ROCHESTER INSTITUTE OF TECHNOLOGY
MICROELECTRONIC ENGINEERING

History of MEMS at RIT

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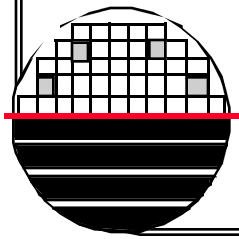


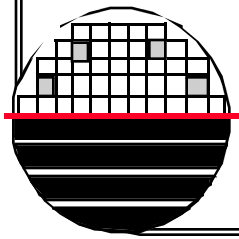
OUTLINE

MEMS Time Line at RIT
MEMS Technology Time Line at RIT

Examples of Research Projects in MEMS
Examples of Senior Project in MEMS
Examples of Masters Thesis Projects in MEMS
Examples of Course Projects in MEMS

Lots of Pictures and Movies of MEMS Devices

The examples in this presentation represents only a few of the many achievements in MEMS at RIT over the past 20 years

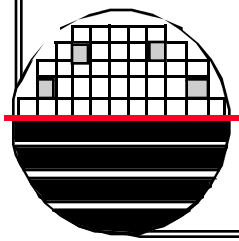


MEMS TIME LINE

1982 Microelectronic Engineering Program Starts
1986 RIT Dedicates Microelectronic Engineering Cleanroom 1987 First Graduates of MicroE and Start of RIT's First Full Time Masters Program in Engineering (ME MME)
1989 First MEMS Research Project – Industry Sponsor
1990 First Federally Funded MEMS Research Project
1991 First Senior Project on MEMS
1994 First MEMS Patent Issued to RIT
1995 Student Run Factory to Manufacture CMOS Devices
1996 First Masters Thesis on MEMS Devices
1997 Incubator to Provide Lab Access for Start Up Companies
1999 First MEMS Courses Taught at RIT
2000 First Short Course on MEMS for Industry People
2001 First MEMS Courses Taught in Mechanical Engineering
2002 Start of the Ph.D. Program in Microsystems Engineering
2003 First NSF Funded MEMS Curriculum Development Project and First MEMS Course Taught by EE
2011 First MEMS Ph.D. Student, Journal Publication, 2nd MEMS Patent

MEMS TECHNOLOGY TIME LINE

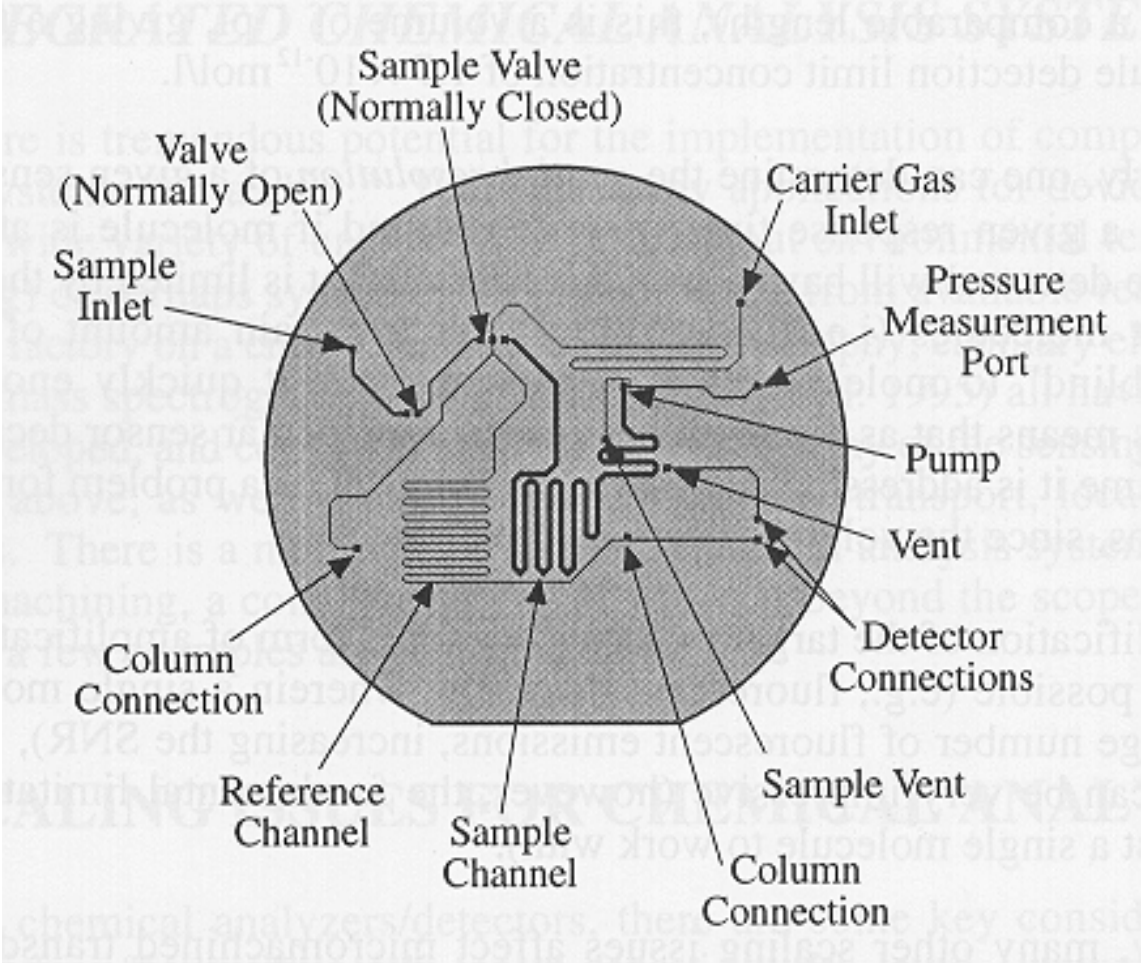
1982	2"& 3" Wafer Fab – Metal Gate PMOS
	Optical Pattern Generator and Maskmaking
	Contact Lithography
	Wafer Saw and Wire Bonder
1986	4" Wafer Fab – Metal Gate PMOS
	Stepper Lithography
1987	E-Beam Maskmaking
1989	LPCVD Poly, Nitride, LTO
	Reactive Ion Etch
	Ion Implant
1991	CMOS Capability
1995	MESA Work-in-Process Tracking System
1999	6" Wafer Fab – CMOS Capability
	CMP Tools
2002	Deep Trench Etch Tool
	PE CVD Tool
2010	ASML Stepper



FIRST MEMS RESEARCH PROJECT - MICRO GAS CHROMATOGRAPHY

1989 Dr. Lane, Dr. Fuller, David Price and Perkin Elmer Co

Research Project to make gas chromatograph channels in silicon wafers.



RIT'S FIRST MEMS PATENT – DR. LANE, 1994

US005357803A

United States Patent [19]

Lane

[11] **Patent Number: 5,357,803**

[45] **Date of Patent: Oct. 25, 1994**

[54] **MICROMACHINED MICROACCELEROMETER FOR MEASURING ACCELERATION ALONG THREE AXES**

[75] Inventor: **Richard L. Lane**, Penfield, N.Y.

[73] Assignee: **Rochester Institute of Technology**, Rochester, N.Y.

[21] Appl. No.: **866,667**

[22] Filed: **Apr. 8, 1992**

[51] **Int. Cl.**[5] **G01P 15/13**

[52] **U.S. Cl.** ..... **73/517 B**; 361/280

[58] **Field of Search** ..... 73/517 B, 517 R, 516 R; 361/280, 283.1; 310/309; 384/439

[56] **References Cited**

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4,932,261	6/1990	Henrion .	
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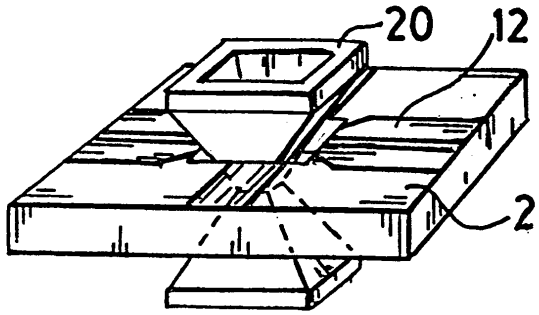
F. Rudolf, et al., "Silicon Microaccelerometer", *Transducers '87, Rec. of the 4th Int. Conf. on Solid–State Sensors and Actuators*, 1987, pp. 395–398.

Primary Examiner—John E. Chapman
Attorney, Agent, or Firm—Nixon, Hargrave, Devans & Doyle

[57] **ABSTRACT**

The present invention relates to a microaccelerometer employing a single free-mass and capable of measuring acceleration along three coordinate axes, and a process for fabricating through micromachining and microelectronic techniques a microaccelerometer employing a free-mass. A microaccelerometer preform is constructed by chemically coating and etching a silicon wafer to form a support member and a free-mass surrounded by the member. The free-mass is movable with respect to, but constrained by the silicon support member. Acceleration measurements are obtained by circuits which sense changes in the position of the free-mass with respect to an equilibrium position, induced by a change in the rate of acceleration of the accelerometer, and the electromagnetic force required to restore the free-mass to its equilibrium position.

18 Claims, 6 Drawing Sheets



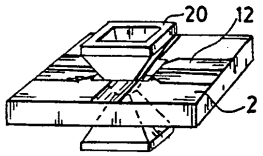


FIG. 15

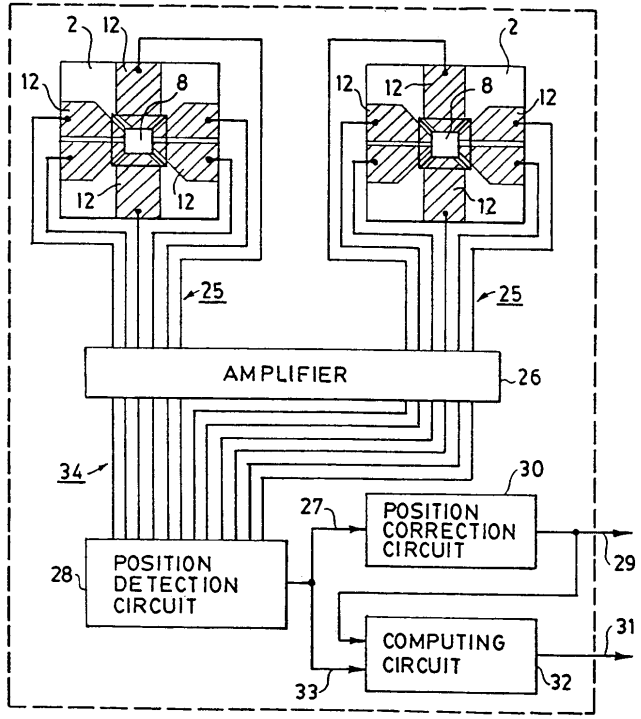
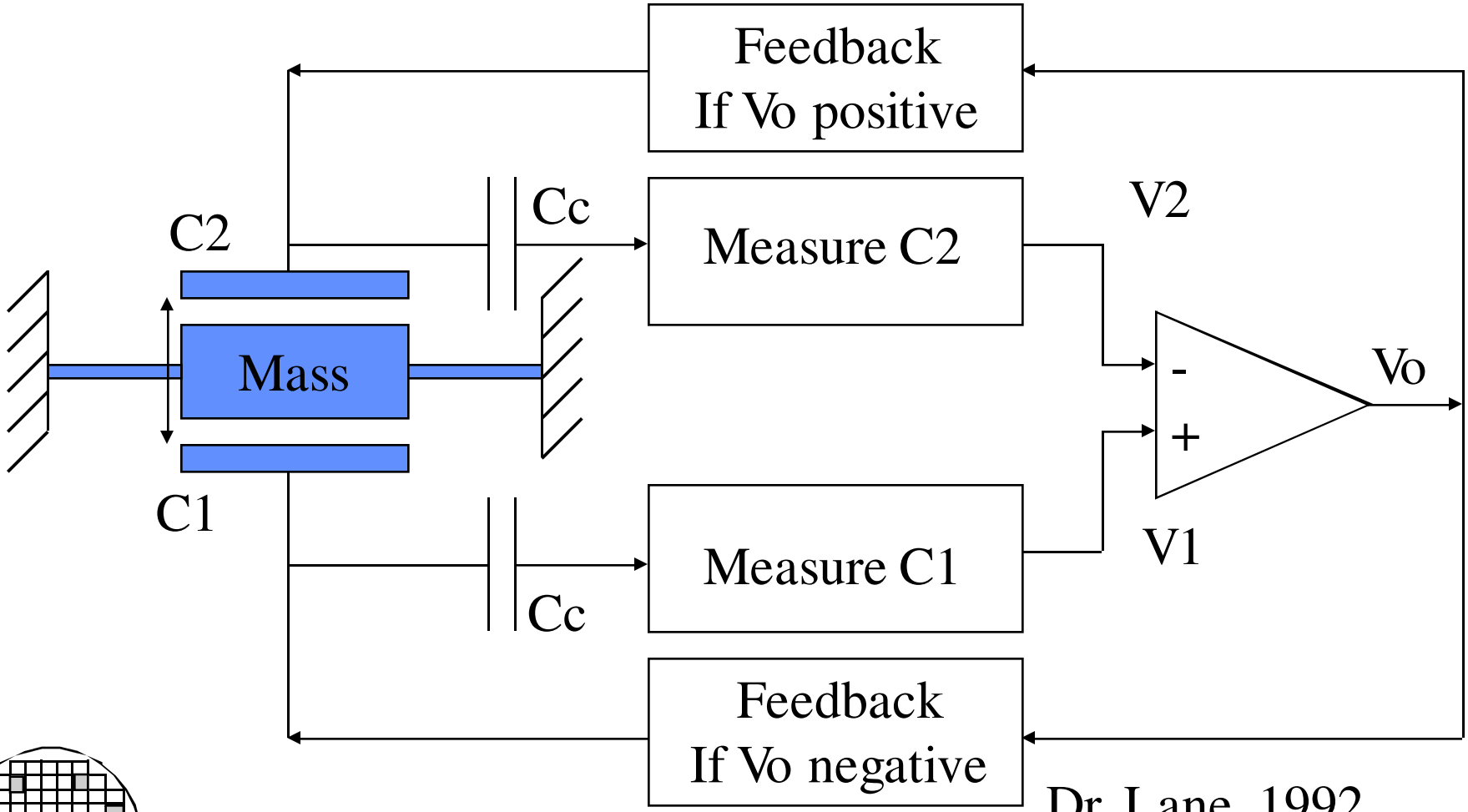


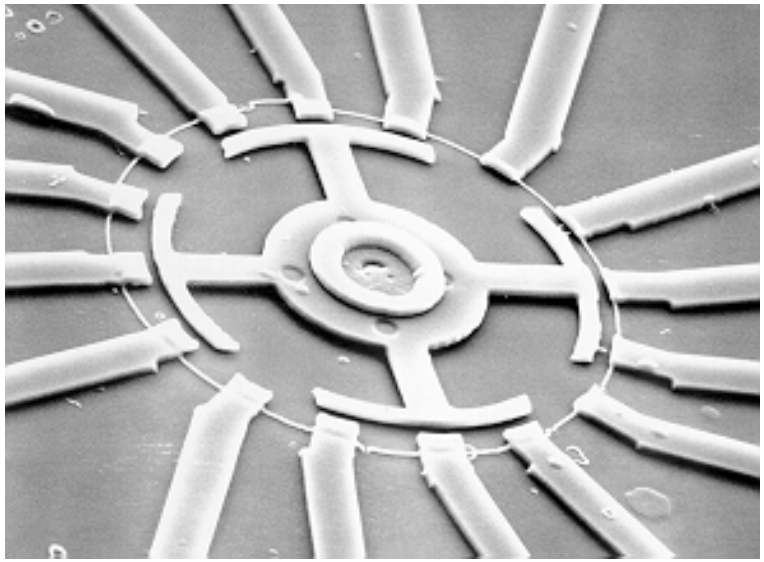
FIG. 16

FORCE BALANCE ACCELEROMETER MICRO SYSTEM

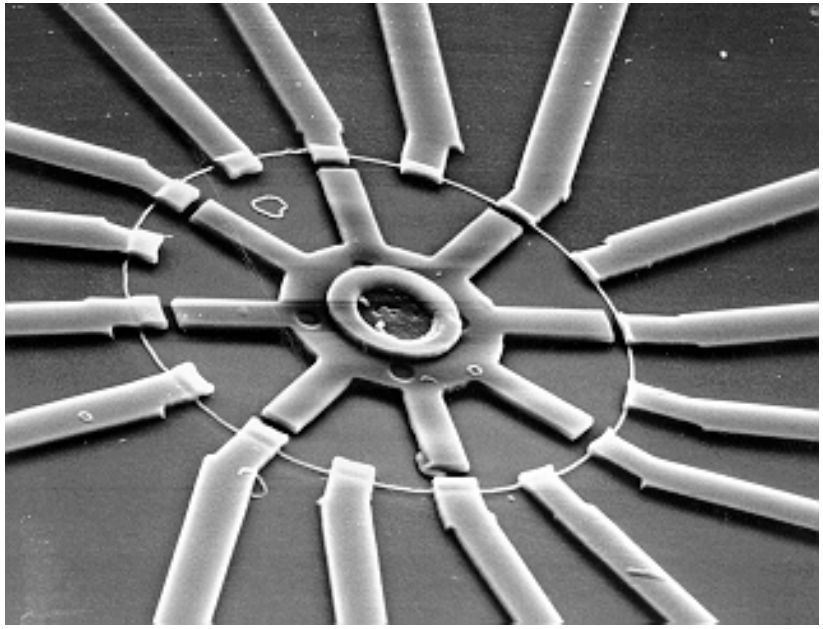


Dr. Lane, 1992
Bell Aerospace, Inc.

RIT'S FIRST MICRO MOTORS – SENIOR PROJECT



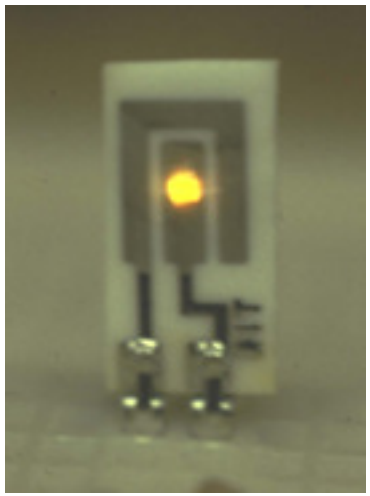
100 µm



Matt Matessa, 1991, BSµE,
Joined Cypress Semiconductor
San Jose, CA

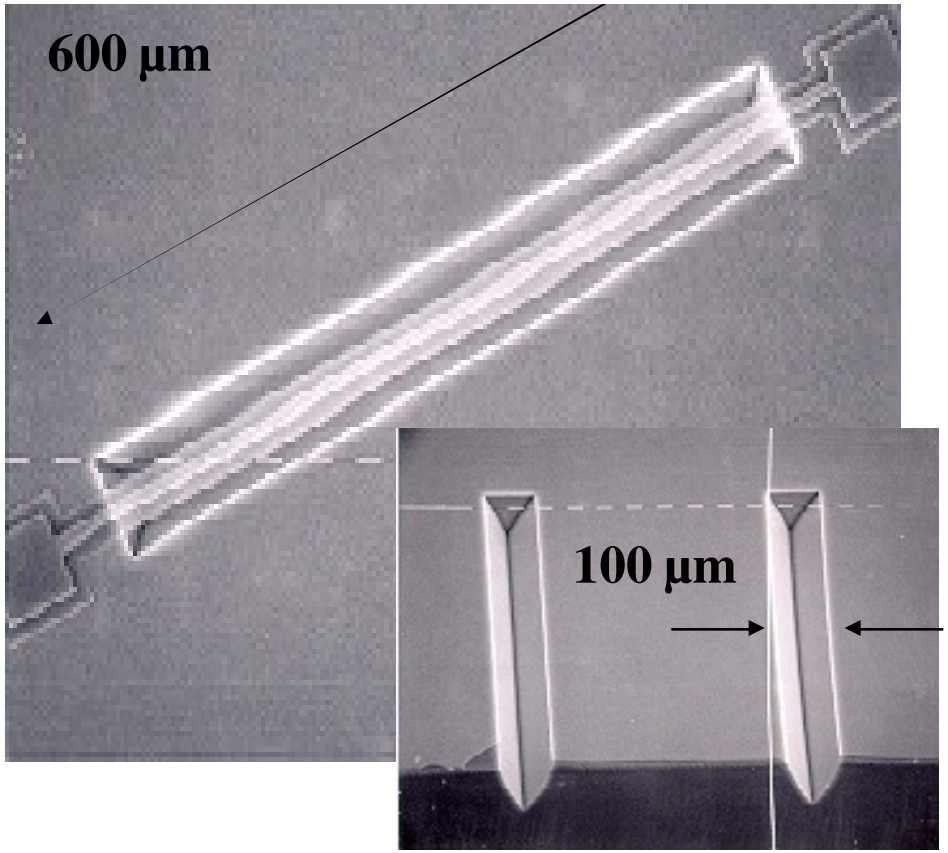
RIT'S FIRST PHOTONIC DEVICES – SENIOR PROJECT

Dave Borkholder, 1994, after graduation from RIT joined Ph.D. program in EE at Stanford University Palo Alto, CA

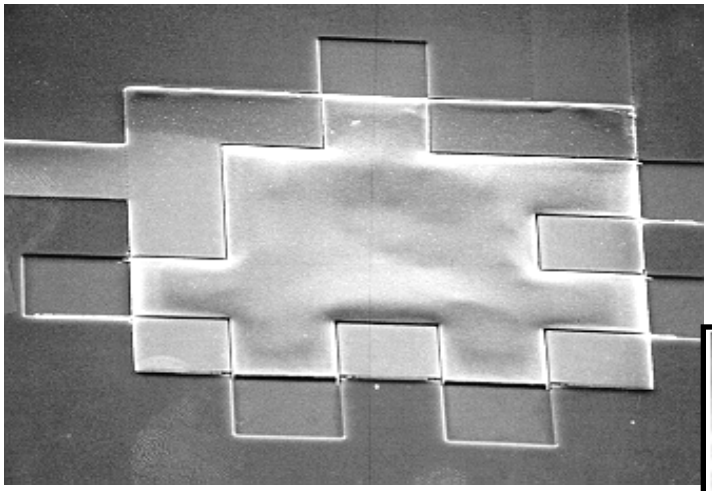


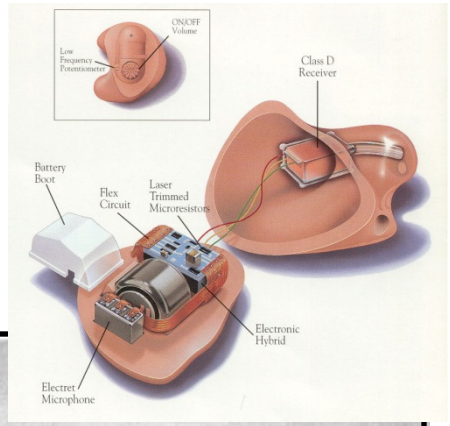
GaP wafers with n-type epilayer, add gold metal, dice and wire bond to RIT thick film ceramic package.

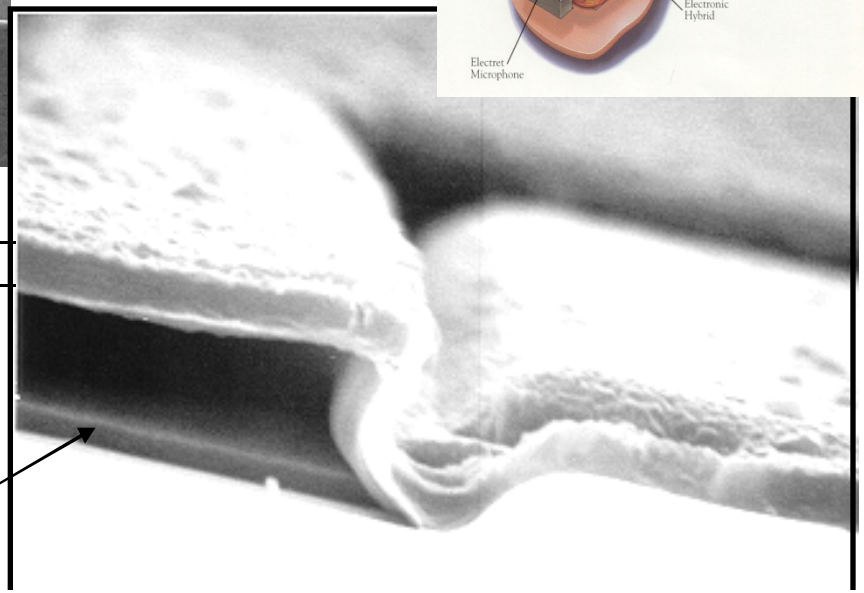
HOT FILAMENT LIGHT SOURCES



CAPACITOR MICROPHONE – SENIOR PROJECT







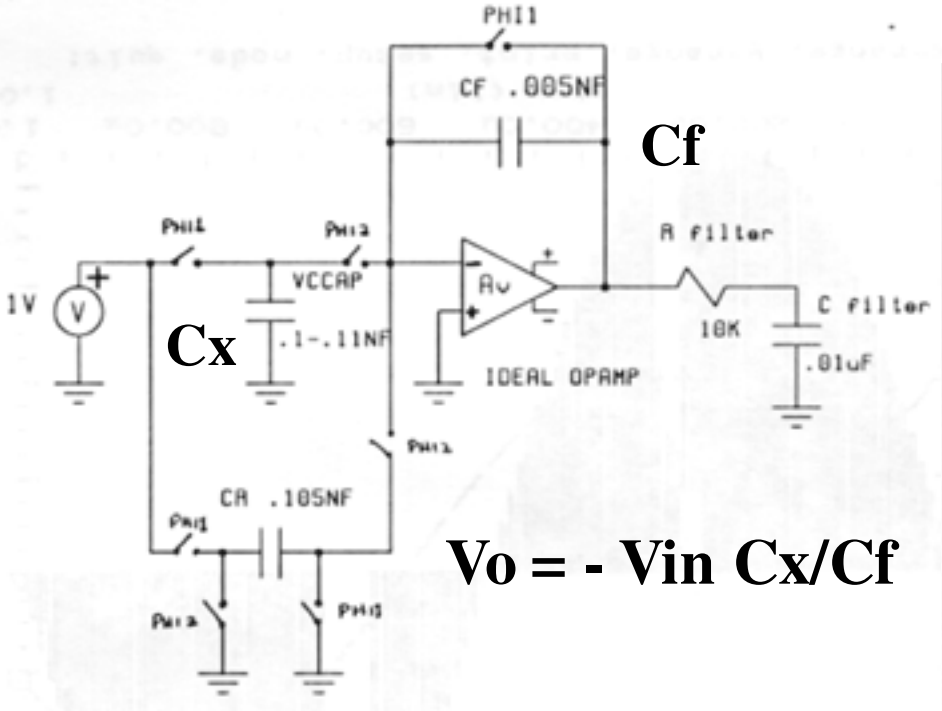
1 μm Aluminum

Jon Stephan, 1995, joined Intel Corporation Folsom, CA

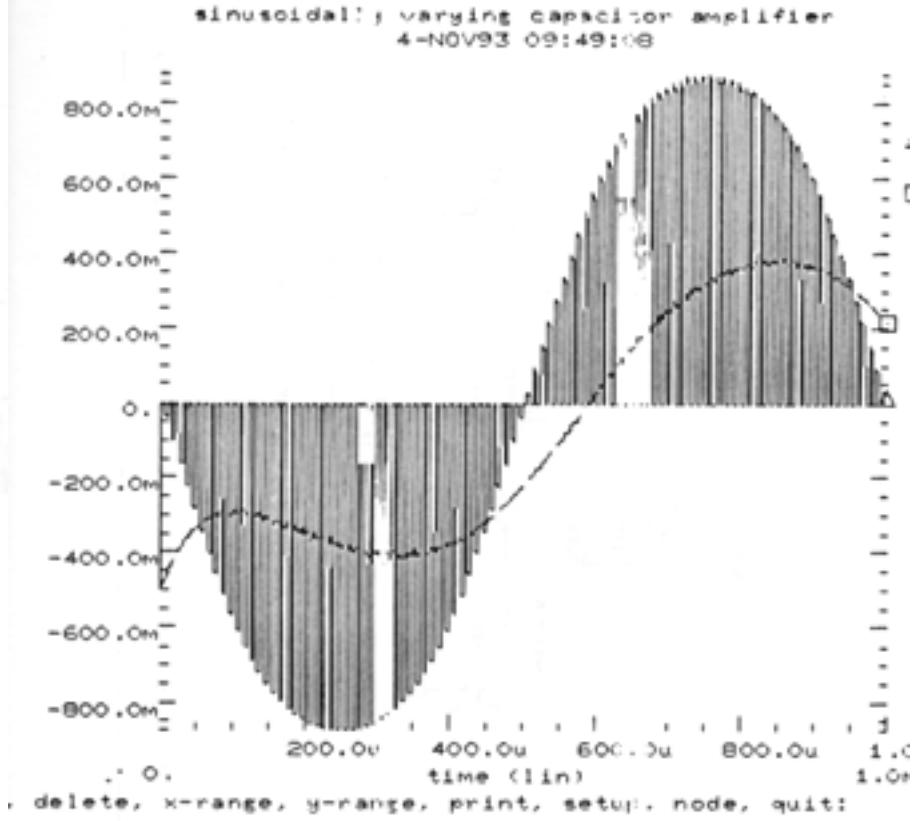
2.0 μm Gap

ALUMINUM DIAPHRAGM CAPACITIVE MICROPHONE

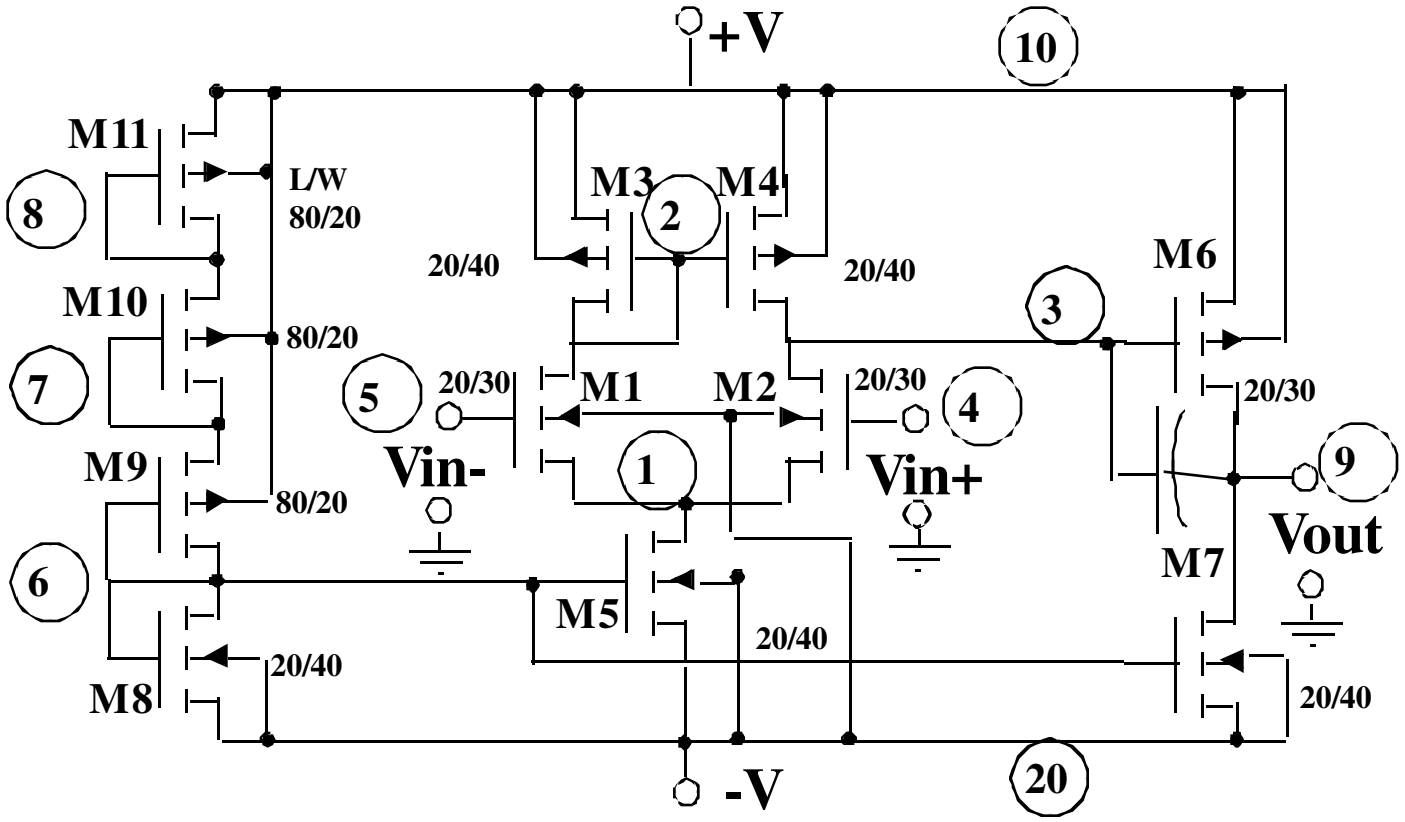
CAPACITANCE MEASUREMENT CIRCUIT SIMULATION AND DESIGN - MASTERS THESIS



$$Vo = - Vin\ Cx/Cf$$



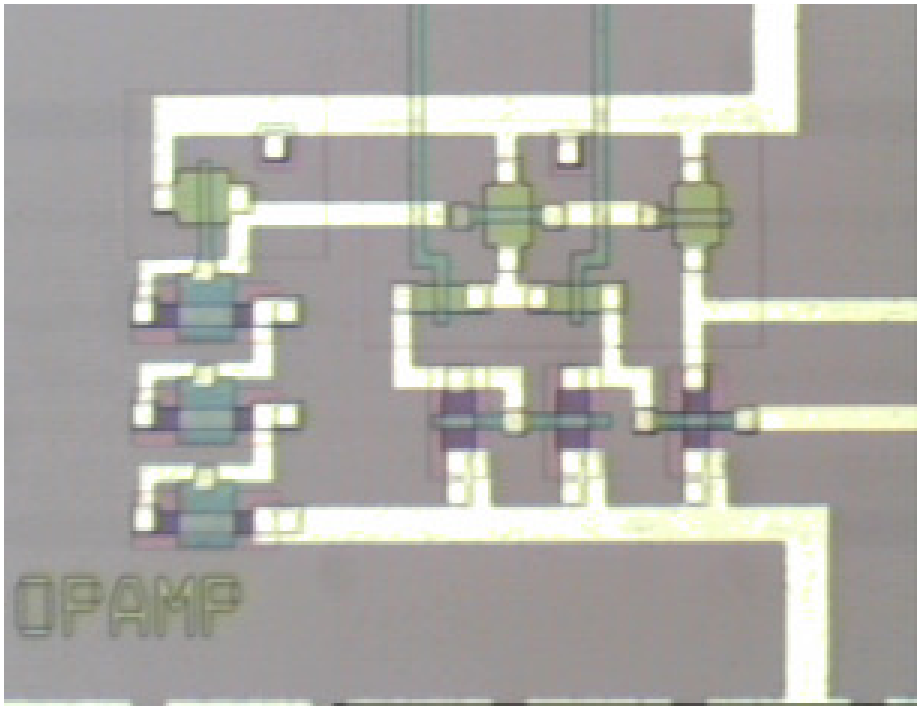
CMOS OPERATIONAL AMPLIFIER – MASTERS THESIS



p-well CMOS

dimensions
L/W
(µm/µm)

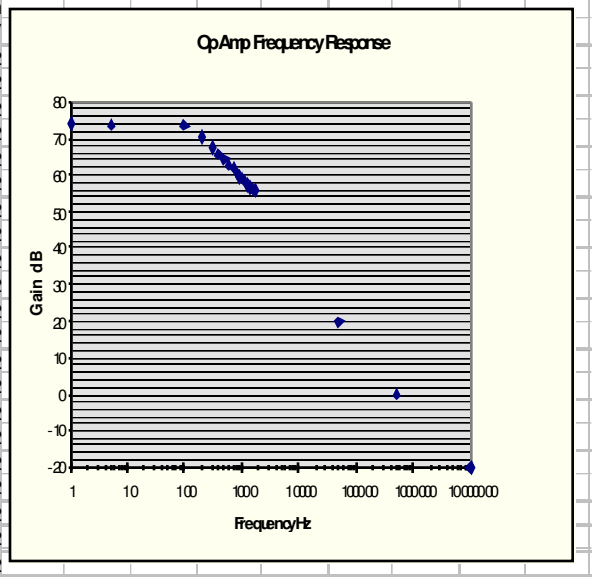
CMOS OPERATIONAL AMPLIFIER – MASTERS THESIS



ROCHESTER INSTITUTE OF TECHNOLOGY
MICROELECTRONIC ENGINEERING LFF OPAMP.XLS FILE3B

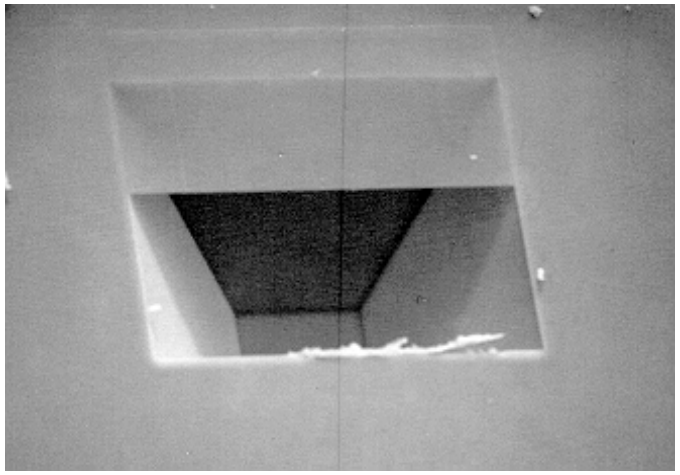
LOTF960319 OPAMP TEST RESULTS - 1-29-97

Frequency hZ	Gain dB	Vout V	Vin mV
1	73.9794	10	2
5	73.53887	9.5	2
100	73.33036	9.28	2
200	70.31748	6.56	2
300	67.53154	4.76	2
400	65.48316	3.76	2
500	63.97314	3.16	2
600	62.41148	2.64	2
700	61.51094	2.38	2
800	60.34067	2.08	2
900	59.46256	1.88	2
1000	58.68997	1.72	2
1100	58.0618	1.6	2
1200	57.50123	1.5	2
1300	57.14665	1.44	2
1400	56.5215	1.34	2
1500	56.1236	1.28	2
1600	55.56803	1.2	2
50000	20	0.02	2
500000	0	0.002	2
10000000	-20	0.0002	2



Ed Sayer, MSEE 1991, joined Digital Equipment Corp., Hudson, MA

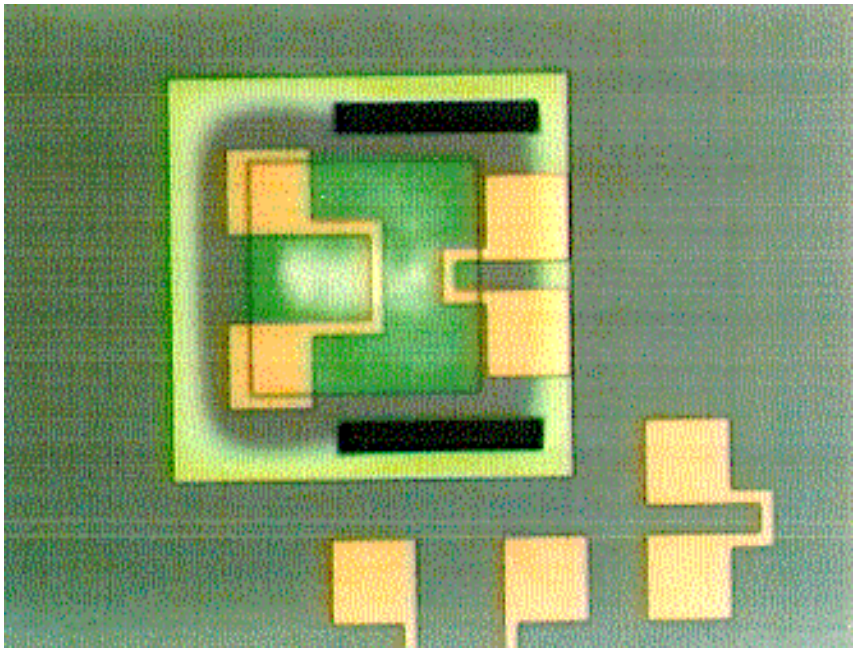
TOP SIDE BULK MICROMACHINED PRESSURE SENSORS – SENIOR PROJECT



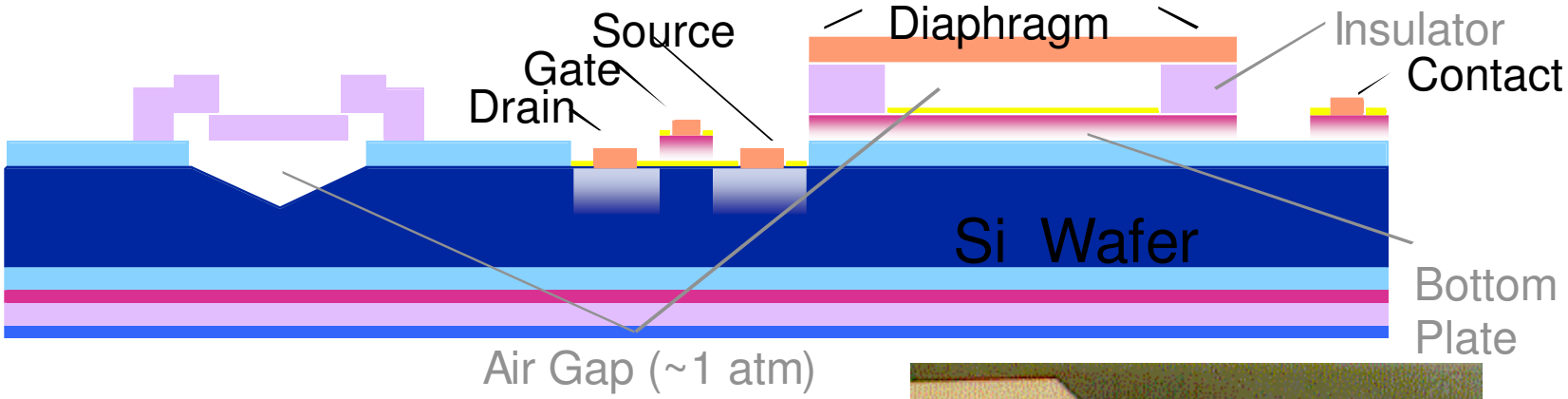
300 µm

Jason Trost, 1995 BSµE, joined Harris Semiconductor Mountaintop, PA

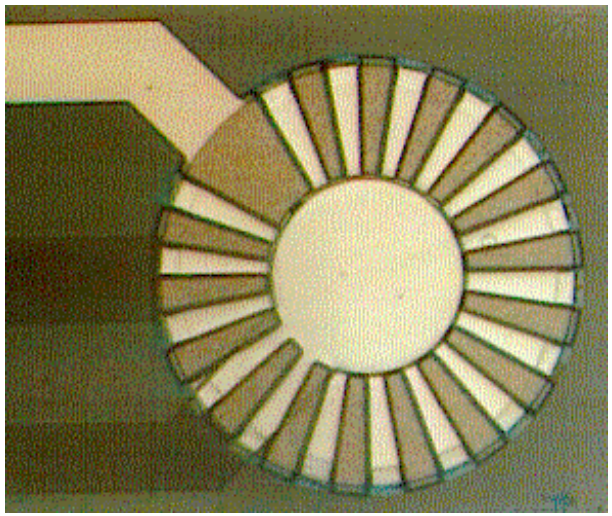
Pressure Sensor with Nitride Diaphragm and Poly Piezo Resistors over Bulk Etched Cavity



NIH FUNDED RESEARCH ON PRESSURE SENSORS

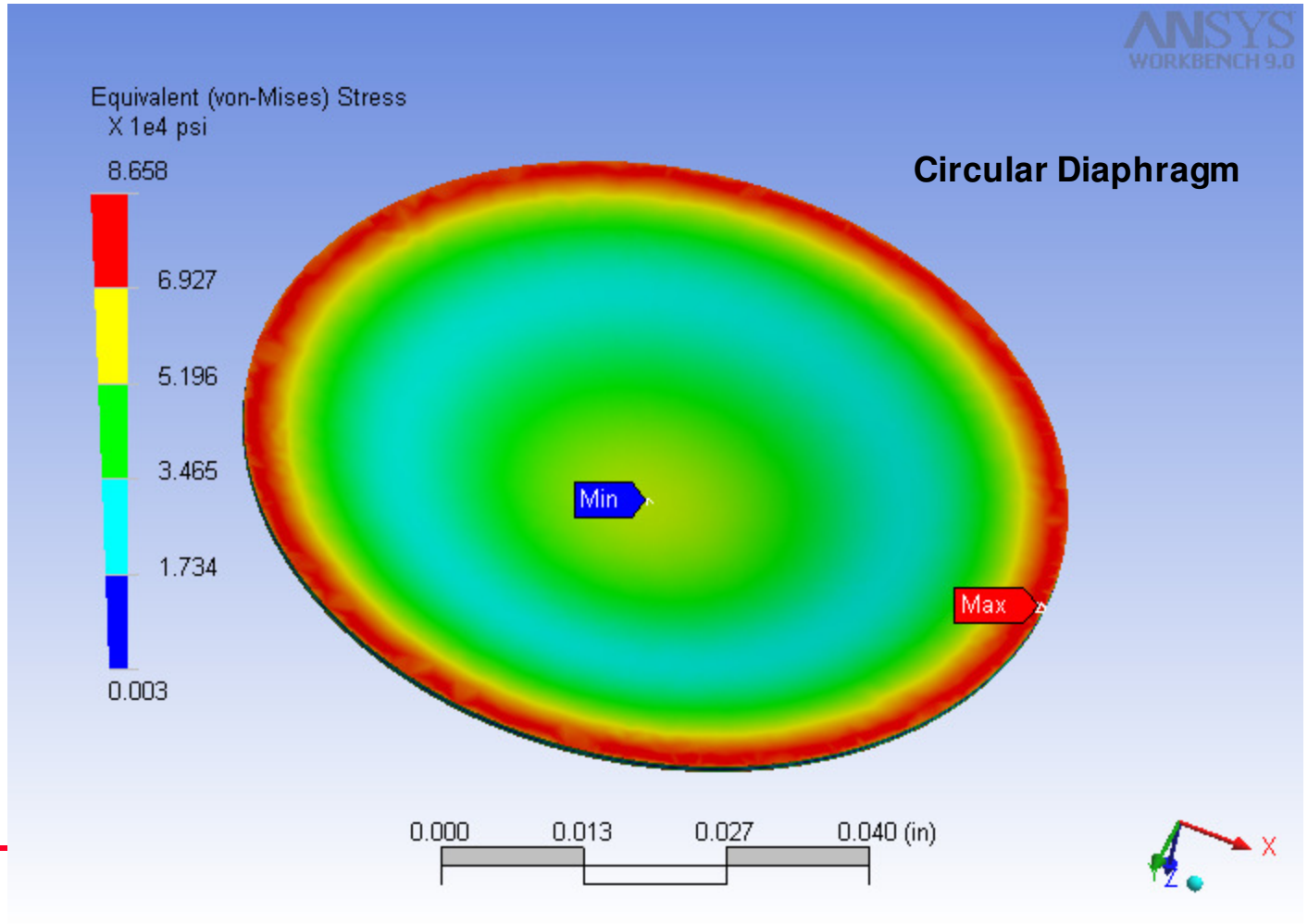


Kerstin Babbitt, 1997
BSEE U of Rochester, joined Motorola, Austin, TX

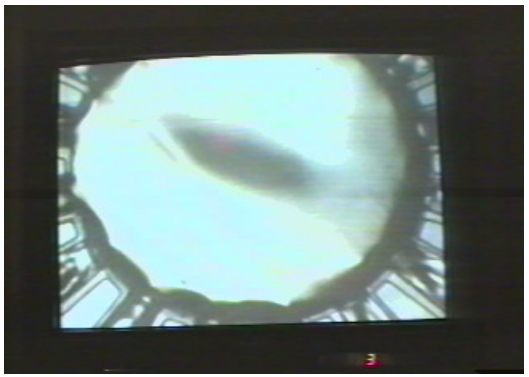


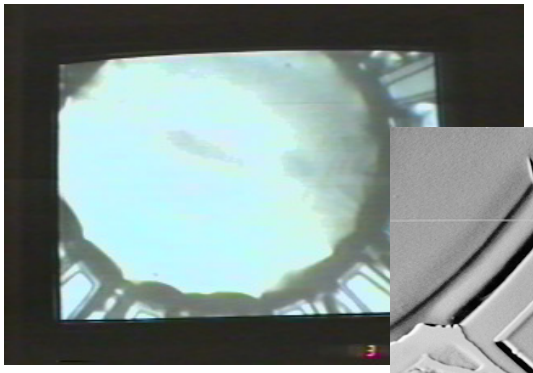
FINITE ELEMENT ANALYSIS

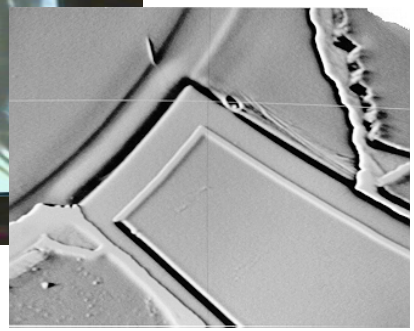
2mm x 2mm Crystalline Silicon Diaphragms 30µm thick 50psi

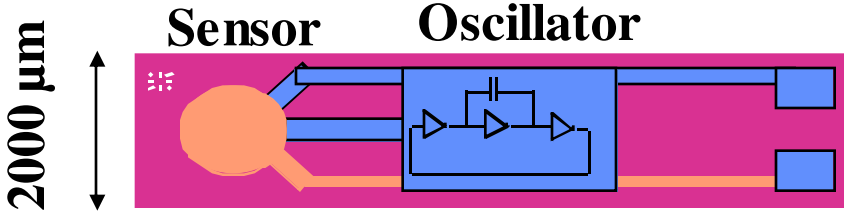


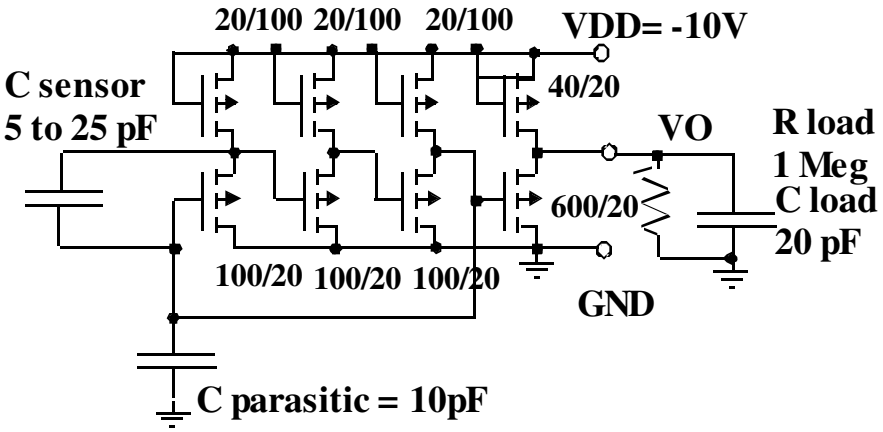
NIH FUNDED RESEARCH ON PRESSURE SENSORS FIRST MEMS DEVICE WITH INTEGRATED ELECTRONICS

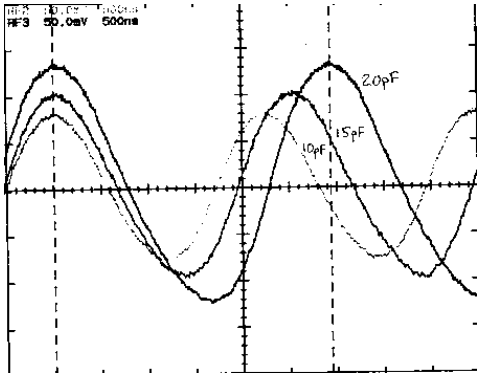






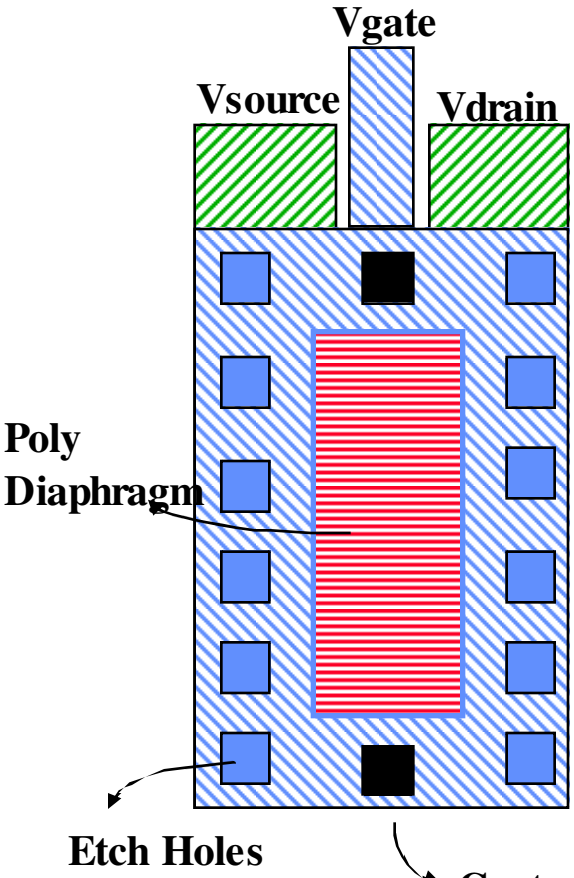


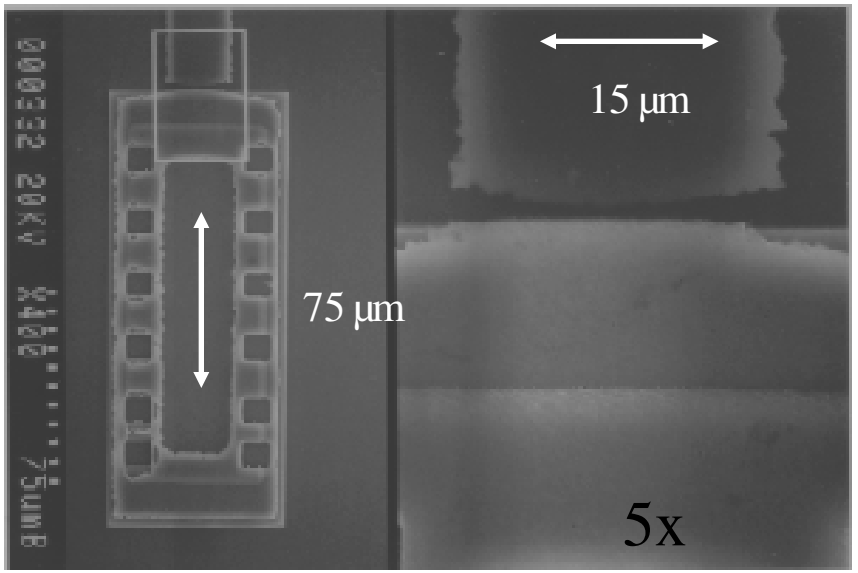


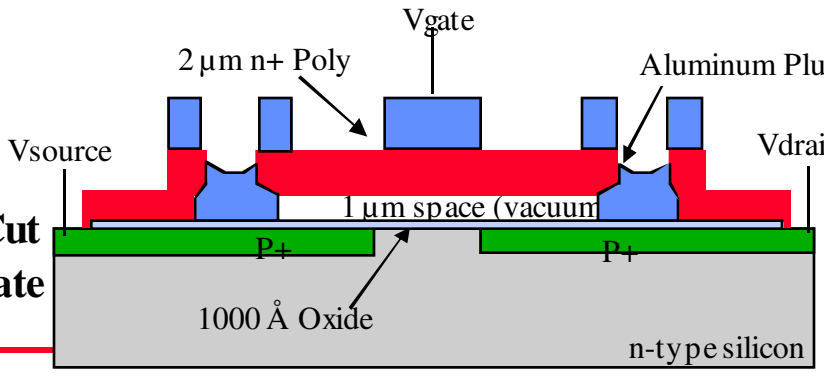


0 to 5 mm Hg Pressure Range

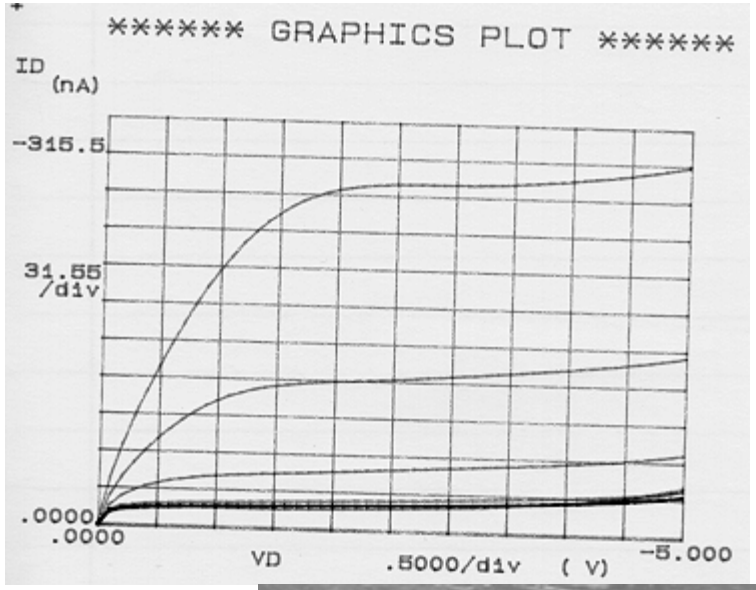
NIH FUNDED RESEARCH ON PRESSURE SENSORS



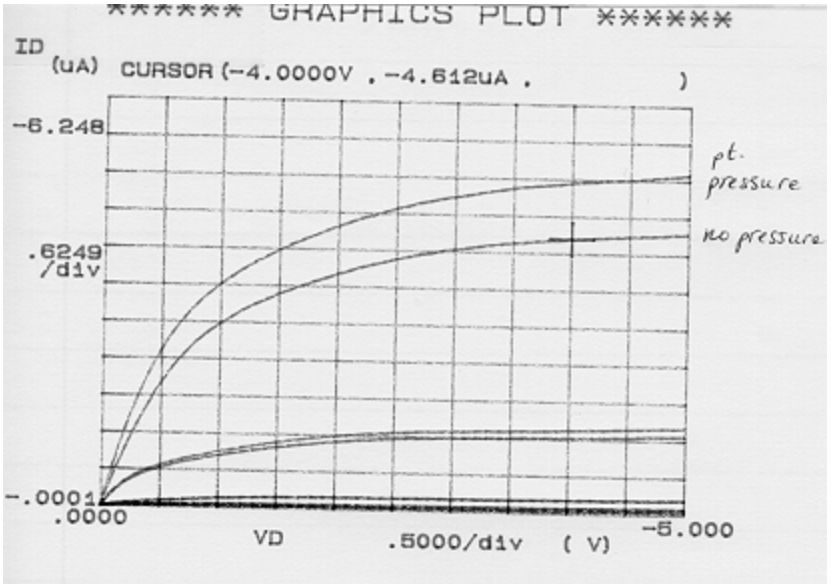


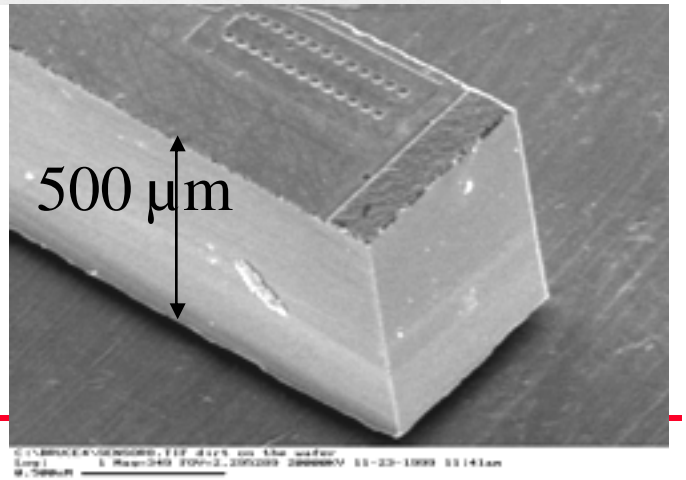


NIH FUNDED RESEARCH ON PRESSURE SENSORS

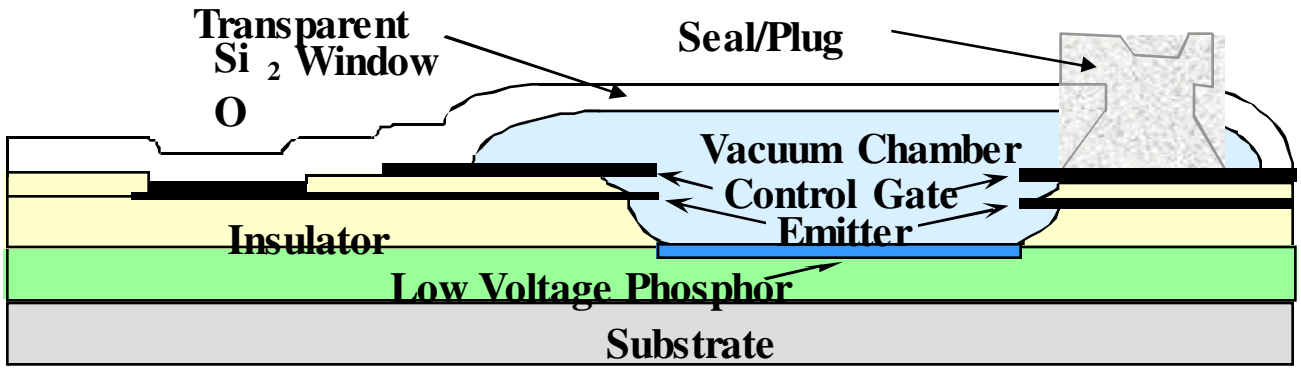


Kerstin Babbitt 1997, Motorola
Stephanie Bennett 1997, ASML
Sheila Kawati 1998, Syracuse Medical School
An Pham 1999, Integrated NanoTechnology
Dr. Lynn Fuller



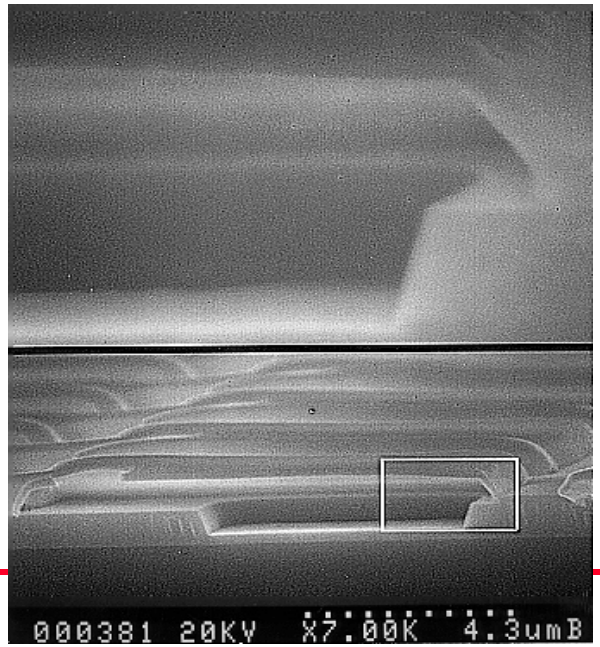


INCUBATOR - ADVANCED VISION TECHNOLOGY INC.

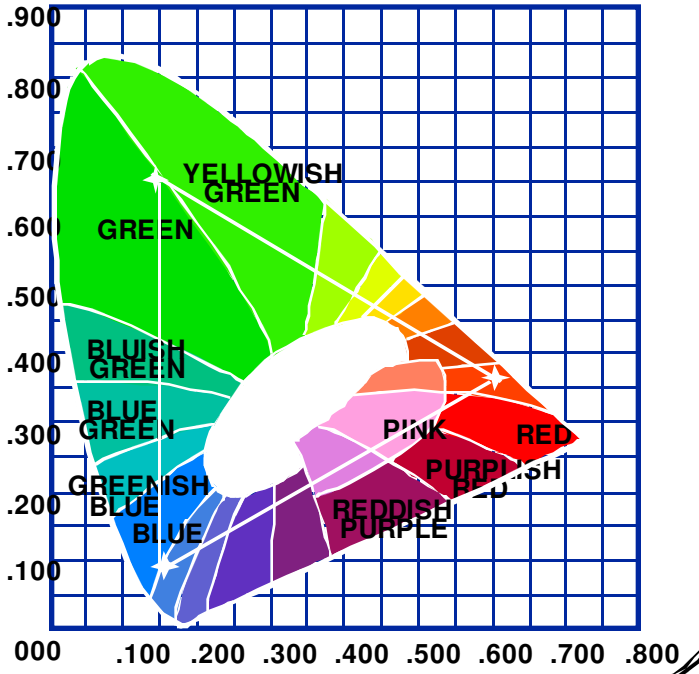


Integrated Phosphor Field Emission Device

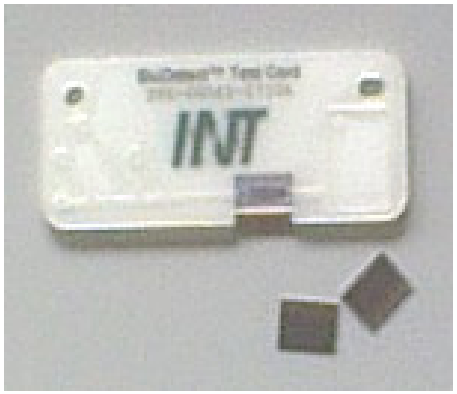
Micro-encapsulated Chamber



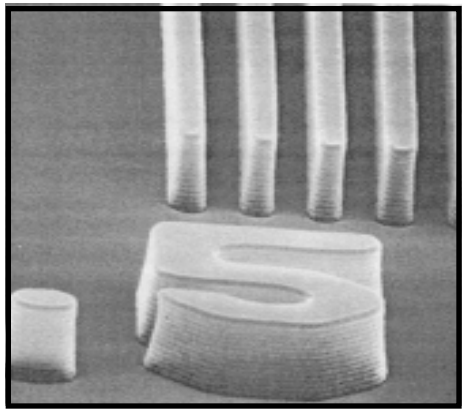
Color Chart of AVT Phoshors



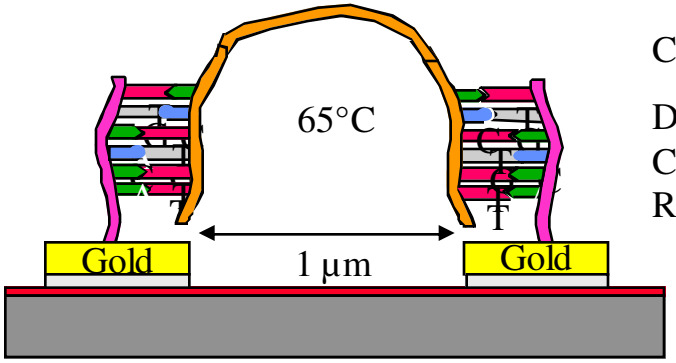
INCUBATOR – INTEGRATED NANO-TECHNOLOGIES, LLC



INT Bio-Detect Card



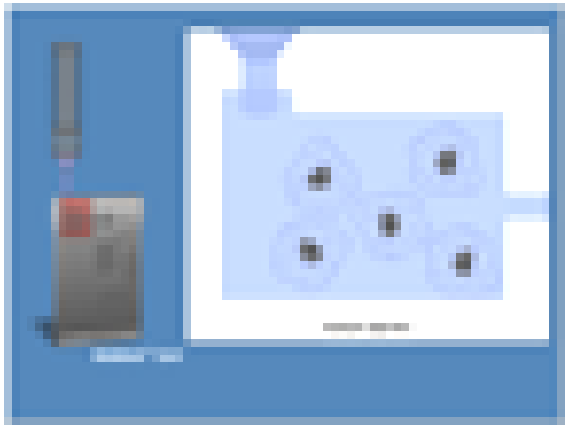
Hybridization



Courtesy of

Dr. David Chafin and Dr. Rick Murante

Because the DNA is hybridized to a probe DNA with 15 matching base pairs, the probability that the attached DNA is the desired DNA is one billion to one or better. (i.e. 4^{15})



FIRST MEMS PROJECT BETWEEN COE AND COS

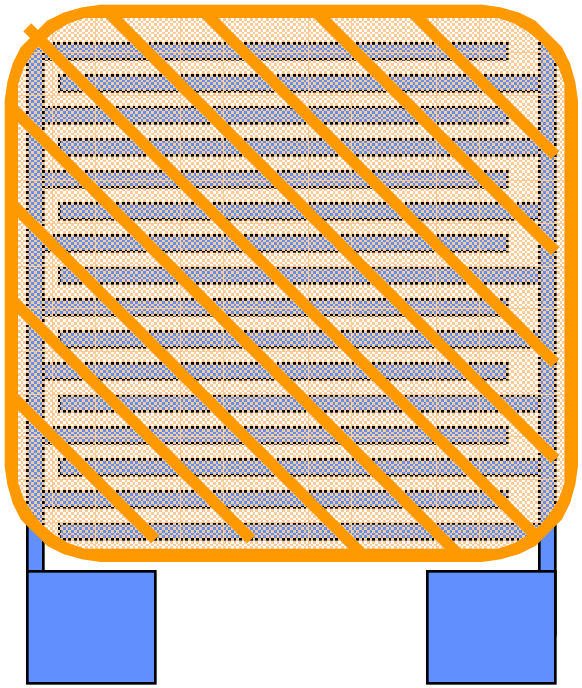
CHEMIRESISTOR

Simple inter-digitated electrodes coated with a chemically sensitive layer that changes the resistance in response to a few ppm of some (or many) chemicals

Copper-substituted Phthalcyanine conductive polymer is sensitive to CCl4, NH3 and N2O

or

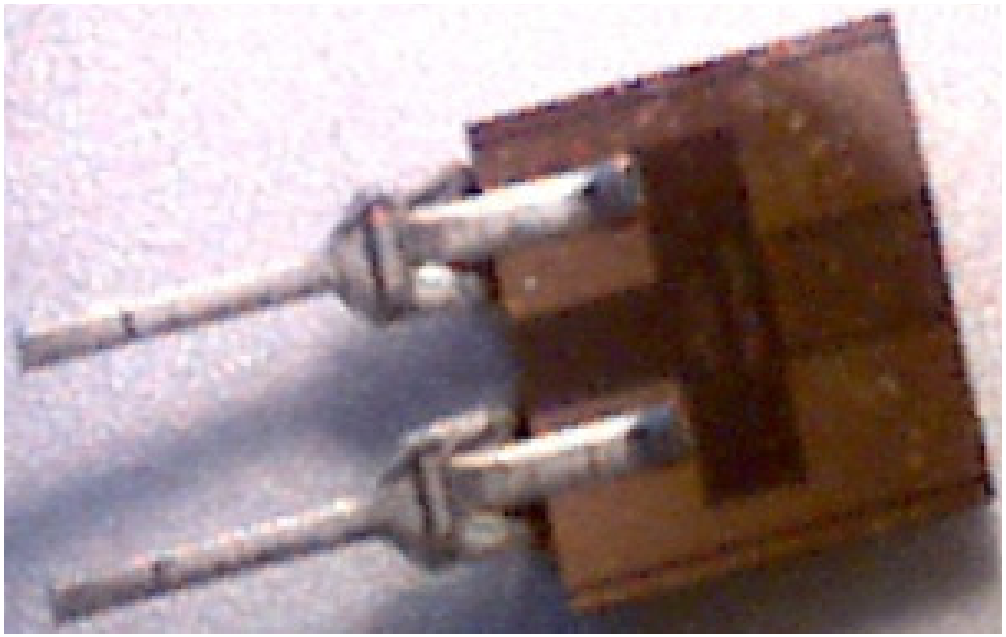
Carbon Nano-Tubes and various polymers

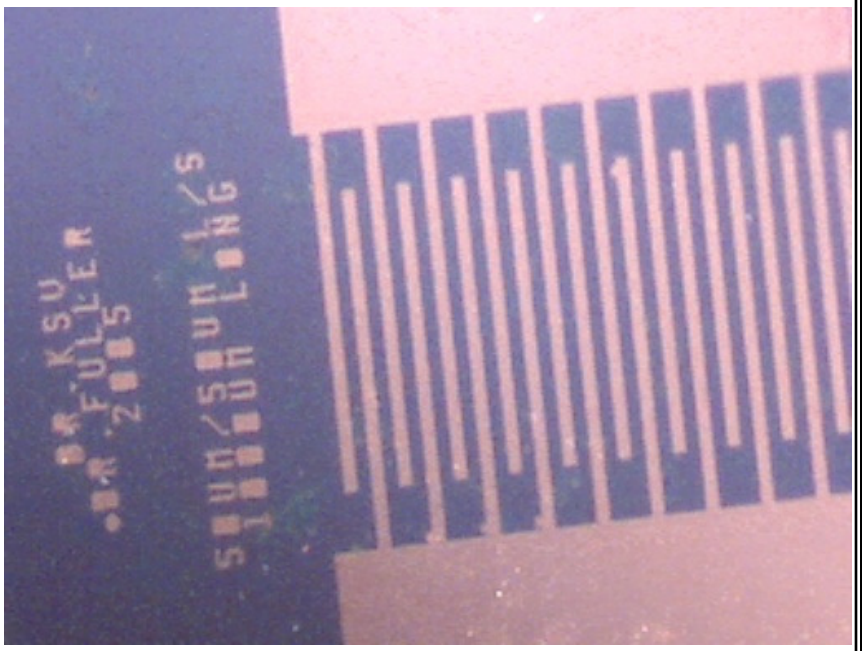


Resistor with
25µm gaps
25µm length
7250µm width

Dr. Lynn Fuller
Dr. KSV Santhanam
Yatin Prayag 1999

CHEMICAL SENSORS



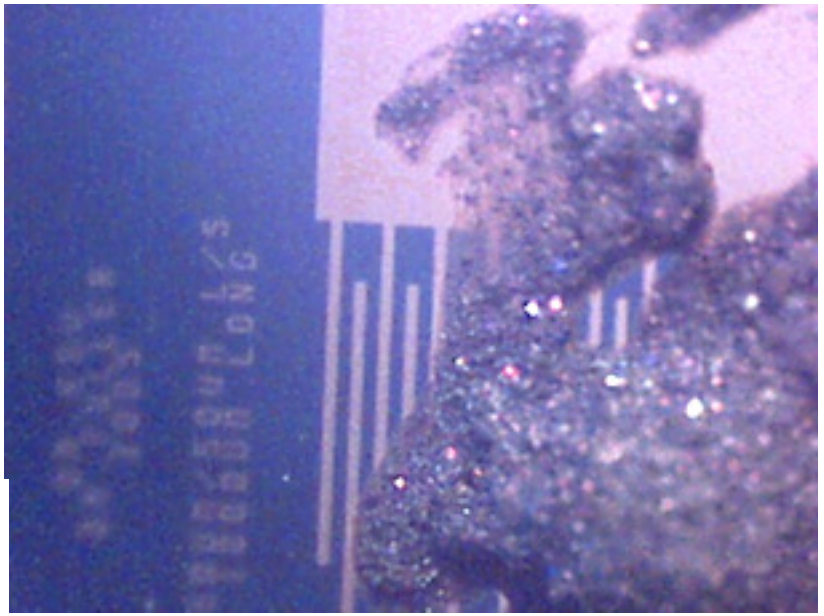


Upper Left: Finished Sensor with chip pins
Upper Right: Close up of interdigitated gold fingers

Elizabeth Gregg 2005

CHEMICAL SENSORS

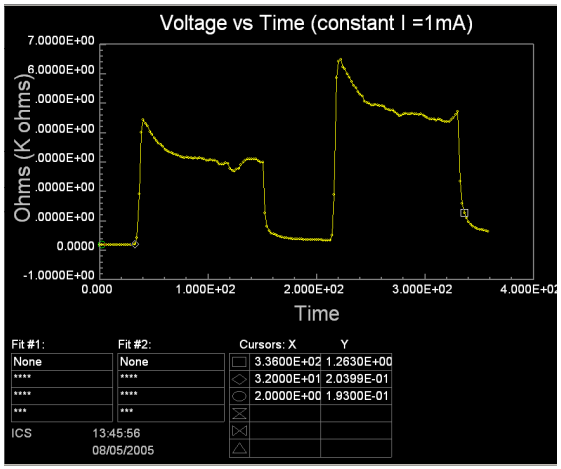
Mix a polymer with Carbon Black and apply a thin coat over interdigitated gold fingers



Testing

30s off, 120s on, 60s off, 120s on, 30s off 0.1 ml Acetone/ 125 ml bottle = 800 ppm

Resistance goes from ~100 ohms (no vapor) to ~ 4,000 ohms (with vapor)

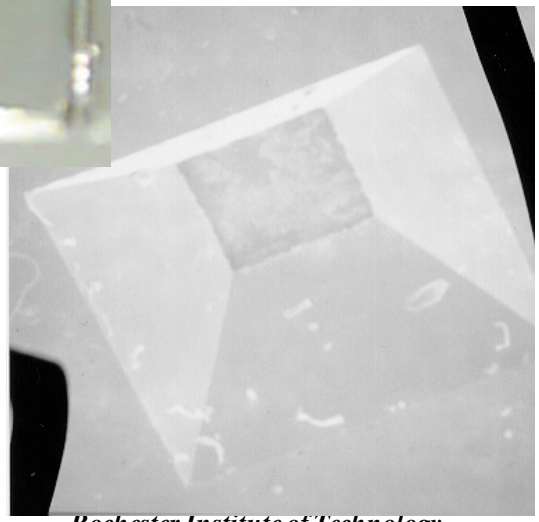


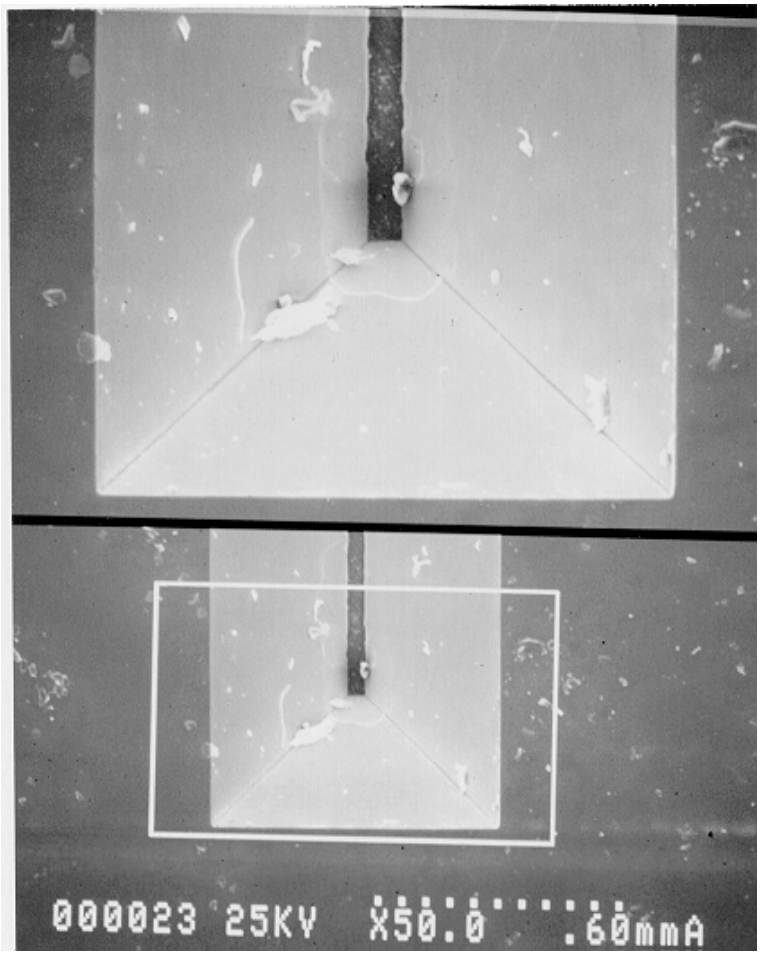
FIRST MECHANICAL ENGINEERING MEMS RESEARCH PROJECT

FLOW PLATES FOR FUEL INJECTION

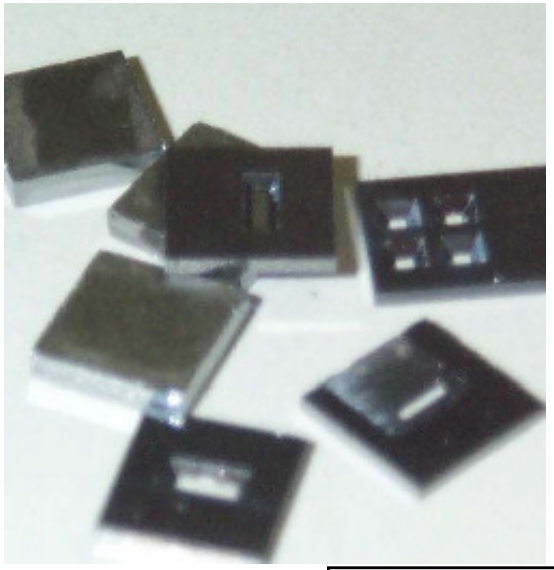
Variety of different size and shape holes etched through 500 µm thick silicon wafer

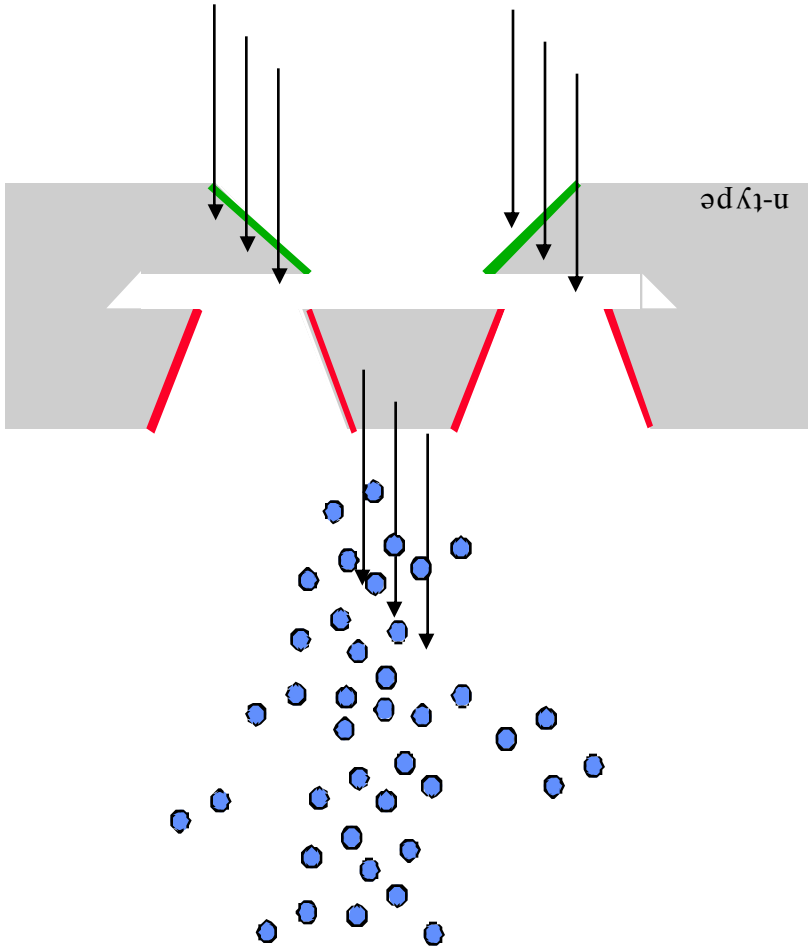
Dr. Risa Robinson
Delphi Products, Inc.

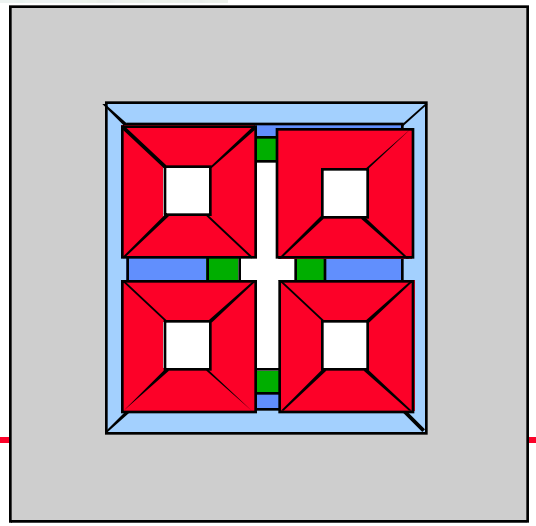




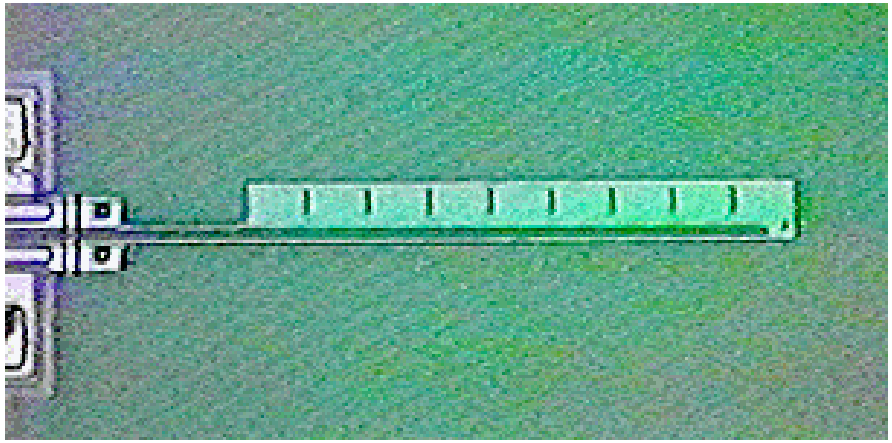
BULK MICROMACHINED ATOMIZER FOR DRUG DELIVERY



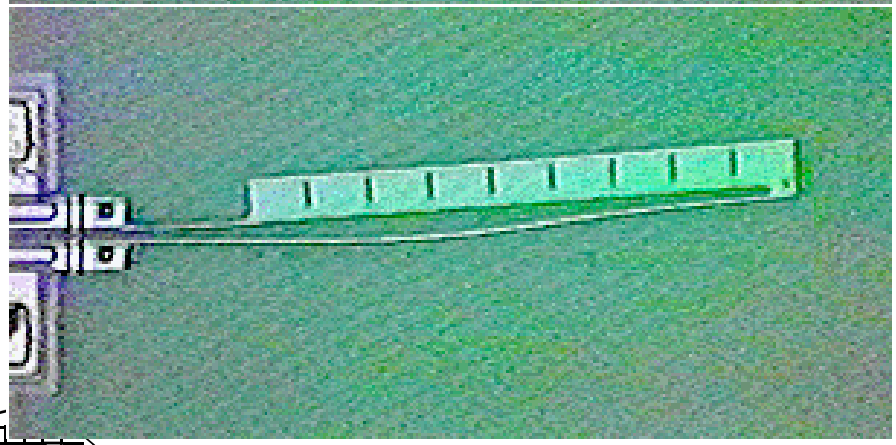




MEMS THERMAL ACTUATOR MASTERS THESIS



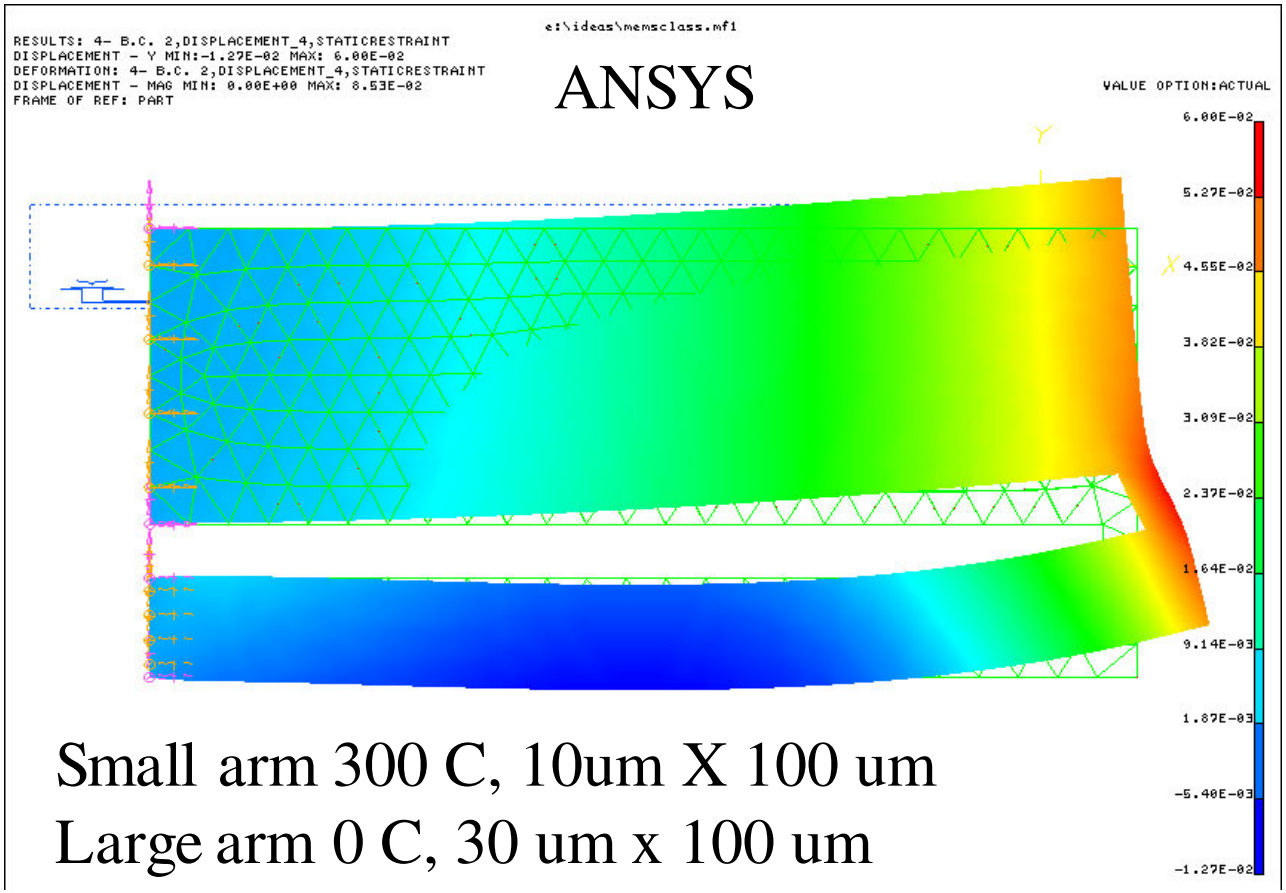
Current Flow = zero



Current Flow = 10 mA

Skinny arm is hotter and expands causing bending motion

FINITE ELEMENT ANALYSIS OF THERMAL BENDING



Small arm 300 C, 10um X 100 um

Large arm 0 C, 30 um x 100 um

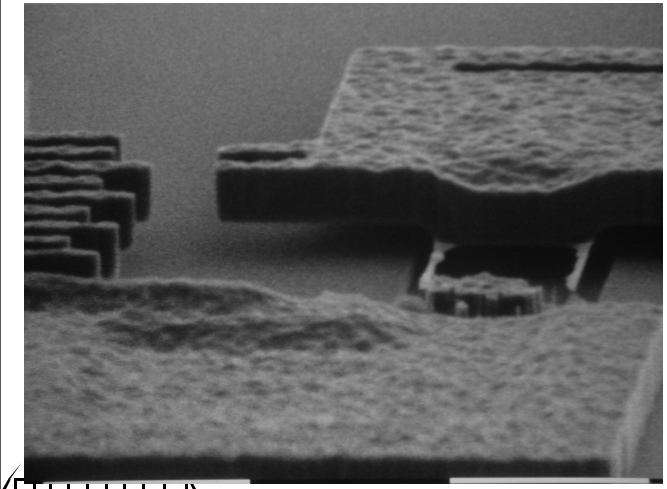
Maximum Displacement = 6 um

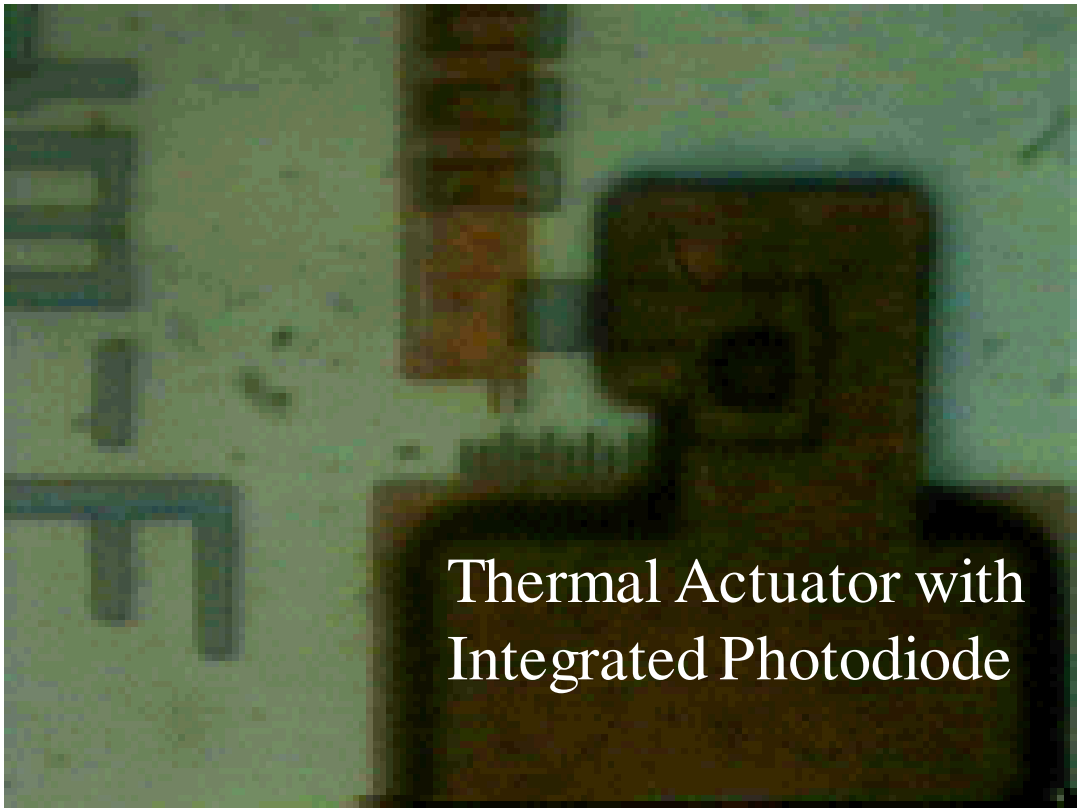
Rochester Institute of Technology
Microelectronic Engineering

Andrew Randles

INTEGRATION OF PHOTODIODE AND MEMS

December 2001
Kevin Munger. joined
IBM Burlington, VT

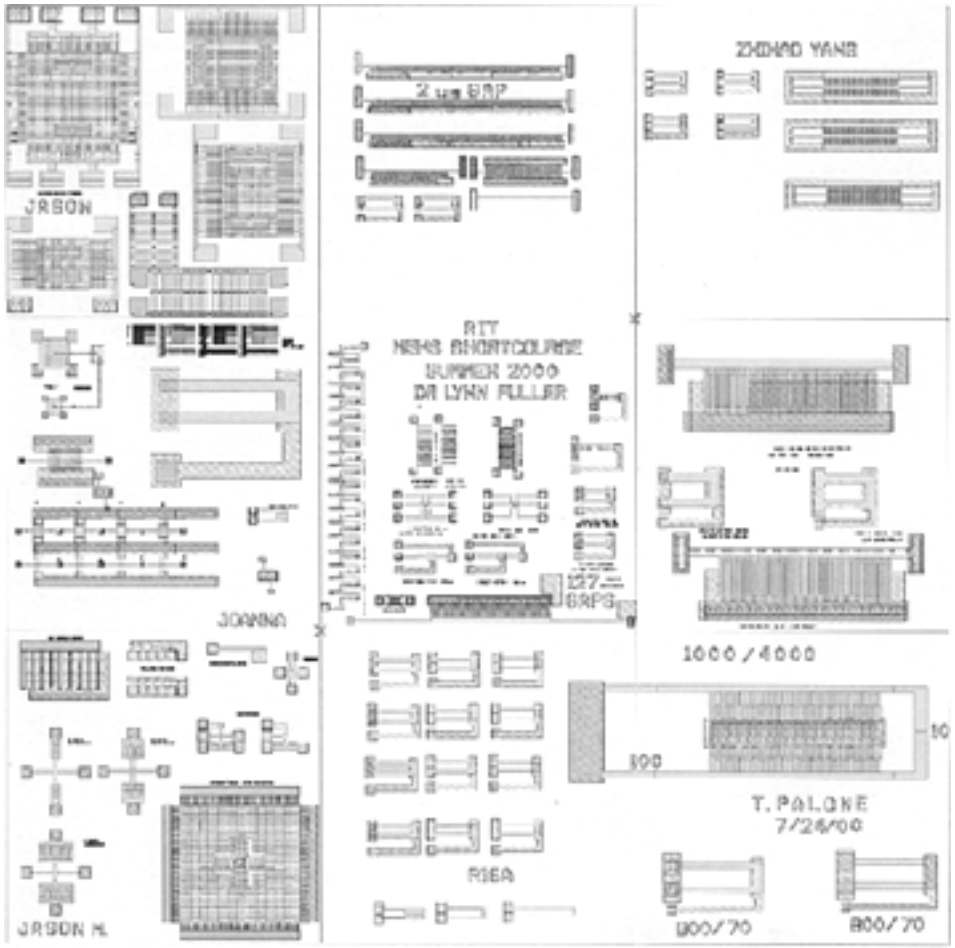




Maximum Deflection 9 µm at 30 µw
162,000 cycles, 6 msec.,

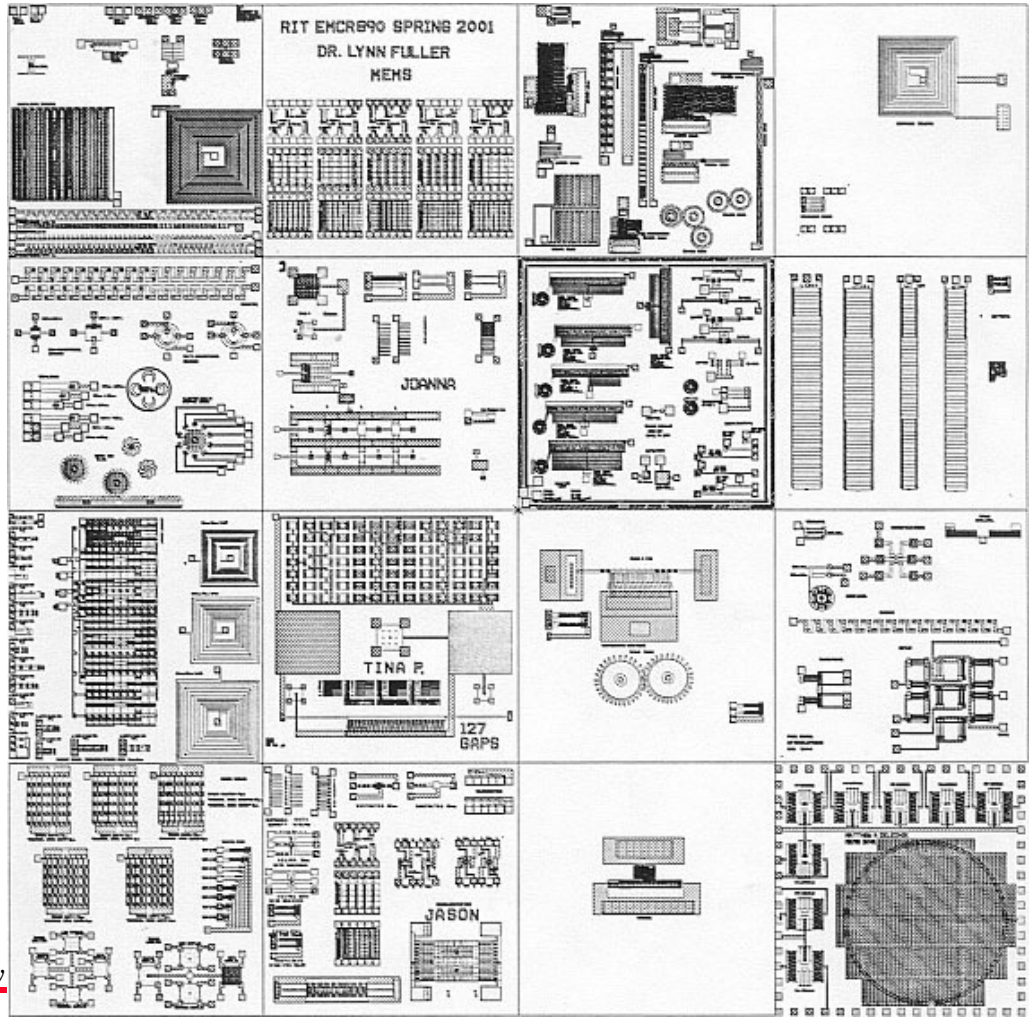
SHORT COURSE JULY 2000 EXAMPLE

- Cantilevers
- Springs
- Accelerometer
- Electrostatic Comb Drive
- Mirrors
- Optical Modulators
- Optical Arrays
- Tweezers
- Inductors
- Contactors

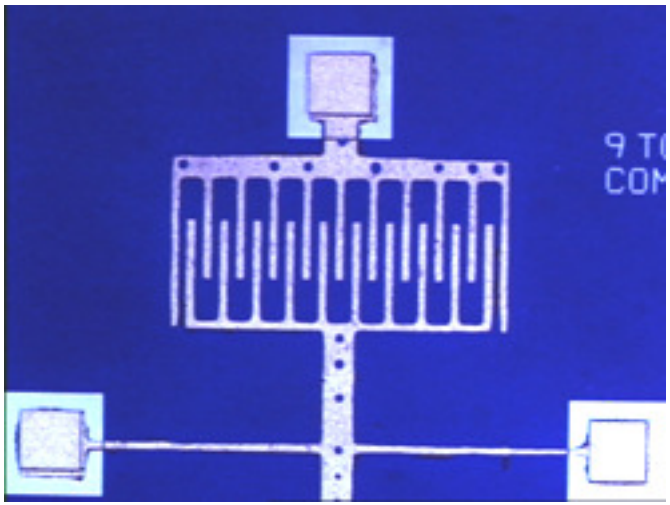


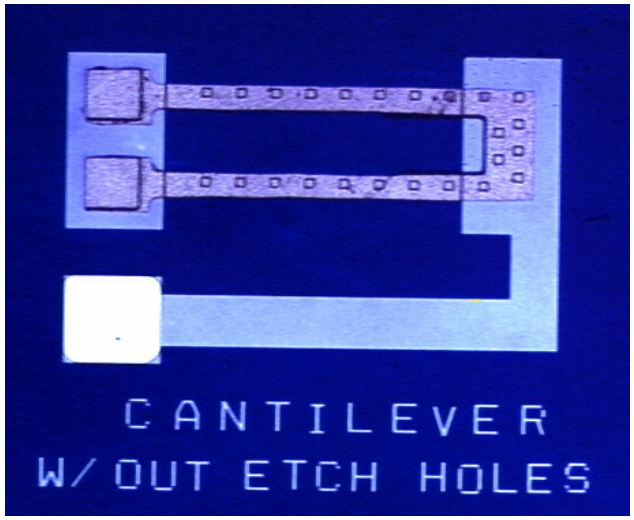
APRIL 1999 CLASS PROJECT

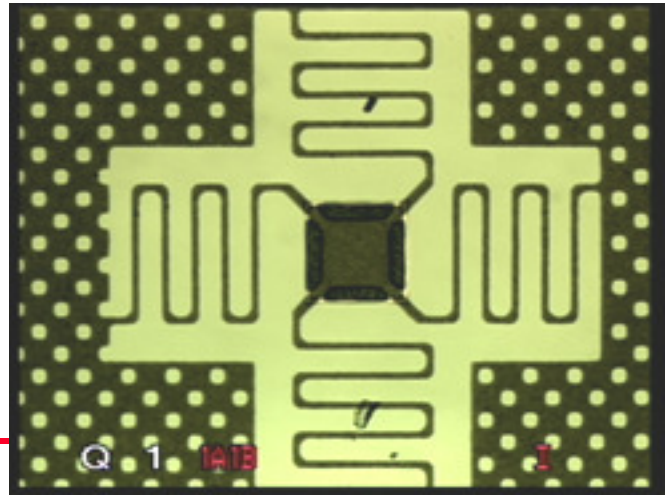
- Cantilevers
- Springs
- Accelerometer
- Electrostatic Comb Drive
- Mirrors
- Optical Modulators
- Optical Arrays
- Tweezers
- Inductors
- Contactors

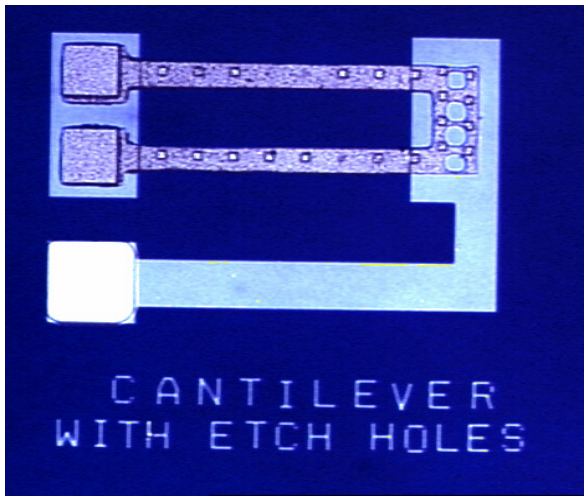


CANTILEVERS AND COMB DRIVES

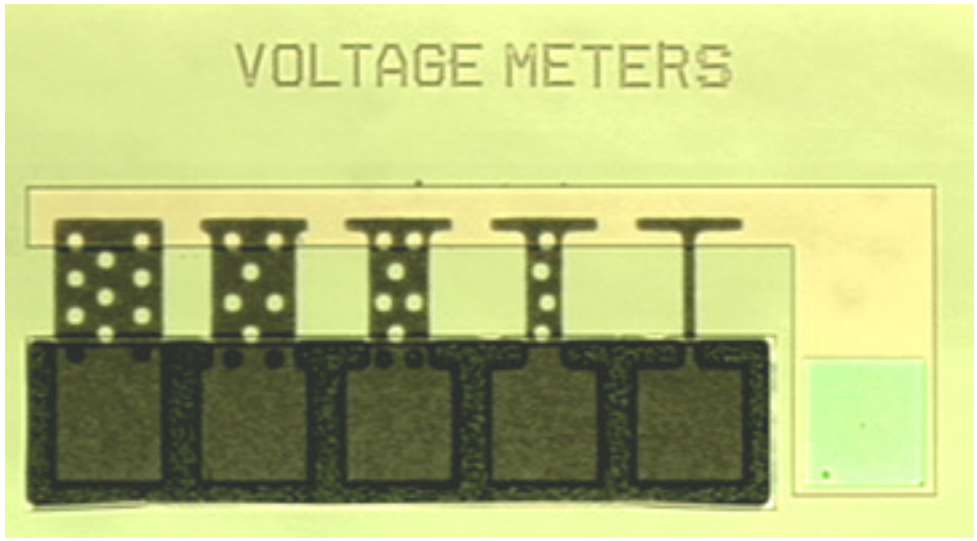


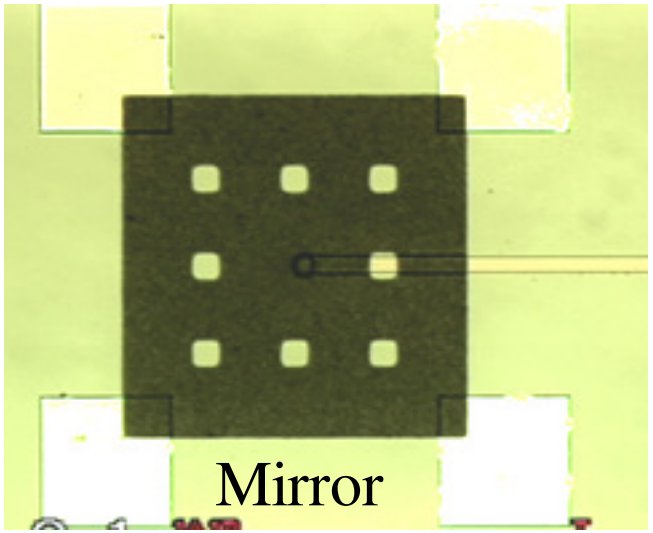


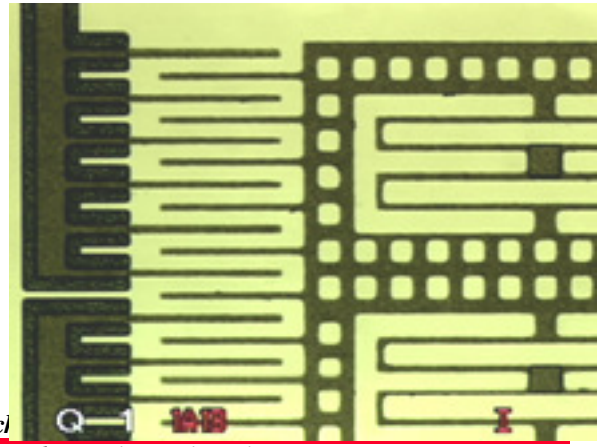


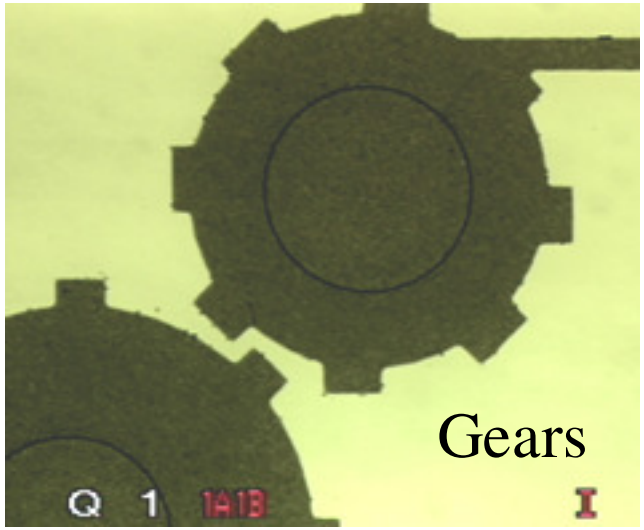


OTHER STRUCTURES



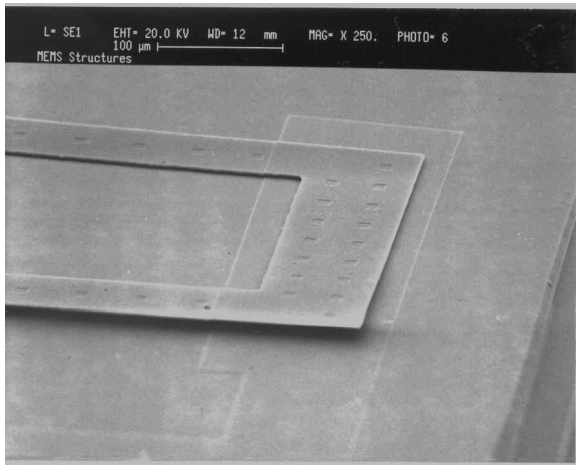


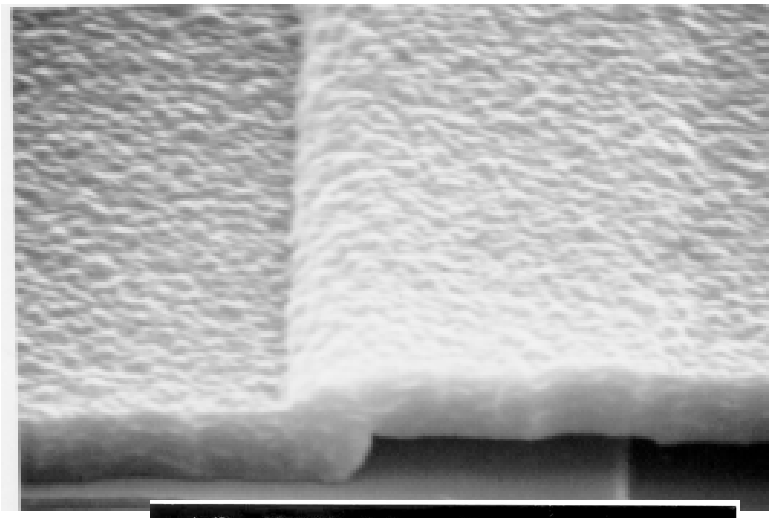


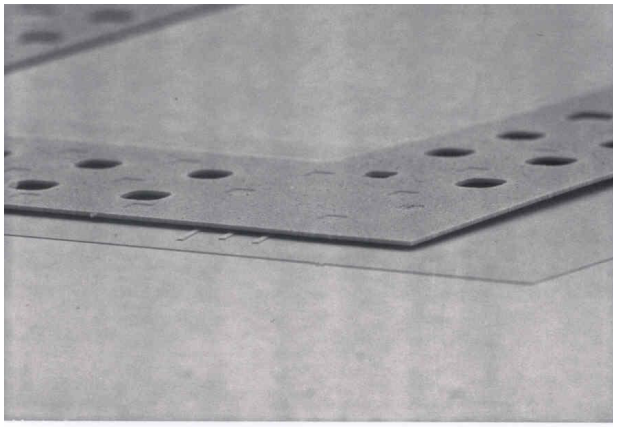


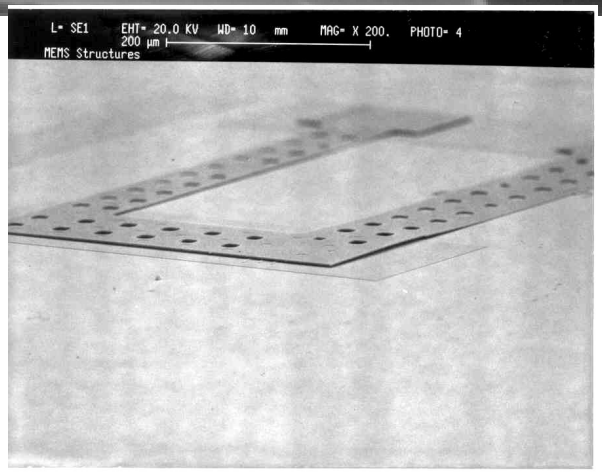
Roch
Microelectronic Engineering

SEM PICTURES

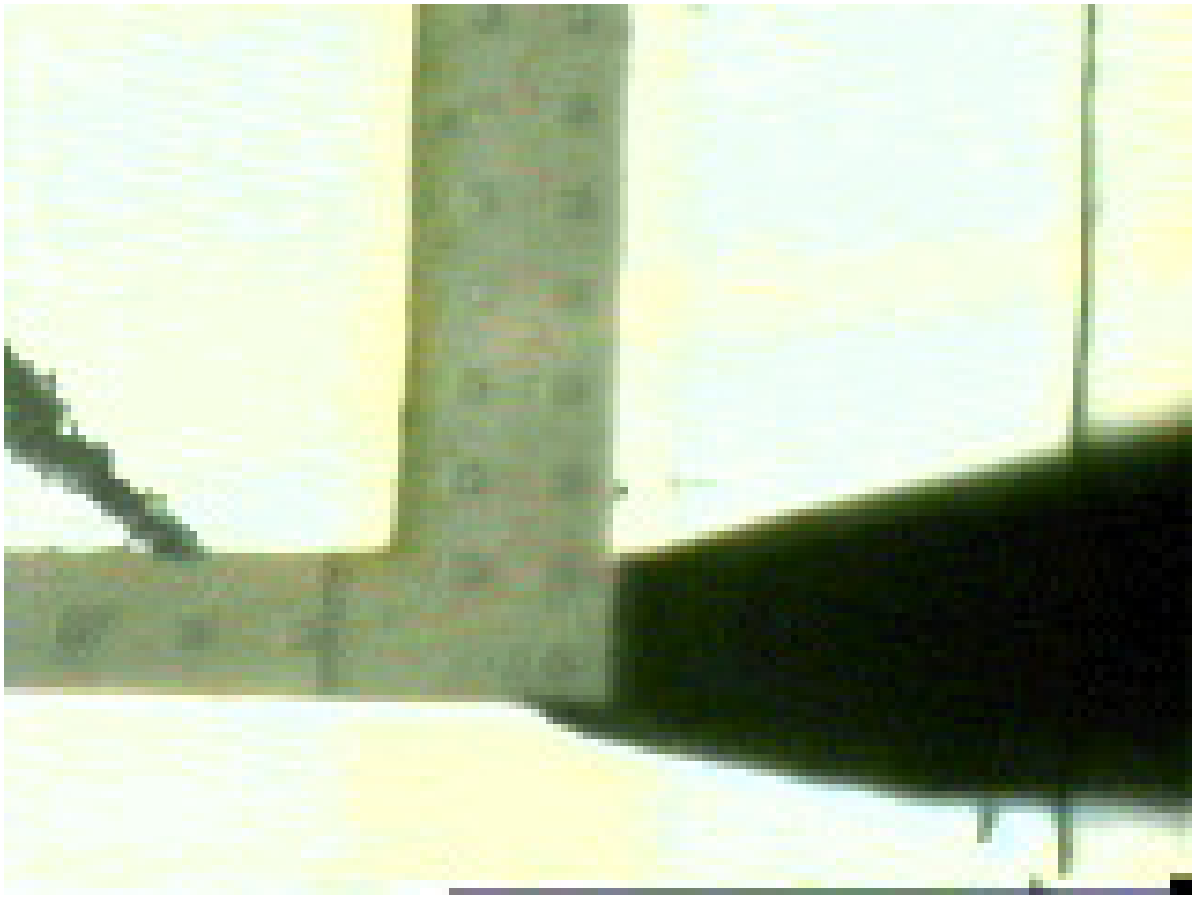




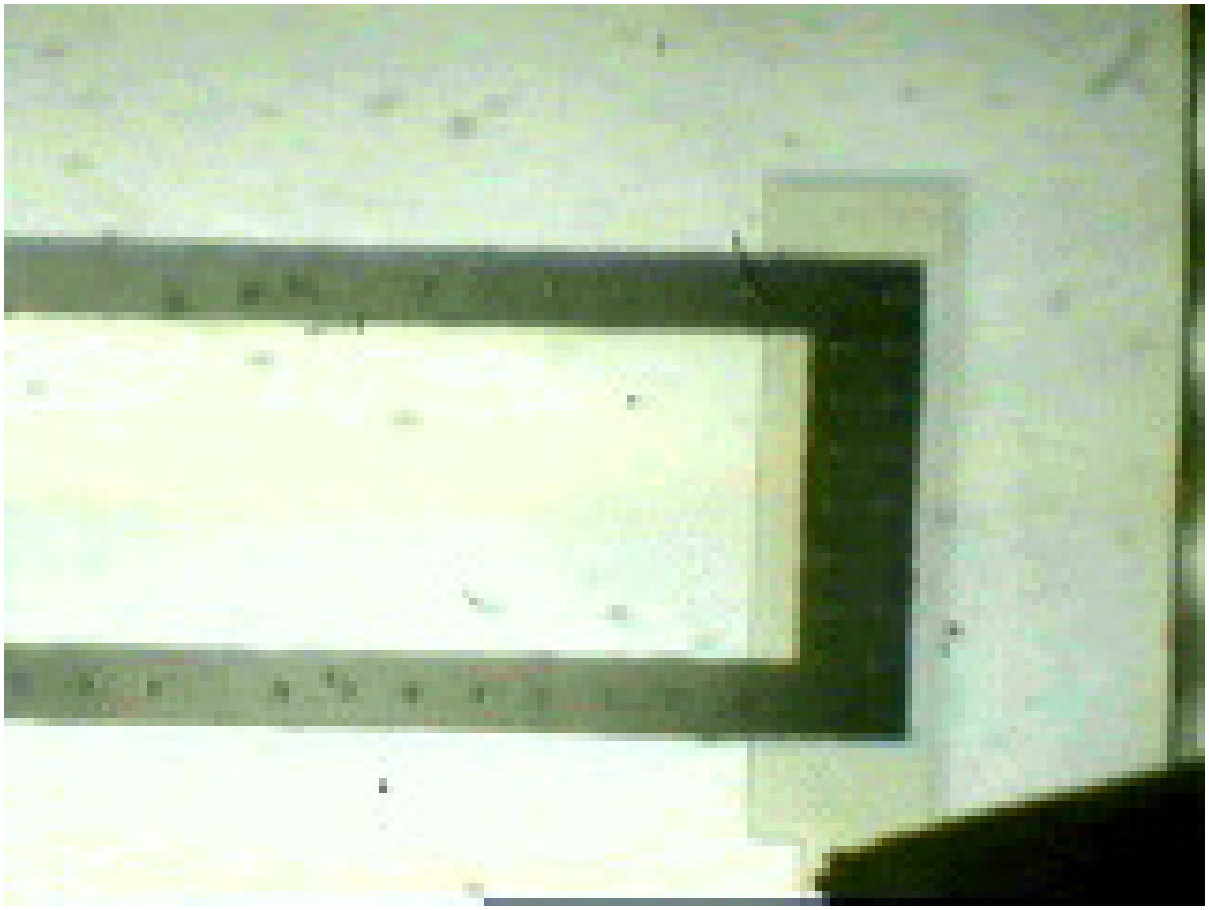




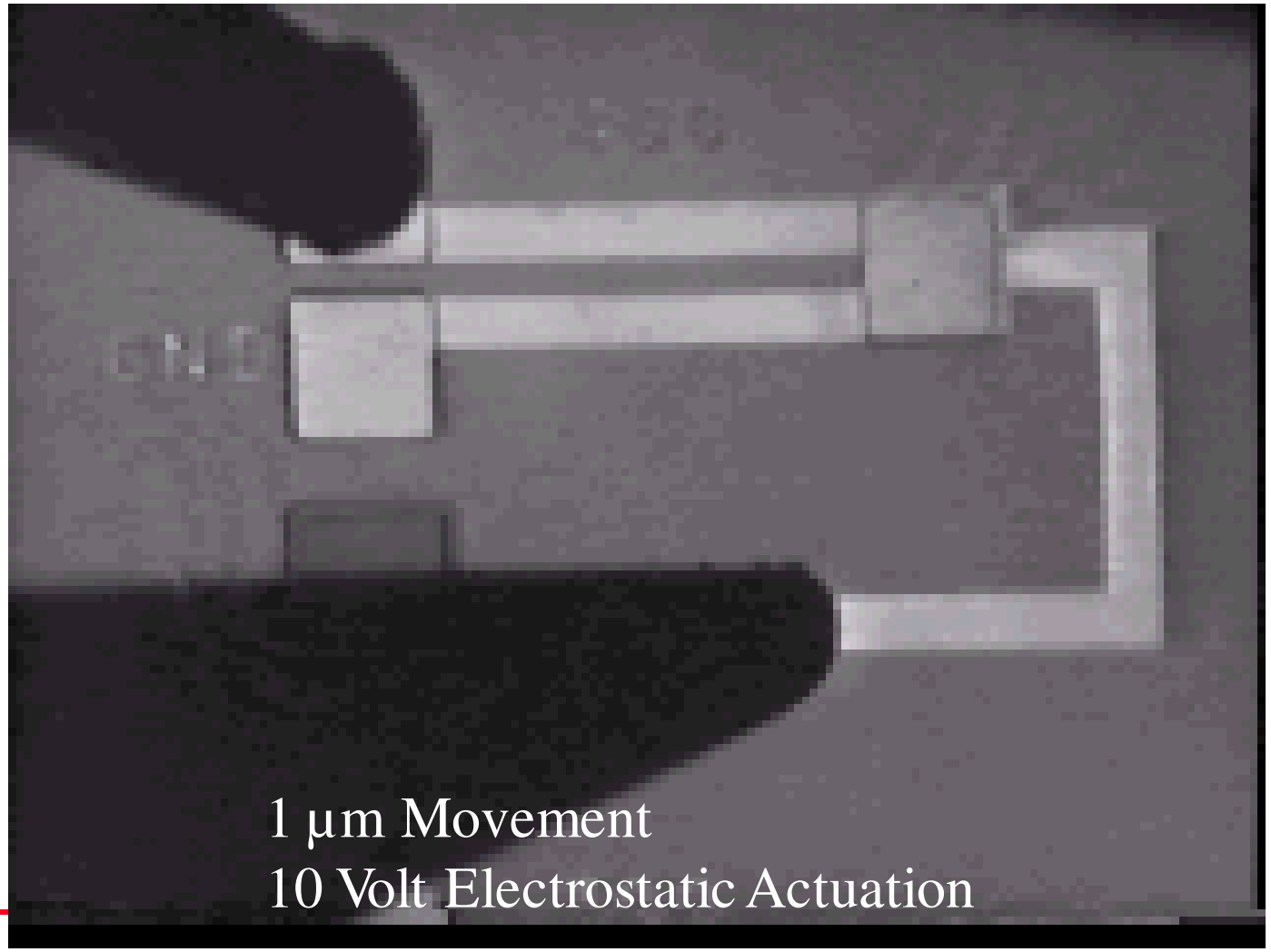
VERIFICATION OF RELEASE



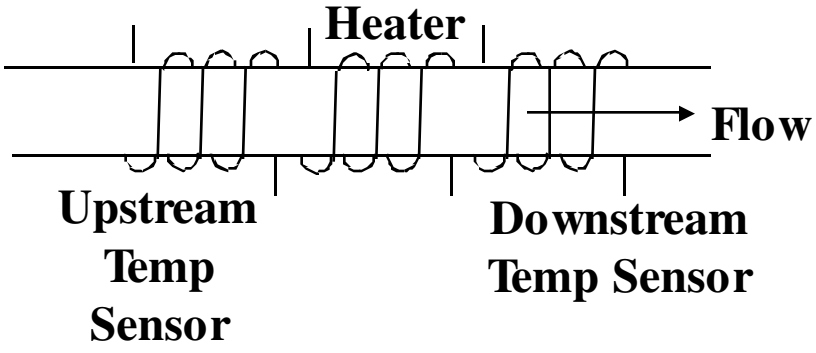
ELECTRICAL RESULTS

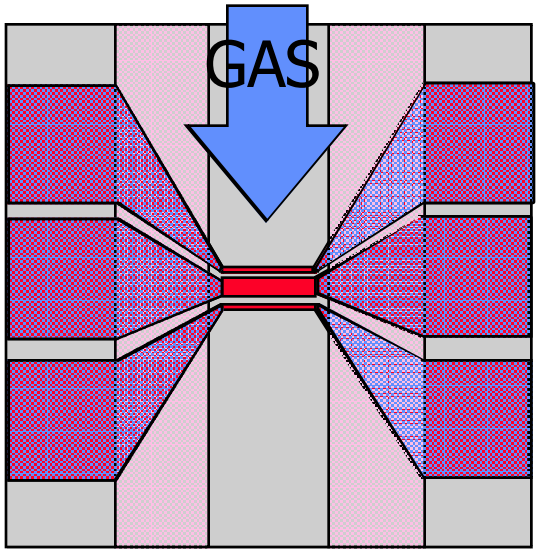


ELECTROSTATIC ACTUATION OF CANTILEVER

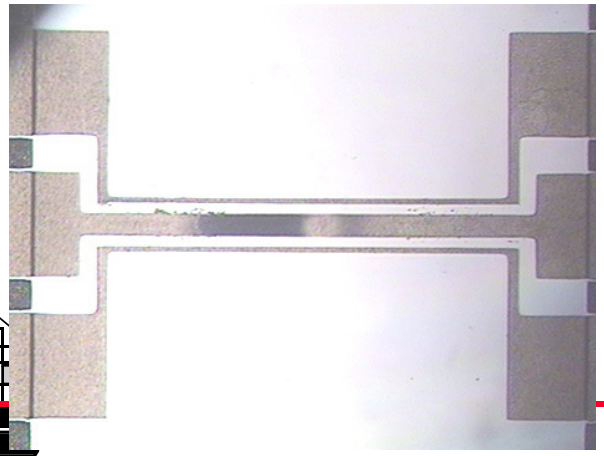


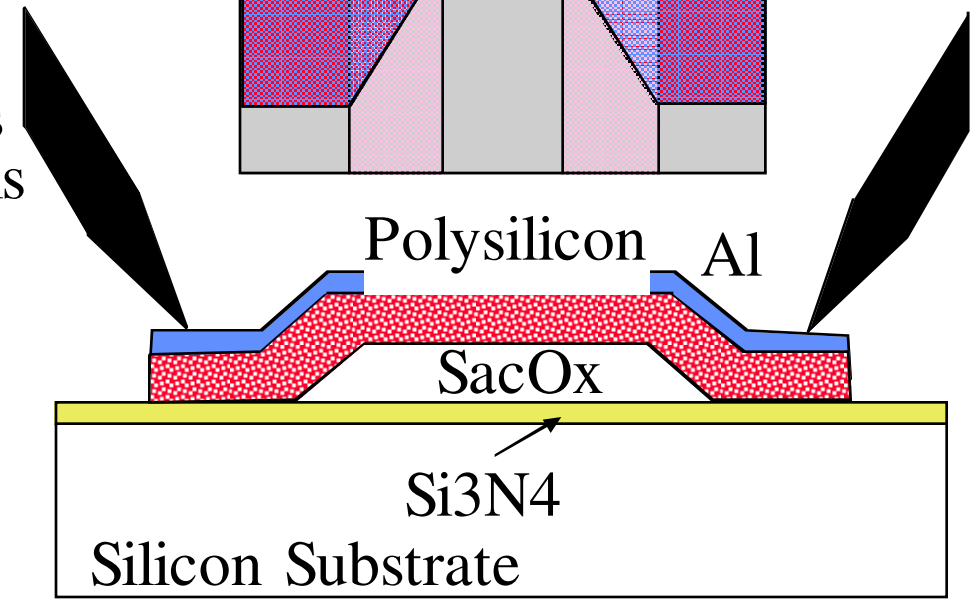
2003 CLASS PROJECT - GAS FLOW DETECTOR



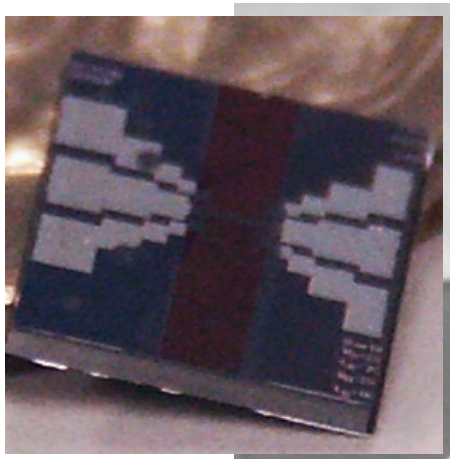


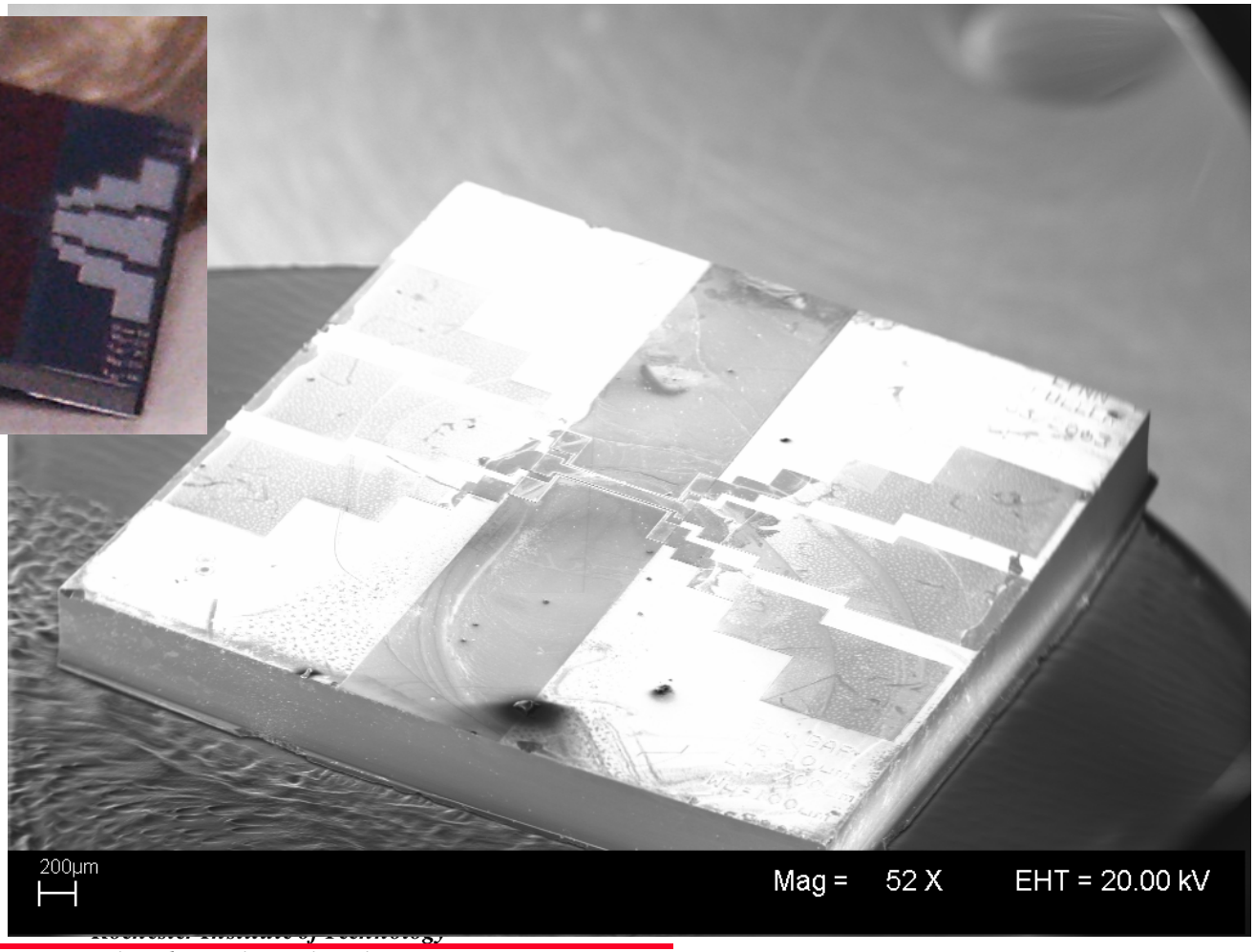
No Voltage to Heater
Resistance of Heater 1000 ohms
Resistance of Resistor 4800 ohms





SURFACE MICROMACHINED GAS FLOW SENSOR



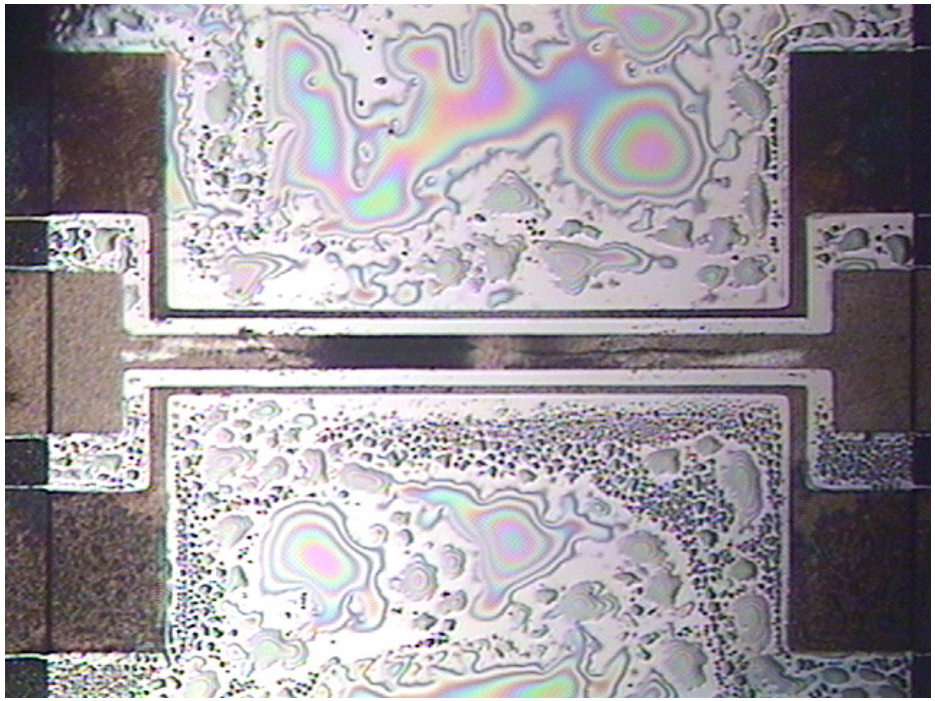


Microelectronic Engineering

Vee Chee Hwang, 2004

PHOTOGRAPHS/SEMS/ELECTRICAL

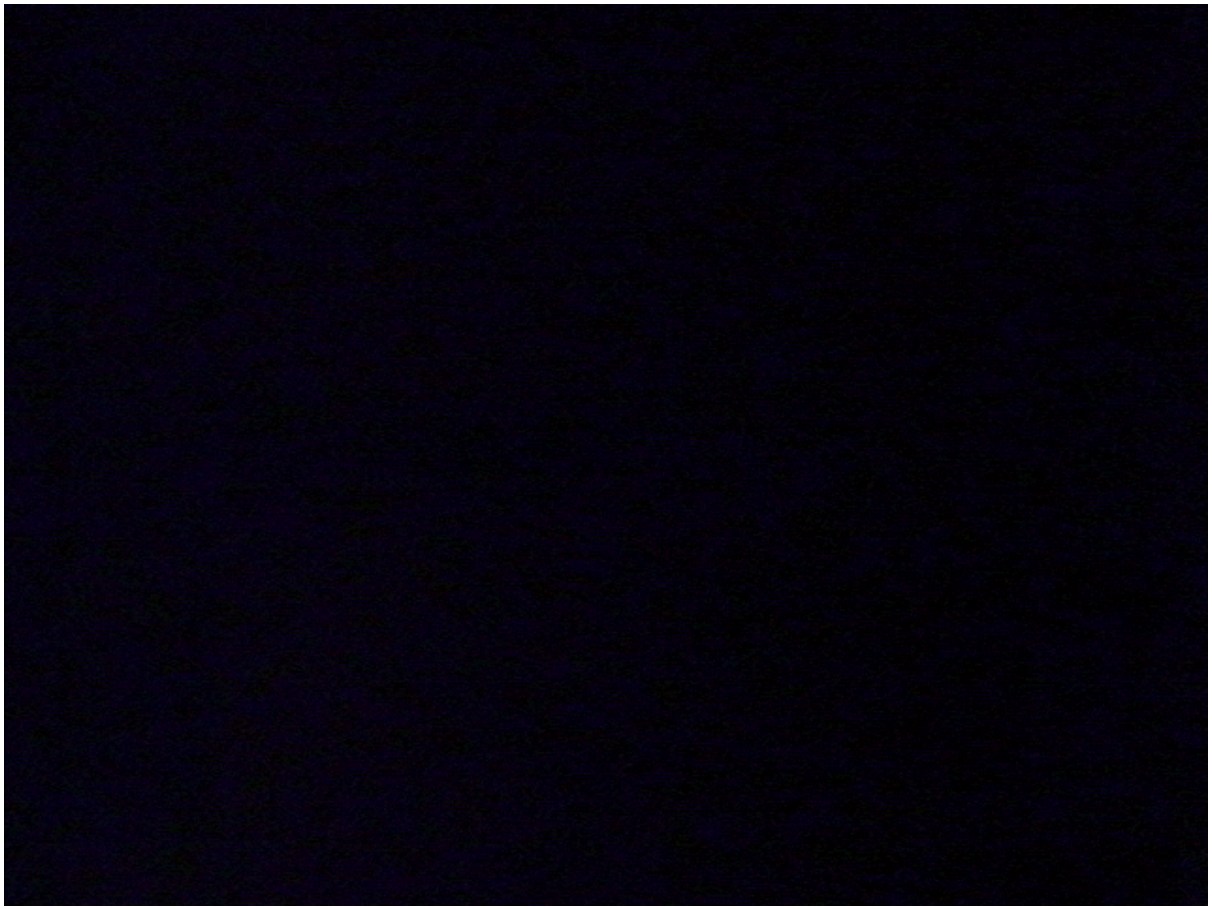
HEATER TESTING



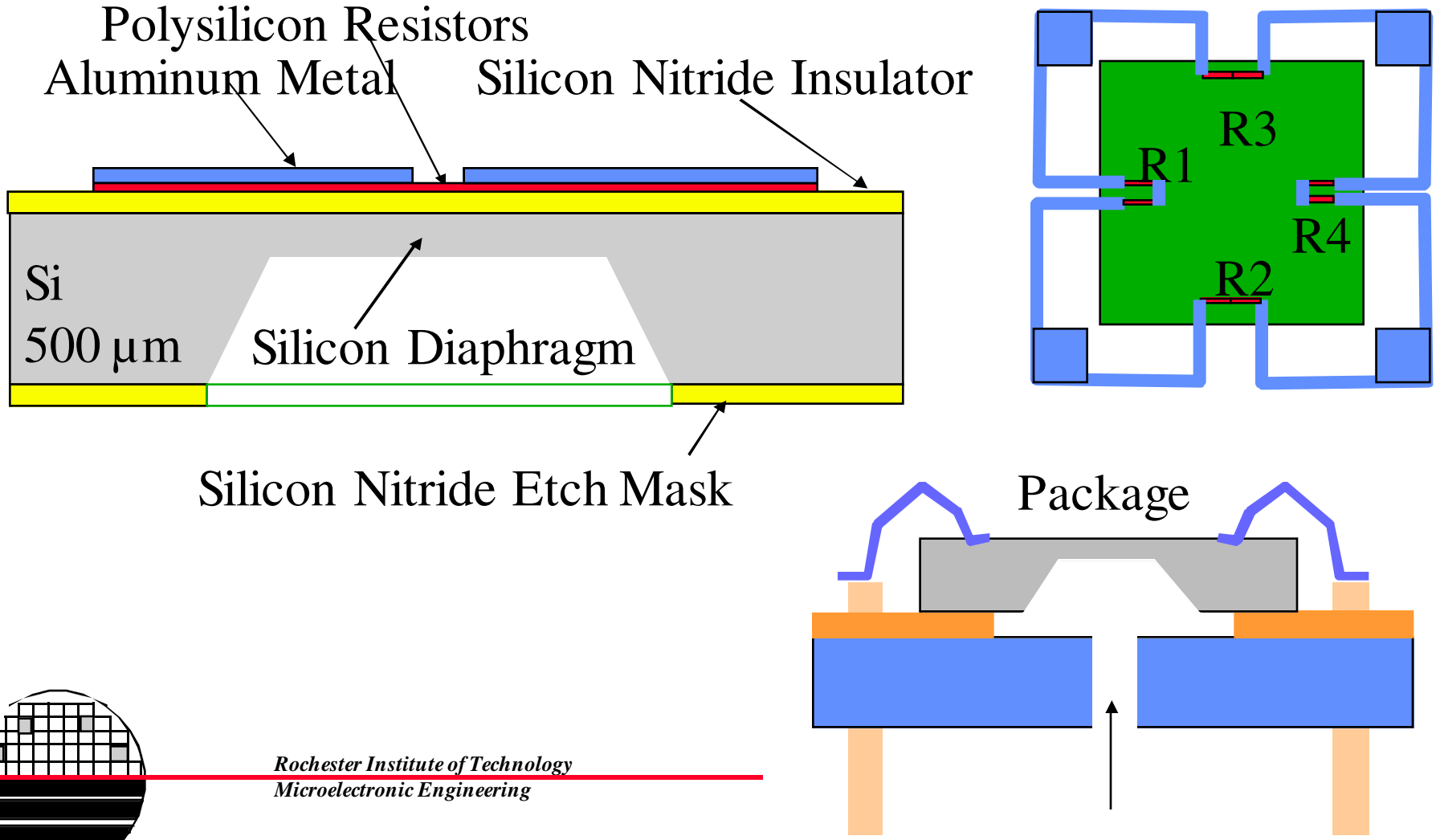
Movie

20 Volts applied to Heater
Resistor changed by 100 ohms

MOVIE OF HEATER

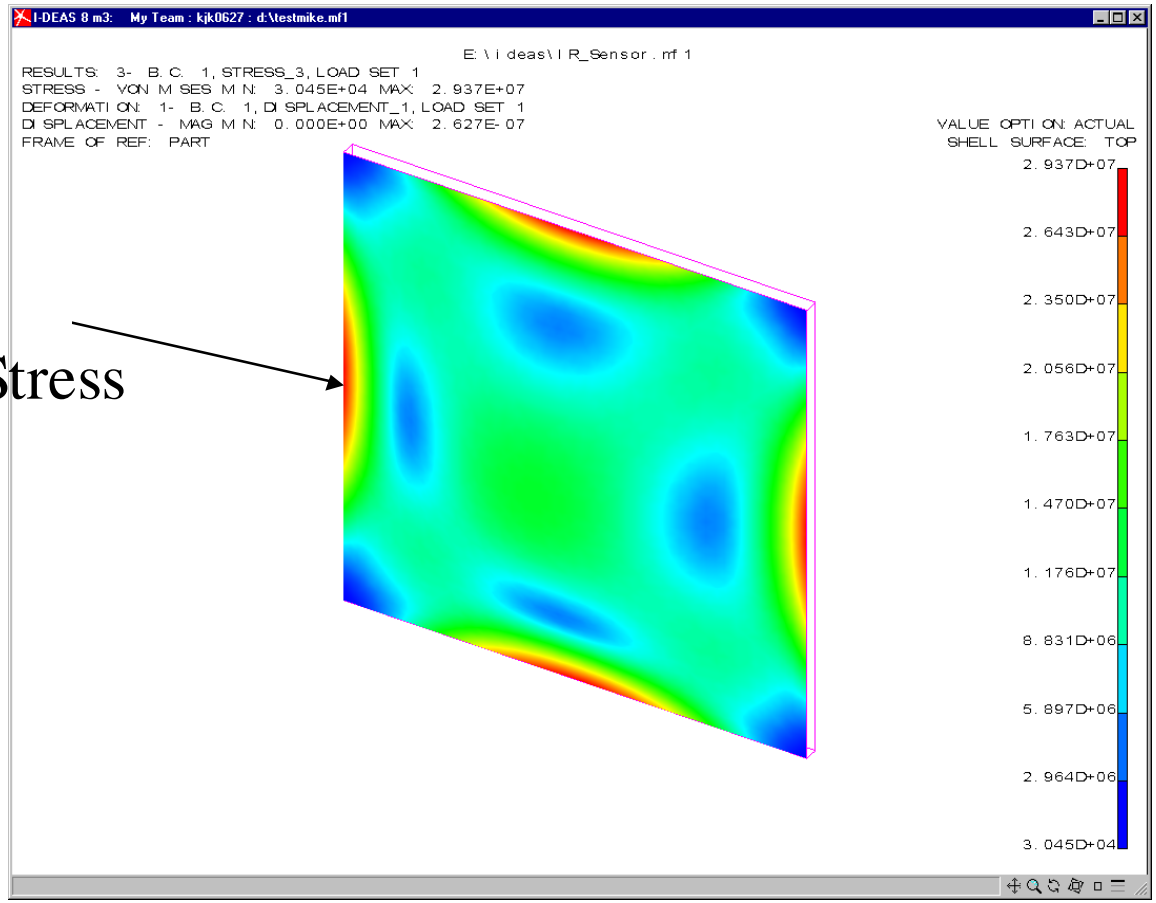


2002 CLASS PROJECT – PRESSURE SENSOR



FINITE ELEMENT ANALYSIS

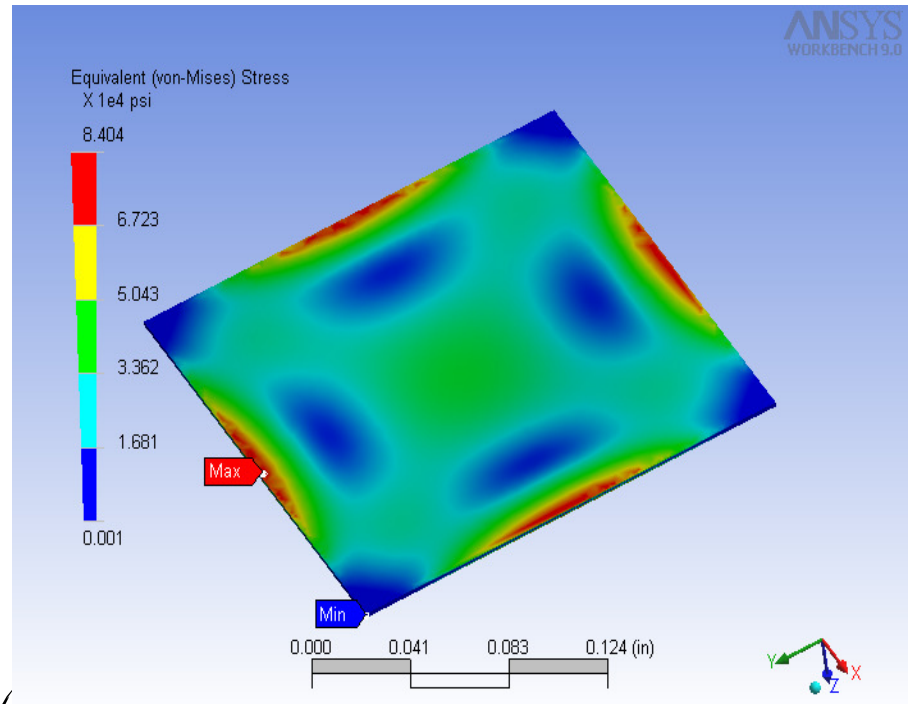
Points of Maximum Stress



FINITE ELEMENT ANALYSIS

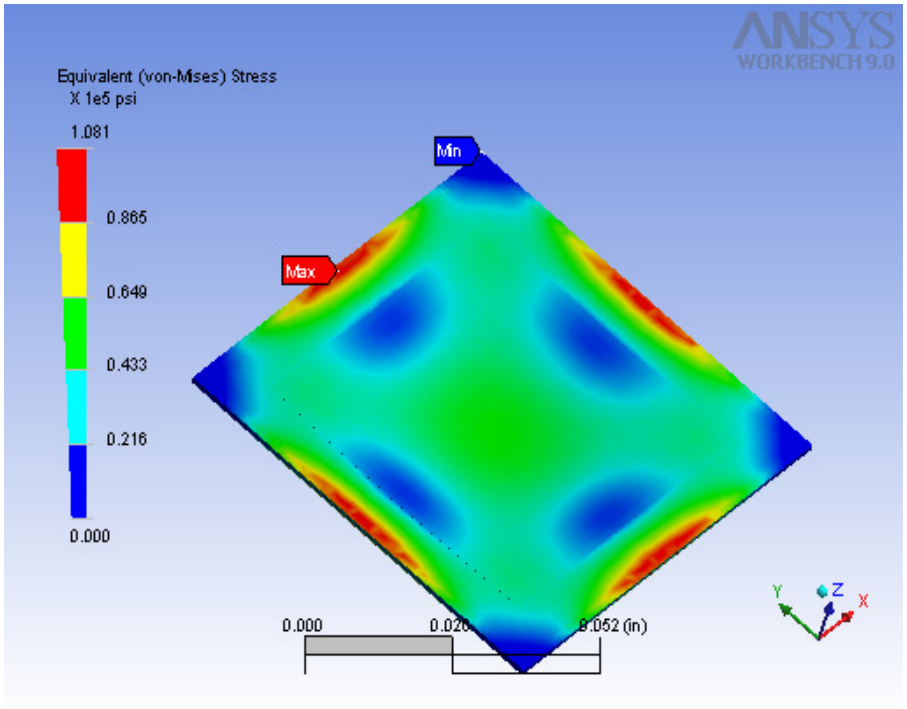
2mm x 2mm Crystalline Silicon Diaphragms 30µm thick 50psi

Regular Si Diaphragm



Corrugated Diaphragm

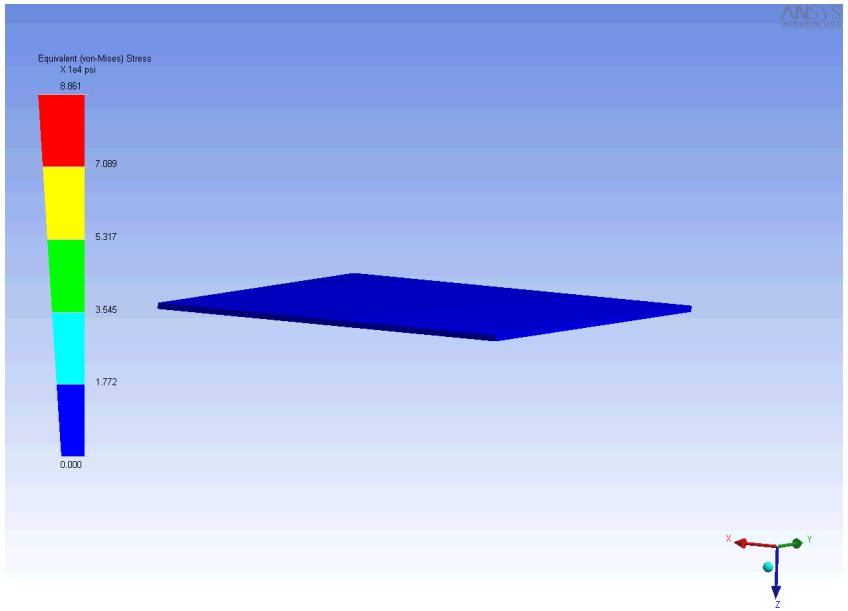
Layer 2: 1.5mm x 1.5mm Polysilicon 1µm thick



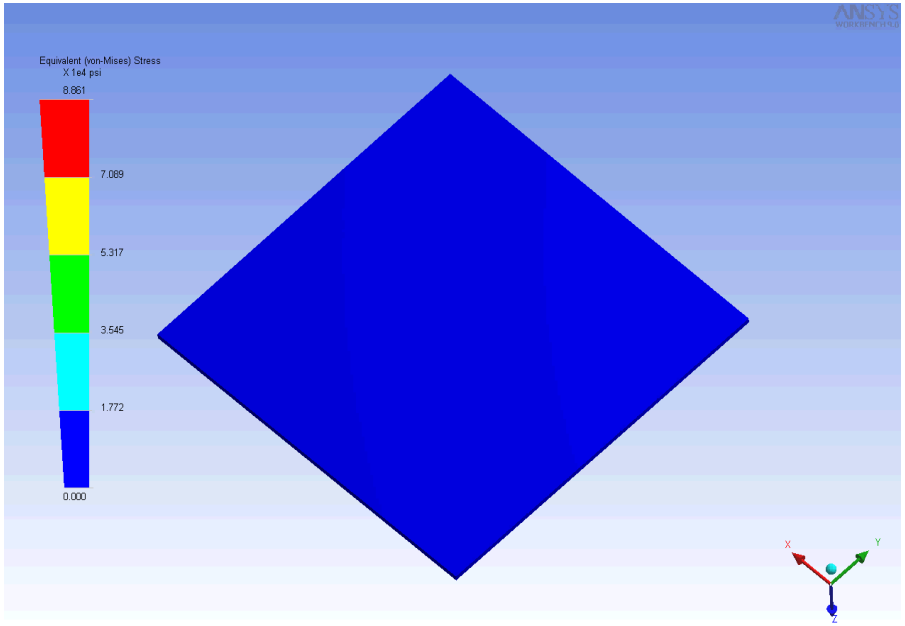
Rochester Institute of Technology
Microelectronic Engineering

By Rob Manley

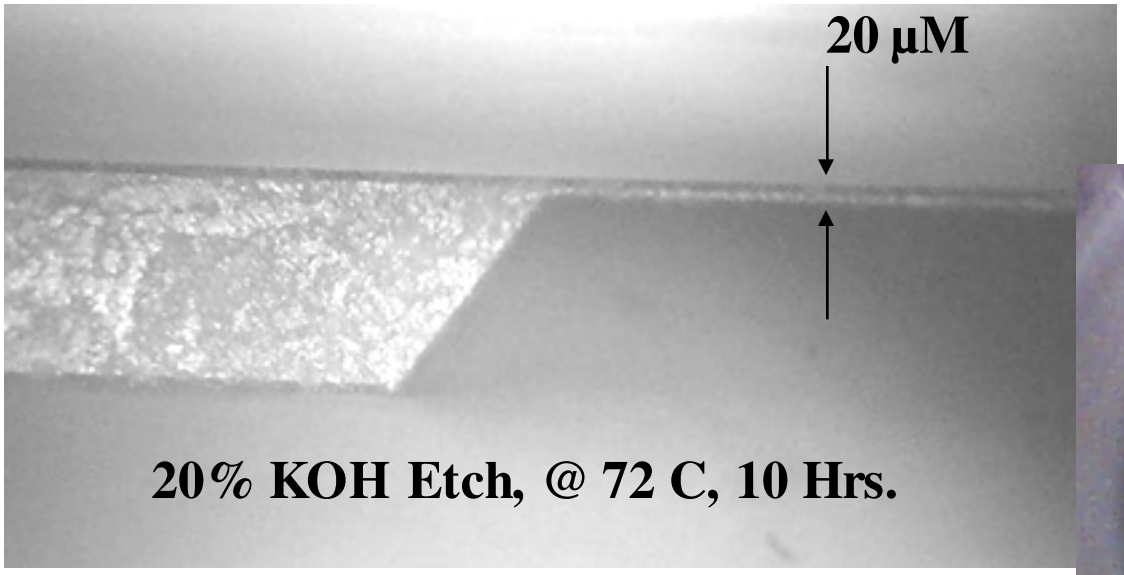
DIAPHRAGM DEFORMATION MOVIE

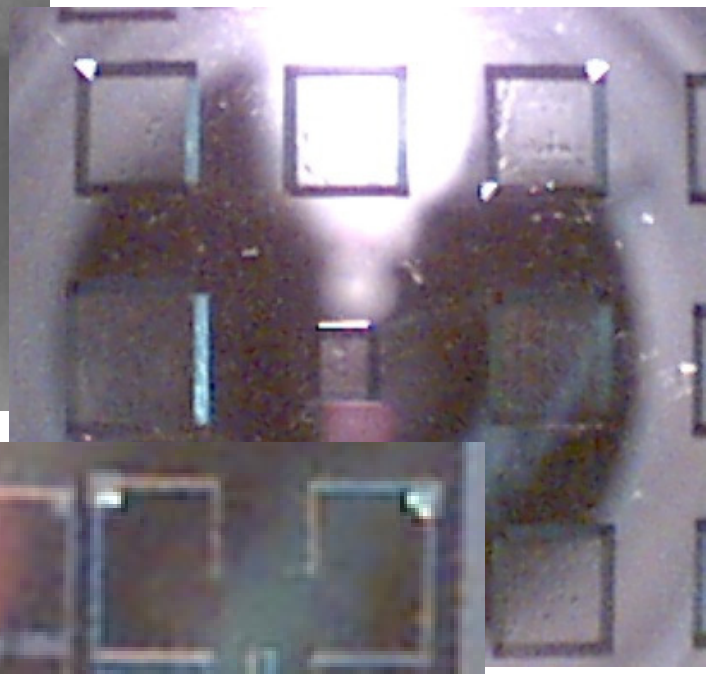


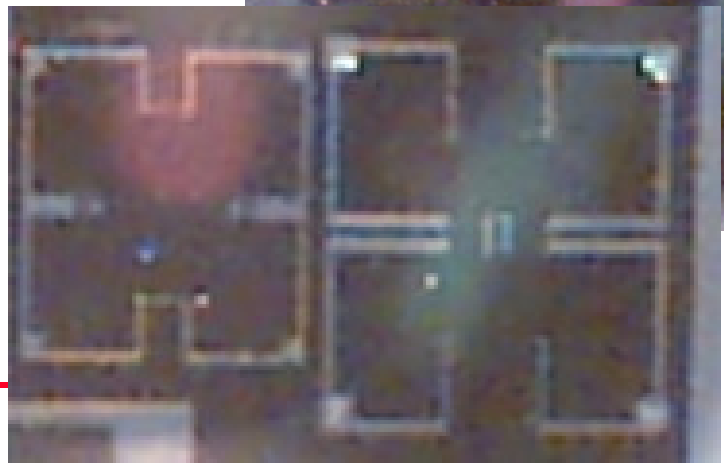
DIAPHRAGM STRESS MOVIE



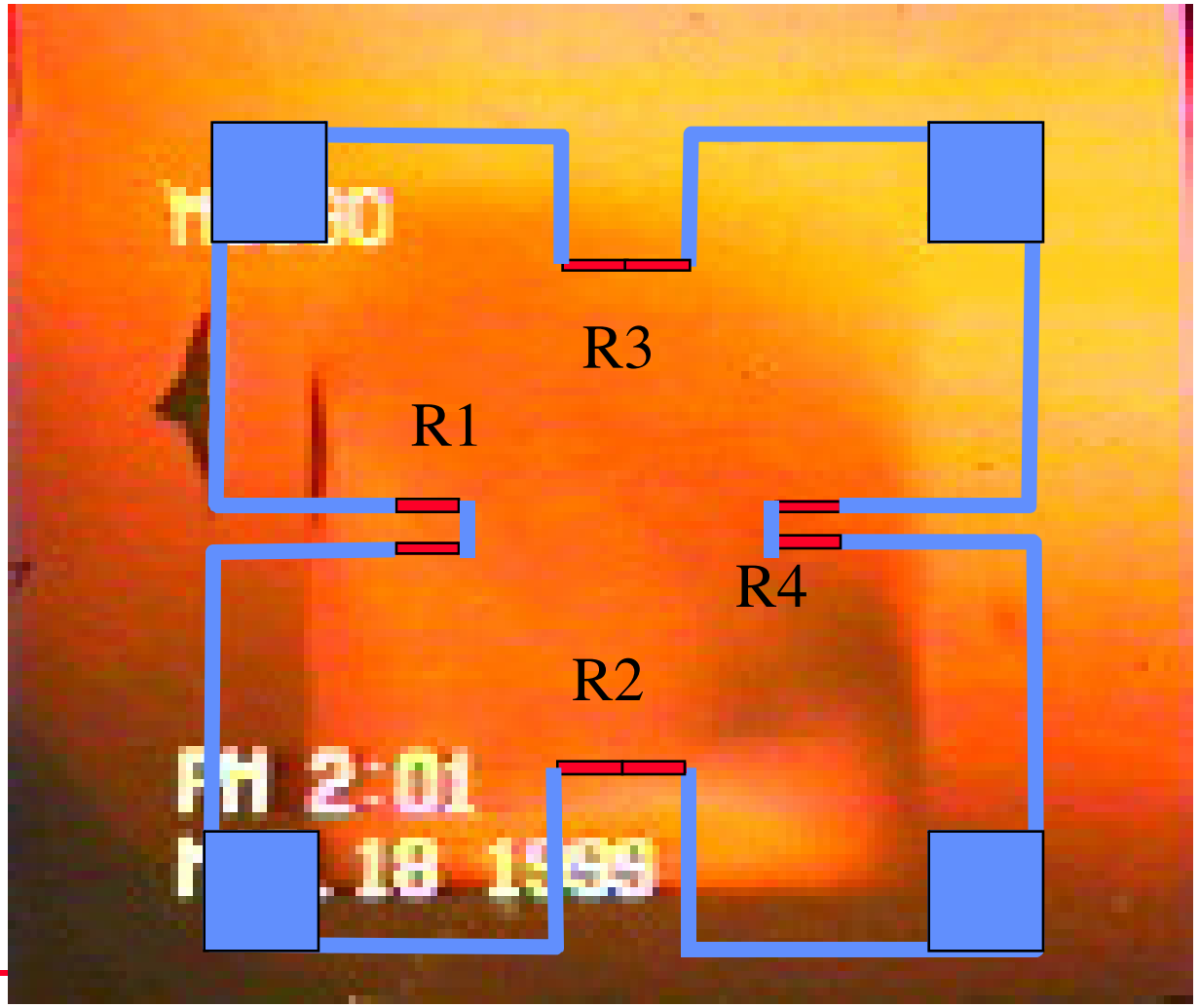
DIAPHRAGM FABRICATION



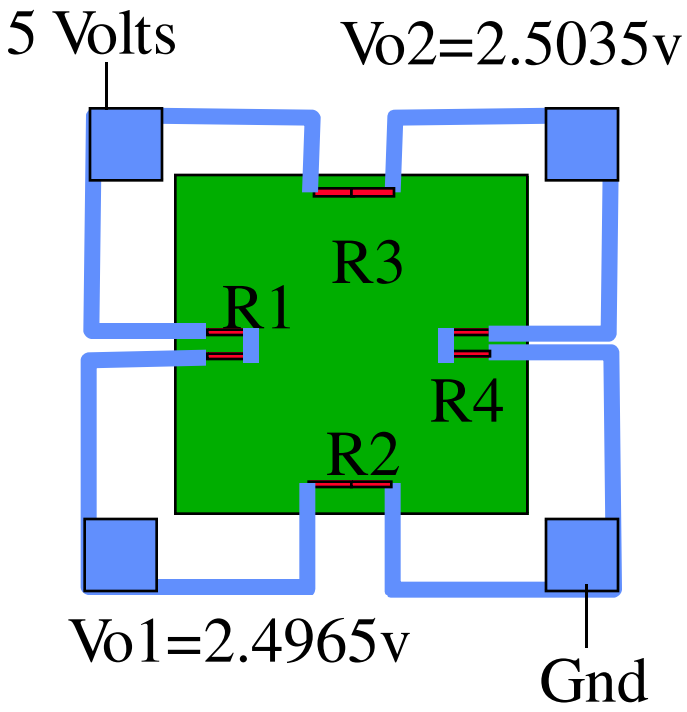


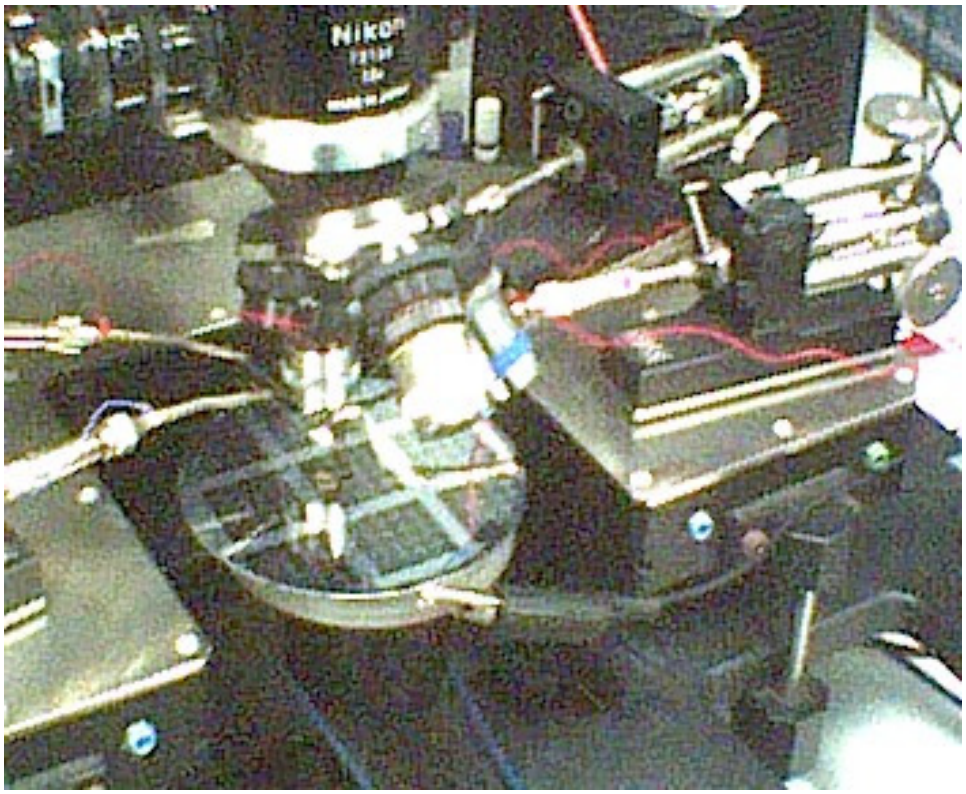


MOVIE OF DIAPHRAGM MOVING



TESTING

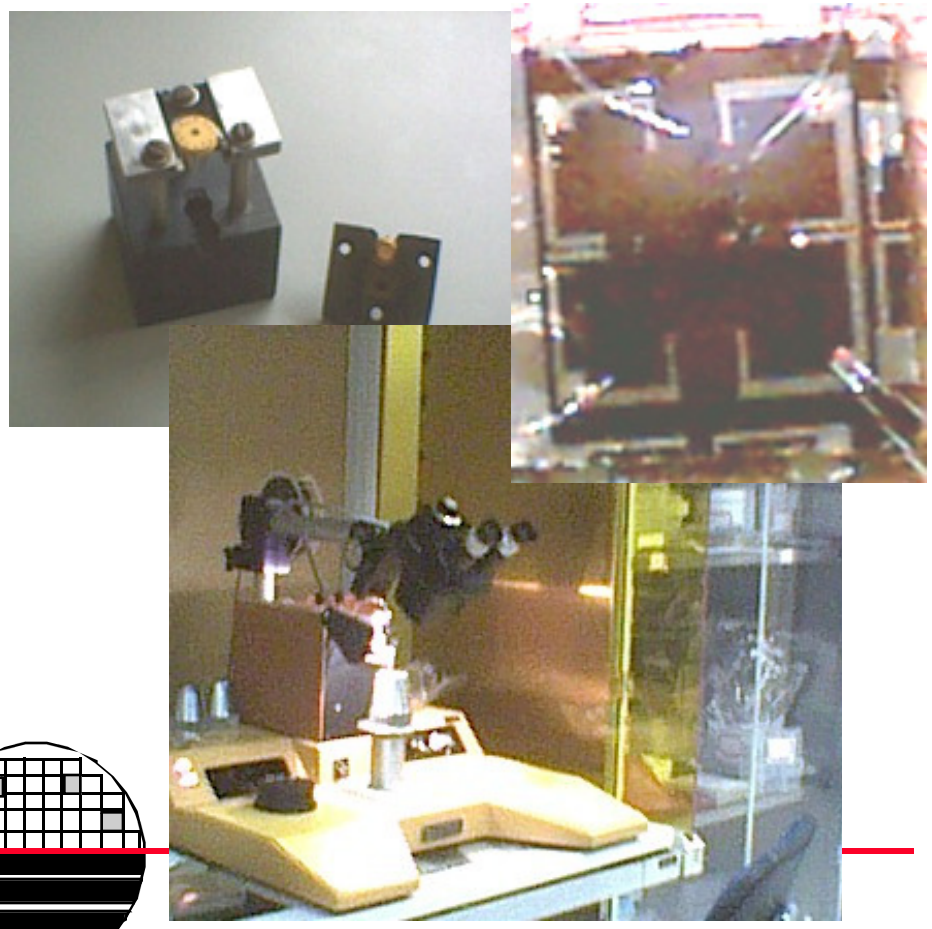




Apply and release chuck vacuum to observe change in output voltage

WIRE BONDING AND PACKAGING

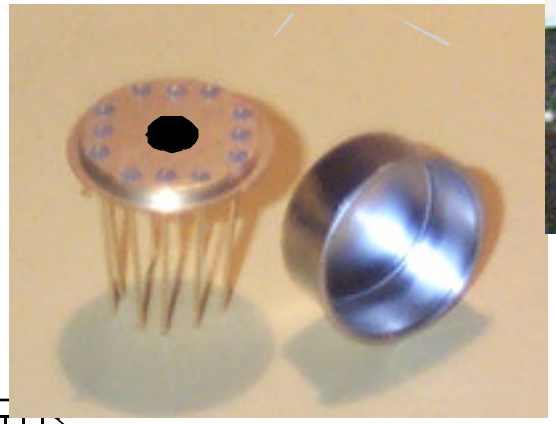
Fixture to hold TO-8 and TO-39 packages for wire bonding.

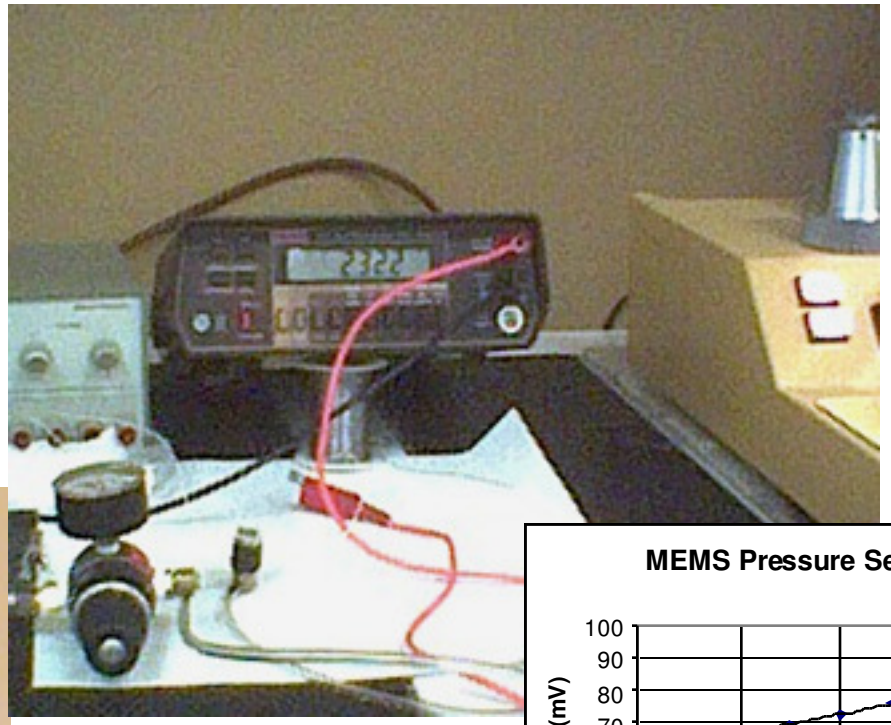


Rob Manley

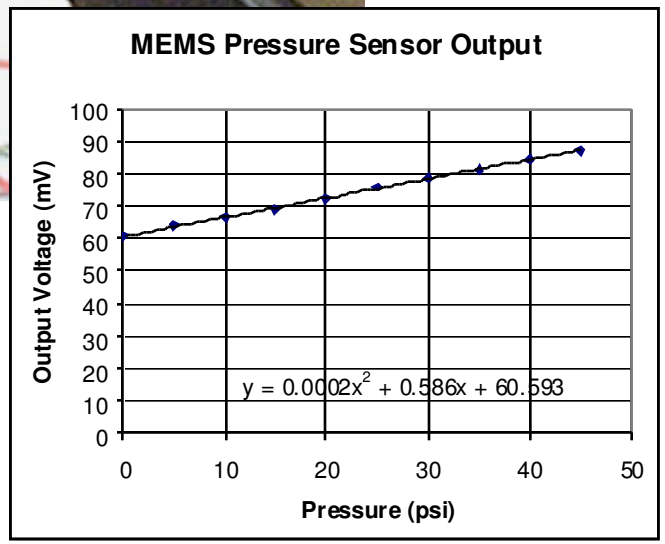
K&S WAFER SAW

TESTING OF PACKAGED PRESSURE SENSORS



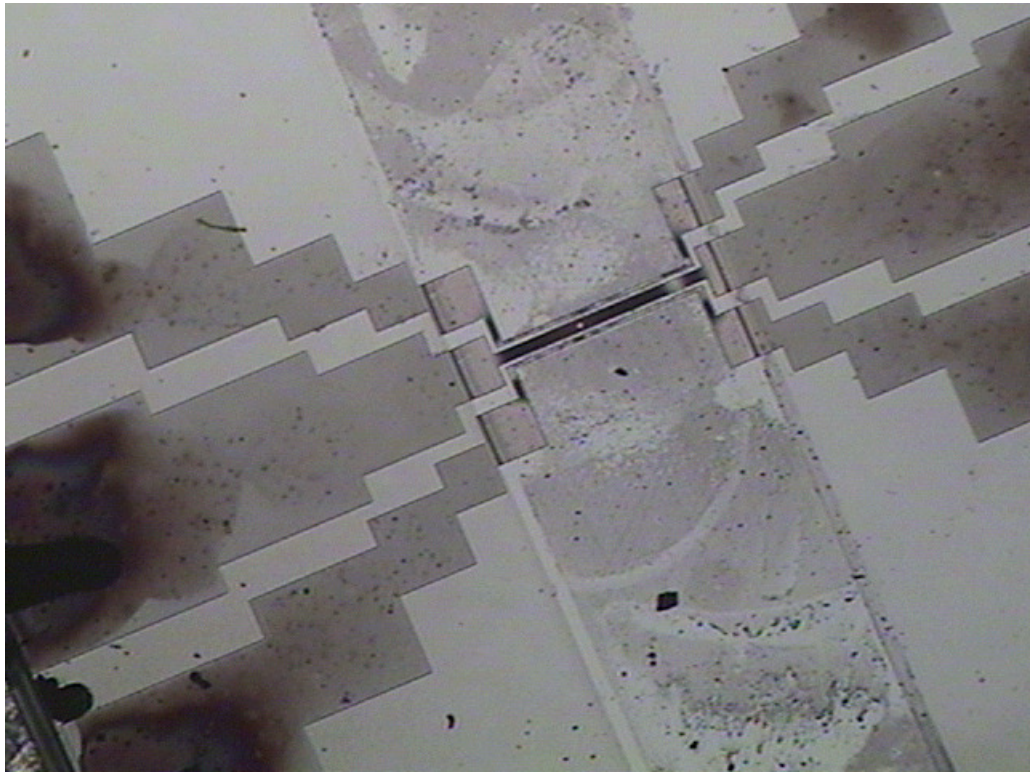


0	60.6
5	63.84
10	66.32
15	68.95
20	72.28
25	75.62
30	78.68
35	81.25
40	84.39
45	87.21



5-15-02

SURFACE MICROMACHINED GAS FLOW SENSOR



L of heater & resistor = 1mm

W (heater) = 50um

W (resistors) = 20um

Gap = 10um

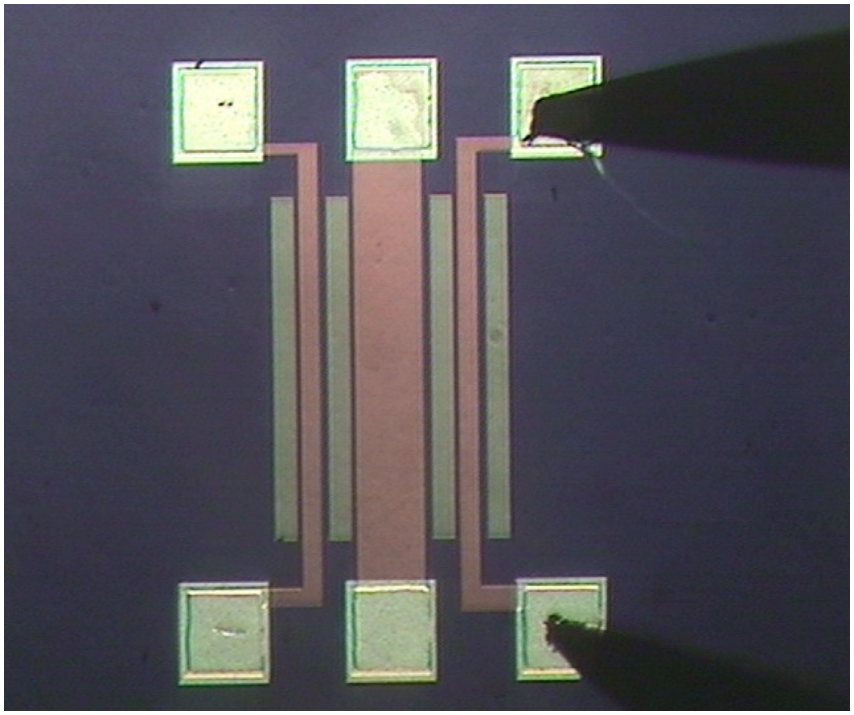
V applied = 27V to 30.5V

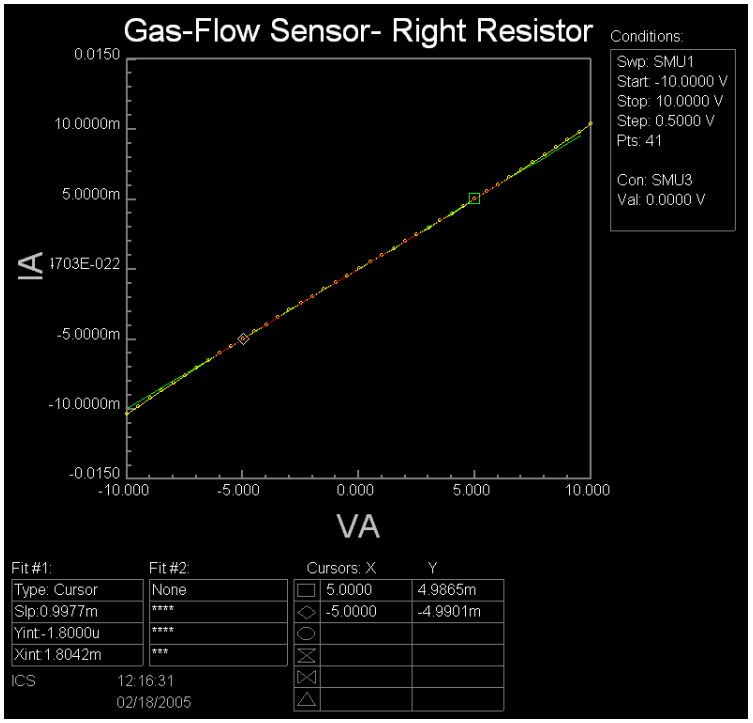
Temp ~600 °C at 26 volts

Lifetime > 10 min at 27 volts
(possibly longer, did not test)

Vee Chee Hwang, 2004

BULK MICROMACHINED GAS FLOW SENSOR





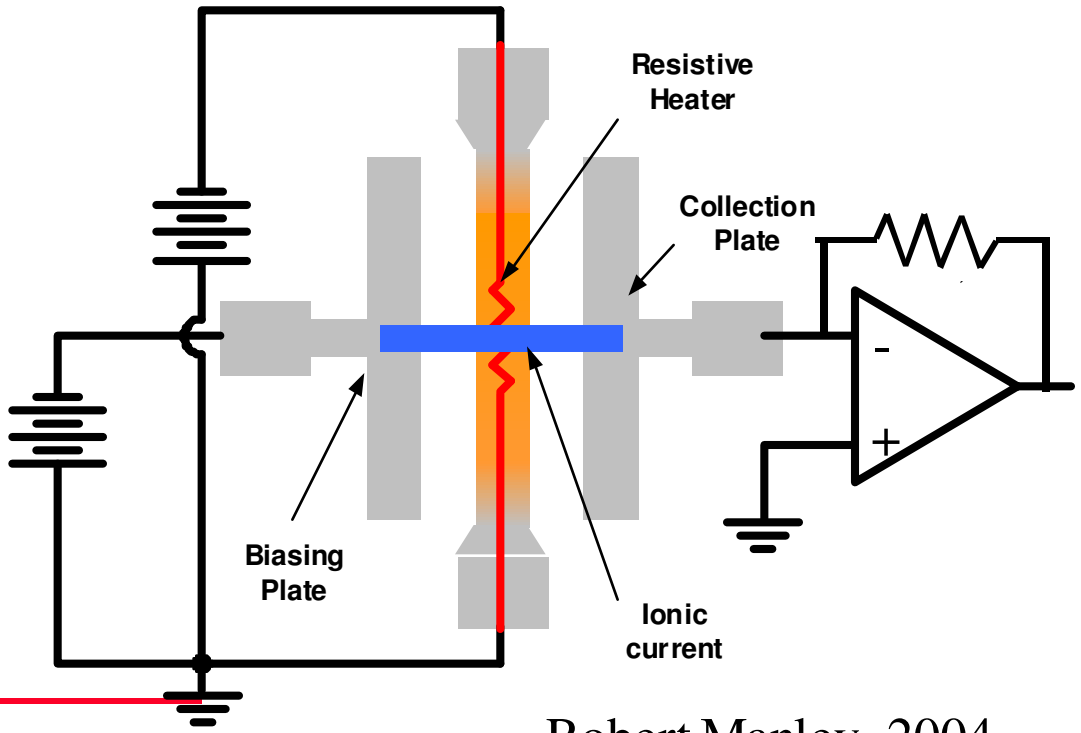
Measured Resistance, V/I=1.2Kohms
Theoretical Resistance, L*Rhos/W= 400µm*60/20µm = 1.2Kohms

Raunak Mann, 2004

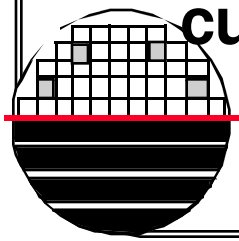
THERMIONIC GAS DETECTOR

- Polysilicon Micro-filament heater

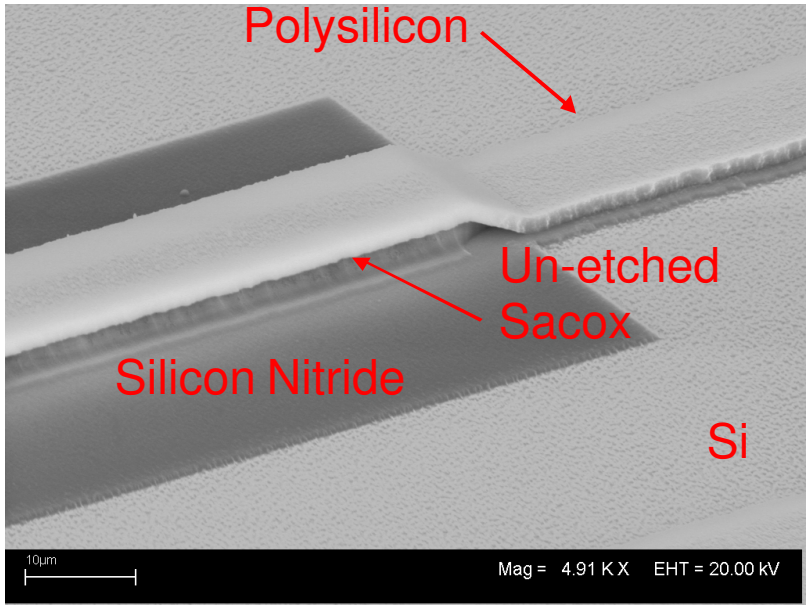
- Make hot
- Thermionic emission occurs causing ionization
- Force ions to a collection plate
- Measure resulting current or voltage

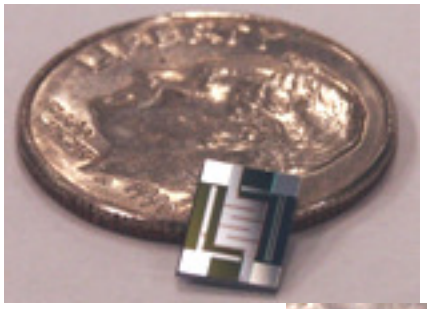


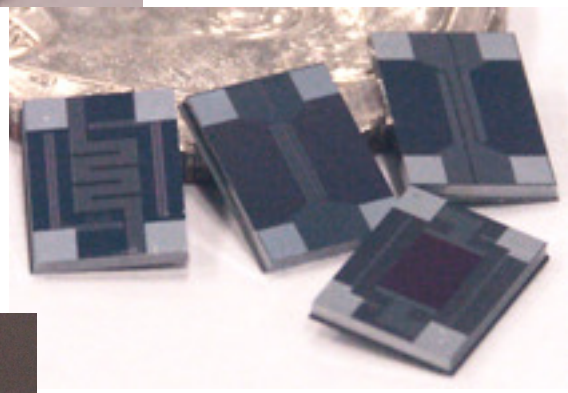
Robert Manley, 2004

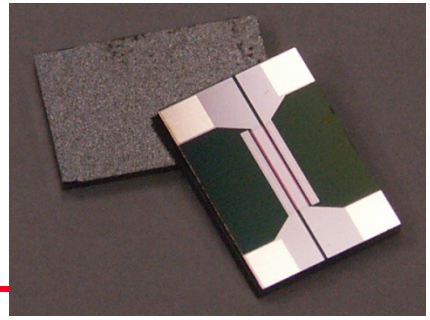


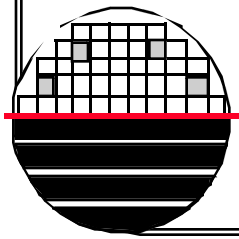
THERMIONIC GAS DETECTOR







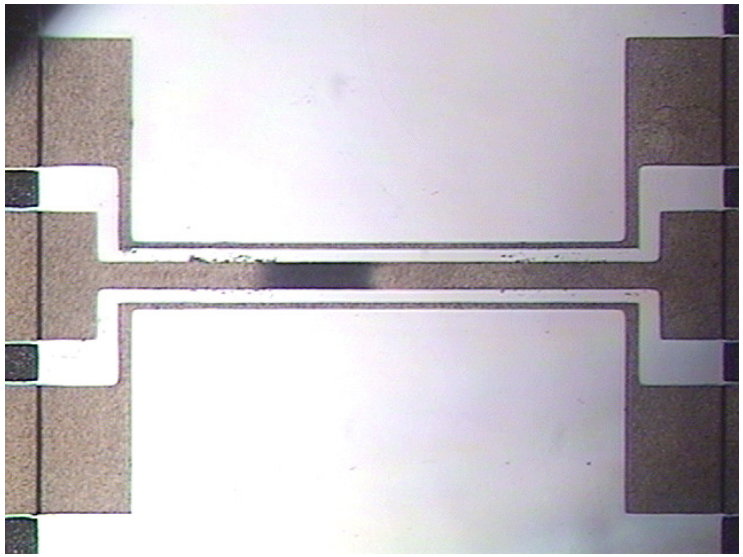


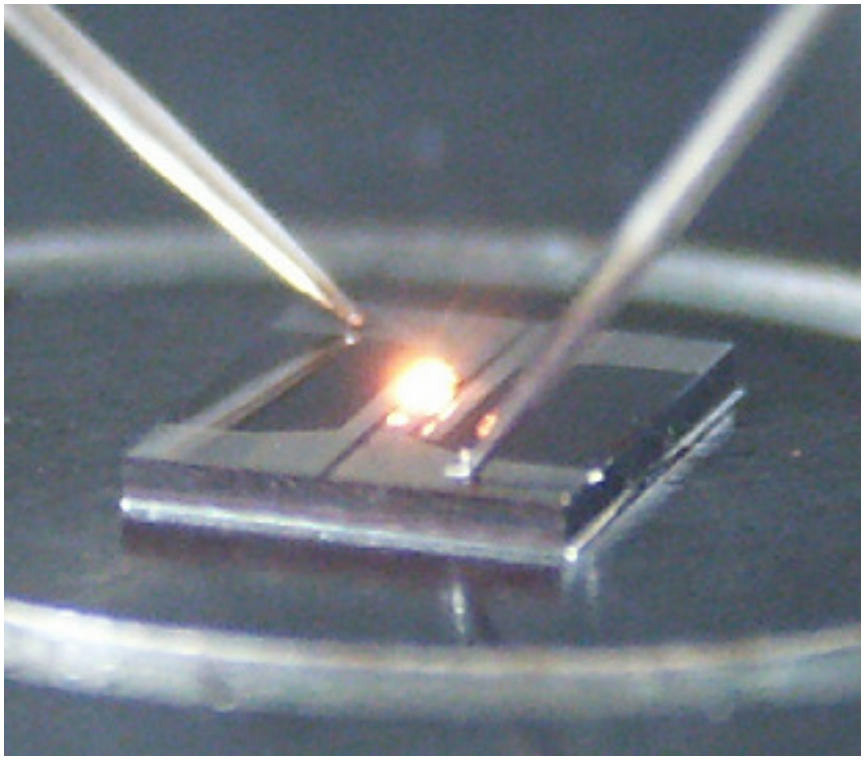


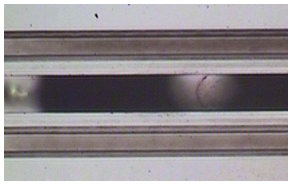
Rochester Institute of Technology
Microelectronic Engineering

Robert Manley, 2004

THERMIONIC GAS DETECTOR

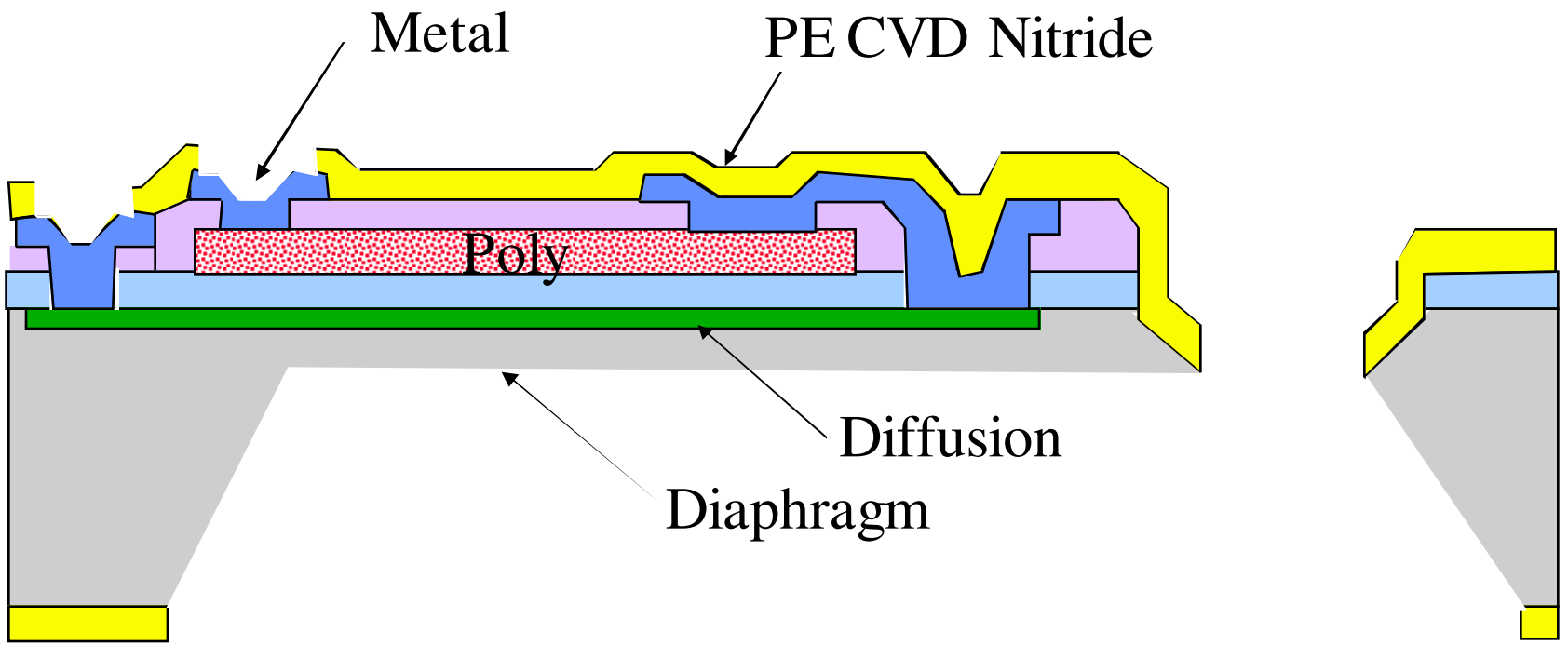






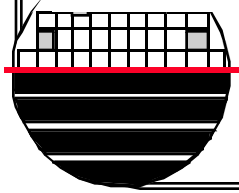
Cold Hot

MODIFIED BULK PROCESS FOR MEMS CLASS 2004-06

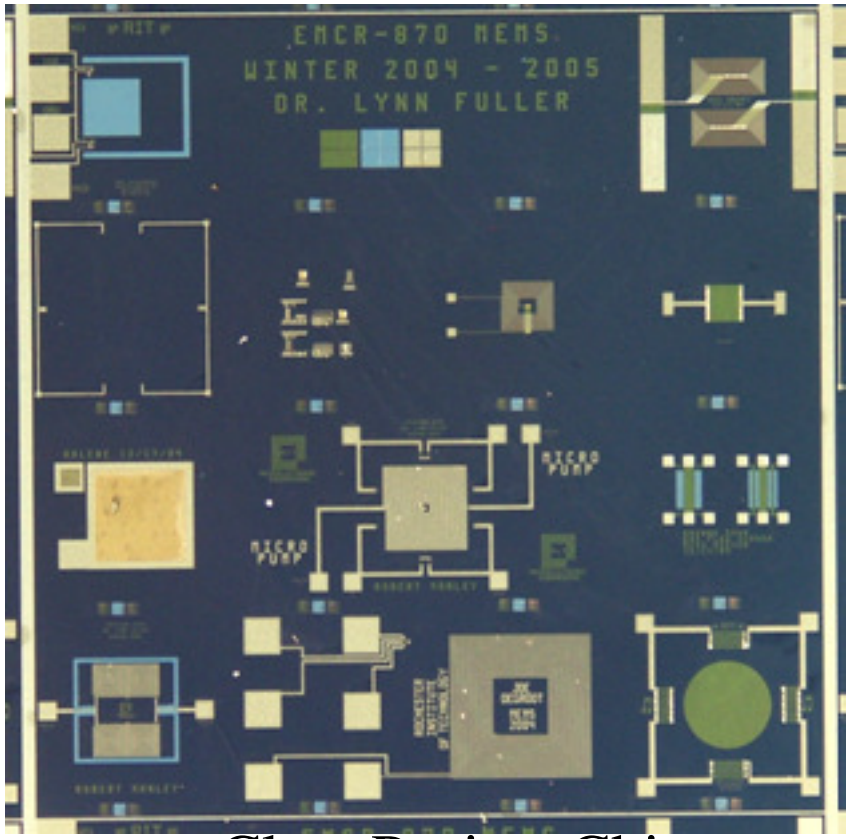


MODIFIED BULK PROCESS FOR MEMS CLASS 2004-06

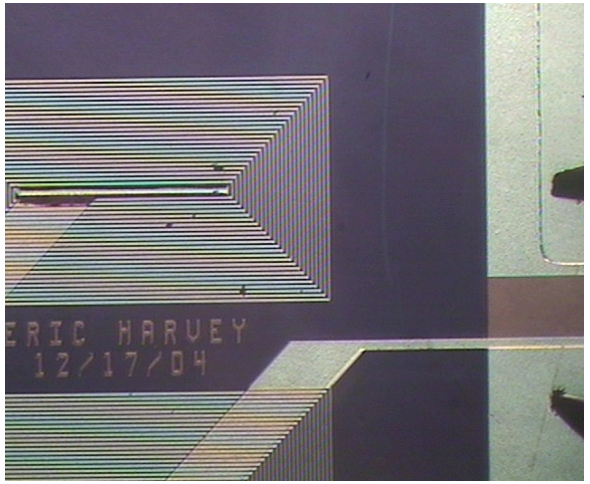
Pressure Sensor, diffused resistors or poly resistors
Microphone- more sensitive pressure sensor
Speaker – diaphragm with coil on it, magnet below
Accelerometer – diaphragm with mass in center from back etch donut
Diaphragm Actuator with coil and resistors for sensing and feedback
Optical pyrometer with thermocouples on diaphragm
Heater on diaphragm either poly or diffused resistor heater
Heater plus temperature sensor (diffused heater, poly resistor sensor)
Heater plus interdigitated chemical sensor
Cantilever accelerometer with piezoresistors either poly or diffusion, mass from back etch donut
Cantilever accelerometer with magnetic coil for sensor, mass from back etch donut
Gas flow sensor single resistor anemometer
Gas flow sensor with heater and two resistors
Torsional mirror with coil actuators
Gyroscope with piezoresistor sensors or coil and magnet sensors, with mass from back etch donut for each ½ of torsion bar
Transistors and logic, RF Inductors



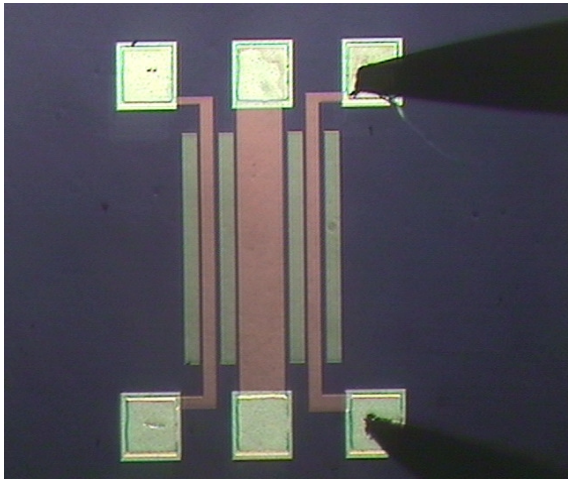
MODIFIED BULK PROCESS FOR MEMS CLASS 2004-06



Class Project Chip

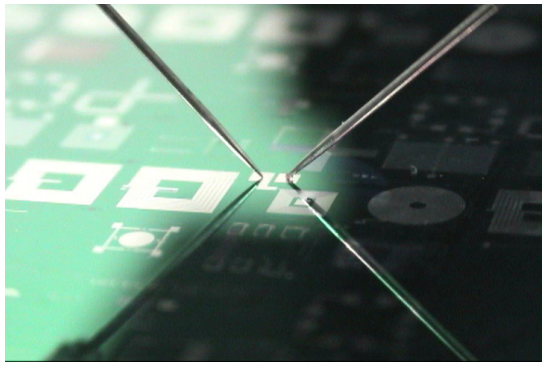


Torisonal Mirror

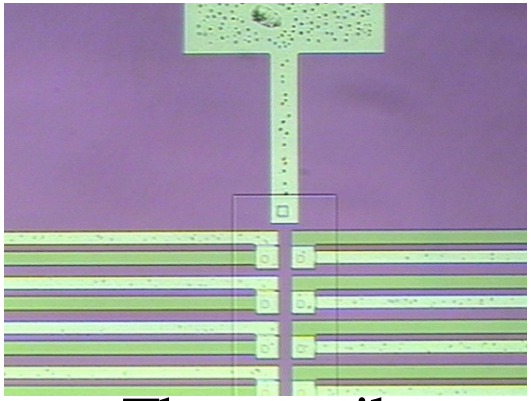


Gas Flow Sensor

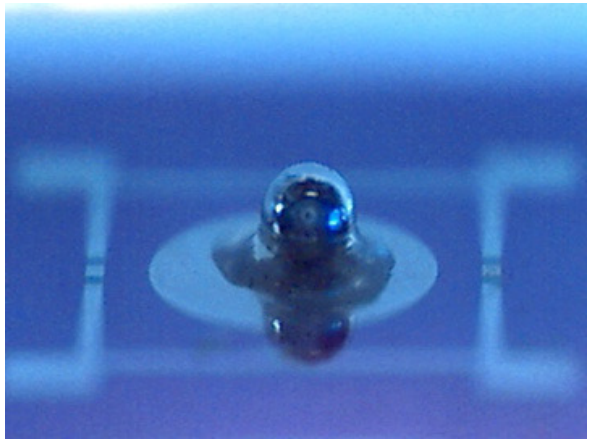
MODIFIED BULK PROCESS FOR MEMS CLASS 2004-06



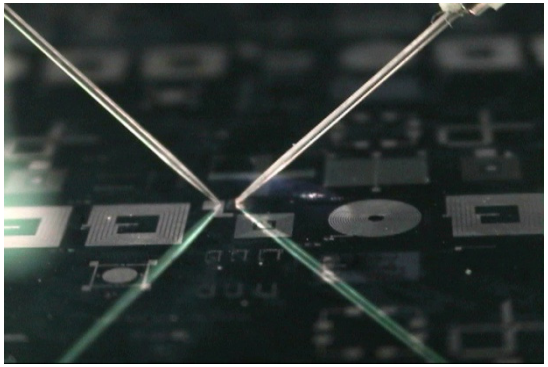
Movie



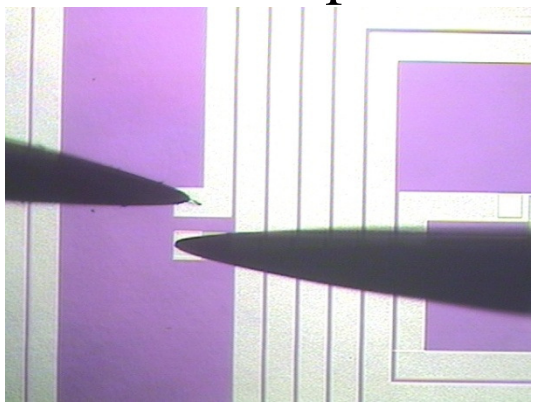
Thermopile



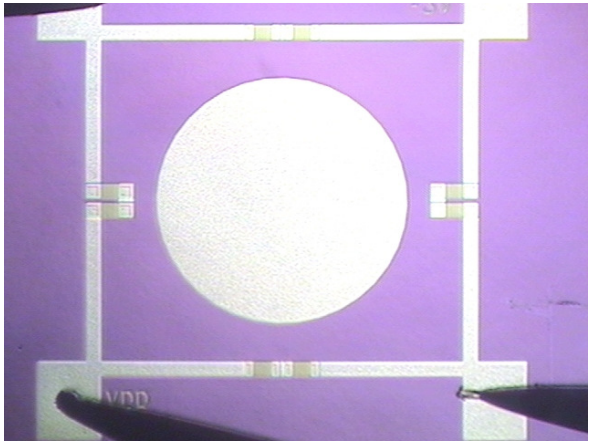
Accelerometer



Speaker

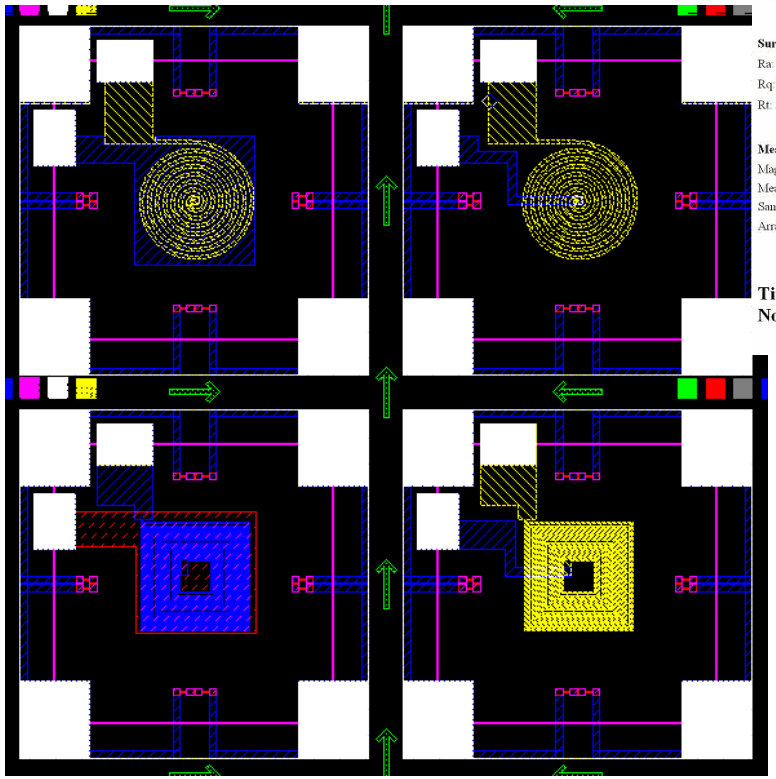


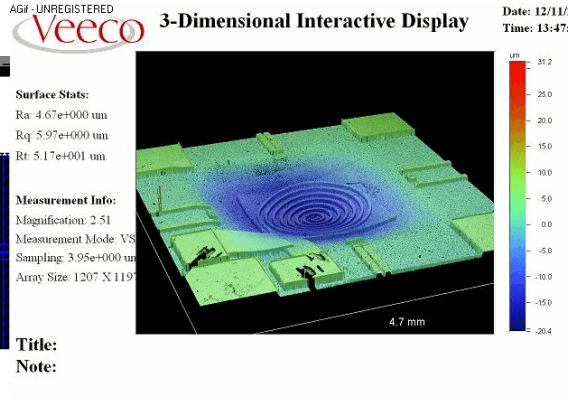
Inductor

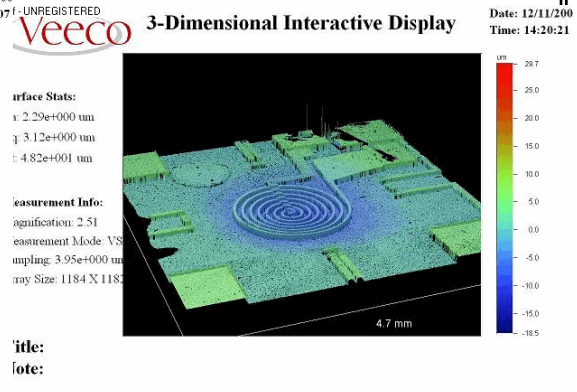


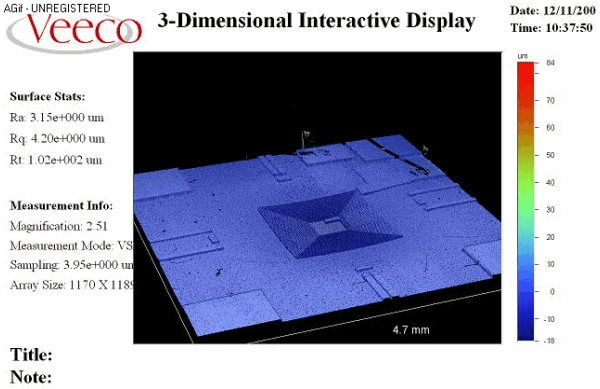
Pressure Sensor

MEMS ACTUATOR AND POSITION SENSOR









VISCOCITY SENSOR JOURNAL PUBLICATION AND PATENT

Journal of Microelectromechanical Systems

A Joint IEEE and ASME Publication on Microstructures, Microactuators, Microsensors, and Microsystems

JUNE 2011 VOLUME 20 NUMBER 3 JMIYET (ISSN 1057-7157)

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(43) Pub. Date: Dec. 30, 2010

(54) MICROELECTROMECHANICAL VISCOSITY MEASUREMENT DEVICES AND METHODS THEREOF

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(21) Appl. No.: **12/826,156**

(22) Filed: **Jun. 29, 2010**

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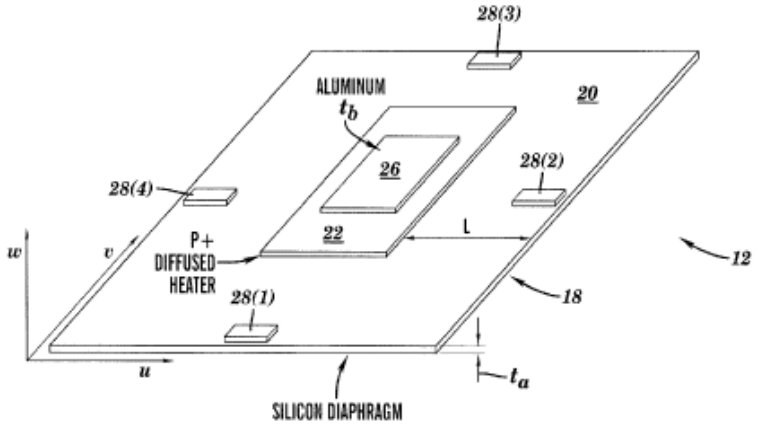
G01N 11/00 (2006.01)
H01L 21/70 (2006.01)

(52) **U.S. Cl.** **702/50**; 73/54.42; 438/51; 438/53; 257/E21.532

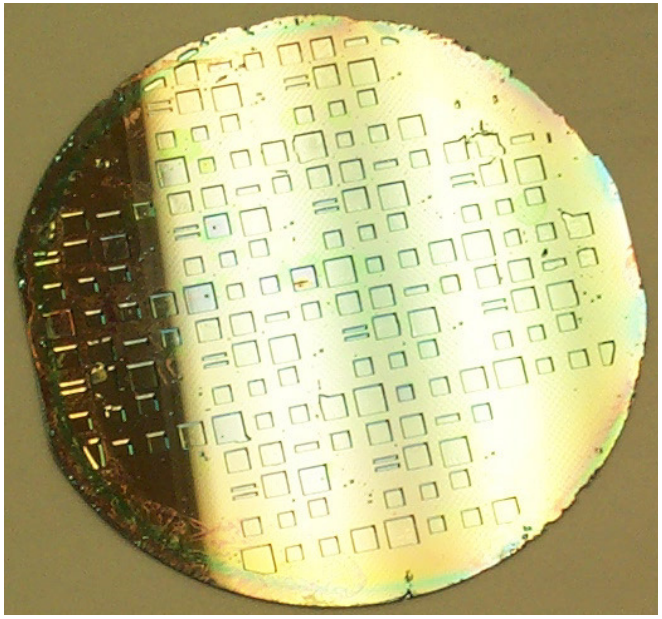
(57) **ABSTRACT**

A viscosity measurement device includes a flexible membrane, an actuation heating element, and a displacement sensor apparatus. The actuation heating element is on and spaced in from an outer periphery of the flexible membrane. The displacement sensor apparatus is coupled to the flexible membrane and measures and outputs a displacement signal representative of a viscosity of a fluid in contact with the flexible membrane



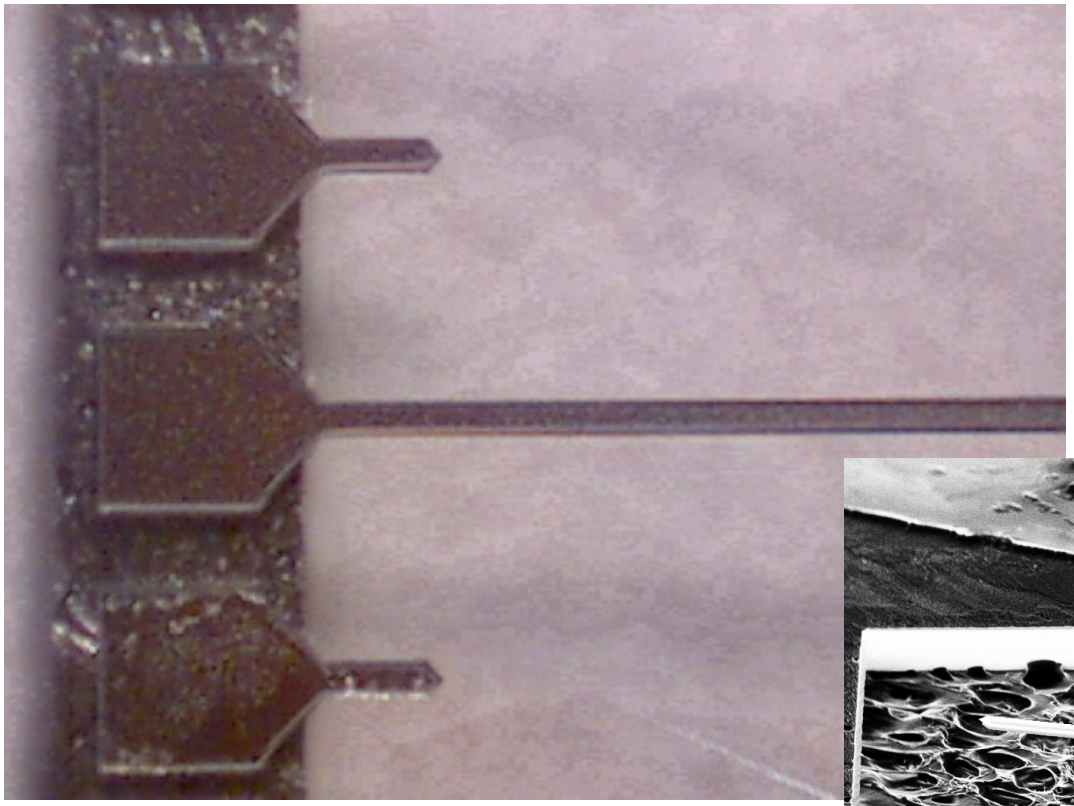
MODIFIED BULK PROCESS FOR MEMS CLASS 2004-06

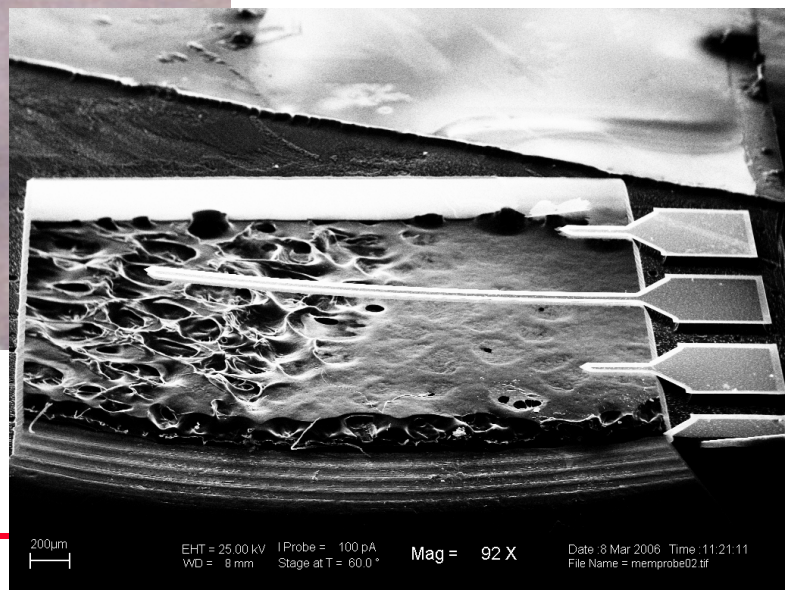
Wafer Inspection



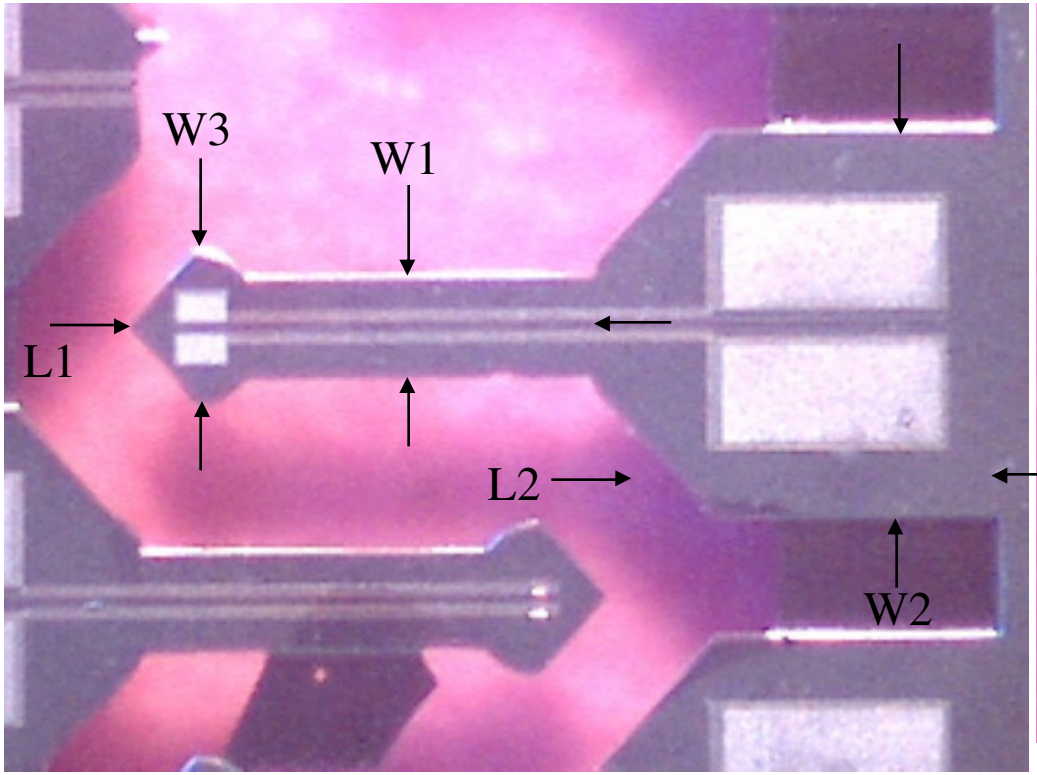
Backside of Wafer

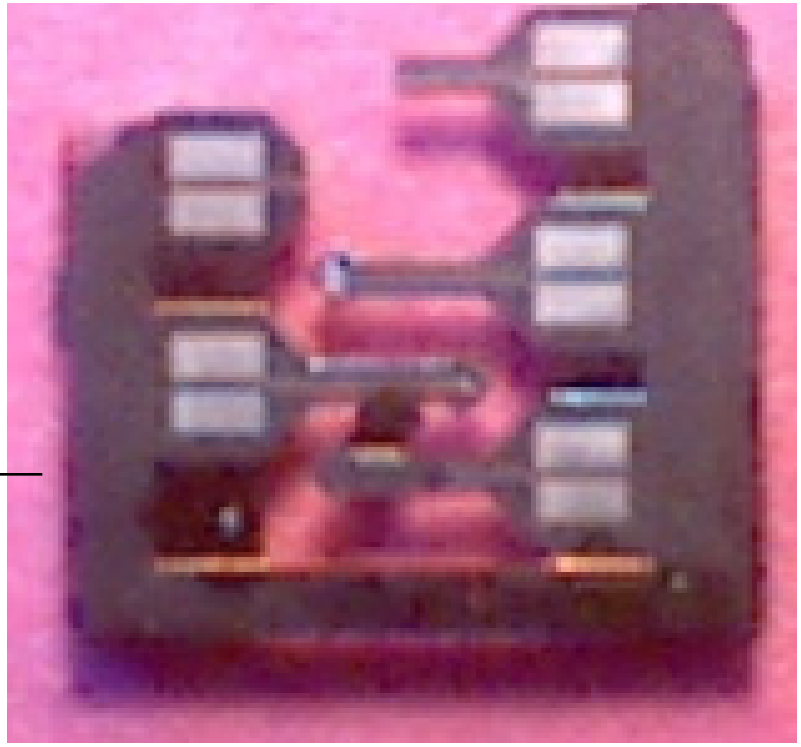
BIO PROBES




200µm
EHT = 25.00 kV
WD = 8 mm
I Probe = 100 pA
Stage at T = 60.0 °
Mag = 92 X
Date :8 Mar 2006 Time :11:21:11
File Name = memprobe02.tif

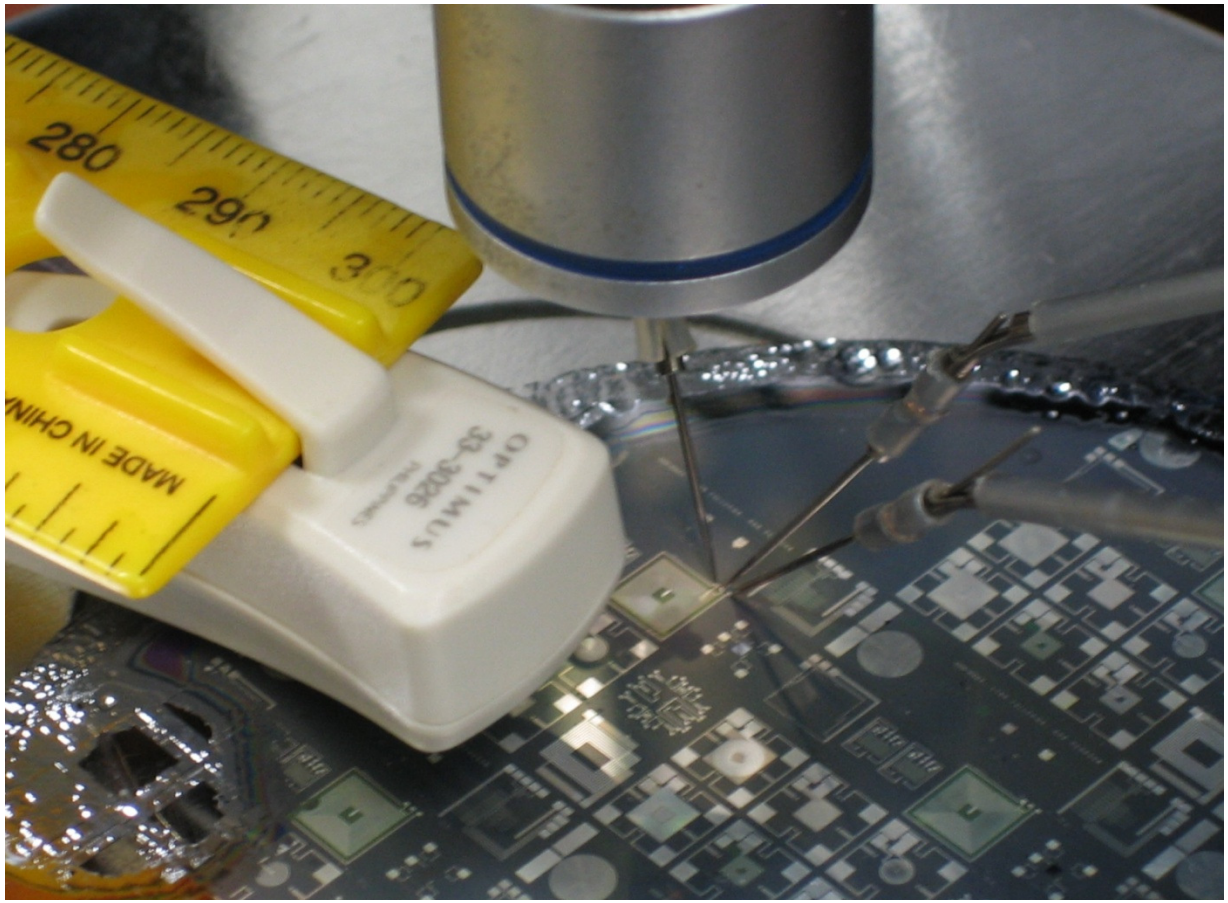
SECOND VERSION COMPLETED DEVICES





W1 = 300 μm
W2 = 1100
W3 = 450
L1 = 1400
L2 = 1250

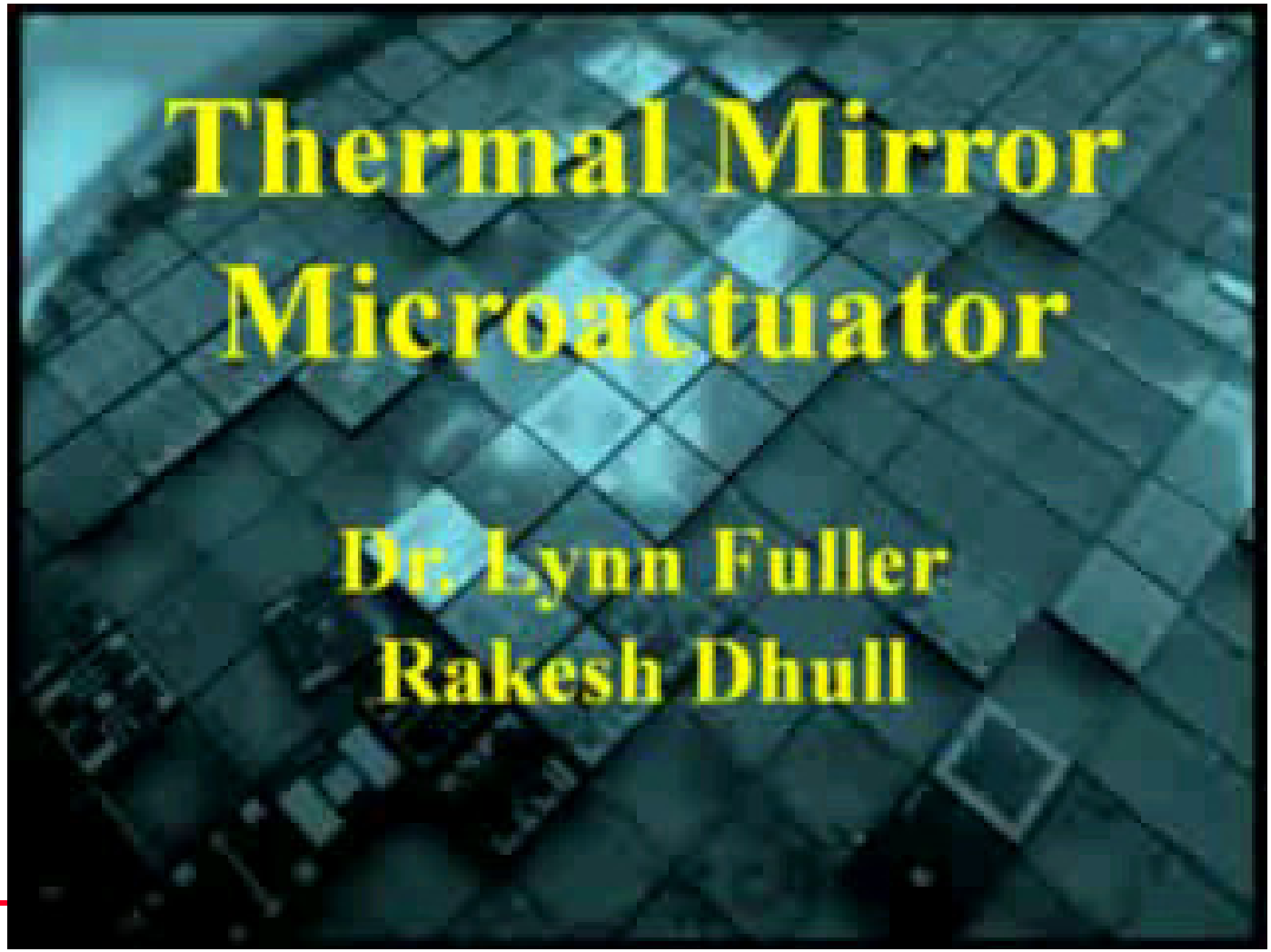
MICROSPEAKER – CHRIS NASSER



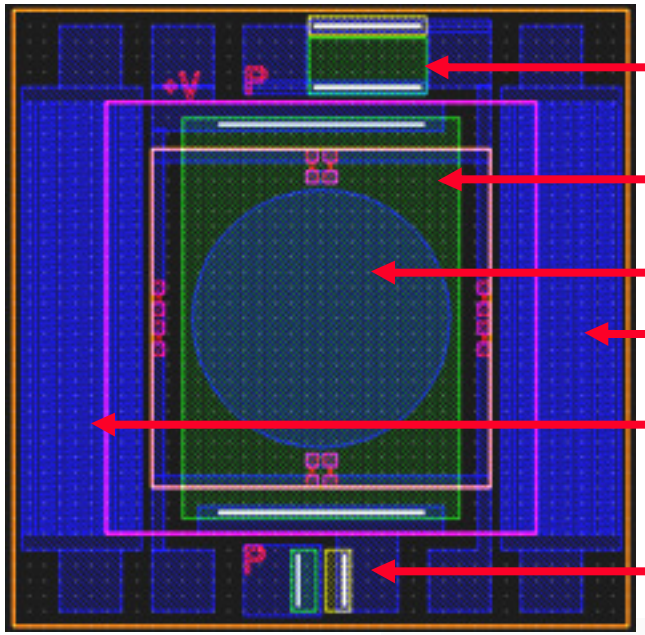
Audio

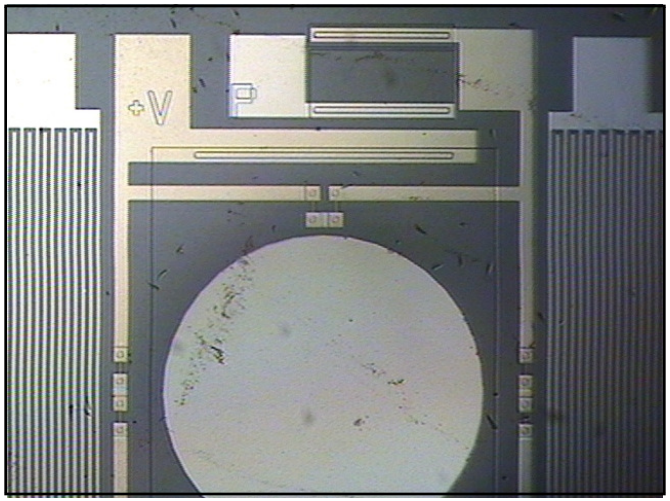
> http://video.google.com/videoplay?docid=4513627860990043960

THERMALLY ACTUATED MEMS MICRO MIRROR

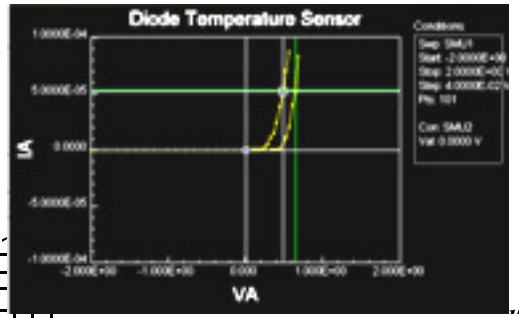


OIL QUALITY MEMS MULTI-SENSOR

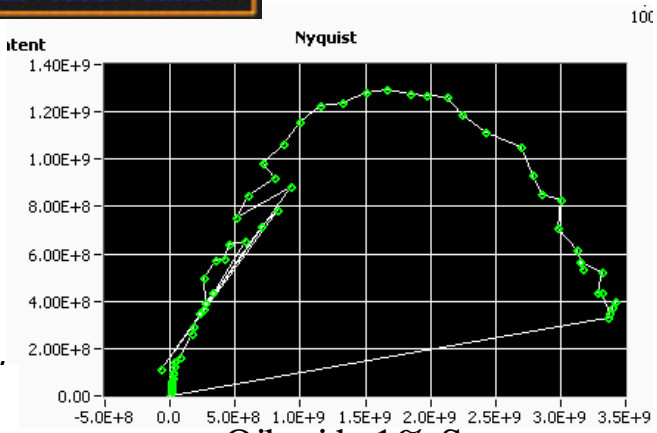




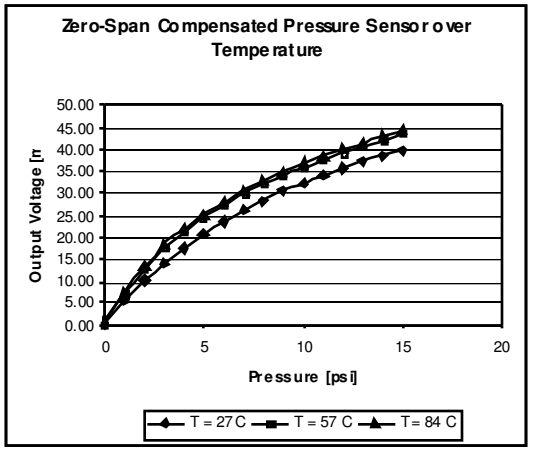
Picture of MEMS Multisensor



Temp Sensor Test



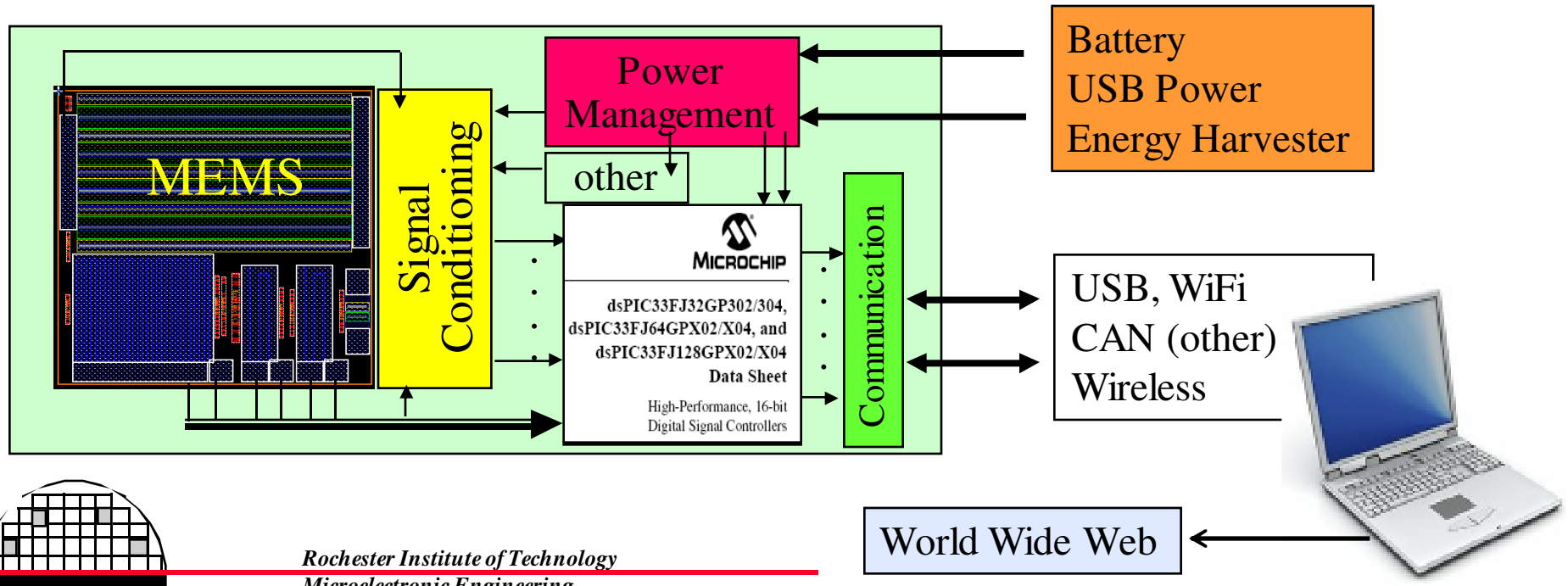
Oil with 1% Soot



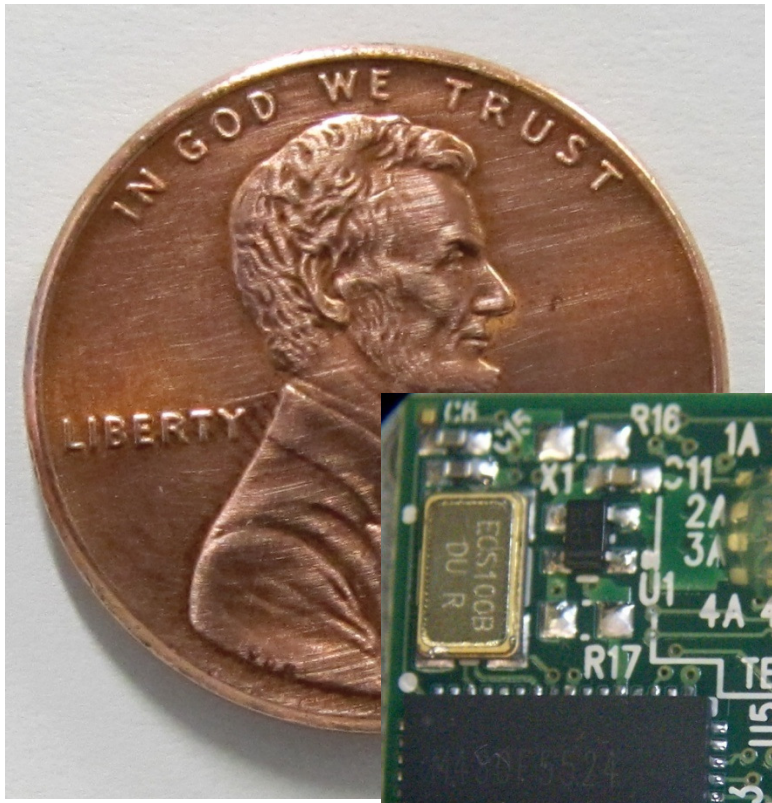
Pressure Study

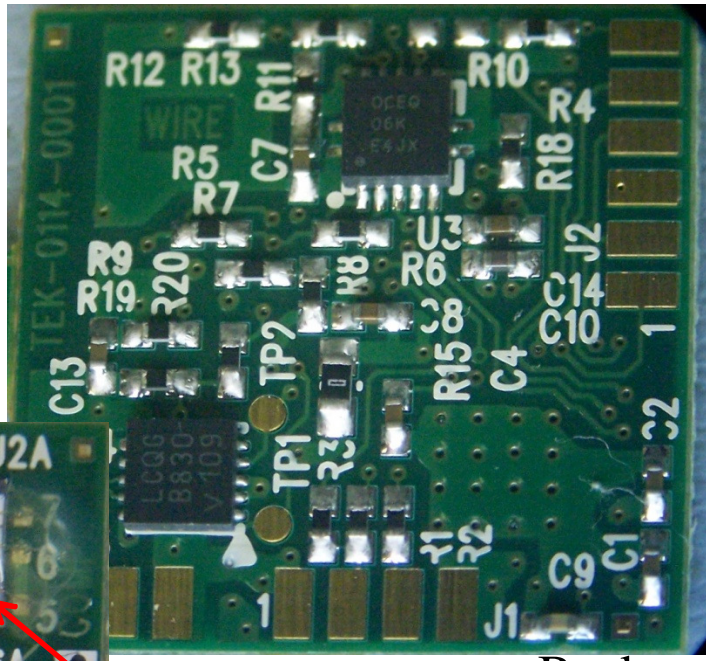
MICROSYSTEM

Team Galt's definition for Microsystems is the integration of MEMS sensors and actuators with CMOS electronics to provide solutions for a wide variety of applications including automotive, military, aerospace, consumer and biomedical.

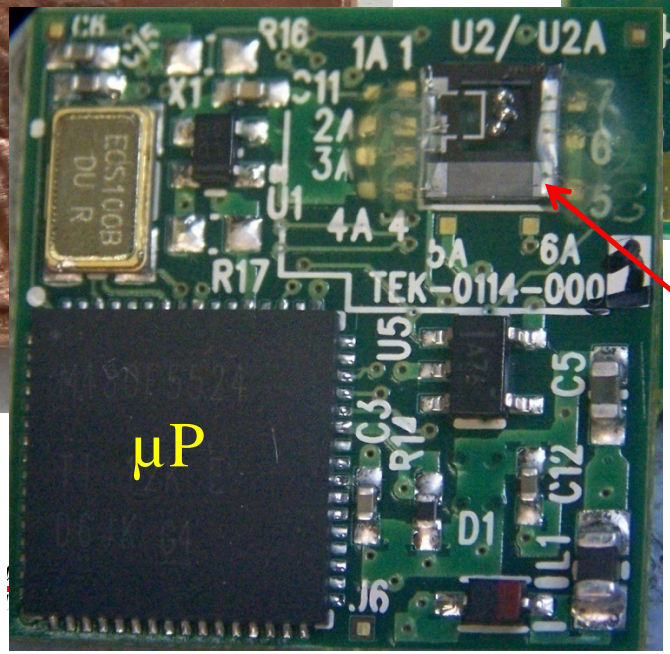


MULTISENSOR MICROSYSTEM





Back

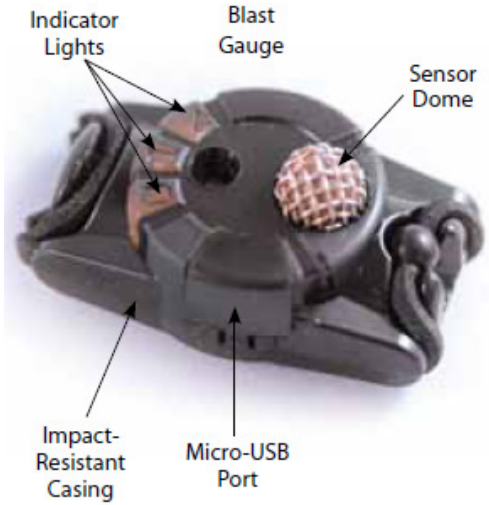


Front

MEMS Multisensor Chip
Acceleration (shock)
Temperature, Humidity

TEAM GALT SUPPORTS OTHER FACULTY PROJECTS

Dr. David Borkholder – PI
Blast Dosimeter / DARPA



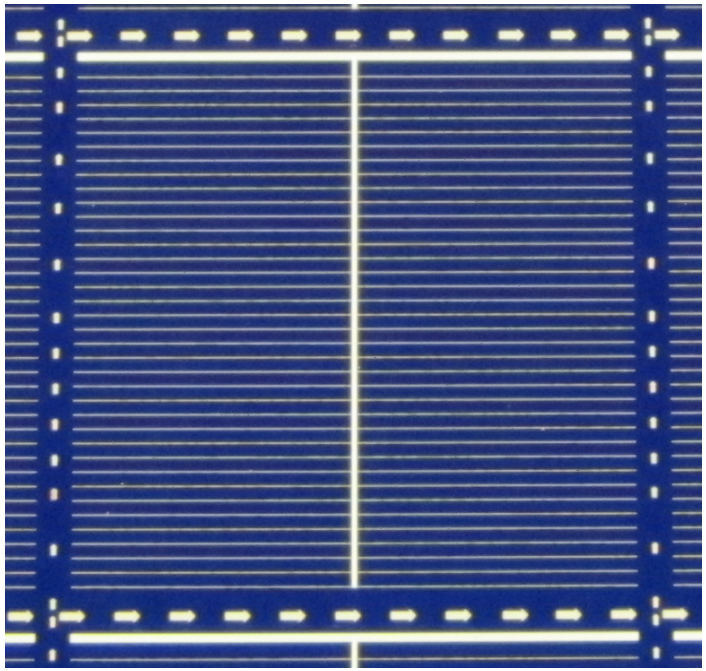
Blast Gauge: The data-logging device measures pressure, resulting head acceleration, and time to help correlate blast events with injuries. The compact device weighs less than one ounce, making it easy for soldiers to wear.

Explosives Testing: Weighted crash test dummies are used to simulate a soldier in the field. A number of orientations are used to allow the team to characterize the space and inform the device algorithms.

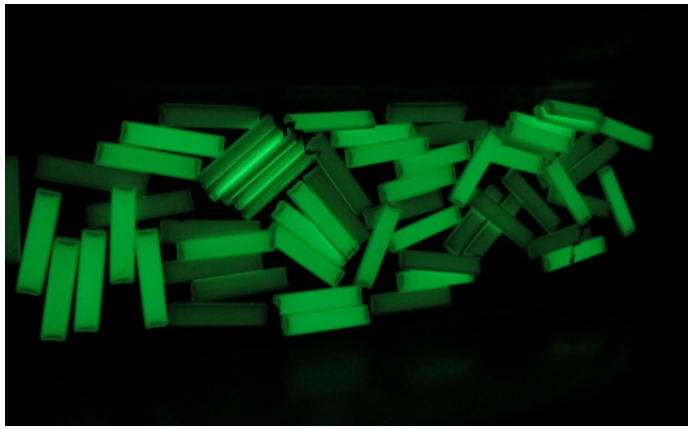
ENERGY HARVESTING

Indirect Conversion of Radiation for 20 Year-Life Batteries

Green Optimized Photocell



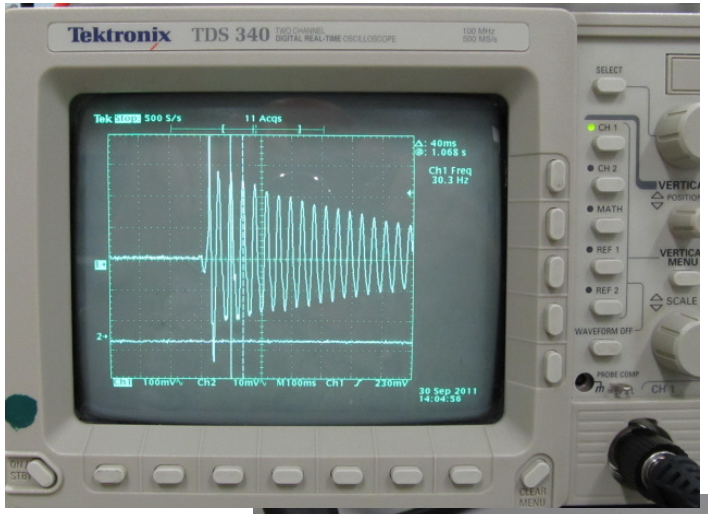
1.6 cm

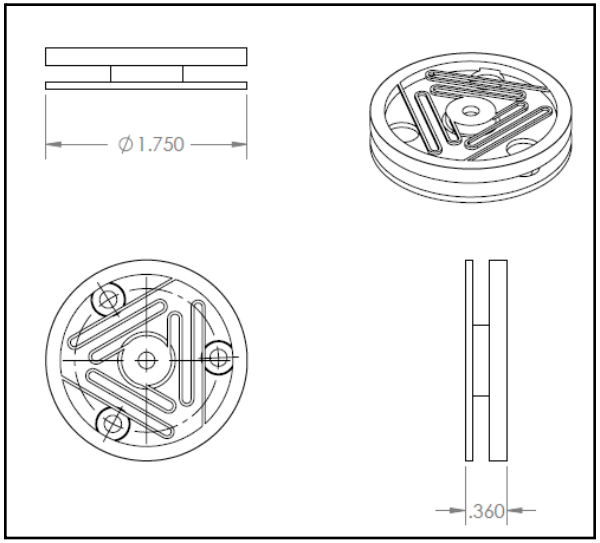


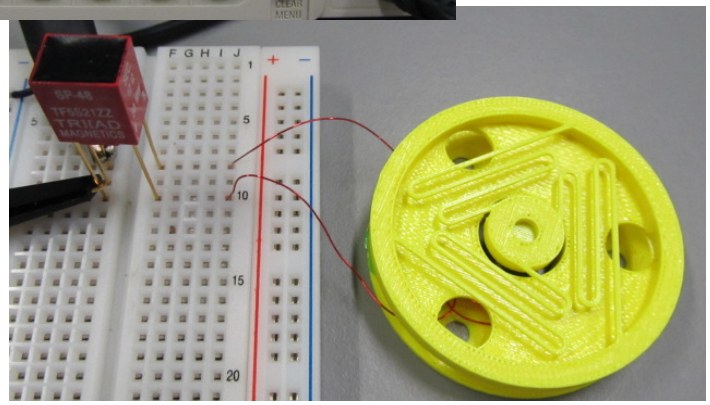
Gaseous Tritium Light Source (GTLS)

(GTLS) – Phosphor Coat Glass Vial with Tritium Inside
Tritium: Radioactive Isotope of Hydrogen, ^{3}H, 12year half life
Emits Electrons Through Beta Decay
Electrons Interact With Phosphor Material
Green Light is Emitted (Radio luminescence)
Photo Detector Captures Light and Converts to Energy
Energy Management Electronics
Stores Energy in a Super Capacitor

VIBRATION ENERGY HARVESTER

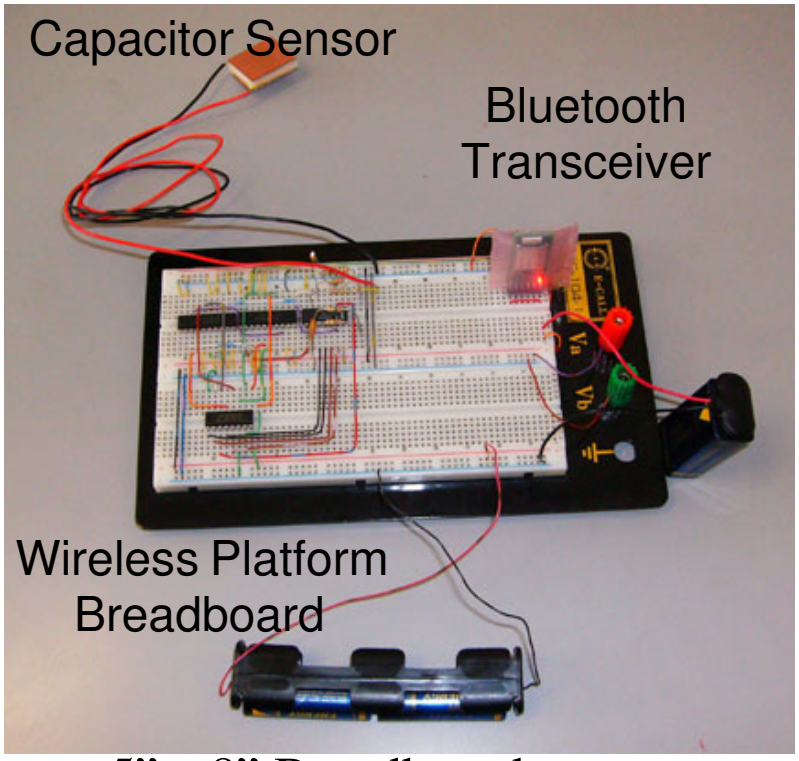




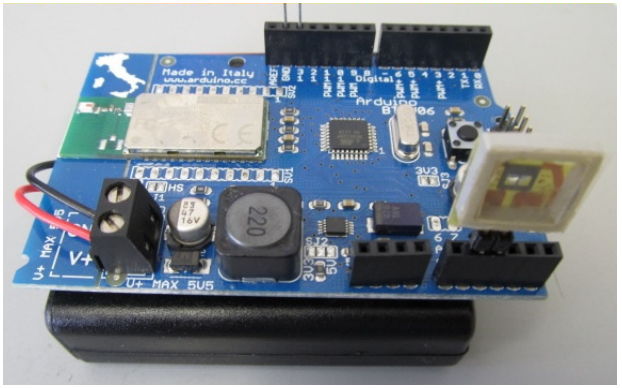


Dr. Denis Cormier
3-D Printer
Brinkman Lab at RIT

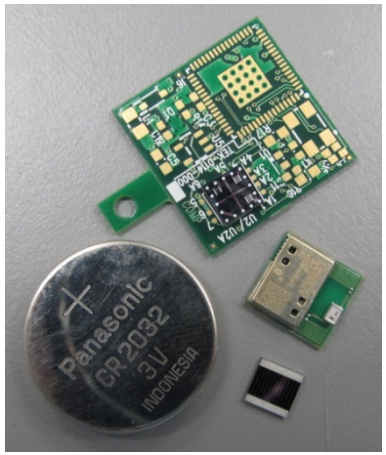
WIRELESS MICROSYSTEMS



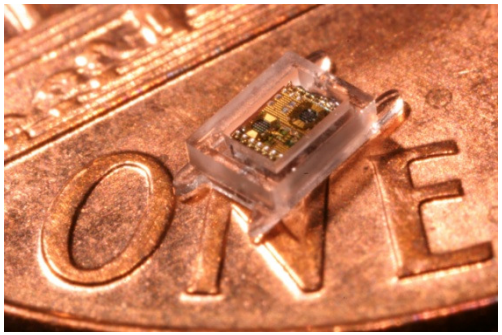
5” x 8” Breadboard



2.5” x 3” BT-Arduino



1” x 1” PCB



2mm x 3mm
Custom CMOS & MEMS

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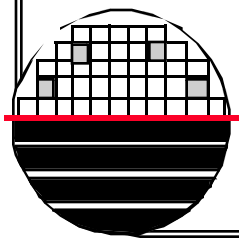
Team Galt



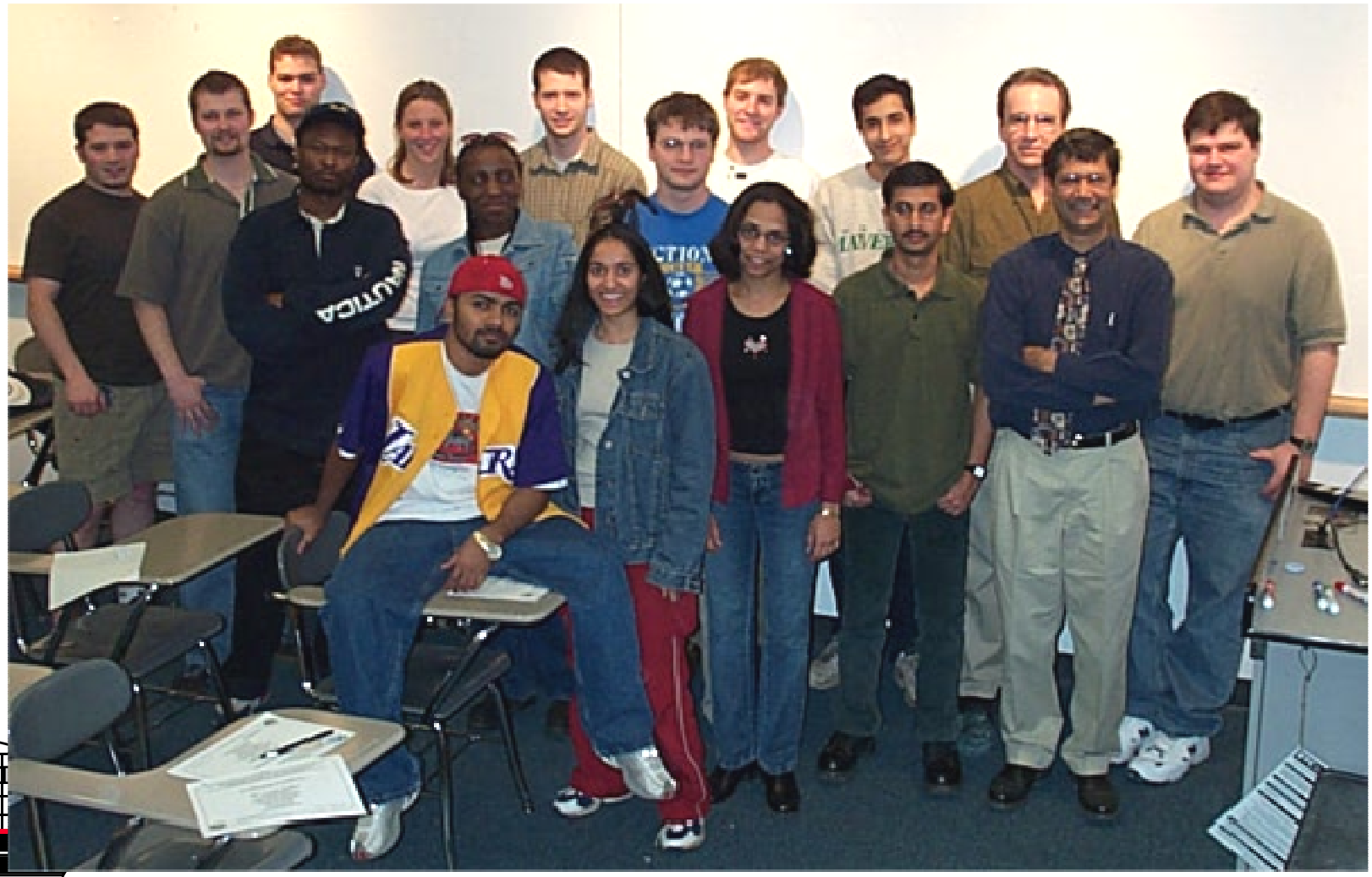
TEAM GALT

Tal, Lynn, Ellen Sedlack, Christian, Artur, Ivan, Renat

Heidi, Murat

B.S., M.S., Ph.D., students from EE, ME, MicroE, CE, Materials Science

DR. FULLER'S STUDENTS IN EMCR 890 MEMS CLASS 2002



CONFERENCE PUBLICATIONS

1. "Nanocomposite Material for Sensing of Halogenated Methanes: A Model Based on Charge Transfer Interaction for Selectivity," R.Sangoi, L.Fuller, K.S.V. Santhanam, MRS Meeting, Boston, Massachusetts, October, 2003.
2. "Design and Analysis of a Shear Stress Sensor for Microcirculation Investigation," ASME Fluid Engineering Division July 6-10, 2003, Honolulu, Hawaii, L.F.Fuller, Risa Robinson, et.el.
3. "Bulk Micromachined Pressure Sensor," L.F.Fuller, Steve Sudirgo, Proceedings of the IEEE UGIM Conference, June 2003, Boise State University.
4. "An Inter-digitated Electrode Detector for the Identification of a Single Specific DNA Molecule Fragment," L.F.Fuller, Renaldo Vega, Robert Manley, Vee Chee Hwang, Dan Jansen, An Pham, Nate Wescott, Mike Connolly, Proceedings of the IEEE UGIM Conference, June 2003, Boise State University.
5. "Fabrication of Polysilicon Surface Micromachined MEMs Structures", Kevin Munger and Lynn F. Fuller, Microelectronic Engineering, Rochester Institute of Technology, Proceedings of the IEEE UGIM Conference, June 2001, Virginia Commonwealth University.
6. "MEMS Activity at Rochester Institute of Technology," L.F.Fuller, A.Pham, P. Merwah, Proceedings of the IEEE UGIM Conference, June 20-23, 1999, Minneapolis, MN
7. "A Surface Micromachined Capacitive Pressure Sensor for Biomedical Applications," K.E.Babbitt, L.F.Fuller, B.Keller, Proceedings of the IEEE UGIM Conference, July 20-23, 1997, Rochester, NY
8. "A Multi-project MEMs Leture and Laboratory Course," L.F.Fuller, Proceedings of the IEEE UGIM Conference, July 20-23, 1997, Rochester, NY
9. "Microelectronic Engineering at RIT - The First 10 Years", L.F.Fuller, R.E.Pearson, S.K.Kurinec, I.R.Turkman, M.A.Jackson, B.W.Smith, R.L.Lane, Proceedings of the 10th Biennial University Industry Government Microelectronics Symposium, May 1993, Durham NC.

HOMEWORK – HISTORY OF MEMS

1. We have made a lot of different types of MEMS at RIT but not every type of MEMS device. Create a comprehensive list of all types of MEMS devices and indicate which devices have not been made at RIT.
2. Read "A thermally Actuated Microelectromechanical (MEMS) Device for Measuring Viscoscity" I. Puchades and L.F. Fuller, IEEE Journal of MEMS, June 2011. Explain how the device works.
3. View the following link and read the article on "Blast Gauge" http://www.rit.edu/research/media/documents/11_SS_Research_at_RIT.pdf
   What types of MEMS devices are inside the "Blast Gauge".
4. Why is packaging important for MEMS devices?
5. List the MEMS devices you use personally.