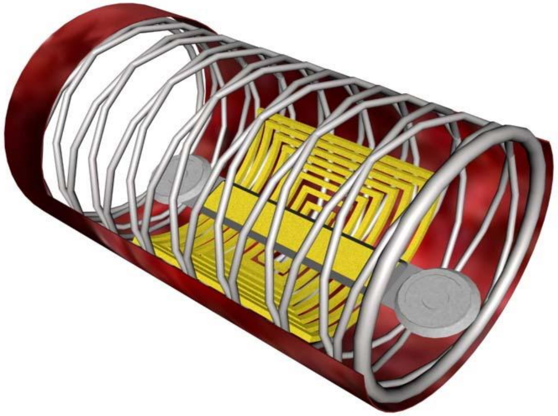
Source: Univ. of MI, Prof. Wise

ACTIVE STENTS: Wireless Readout of Intra-Arterial Pressure and Flow



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

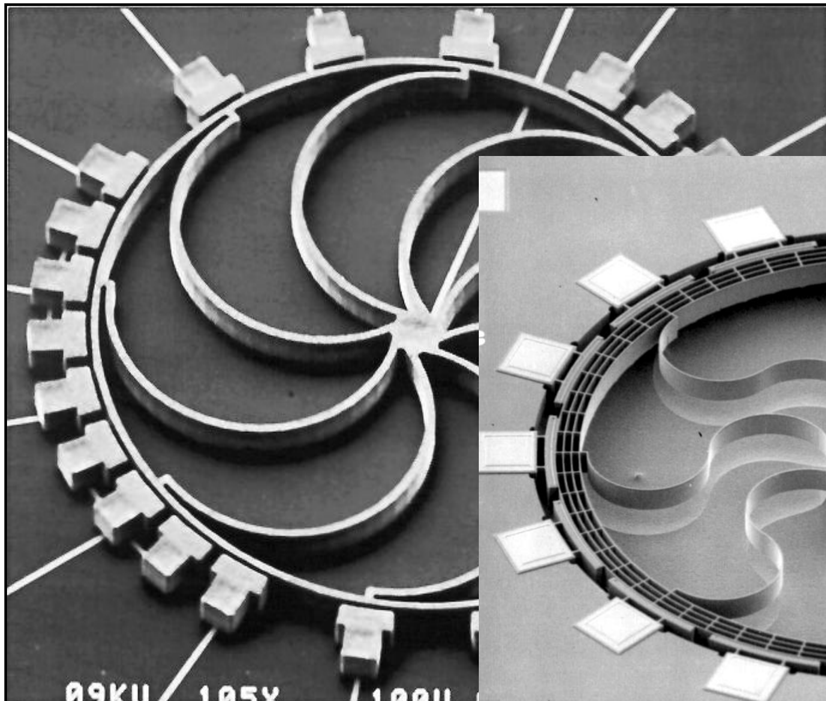




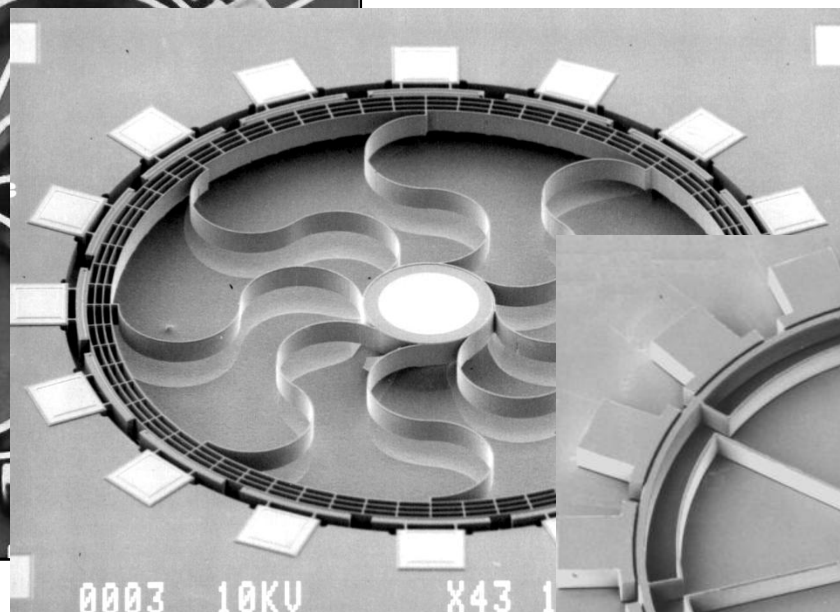
Source: Univ. of MI, Prof. Wise

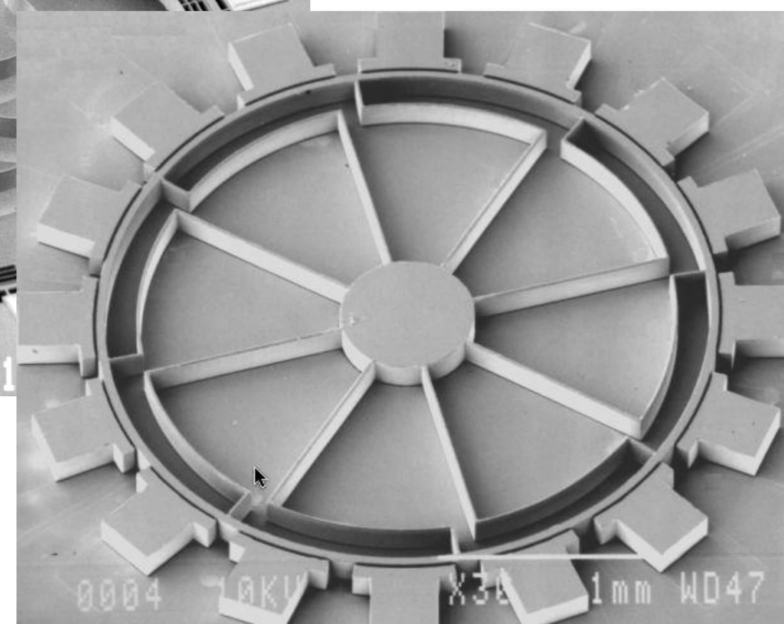
VIBRATING RING GYROSCOPES

Nickel Vibrating Ring Gyroscope, 1994
Resolution:0.5°/sec, Q: 4000



Polysilicon Vibrating Ring Gyroscope, 1999
Resolution:20°/Hour, Q: 10000





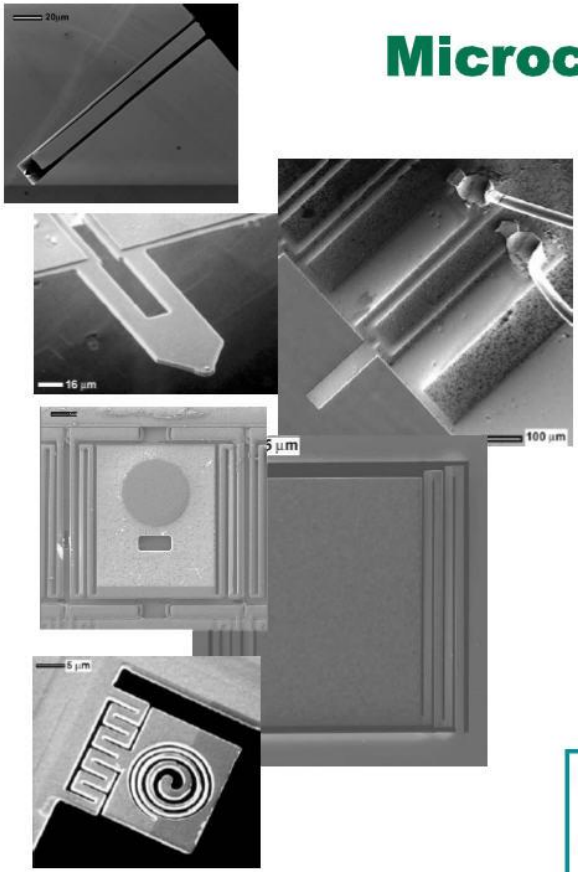
Single-Crystal Si Vibrating Ring Gyroscope, 2002
Resolution:7.5°/Hour, Q: 14000

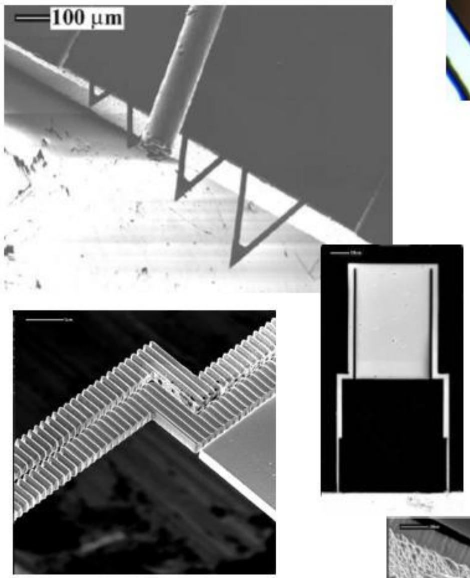
Source: Univ. of MI, Prof. Wise

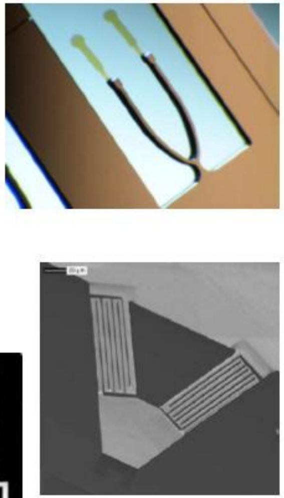
Situational Awareness: Soldier Magnetometer

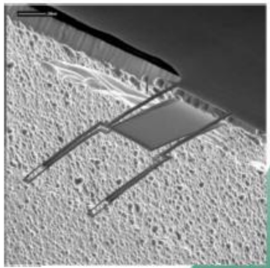
- **MEMS Magnetometers can detect presence of equipment up to 100 feet below ground.**
- **Magnetometers can be scattered by air drop or individually positioned to provide tactical information.**
- **These Magnetometers sense changes in earths magnetic field to detect metallic objects anytime they move.**

Microcantilevers





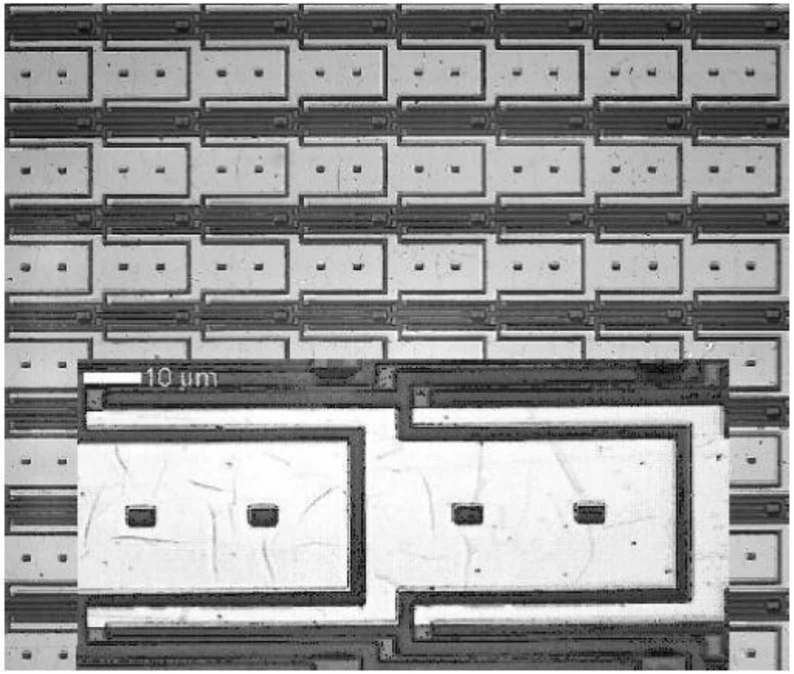


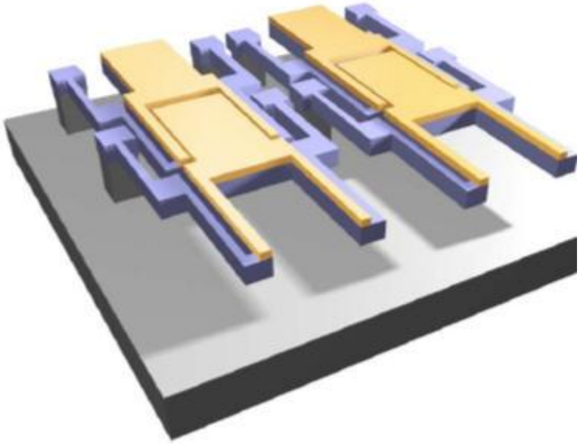


Length	: 50- 500 µm
Width	: 10-50 µm
Thickness	: 0.1-4 µm

Oak Ridge National Laboratory

Example of MEMS IR array





Source: Oak Ridge Labs

MEMS SOFTWARE

Designing and Modeling Using MEMS Simulation Software

Introduction

- **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.

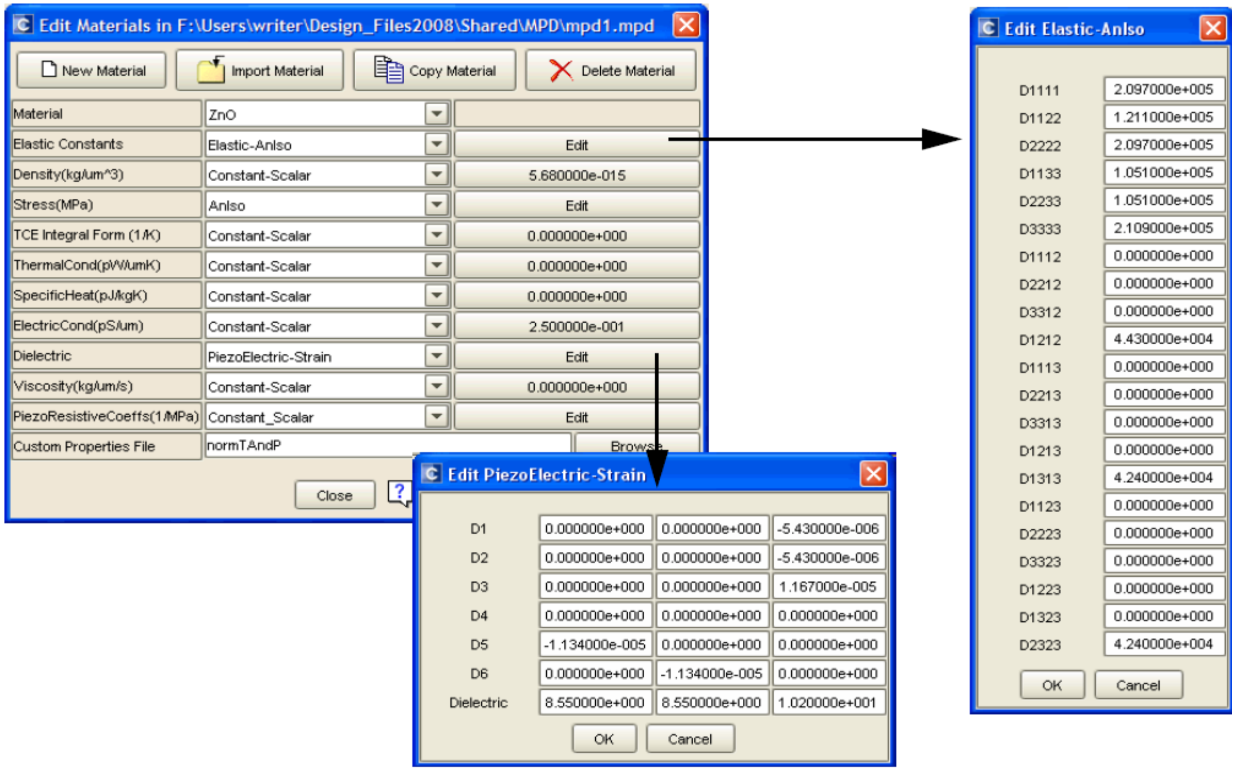
Overview

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

Procedure: Materials

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

Materials (cont.)



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

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

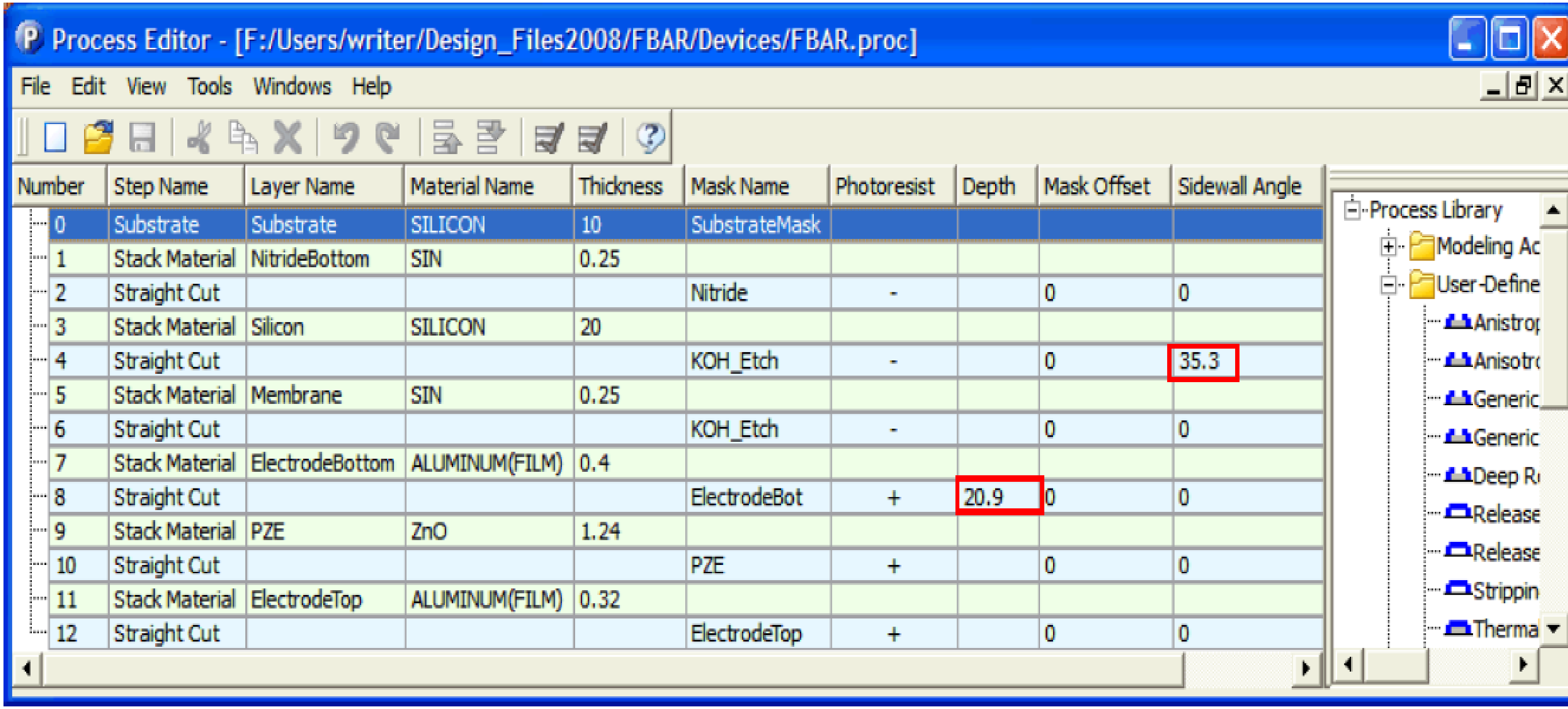
Property	Data Type	Sub prop	Aluminum (film)	Silicon	SIN	Units
Elastic Constants	Elastic-Iso	E	7.70e+04	1.69e+05	2.22e+05	MPa
		Poisson	3.00e-01	3.00e-01	2.7e-01	
Density	Constant-Scalar		2.30e-15	2.50e-15	2.7e-15	kg/μm^3
Stress	AnIso	S_x	0	0	0	MPa
		S_y	0	0	0	
		S_z	0	0	0	
Dielectric			0	1.19e01	8.0e+00	

Fabrication Process

- **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.

Fabrication Process (cont.)



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

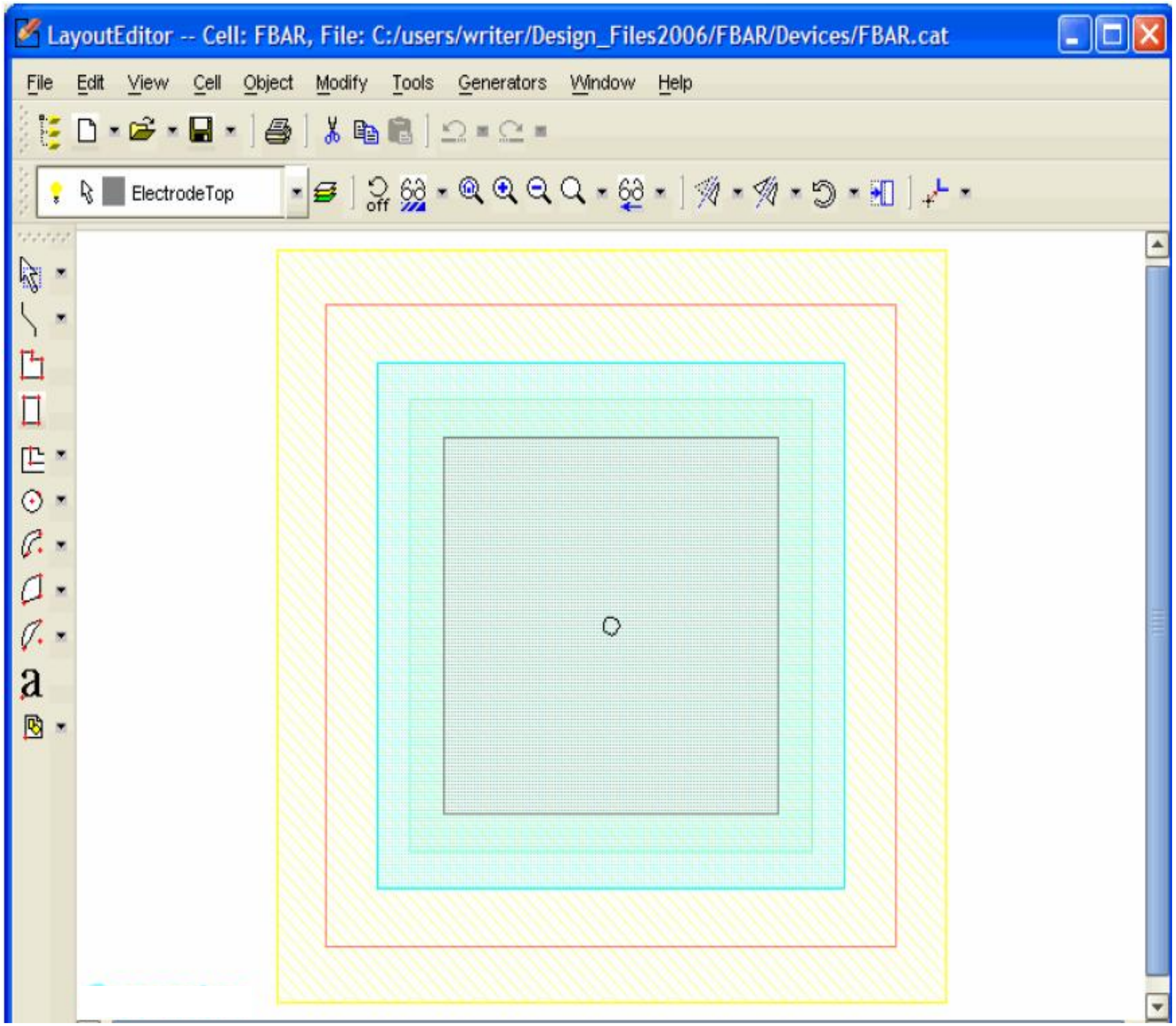
- This is the fabrication process we intend to use for our FBAR device. There are 12 steps which include straight cutting and stacking of the various materials.

Create the 2D Layout

- **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.

Create the 2D Layout (cont.)



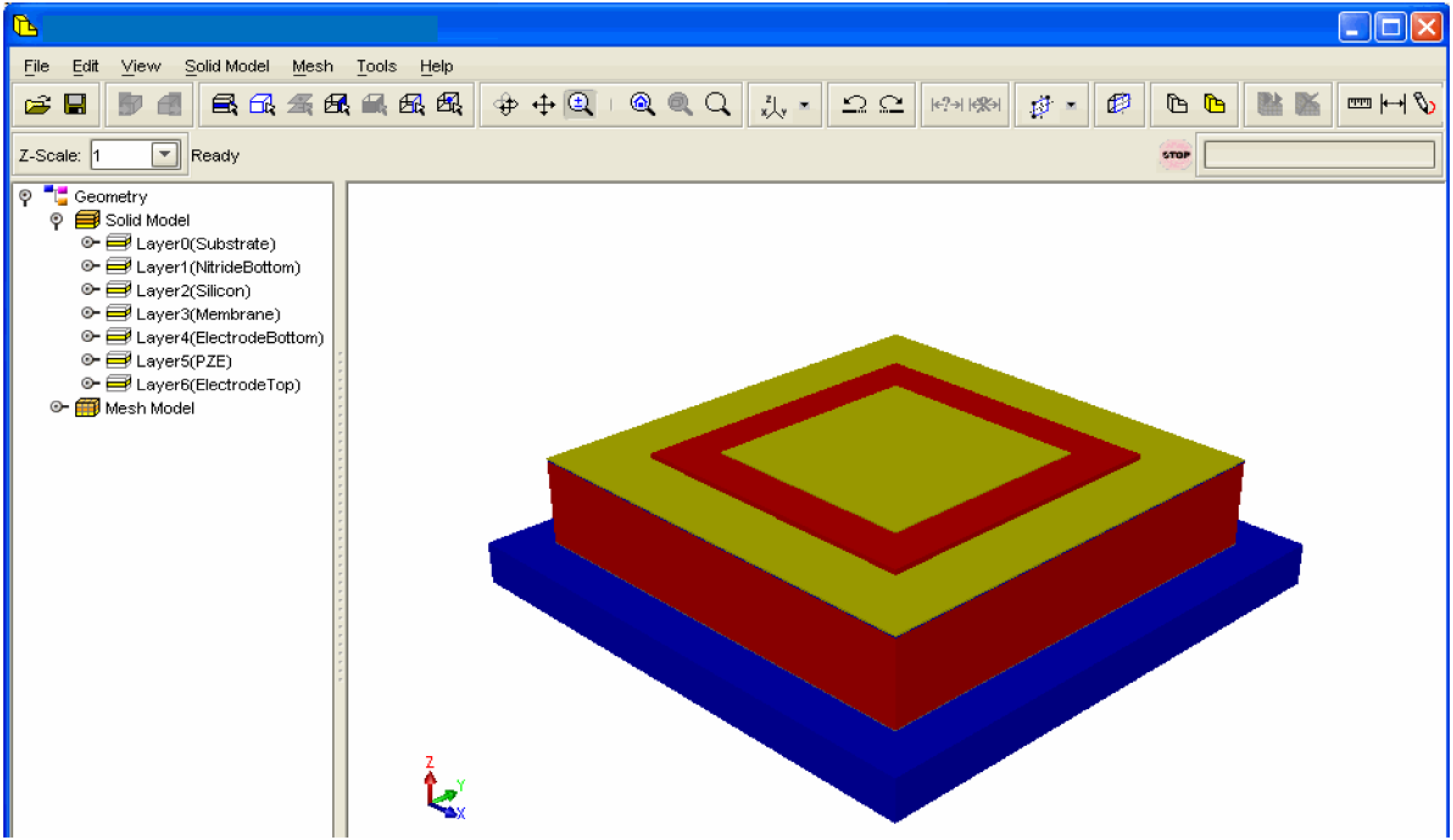
- You can see 5 different layers in this layout.
- You can draw rectangles, circles, triangles, and many other shapes in this layout editor.

3D Model

- **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.

3D Model (cont.)

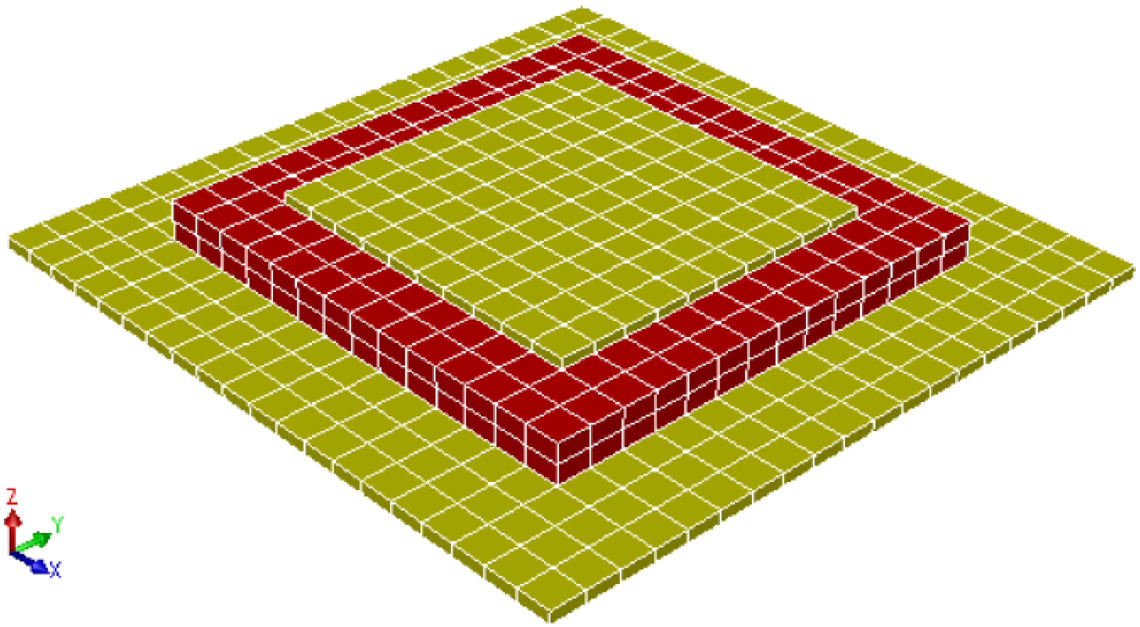


- Our data has been used to create the above 3D model.

Meshing

- 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.

Meshing (cont.)



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

Simulation

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

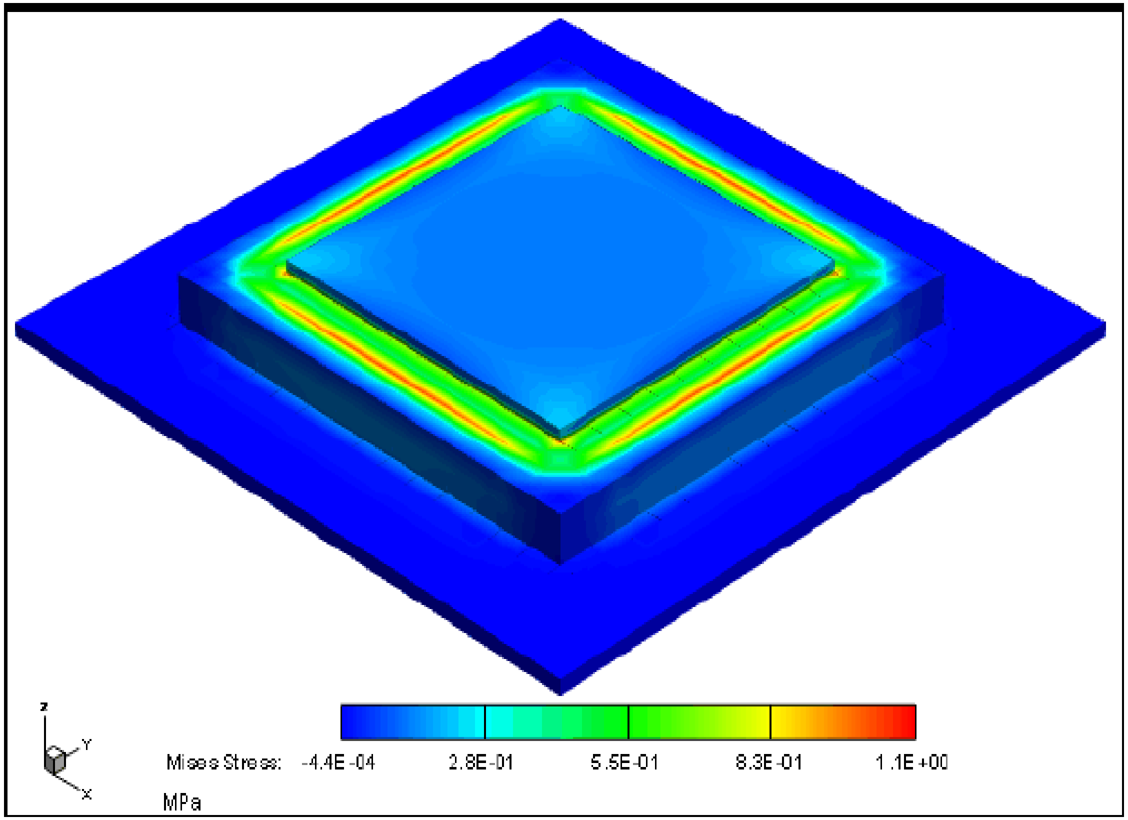
  * It is possible to simulate many physical phenomenon using this MEMS simulation packages such as pressure, conductivity, motion, DC analysis, and more.

Simulation (cont.)

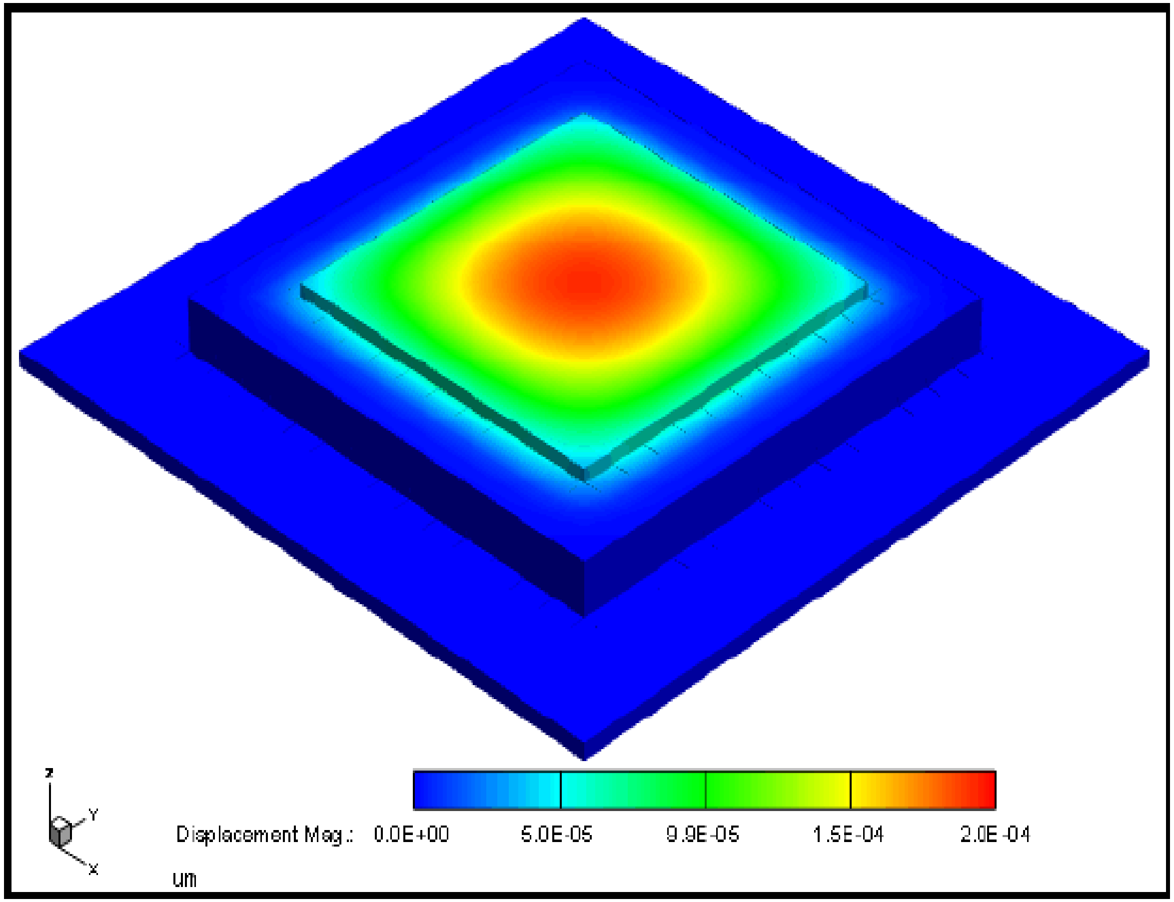
- **For our FBAR, we apply a 1V charge to the top and notice various aspects of change that occur.**

Simulation (cont.)

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



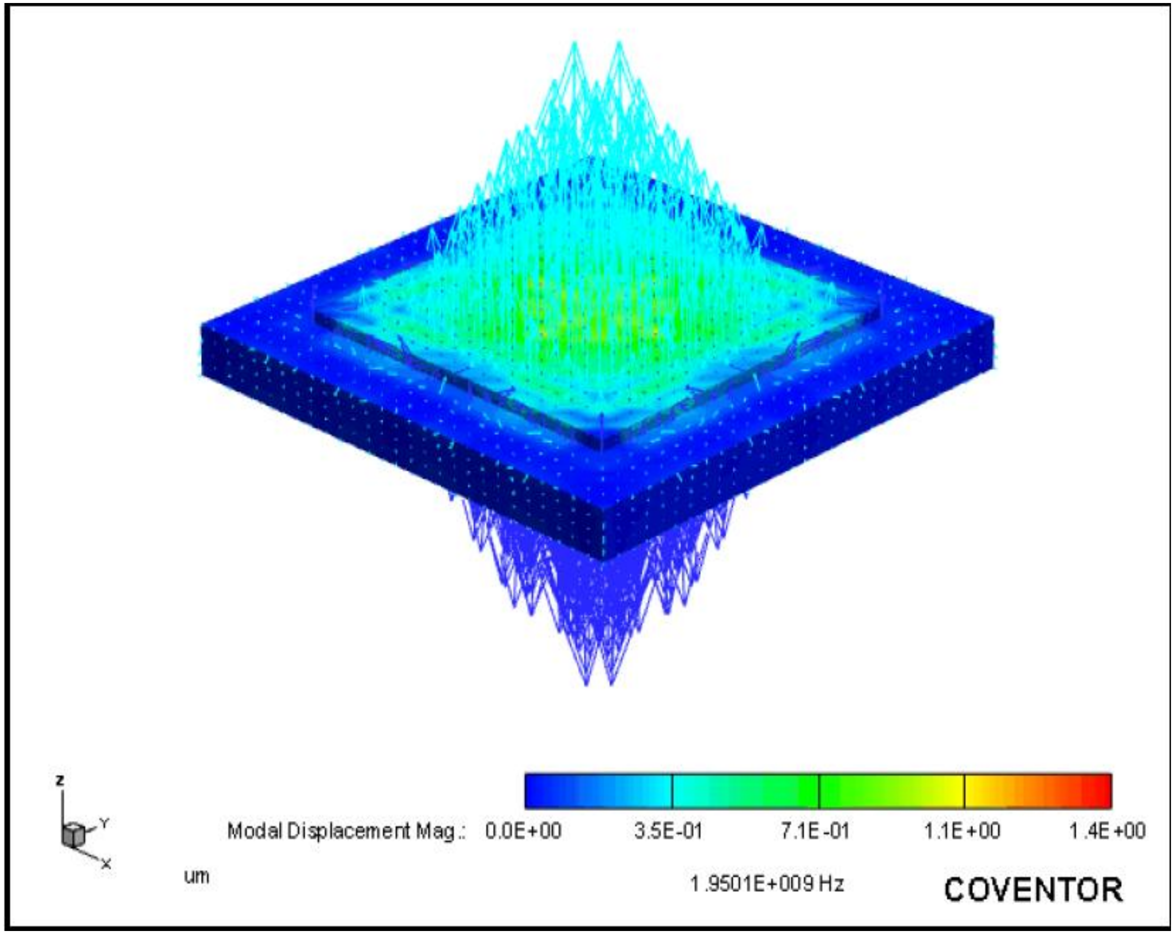
Simulation (cont.)



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

Simulation (cont.)

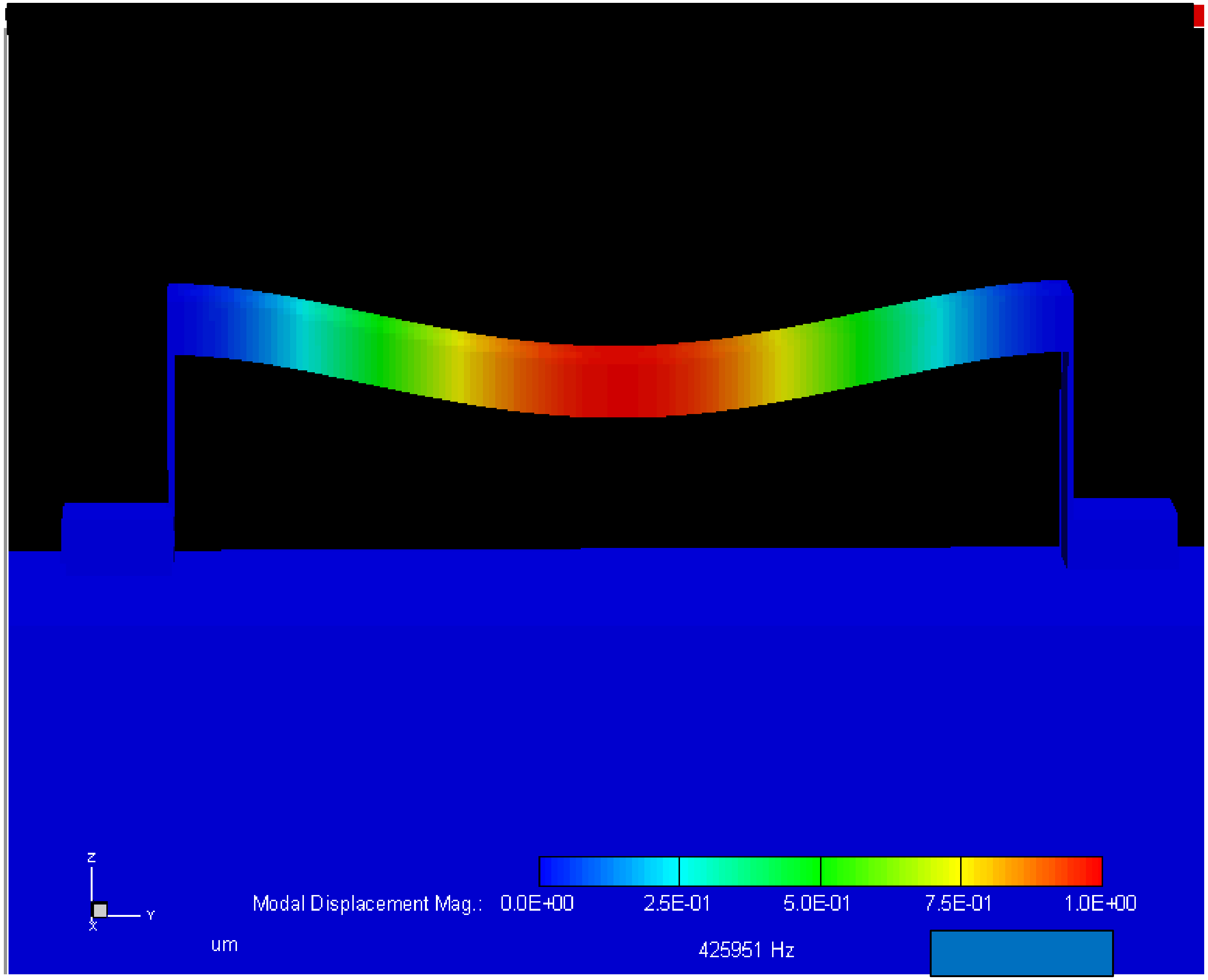
- **Here we see the resonance the 1V input causes our FBAR.**



Other Examples: Beam Vibrations

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

Beam Vibrations



RDECOM

Summary

TARDEC

- **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

Spintronics

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

Spintronics for Ground Vehicles

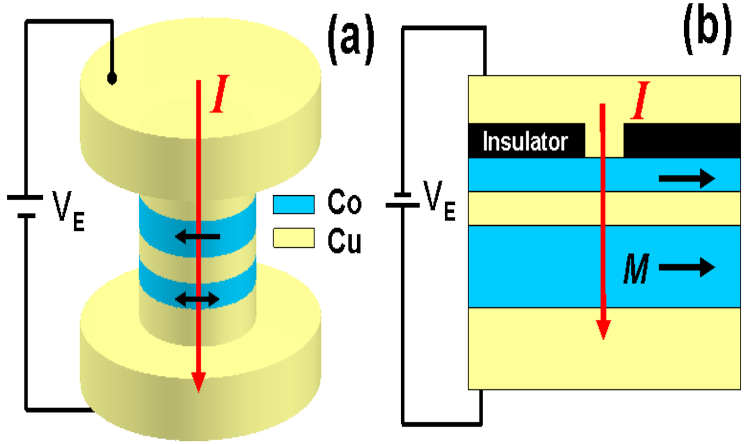
A technology has emerged called spintronics (spin transport electronics or spin-based electronics), where it is not the electron charge but the ***electron spin*** that carries information.

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

Nano structures for Embedded Armor Antennas and Radar Detectors



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).