ROCHESTER INSTITUTE OF TECHNOLOGY
MICROELECTRONIC ENGINEERING

Probes and Electrodes

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5-8-2012 mem_probes.ppt

OUTLINE

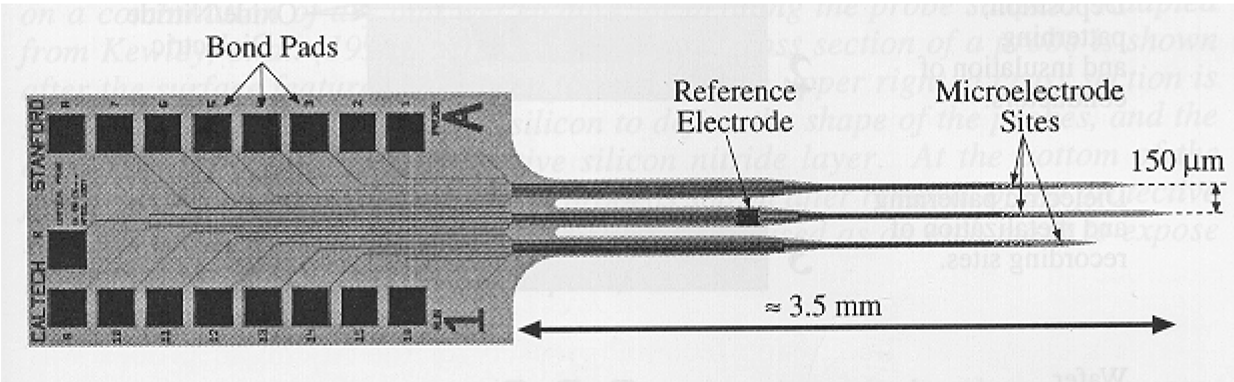
INTRODUCTION

Electrical Sensing or Recording Electrodes
Electrical Stimulus Electrodes
Chemical Analysis Probes (not discussed in this lecture)

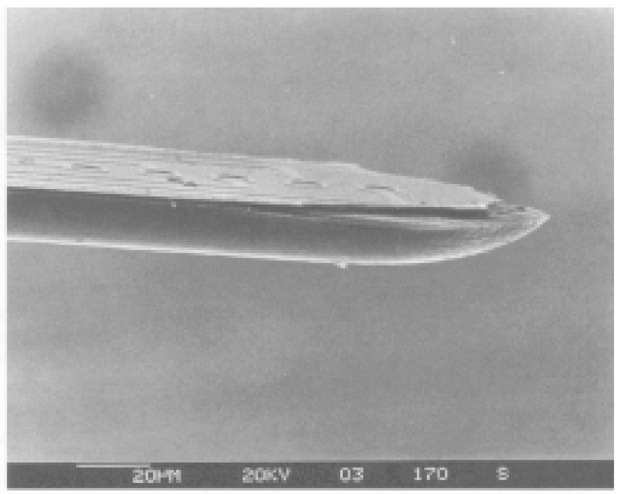
Applications:

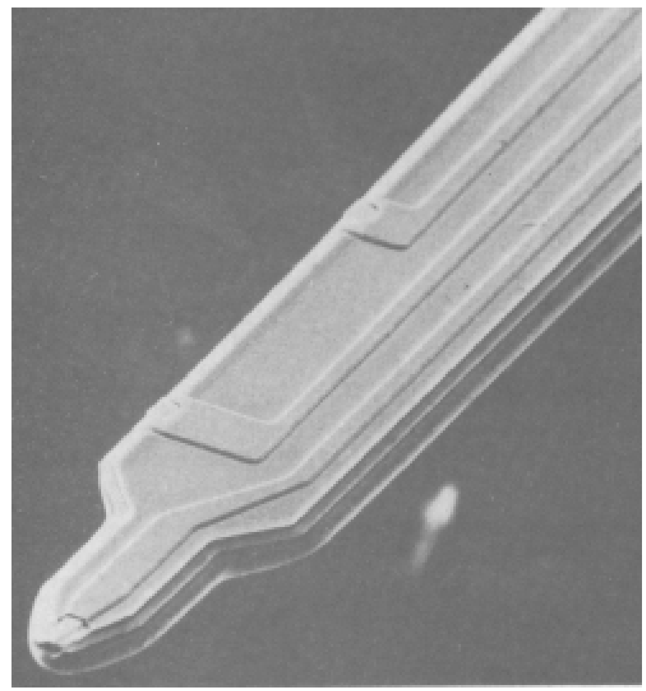
- Research
- Vision Restoration
- Hearing Restoration
- Heart Pacemaker and Defribulation
- Bladder control
- Muscle Stimulation
- Other

MEMS SENSING ELECTRODES

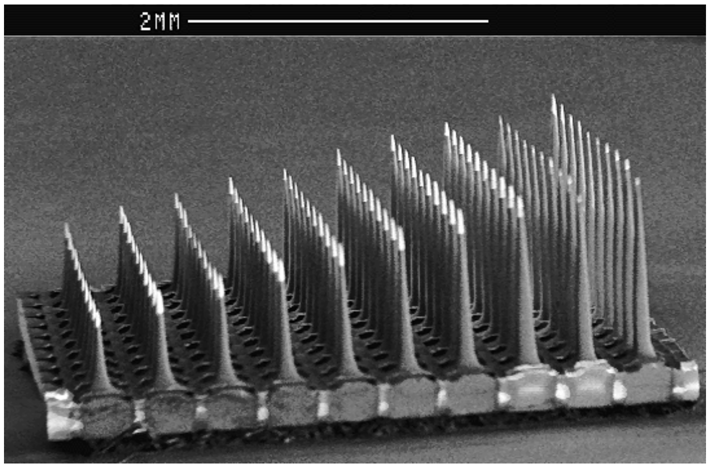


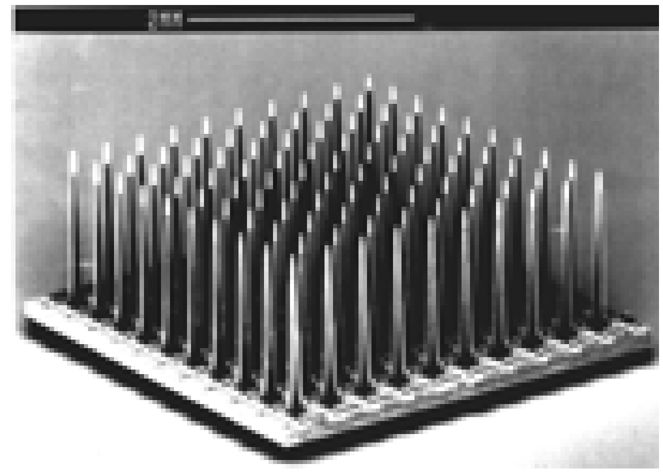
Silicon Electrodes

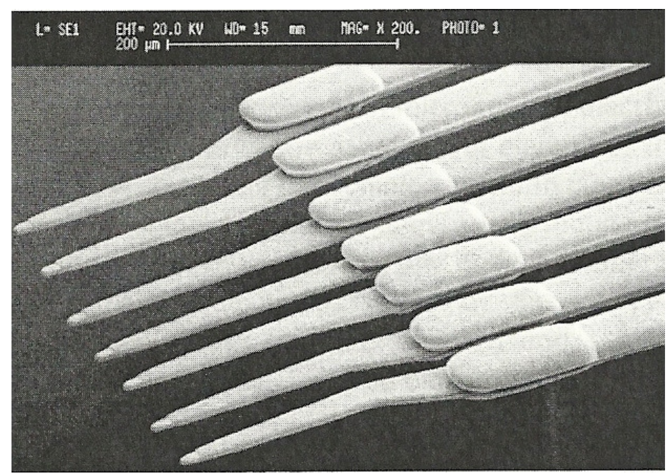




RECORDING ELECTRODES

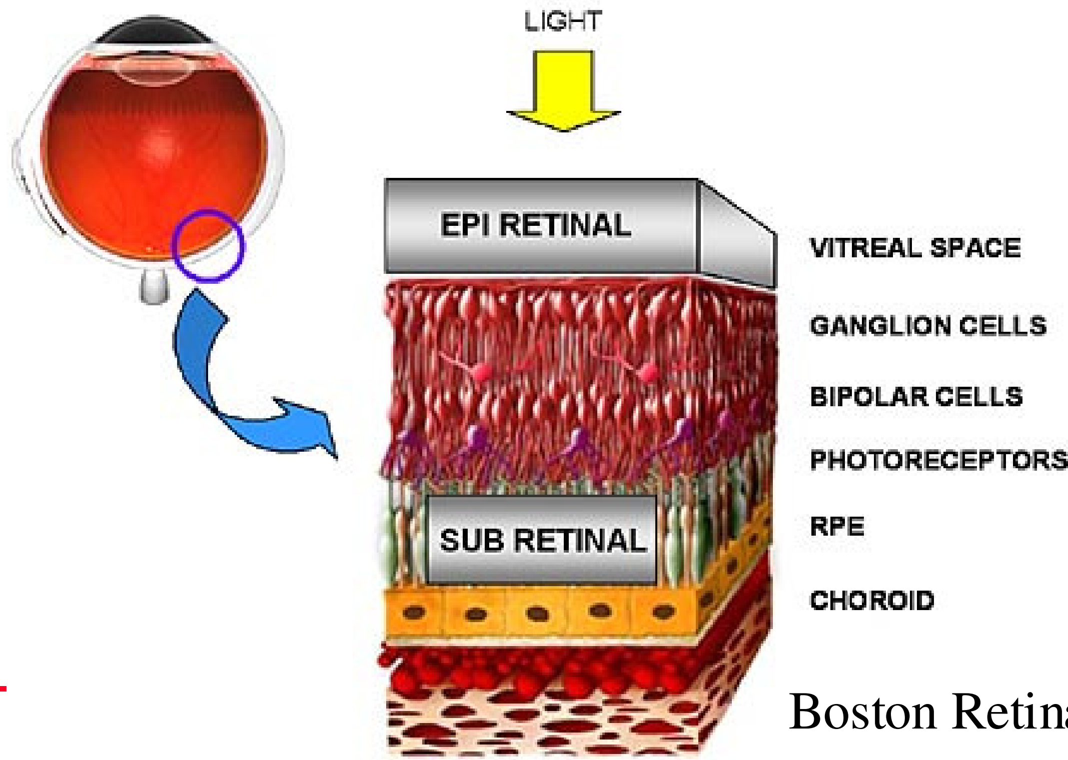






VISION RESTORATION

In conditions such as retinitis pigmentosa and macular degeneration, the light sensing rod and cone cells ("photoreceptors") no longer function. Visual prostheses, implanted in the brain's visual cortex, the optic nerve, or in the retina. A retinal prosthesis can be fixated either on the retinal surface (epiretinal) or below the retina (subretinal).



Boston Retinal Implant Project

THE EYE

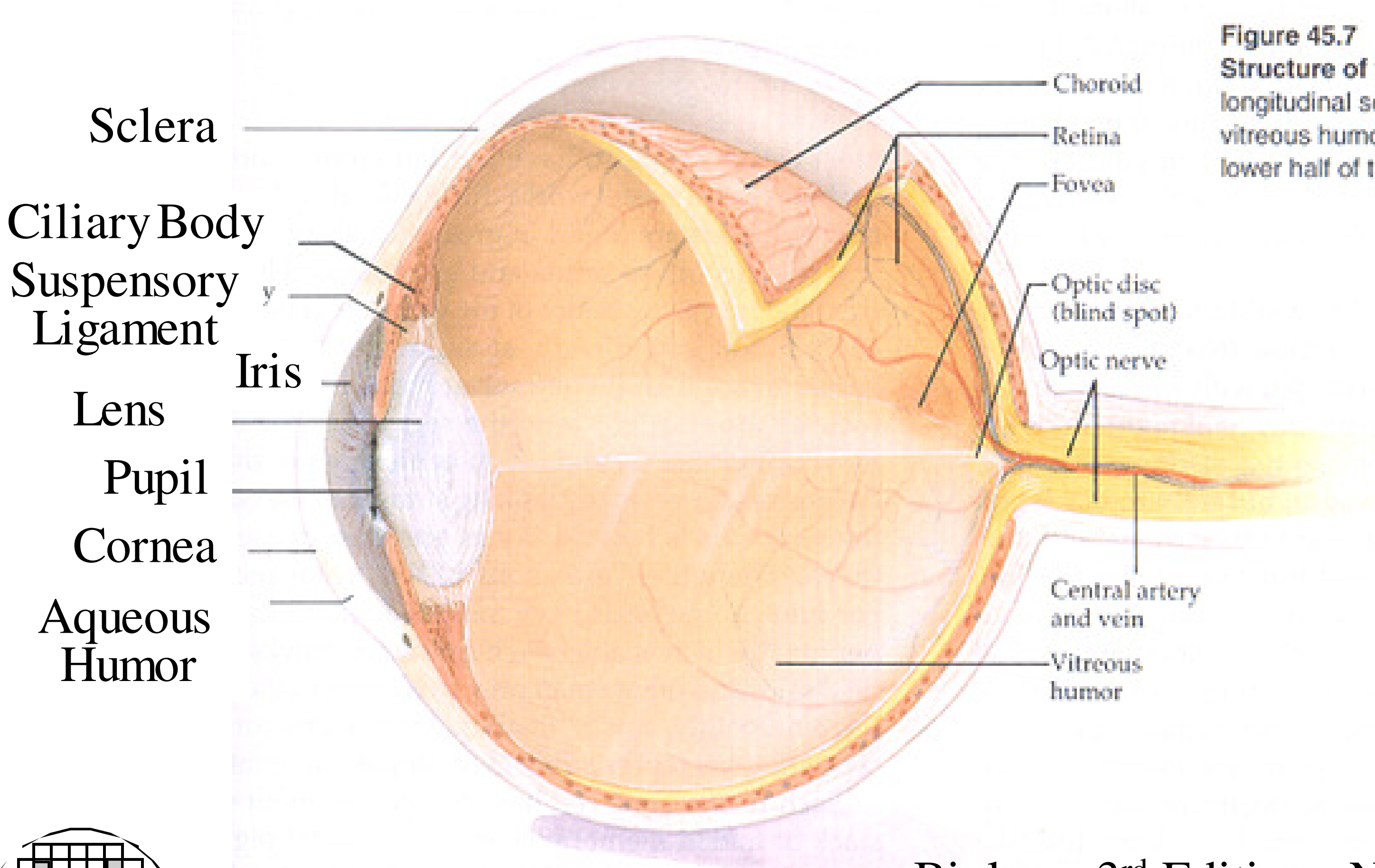
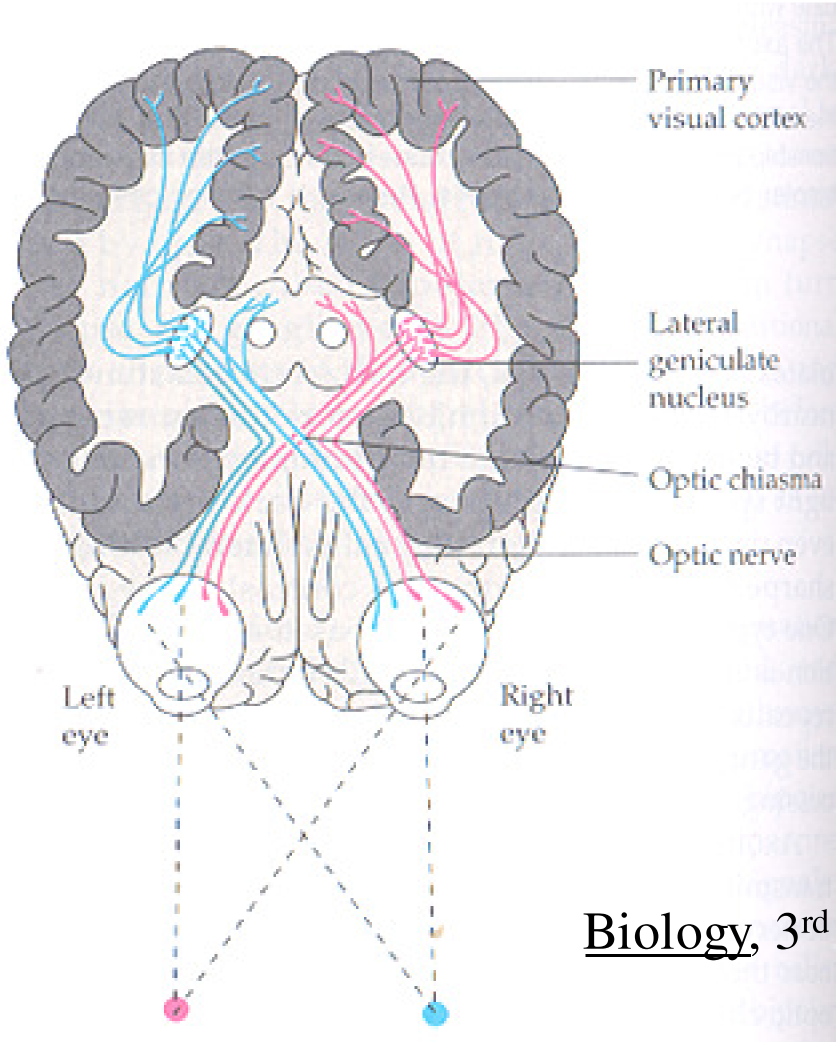


Figure 45.7
Structure of the vertebrate eye. In this longitudinal section of the eye, the jellylike vitreous humor is illustrated only in the lower half of the eyeball.

Biology, 3rd Edition, Neil A. Campbell

VISUAL CORTEX



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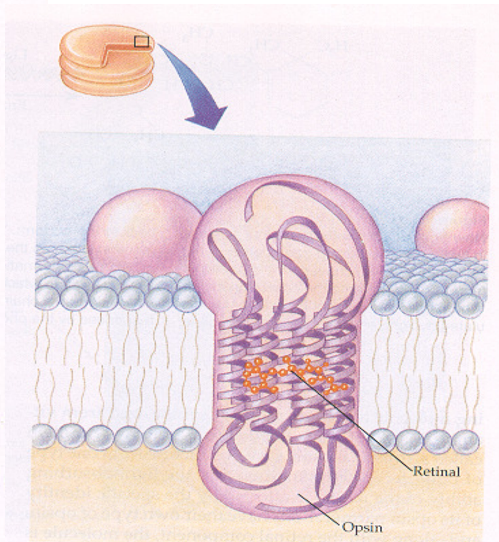
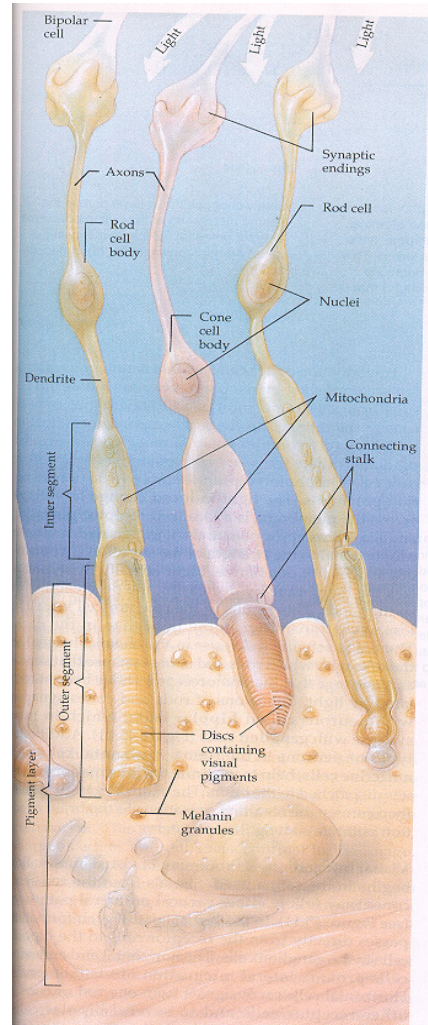
THE RETINA

Figure 45.9

Photoreceptors of the retina. **(a)** The retina is populated by two types of photoreceptors. Rods are very sensitive to light and function in black-and-white vision at night; cones are less sensitive to light and account for color vision during the day. Both types of cells are modified neurons. Each rod and cone has an outer segment partly embedded in a layer of darkly pigmented epithelial cells. The outer segment is connected by a short stalk to an inner segment, which is in turn connected to the cell body. Axons of the rods and cones synapse with other retinal neurons called bipolar cells. Within the outer segment of a rod or cone is a stack of folded membrane. The visual pigments responsible for detecting light focused onto the retina are built into these stacked membranes. **(b)** The visual pigments consist of a light-absorbing molecule called retinal (derived from vitamin A) bonded to a protein called an opsin. Each type of photoreceptor has a characteristic kind of opsin, which affects the absorption spectrum of the retinal. In the case of rods, the whole pigment complex—retinal plus the specific type of opsin—is called rhodopsin, which is the visual pigment illustrated here. Notice that the opsin has several regions of alpha helix (see Chapter 5) spanning the membrane. At the core of the opsin is the light-absorbing retinal.



(b) Rhodopsin, the visual pigment in rods



a) Rods and cones, the photoreceptors in the retina

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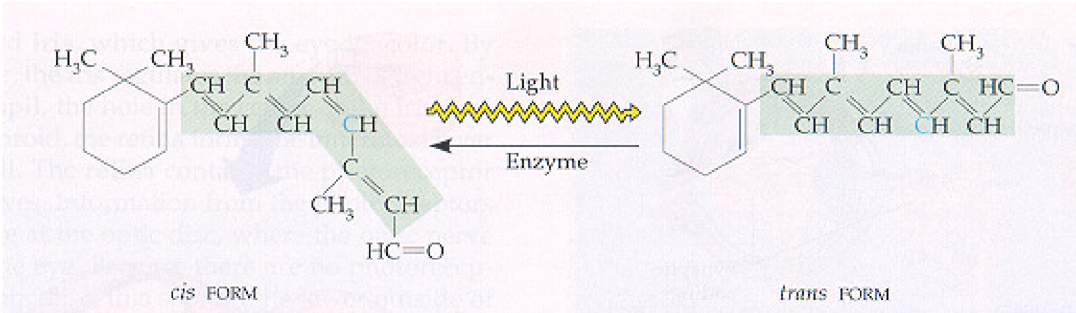
CONVERSION OF LIGHT



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THE RETINA

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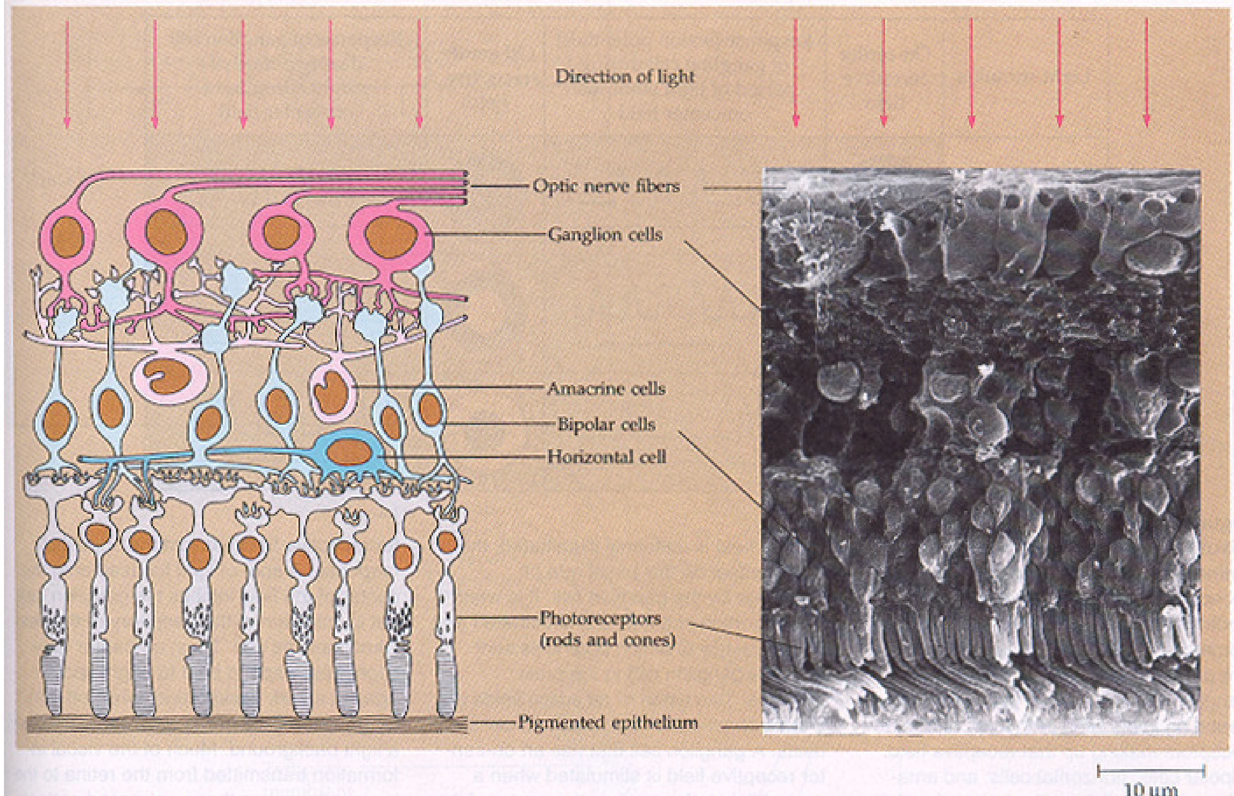
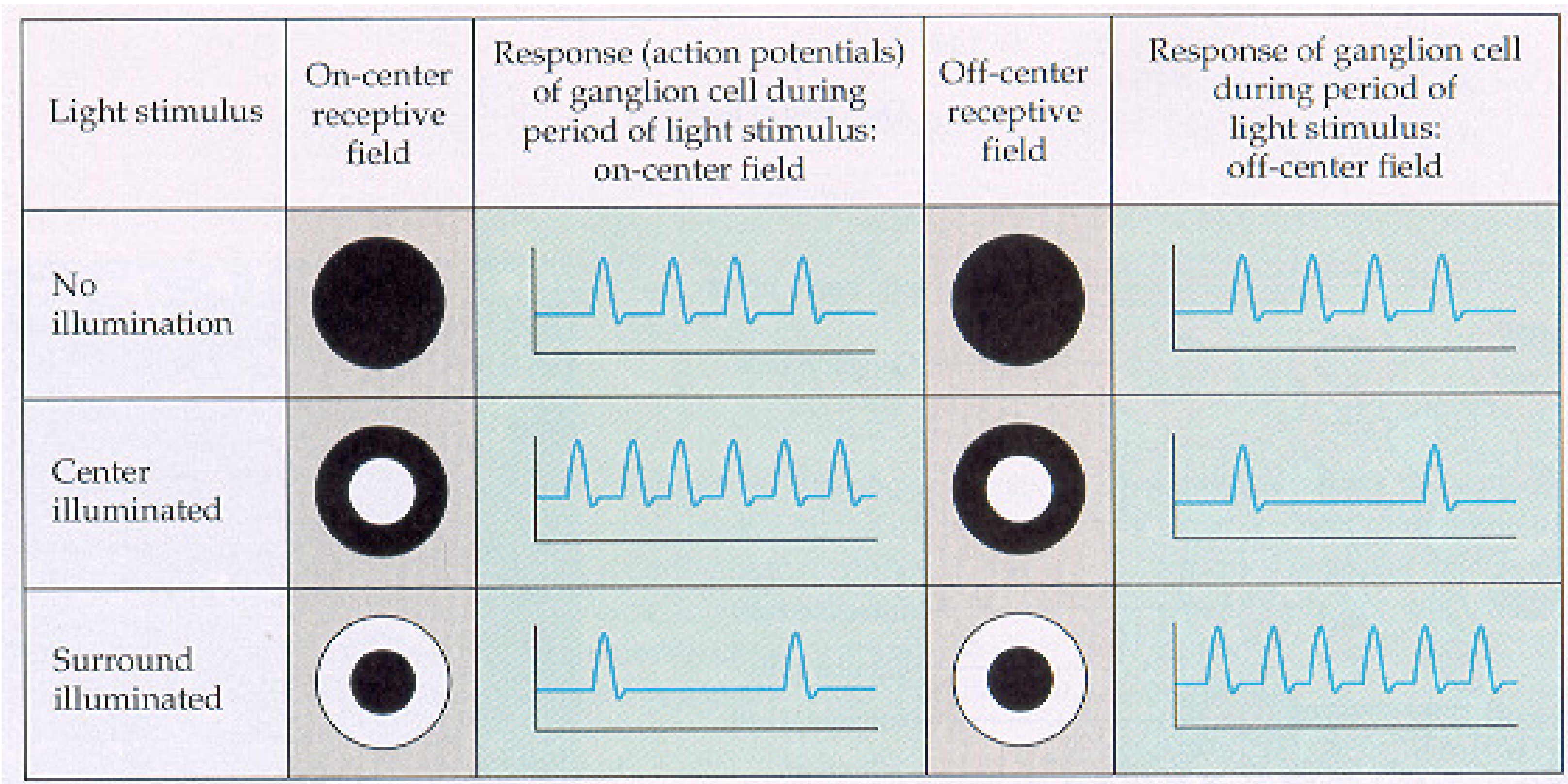


Figure 45.11

The human retina. Light must pass through several relatively transparent layers of cells before reaching the rods and cones. These photoreceptors communicate with ganglion cells via bipolar cells. The axons of the ganglion cells transmit the visual sensations (action potentials) to the brain. There is not a one-to-one relationship between the rods and cones, bipolar cells, and ganglion cells. Rather, each bipolar cell receives information from several rods or cones, and each ganglion cell from several bipolar cells. The horizontal and amacrine cells carry information across the retina to integrate the signals. All the rods or cones that feed information to one ganglion cell form the receptive field for that cell. The larger the receptive field (the more rods or cones that supply a ganglion cell), the less sharp the image, because it is less evident exactly where the light struck the retina. The ganglion cells of the fovea have very small receptive fields, so visual acuity is very sharp in this area. (SEM from *Tissues and Organs: A Text-Atlas of Scanning Electron Microscopy* by Richard G. Kessel and Randy H. Kardon. W. H. Freeman and Company. Copyright © 1979.)

GANGLION CELL ACTION POTENTIALS



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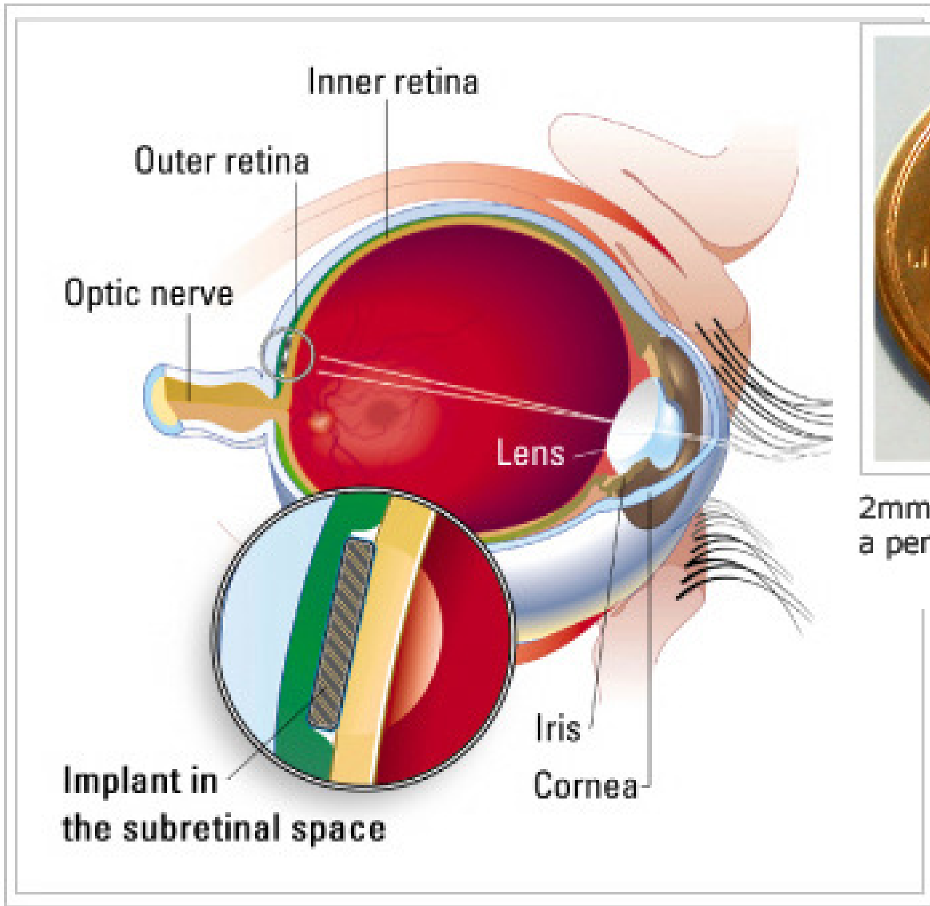
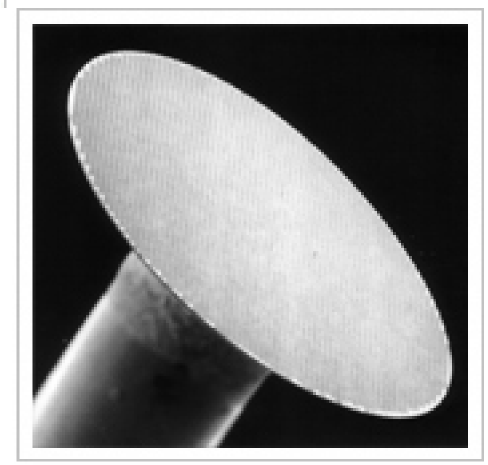
OPTOTRONICS CORPORTION APPROACH



Drawing by Mike Zang

Optobionics Corporation

2mm ASR® device lying on a penny



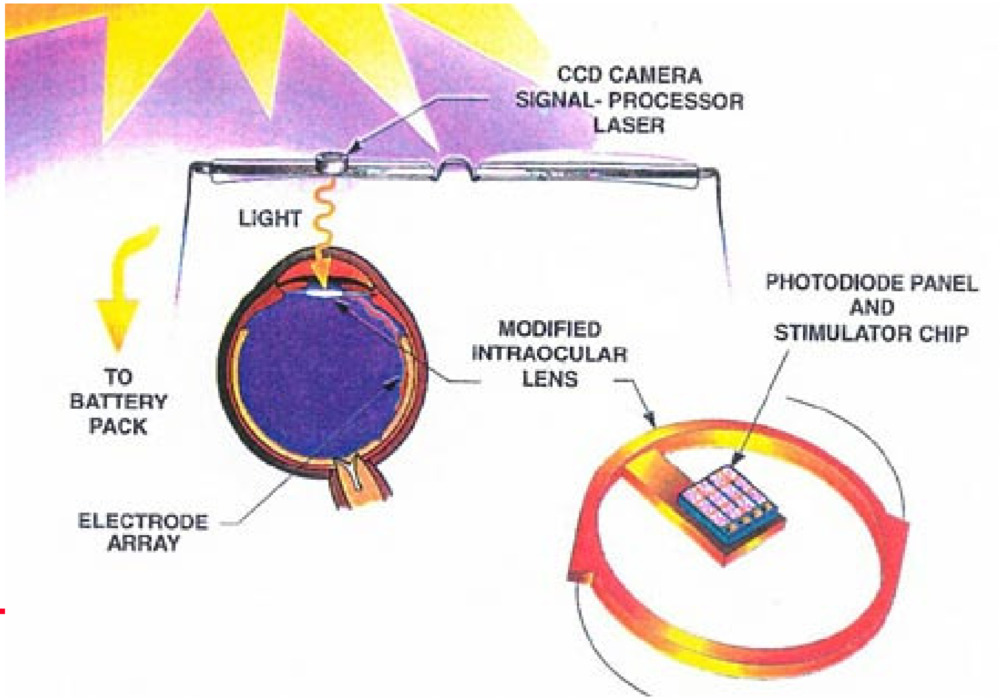
Magnified image of an ASR® device

25 µm thick, 2 mm dia, 5000 microphotodiodes

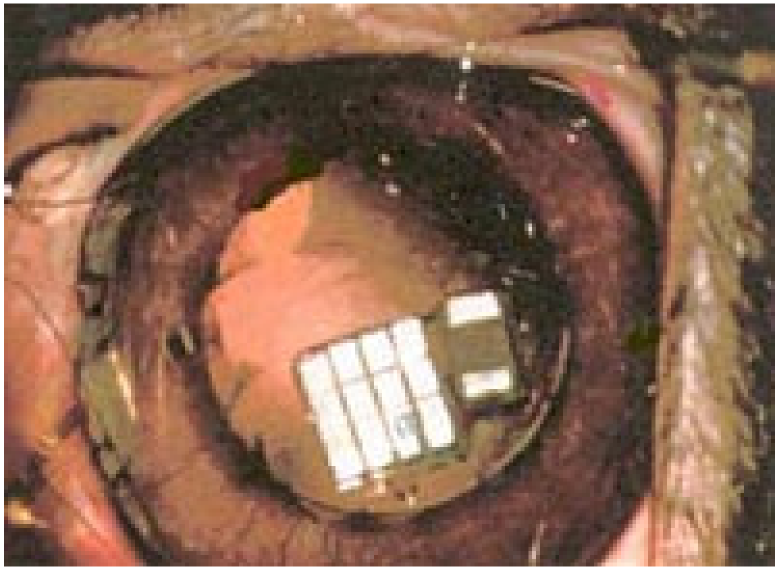
CCD CAMERA APPROACH

The retinal prosthesis is designed to bypass damaged photoreceptors (rods and cones) and directly stimulate the surviving ganglion cells connected to the brain through the optic nerve. A camera mounted on specially designed glasses capture the visual scene and transmits this information (in this figure, using an invisible laser beam). The laser strikes a solar panel (photodiode array) located behind the pupil and generates internal power and transmits the encoded visual information. An ultra-thin electrode array carries the power and information to the retinal surface where it stimulates the ganglion cells.

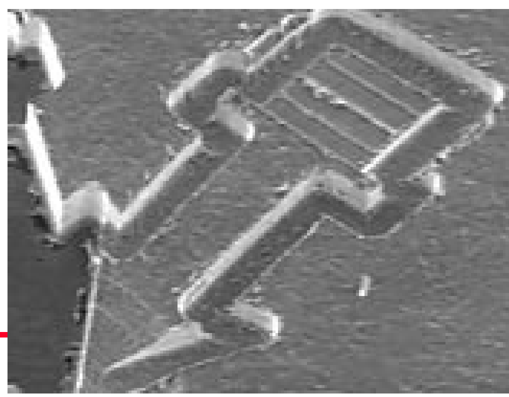
Boston Retinal Implant Project



RETINAL PROSTHESIS



Photodiode array made of silicon measuring 2.2 mm^2 inserted in a pig retina. The 12 photodiodes are connected in series and can be independently stimulated. In order to function properly within the eye, the array must be hermetically sealed (effectively encapsulated) to prevent its deterioration.



This is a prototype tack for attaching an array to the retina. The tack thickness is 10µ.

Boston Retinal Implant Project

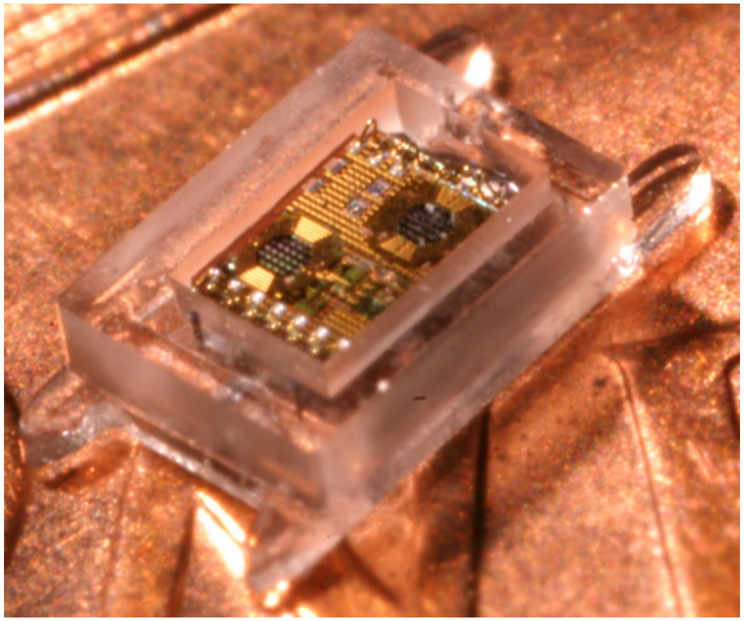
DISCUSSION OF LIGHT CONVERSION AND SIGNAL PROCESSING AT THE RETINA

Photo diode converts light to current. Cones and rods in the retina converts light into voltage pulses (action potentials) where information is encoded in the voltage frequency rather than amplitude. Cones and rods communicate with neighboring cells through amacrine, bipolar and horizontal cells. The ganglion cells receive signals from these cells and transmit information along the optic nerve. Further processing is done by the brain.

EYE PRESSURE MONITOR

Feb. 22, 2011

Toward computers that fit on a pen tip: New technologies usher in the millimeter-scale computing era

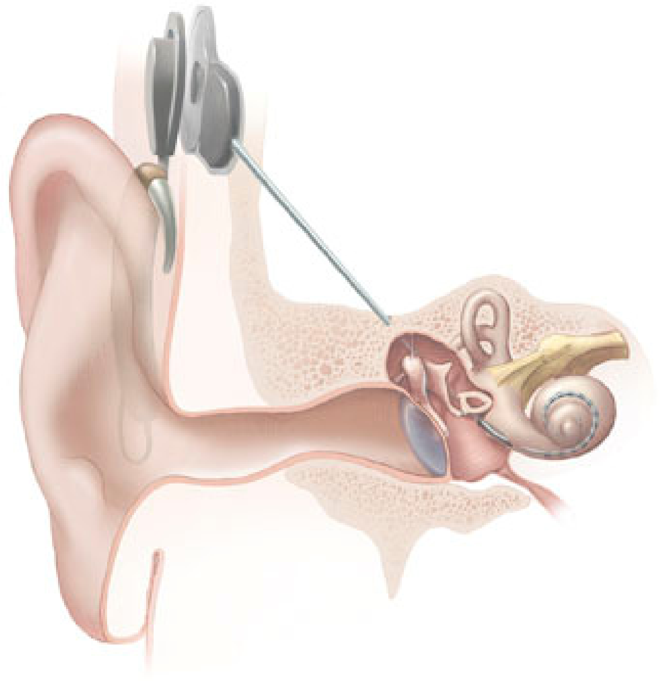


ANN ARBOR, Mich.—A prototype implantable eye pressure monitor for glaucoma patients is believed to contain the first complete millimeter-scale computing system.

And a compact radio that needs no tuning to find the right frequency could be a key enabler to organizing millimeter-scale systems into wireless sensor networks. These networks could one day track pollution, monitor structural integrity, perform surveillance, or make virtually any object smart and trackable.

HEARING RESTORATION – COCHLEAR IMPLANTS

Another application of electrodes is the cochlear implant.



THE EAR

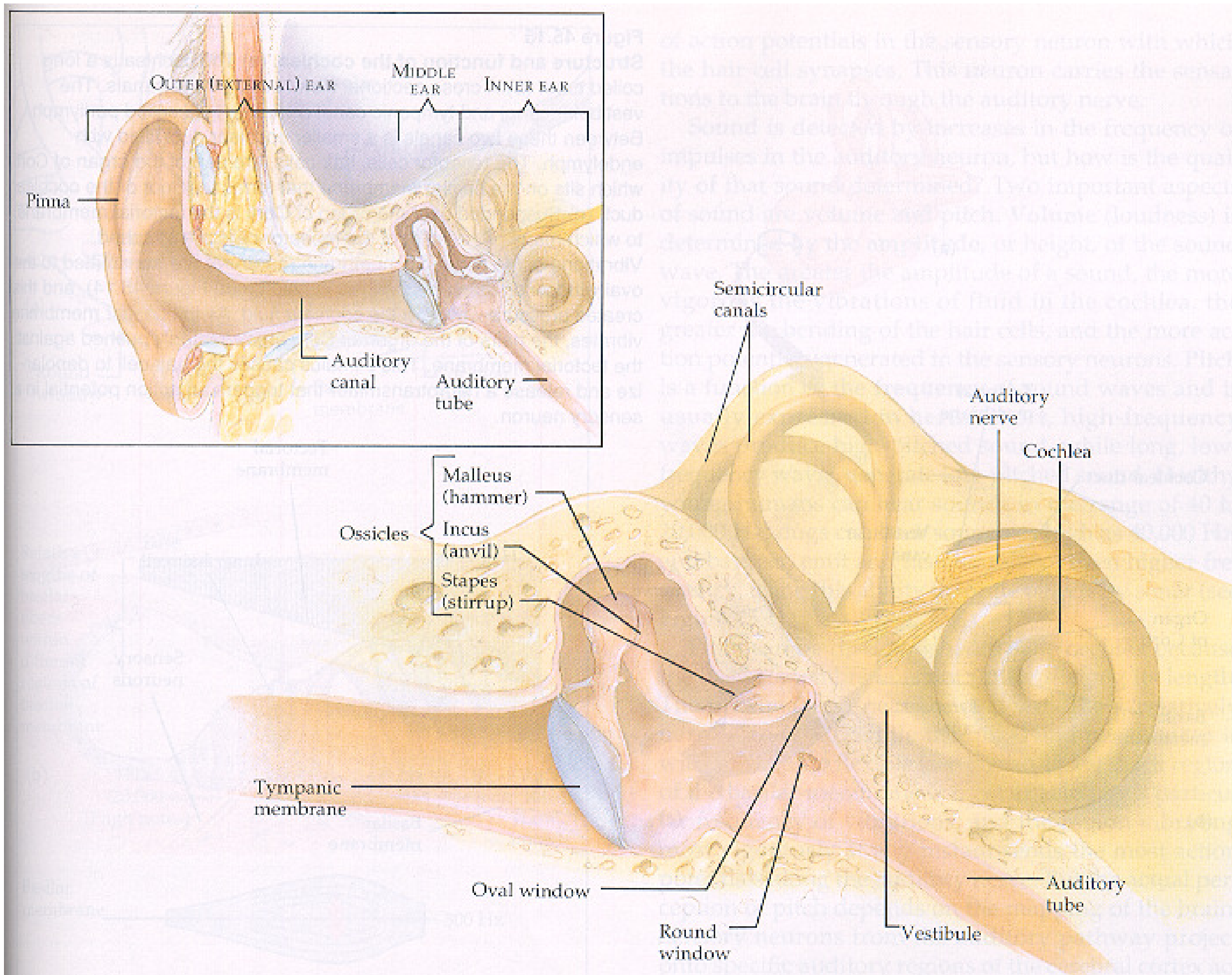


Figure 45.14
Structure of the human ear. The hair cells, the actual sensory receptors of the ear, are located within the labyrinth of canals of the inner ear. The cochlea contains hair cells that function in hearing. The vestibule and semicircular canals contain hair cells responsible for the sense of balance.

THE COCHLEA

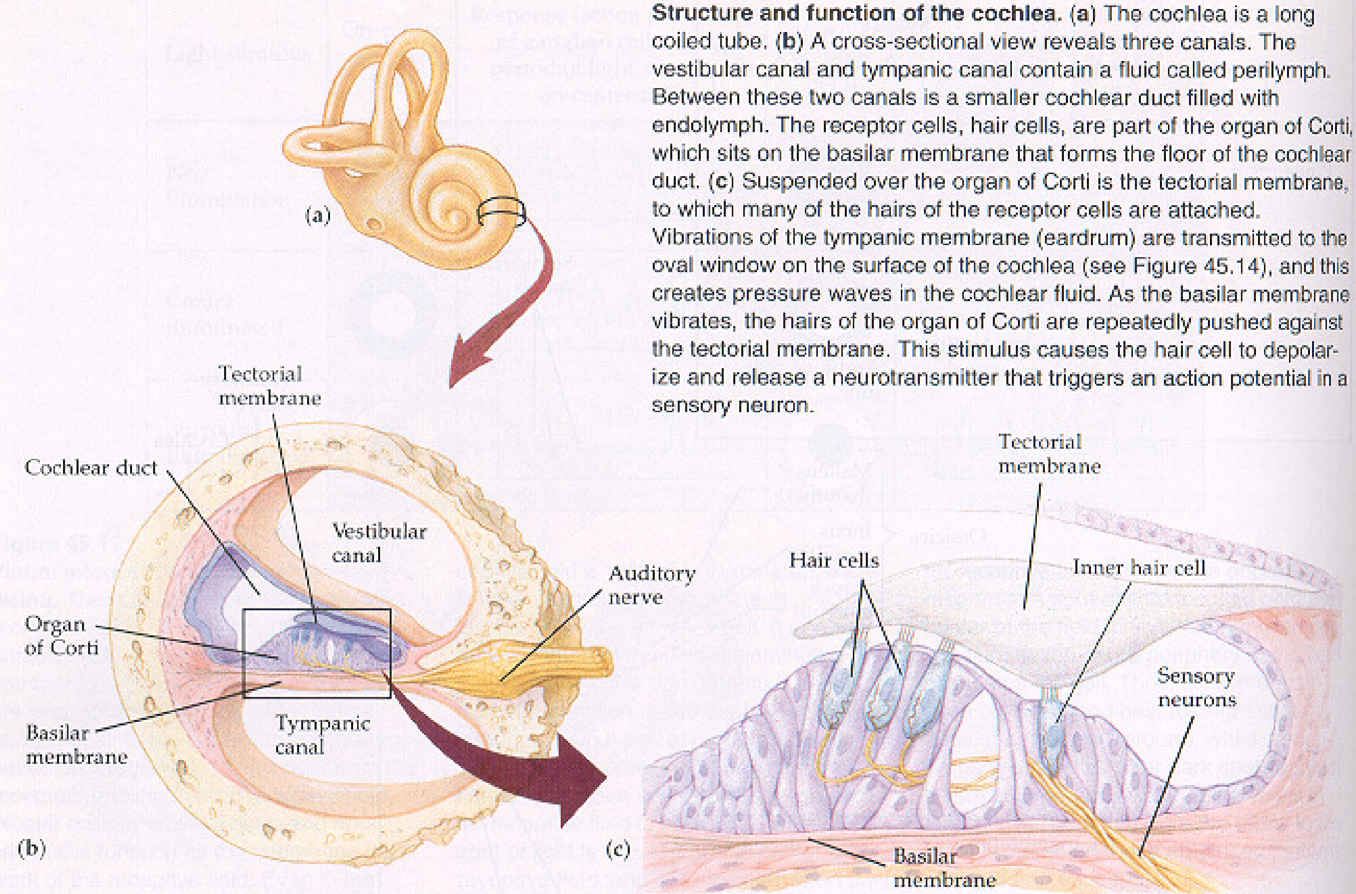
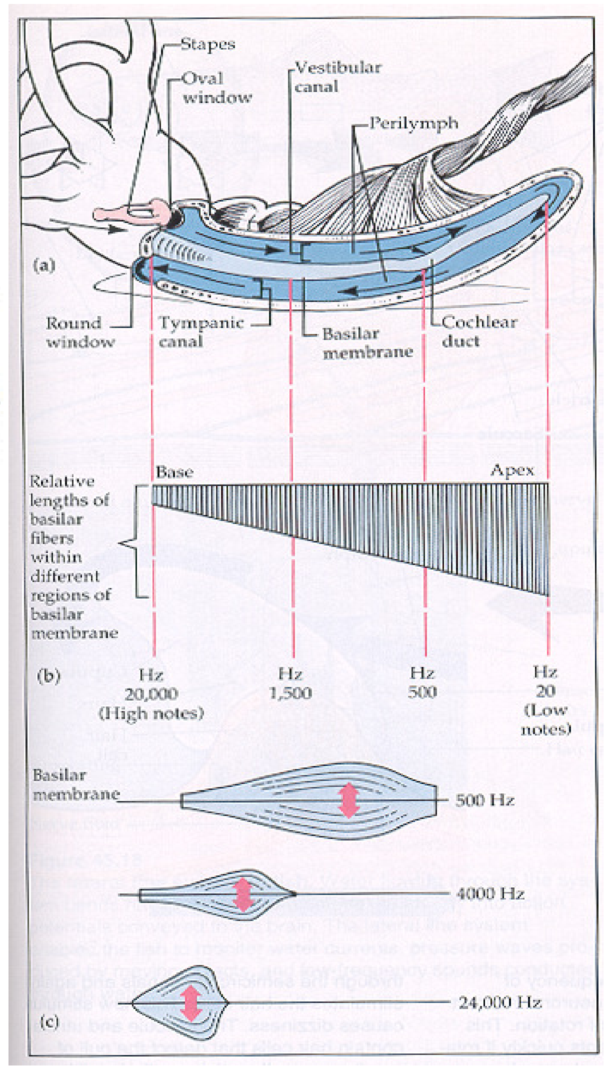


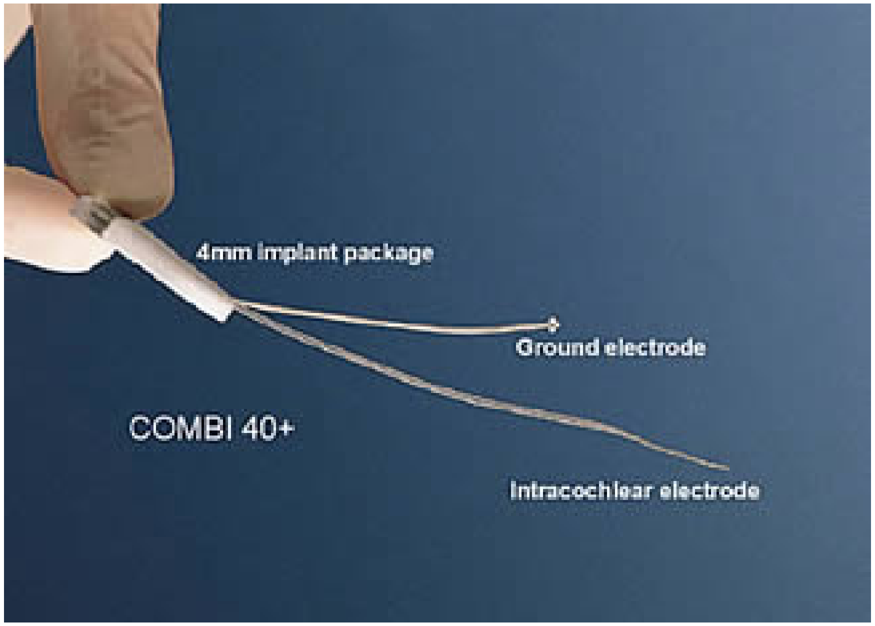
Figure 45.15
Structure and function of the cochlea. (**a**) The cochlea is a long coiled tube. (**b**) A cross-sectional view reveals three canals. The vestibular canal and tympanic canal contain a fluid called perilymph. Between these two canals is a smaller cochlear duct filled with endolymph. The receptor cells, hair cells, are part of the organ of Corti, which sits on the basilar membrane that forms the floor of the cochlear duct. (**c**) Suspended over the organ of Corti is the tectorial membrane, to which many of the hairs of the receptor cells are attached. Vibrations of the tympanic membrane (eardrum) are transmitted to the oval window on the surface of the cochlea (see Figure 45.14), and this creates pressure waves in the cochlear fluid. As the basilar membrane vibrates, the hairs of the organ of Corti are repeatedly pushed against the tectorial membrane. This stimulus causes the hair cell to depolarize and release a neurotransmitter that triggers an action potential in a sensory neuron.

HOW THE COCHLEA WORKS

How the cochlea distinguishes pitch. (**a**) Vibrations of the stapes against the oval window agitate the fluid within the cochlea (uncoiled here), setting up pressure ripples that have a frequency equivalent to the sound waves that entered the ear. The waves pass through the vestibular canal to the apex of the cochlea, then back toward the base of the cochlea via the tympanic canal. The energy causes the cochlear duct, with its basilar membrane and organ of Corti (see Figure 45.15), to vibrate up and down. The bouncing of the basilar membrane stimulates the hair cells within the cochlear duct. (**b**) Fibers span the width of the basilar membrane. Like harp strings, these fibers vary in length, being shorter near the basal end of the membrane and longer near the apex. The length of the fibers "tunes" them to vibrate at specific frequencies. (**c**) Thus, pressure waves in the cochlea cause a specific region along the length of the basilar membrane to oscillate more vigorously than other regions not "tuned" to that frequency. The preferential stimulation of hair cells is perceived in the brain as sound of a certain pitch.

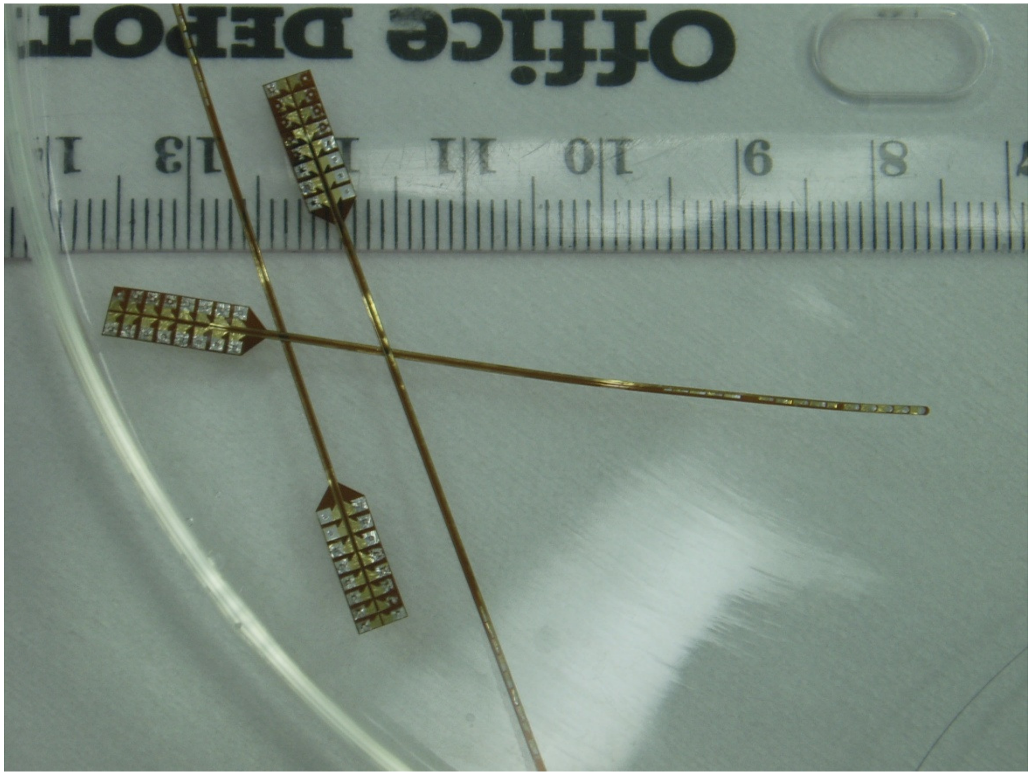


CHOCHLEAR IMPLANT

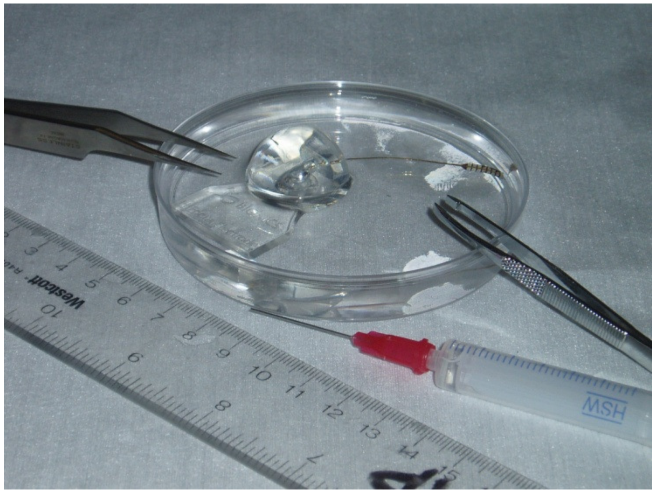


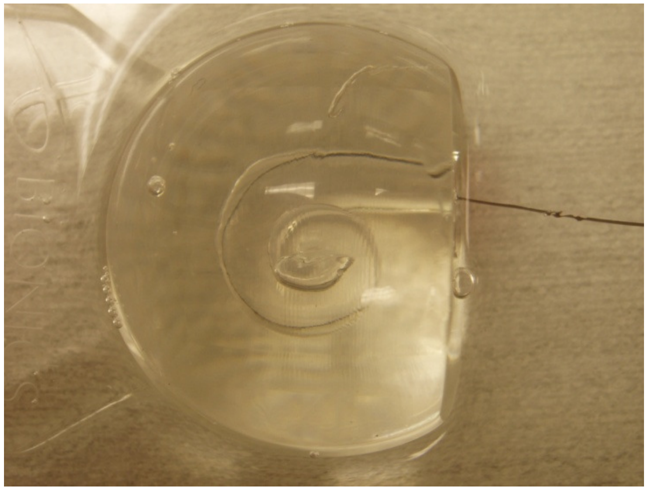
http://www.bcm.edu/oto/jsolab/cochlear_implants/ cochlear_implant.htm

RIT THIN FILM COCHLEAR IMPLANTS

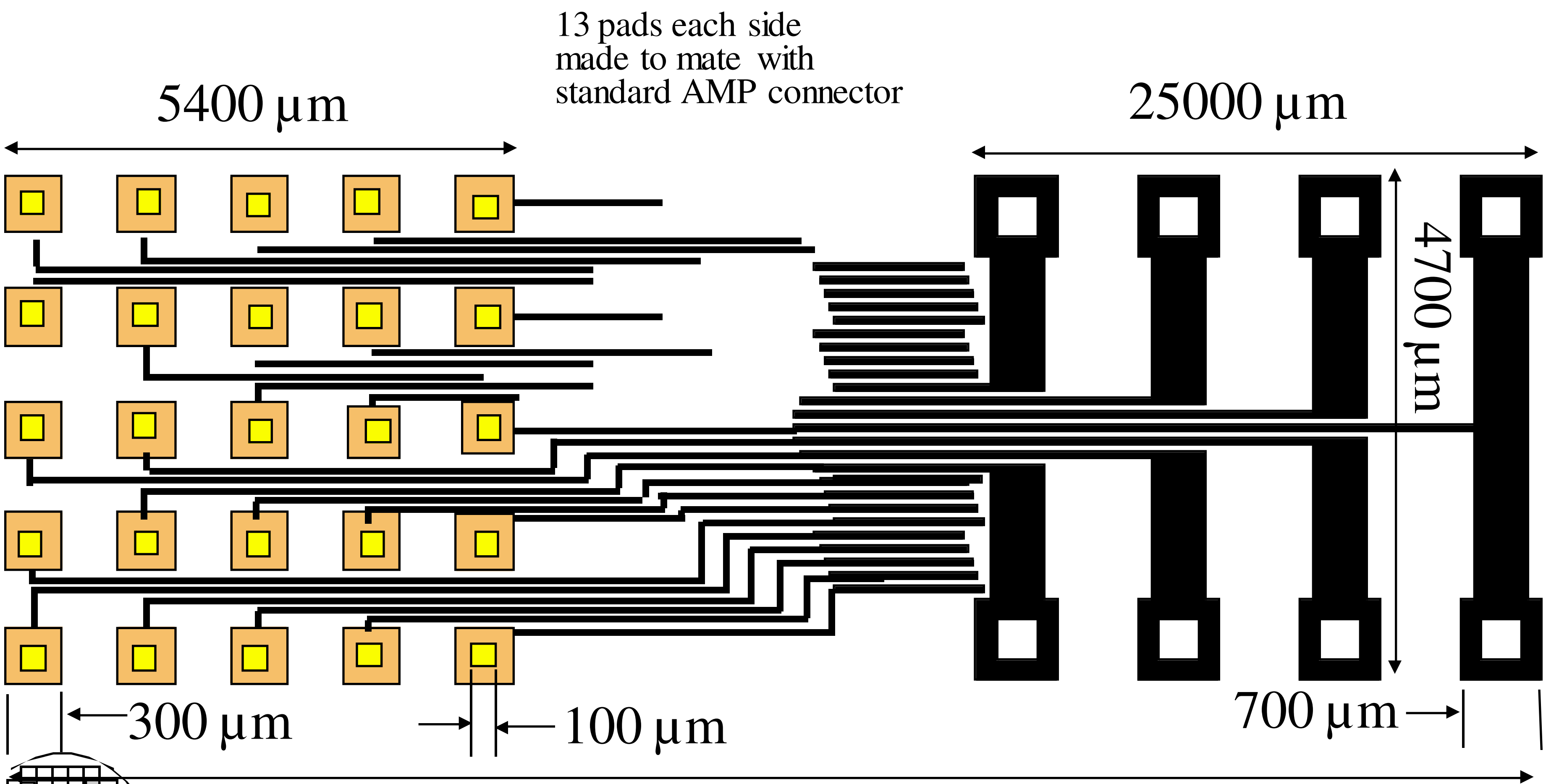


Ward Johnson, Senior Project, 2006

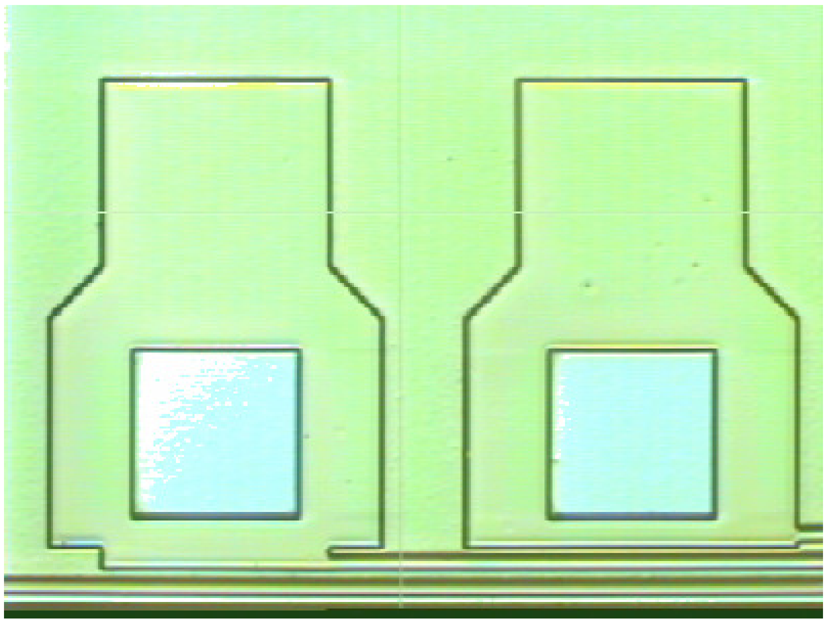


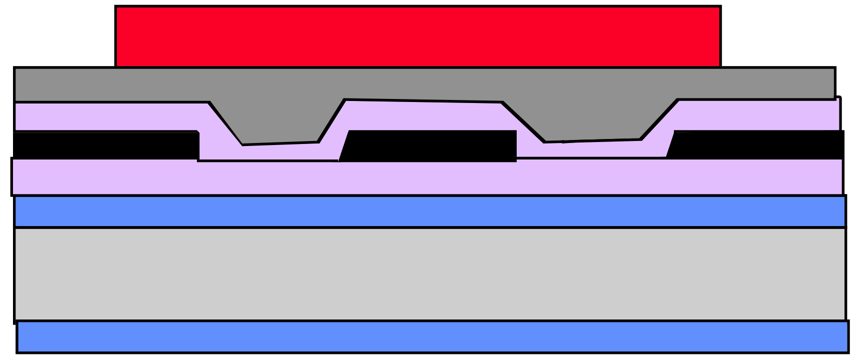


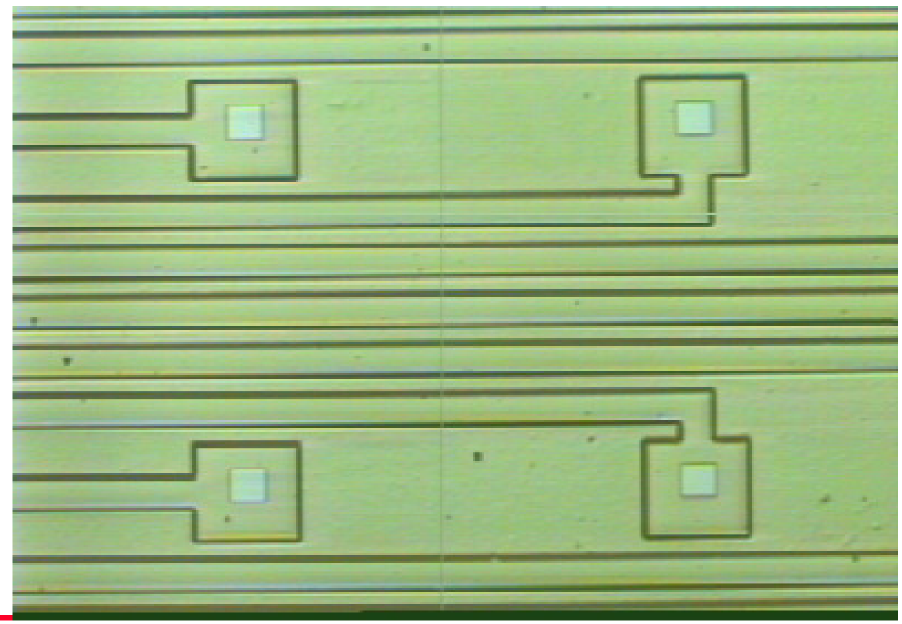
THIN FILM RECORDING ELECTRODES



THIN FILM RECORDING ELECTRODES MADE AT RIT

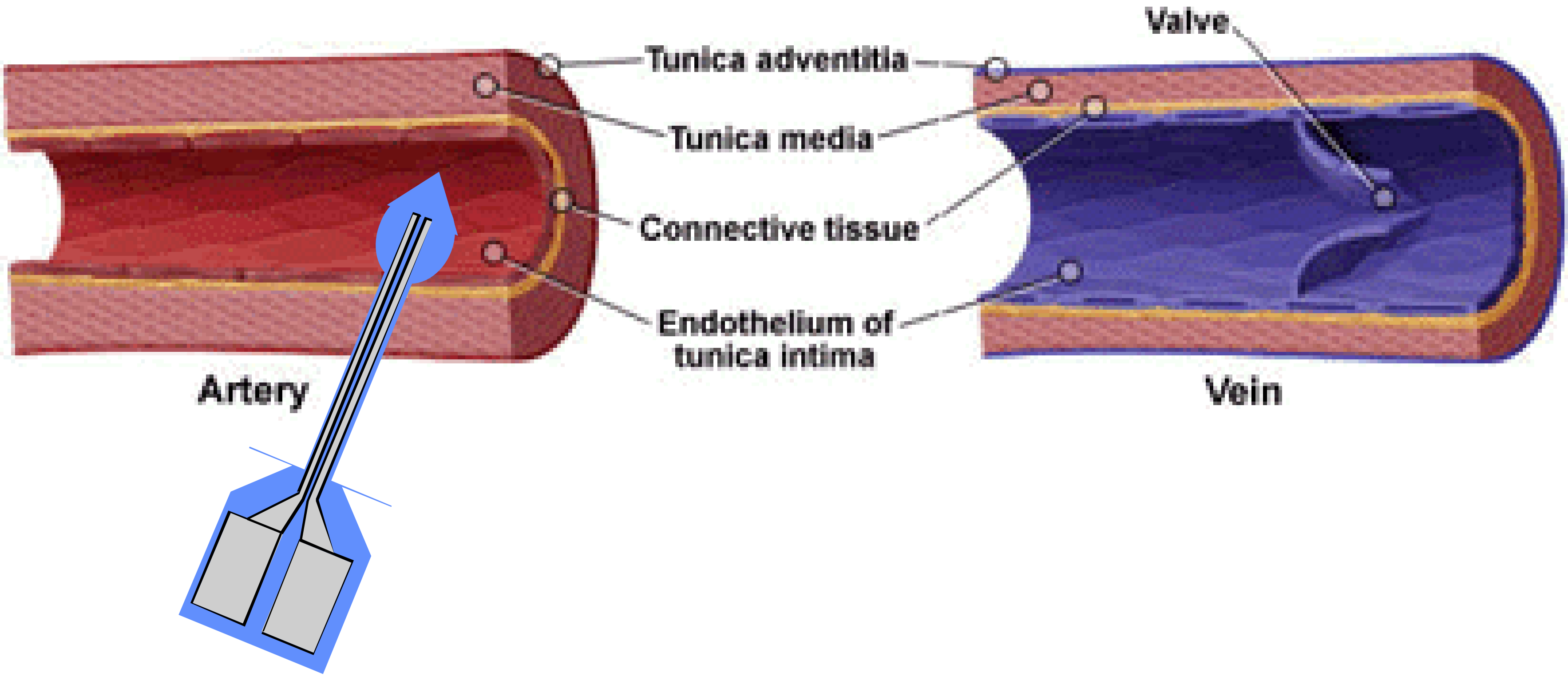




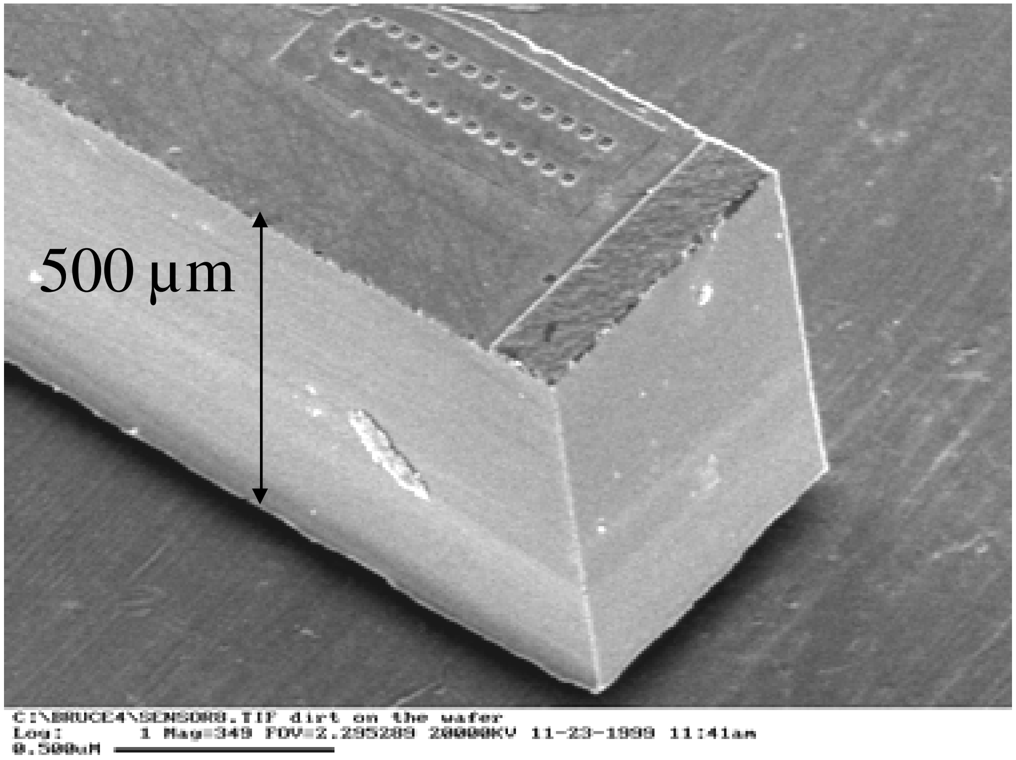


Keith Udut 1999
Dr. Lynn Fuller

BLOOD FLOW, PRESSURE, CHEMICAL ANALYSIS



0^{th} VERSION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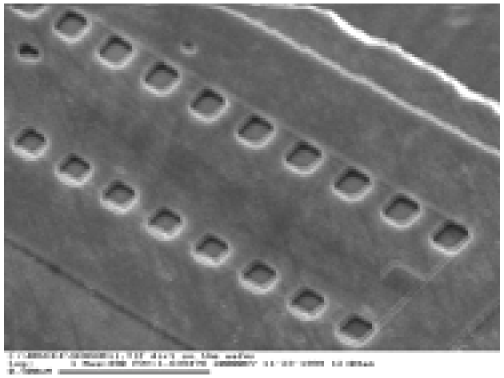
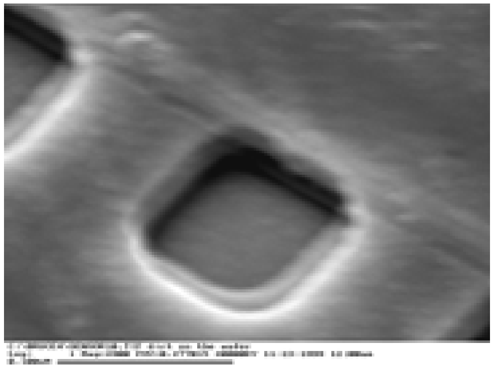
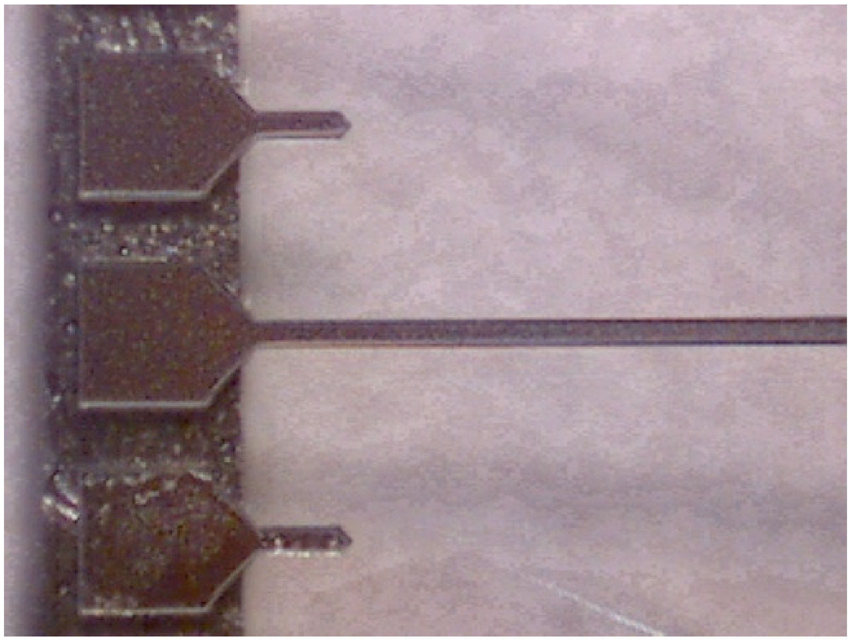
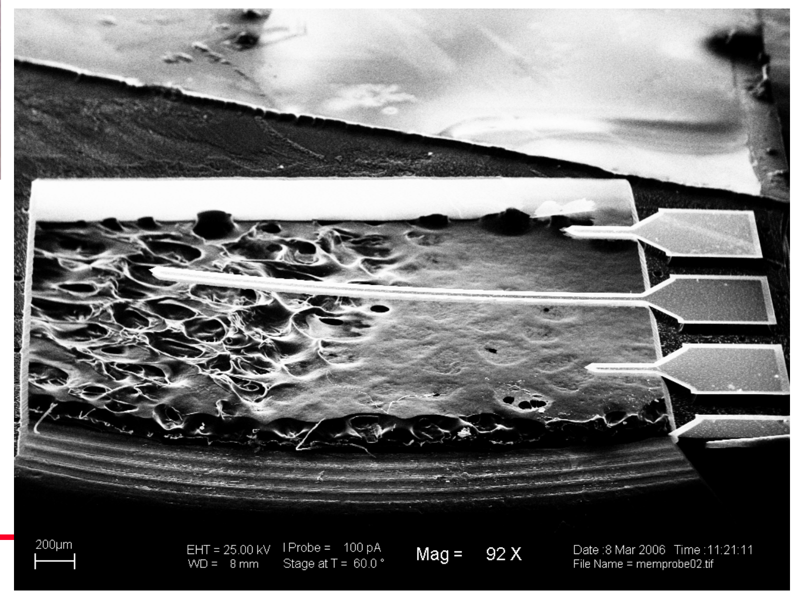
C:\BRUCE4\SENSOR8.TIF dirt on the wafer
Log: 1 Mag=349 FOV=2.295289 20000KV 11-23-1999 11:41am
0.500uM





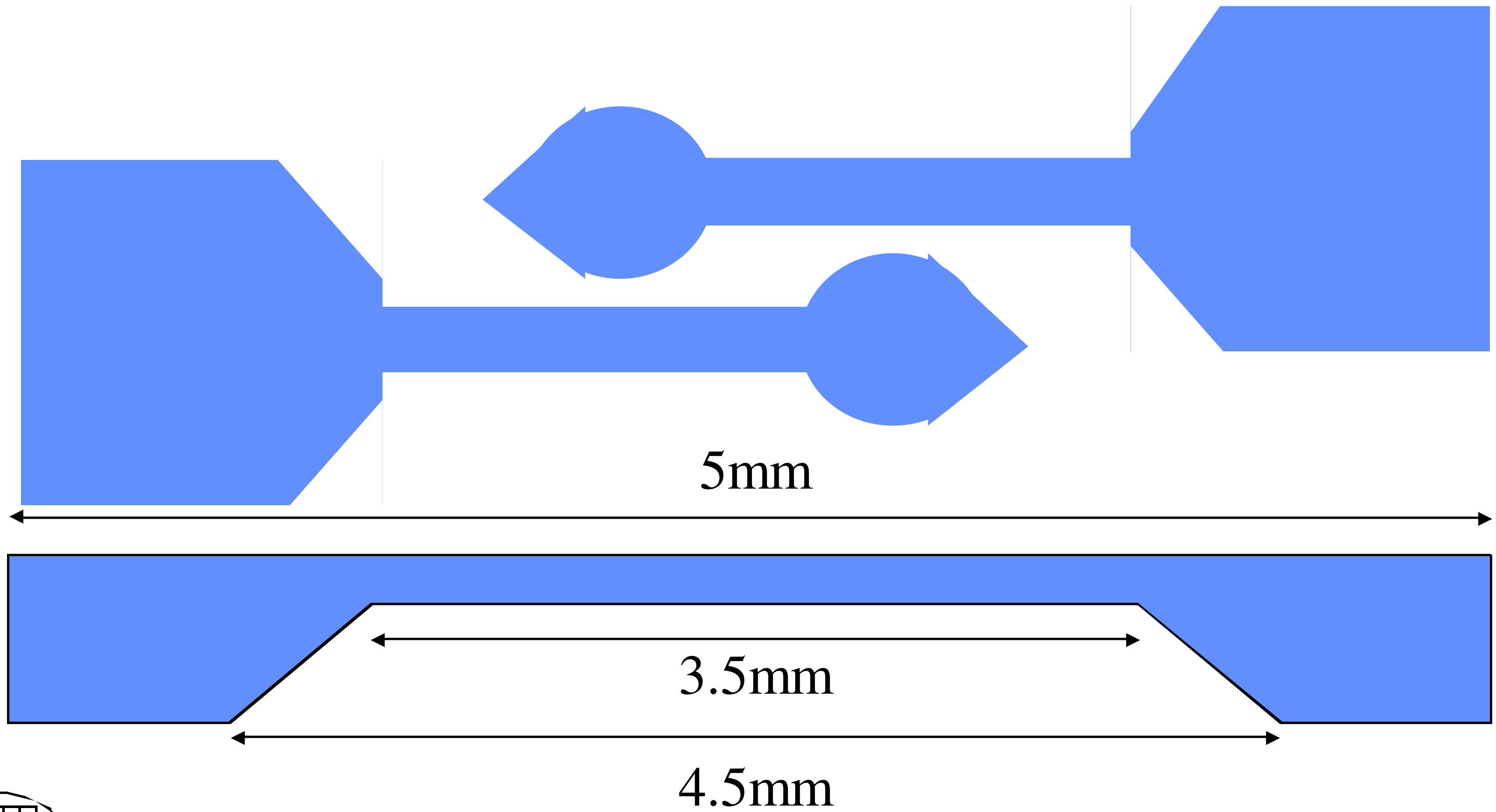
FIRST VERSION RIT SILICON BIOPROBES





Rochester Institute of Technology
Microelectronic Engineering

SECOND VERSION RIT SILICON BIOPROBES

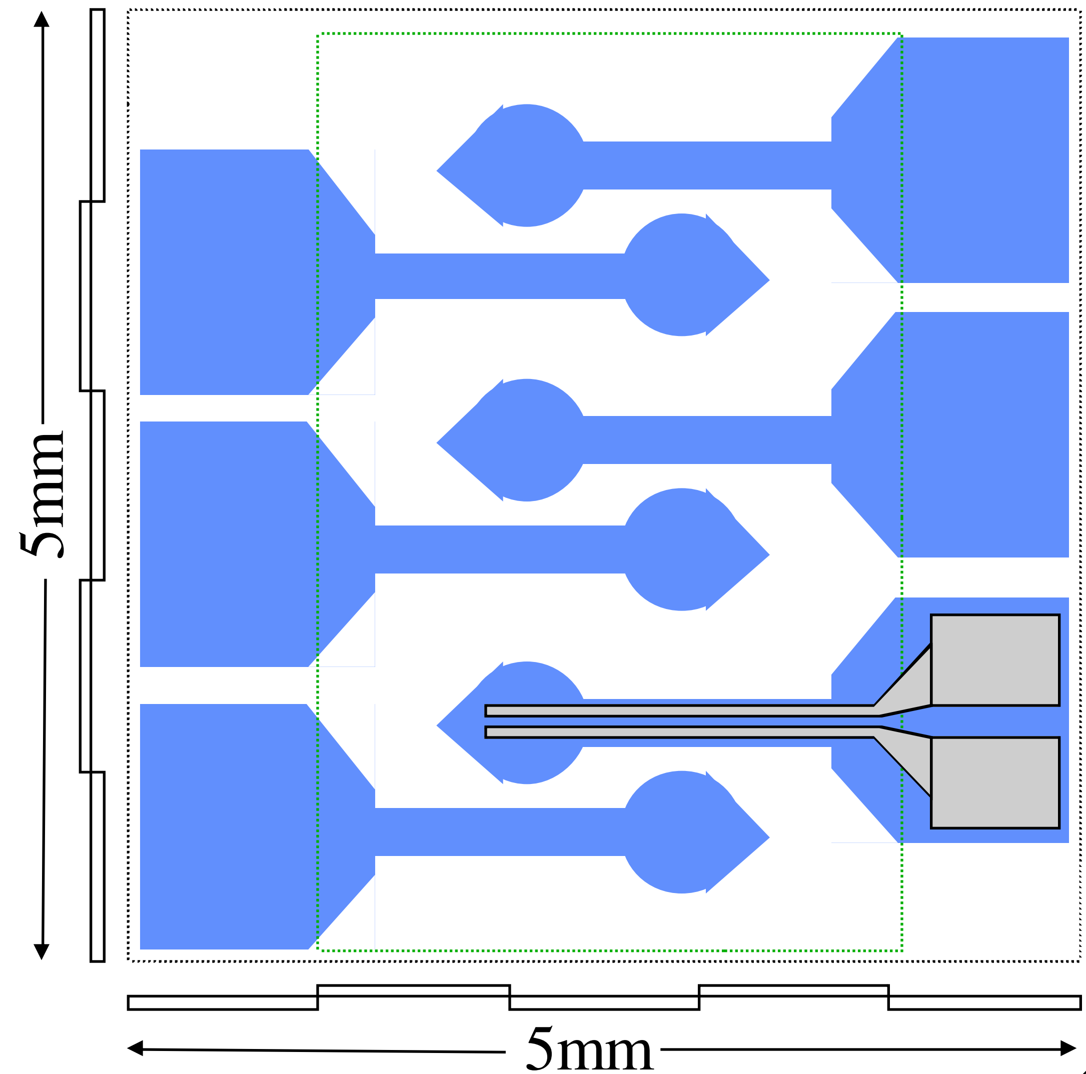


SECOND VERSION RIT DESIGN

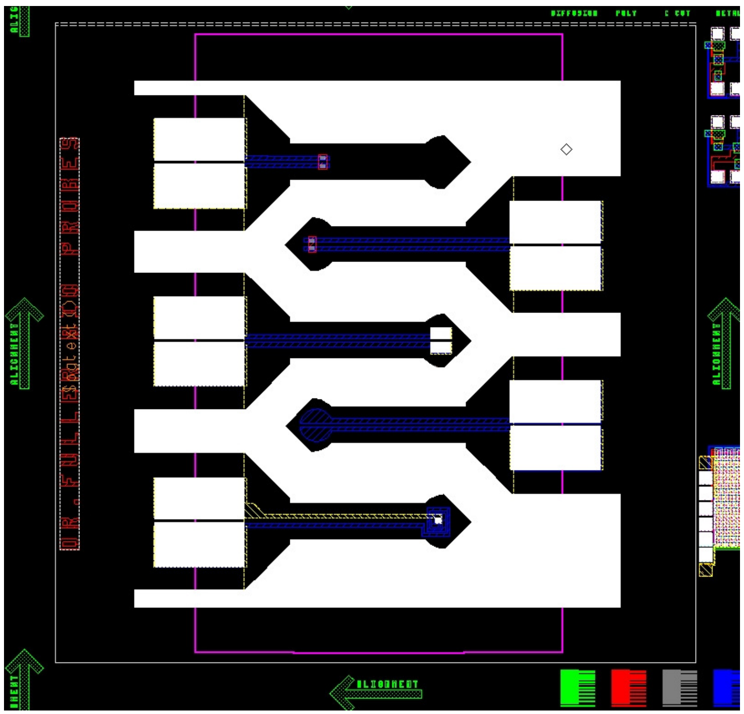
No Pads
LC

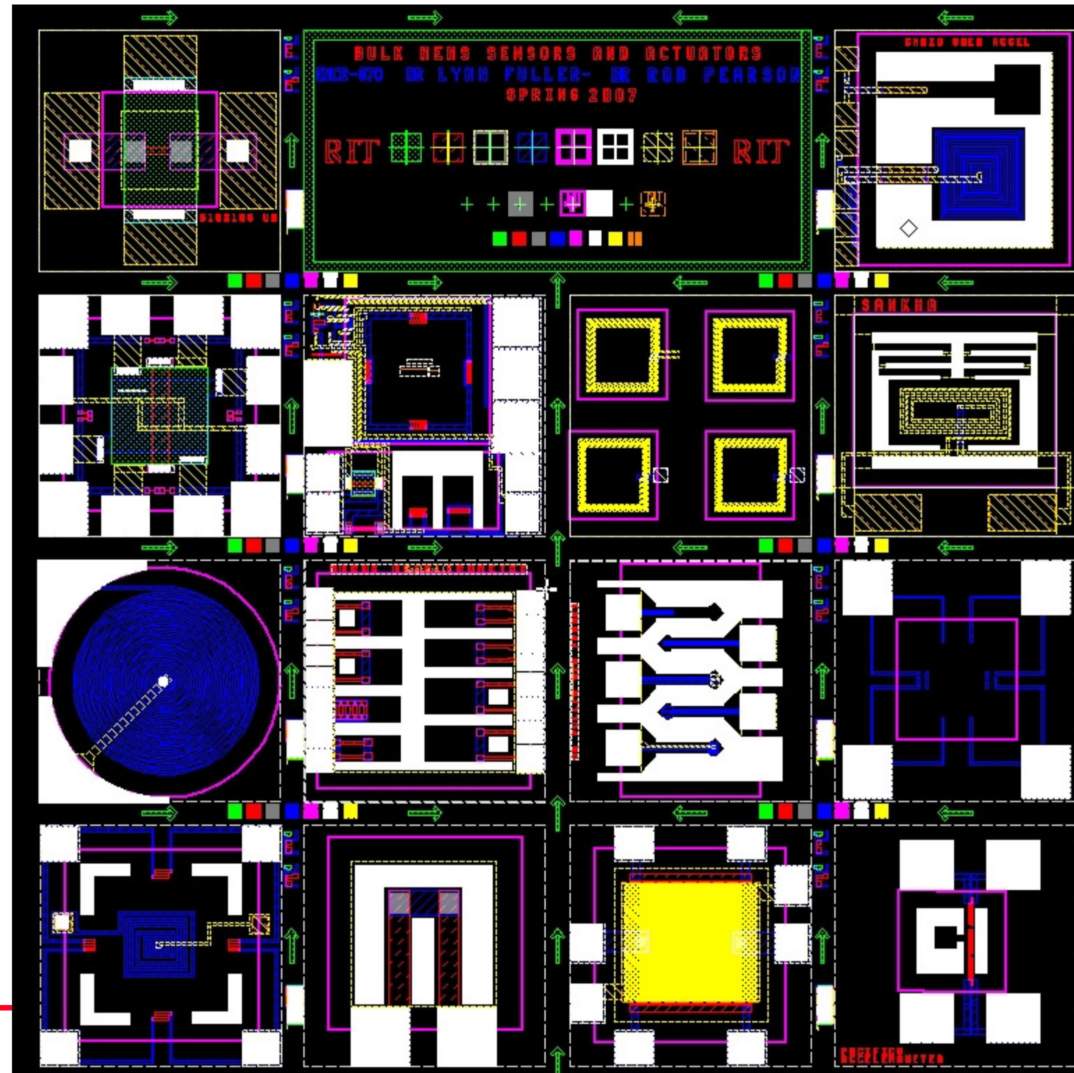
Two Pads
Two Electrodes
Poly Resistor
Capacitor
Photo diode
Temperature Diode
Coil

Three Pads
Heater and Thermocouple

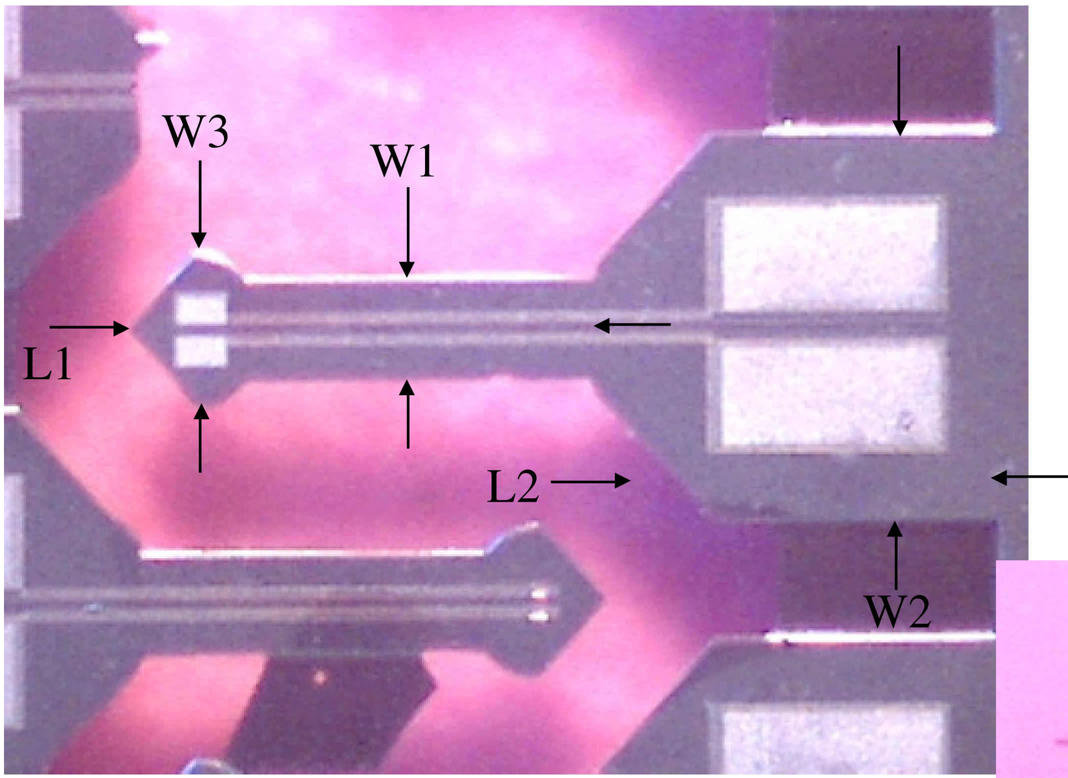


SPRING 2007 PROJECT CHIP – RIT MEMS CLASS

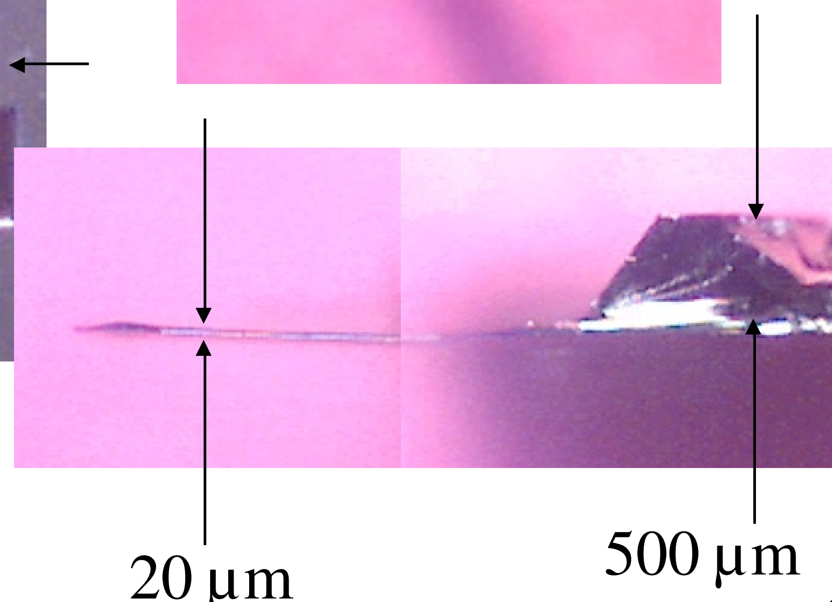




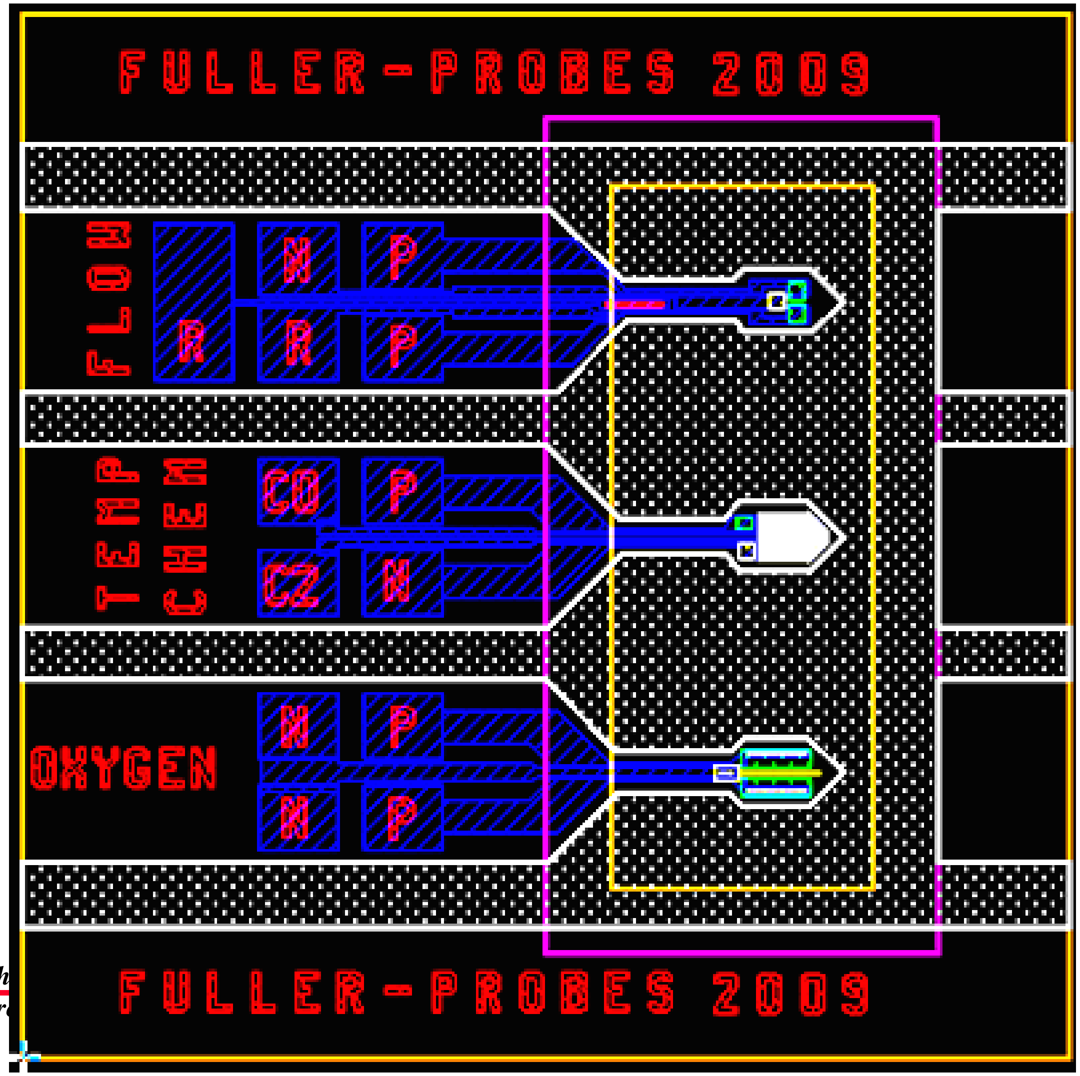
SECOND VERSION COMPLETED DEVICES - RIT



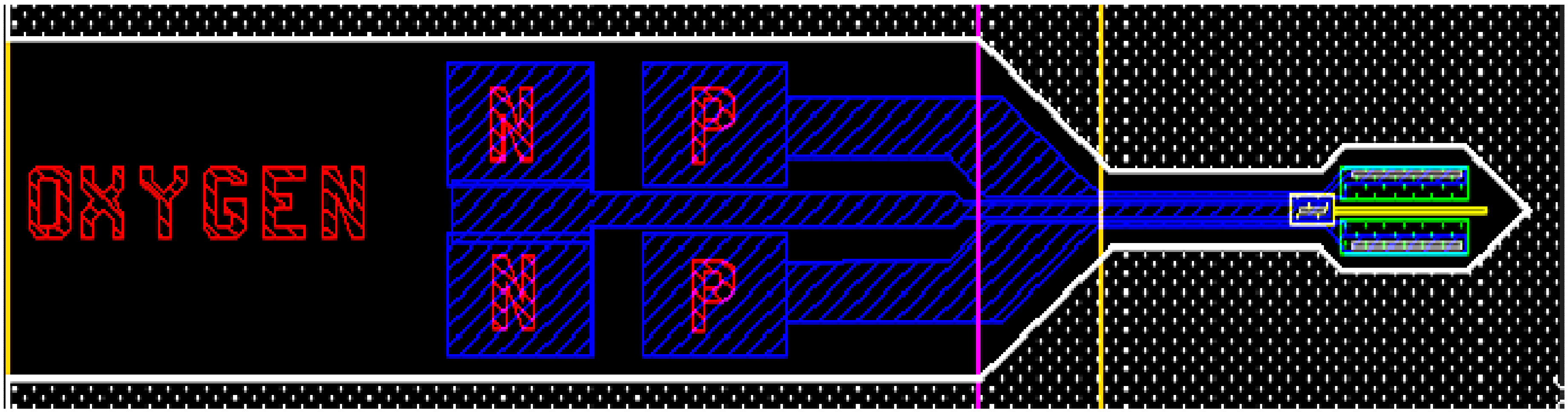
W1 = 300 µm
W2 = 1100
W3 = 450
L1 = 1400
L2 = 1250



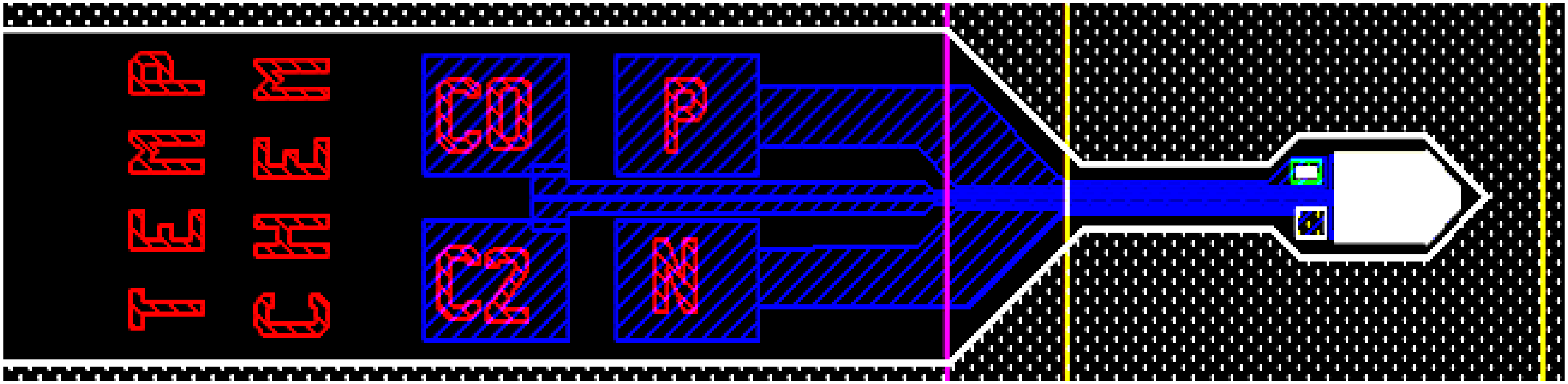
THIRD VERSION - BIO PROBES



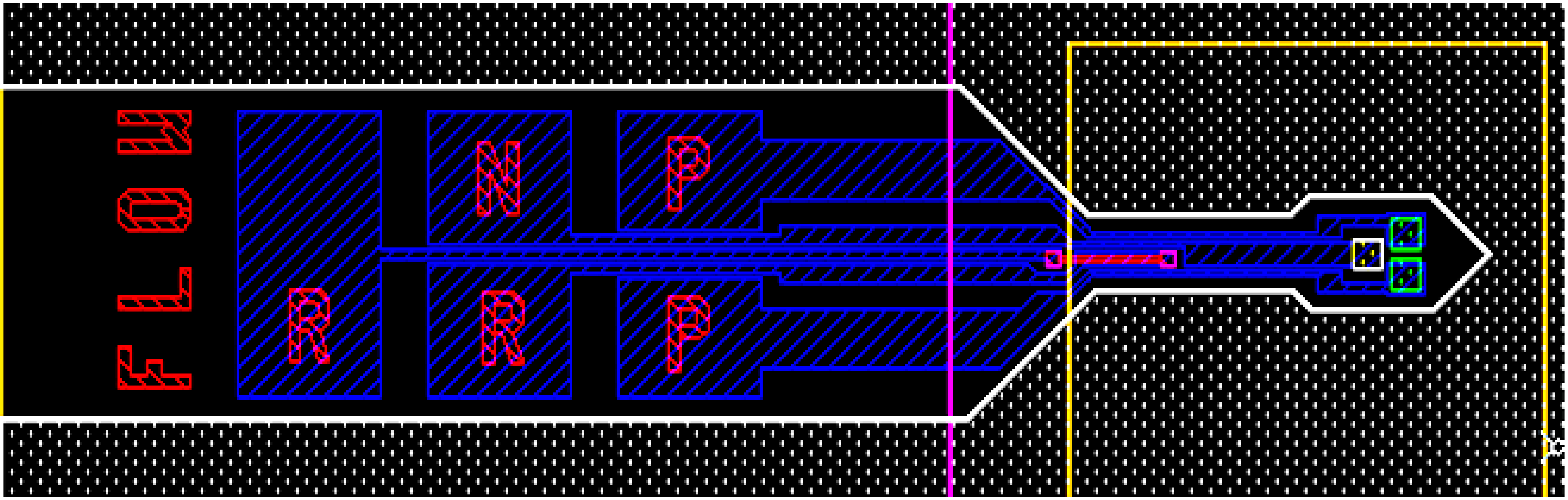
OXYGEN PROBE



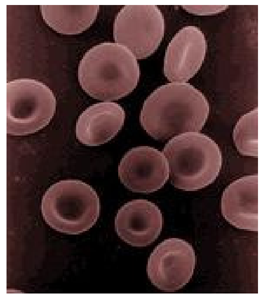
TEMPERATURE AND CHEMICAL



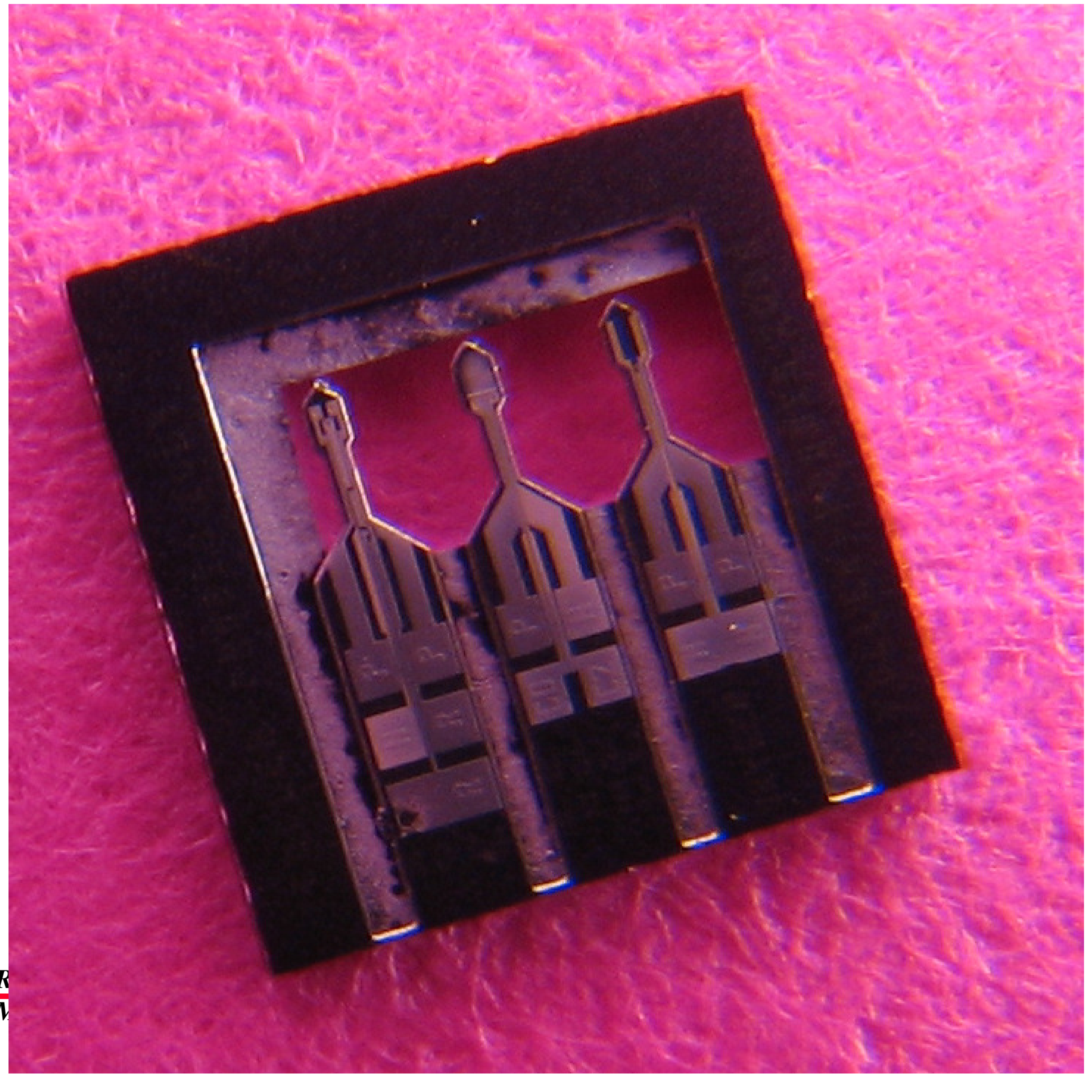
BLOOD FLOW



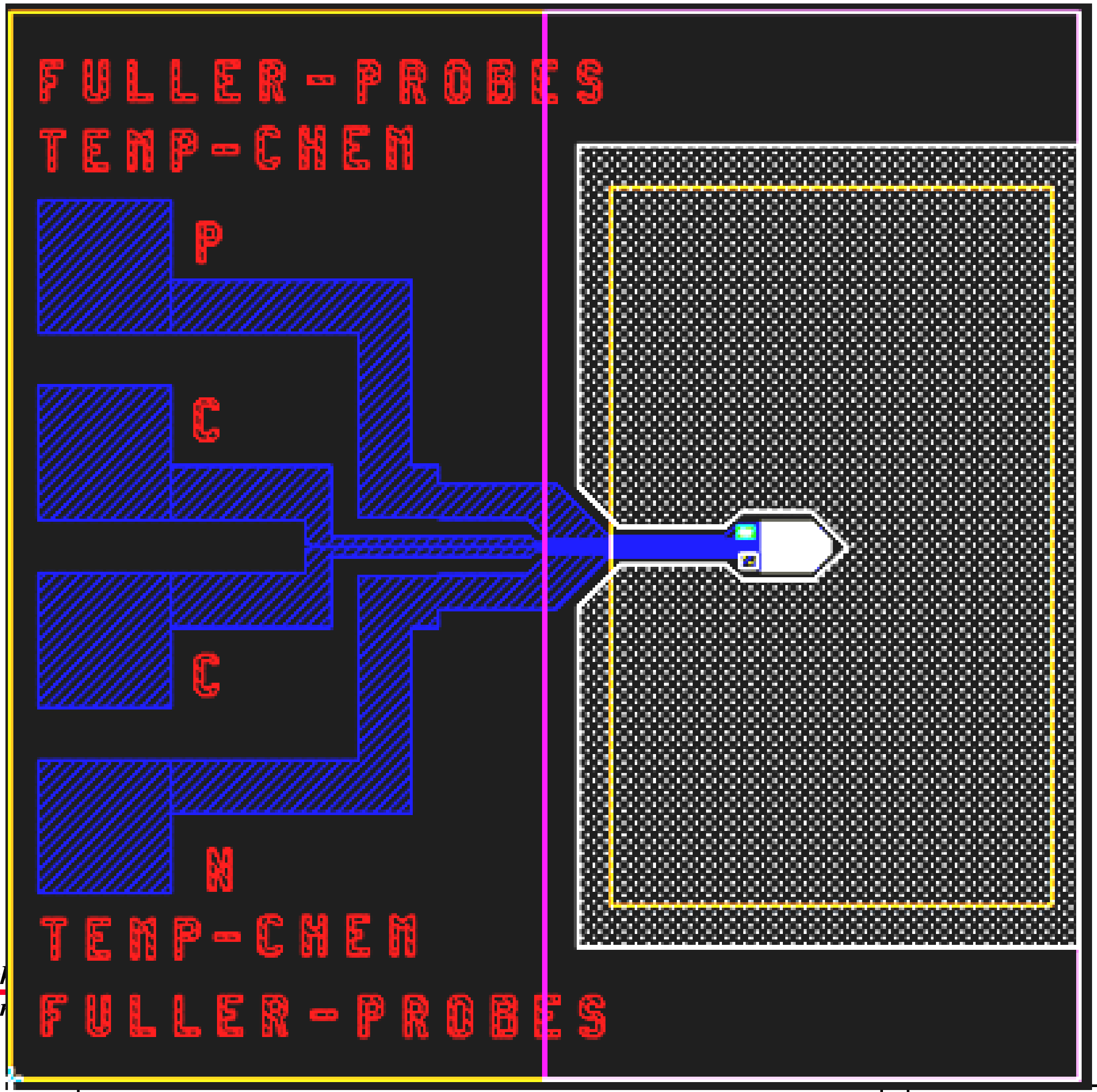
MOVIE



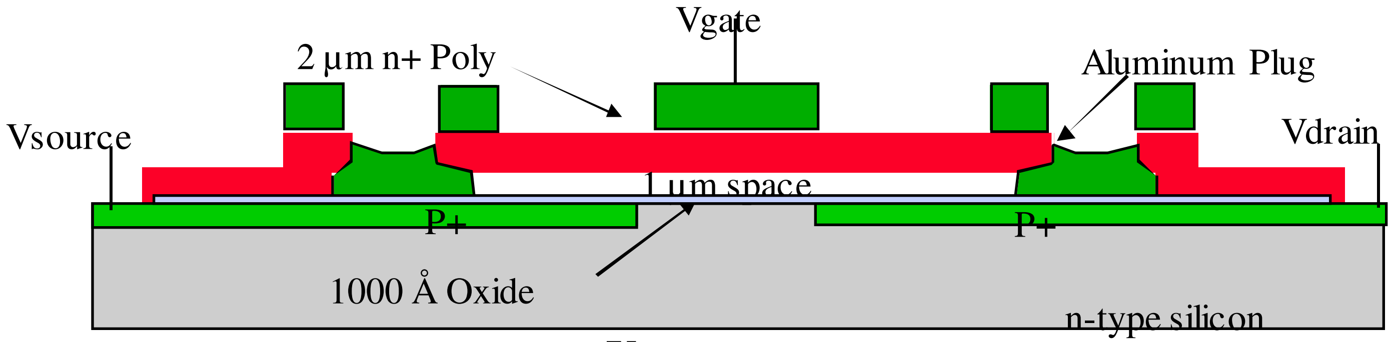
PROBES AFTER FABRICATION BEFORE SEPARATION

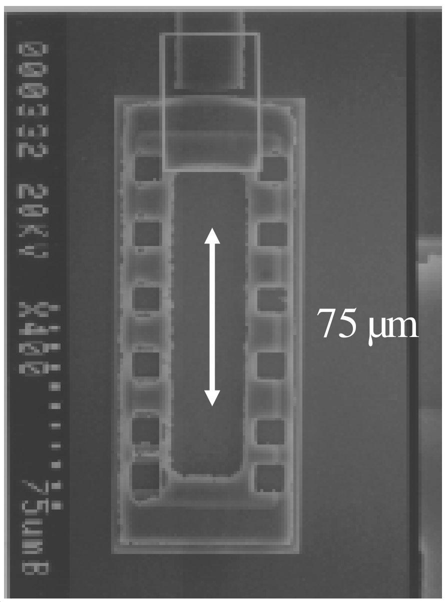


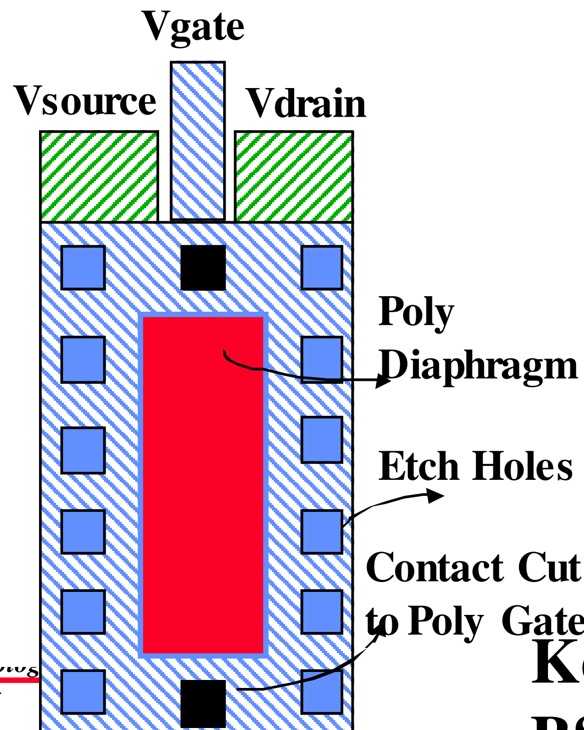
4TH VERSION - TEMP AND CHEMICAL SENSOR PROBE

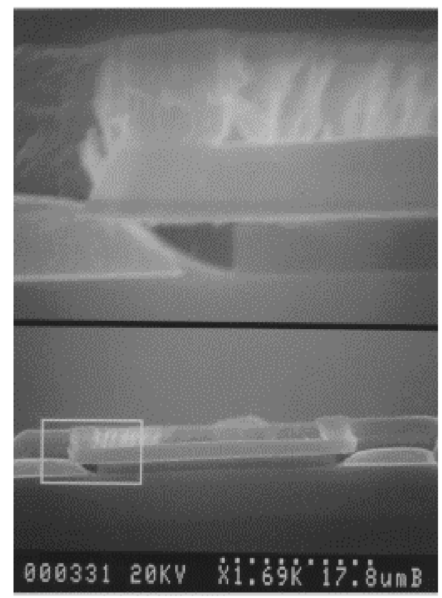


POLY DIAPHRAGM FIELD EFFECT TRANSISTOR



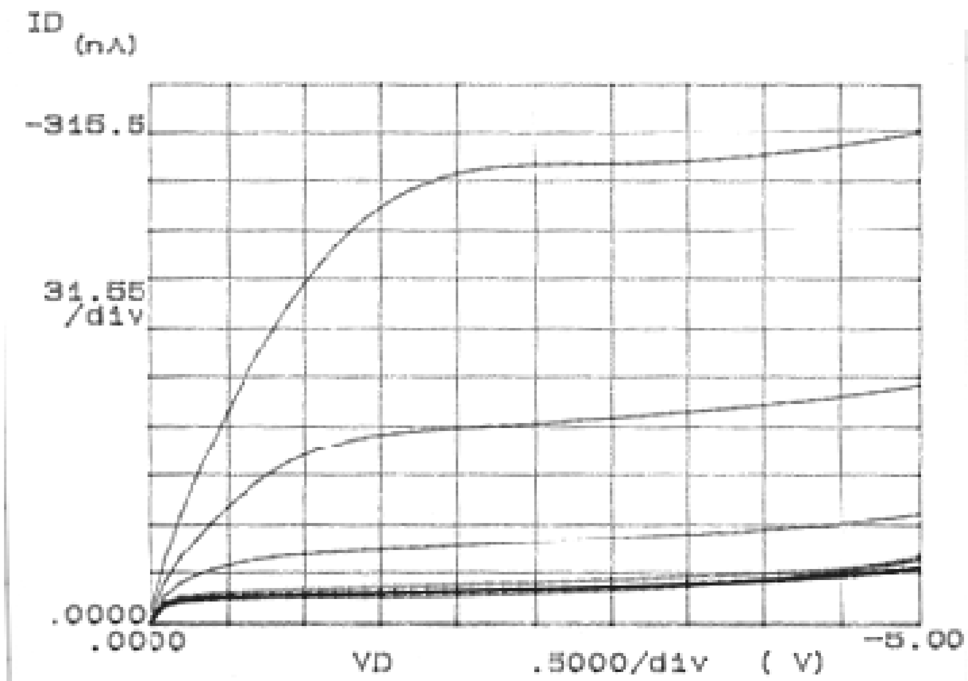


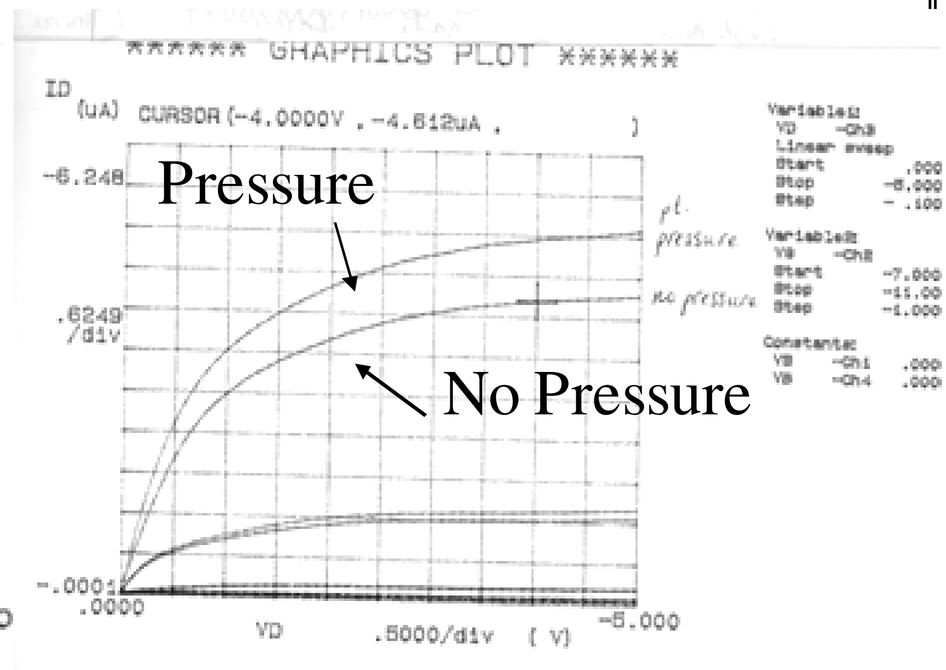




Kerstin Babbitt, 1997
BSEE U of Rochester

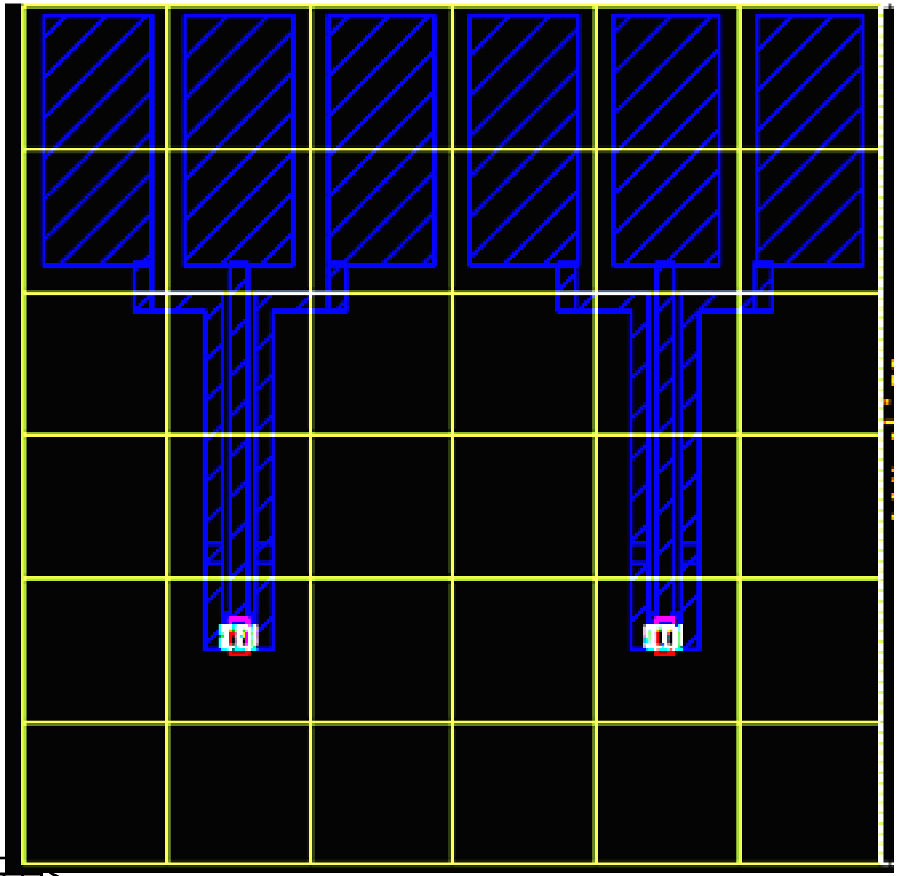
POLY DIAPHRAGM PRESSURE SENSOR TEST RESULTS



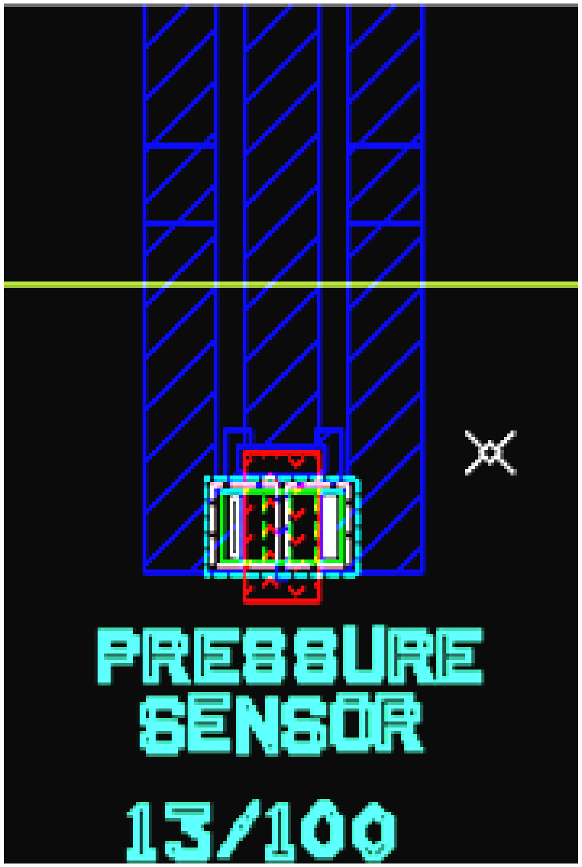


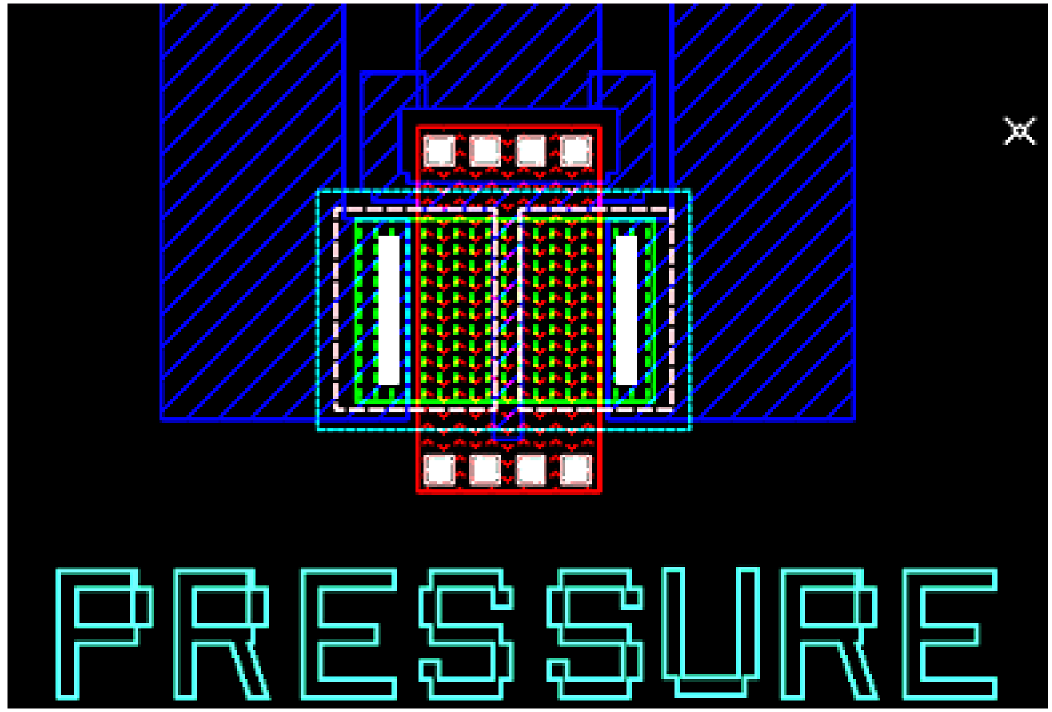
An Pham – 1999
Rochester Institute of Technology

5TH VERSION CMOS Compatible Tiny Pressure Sensor

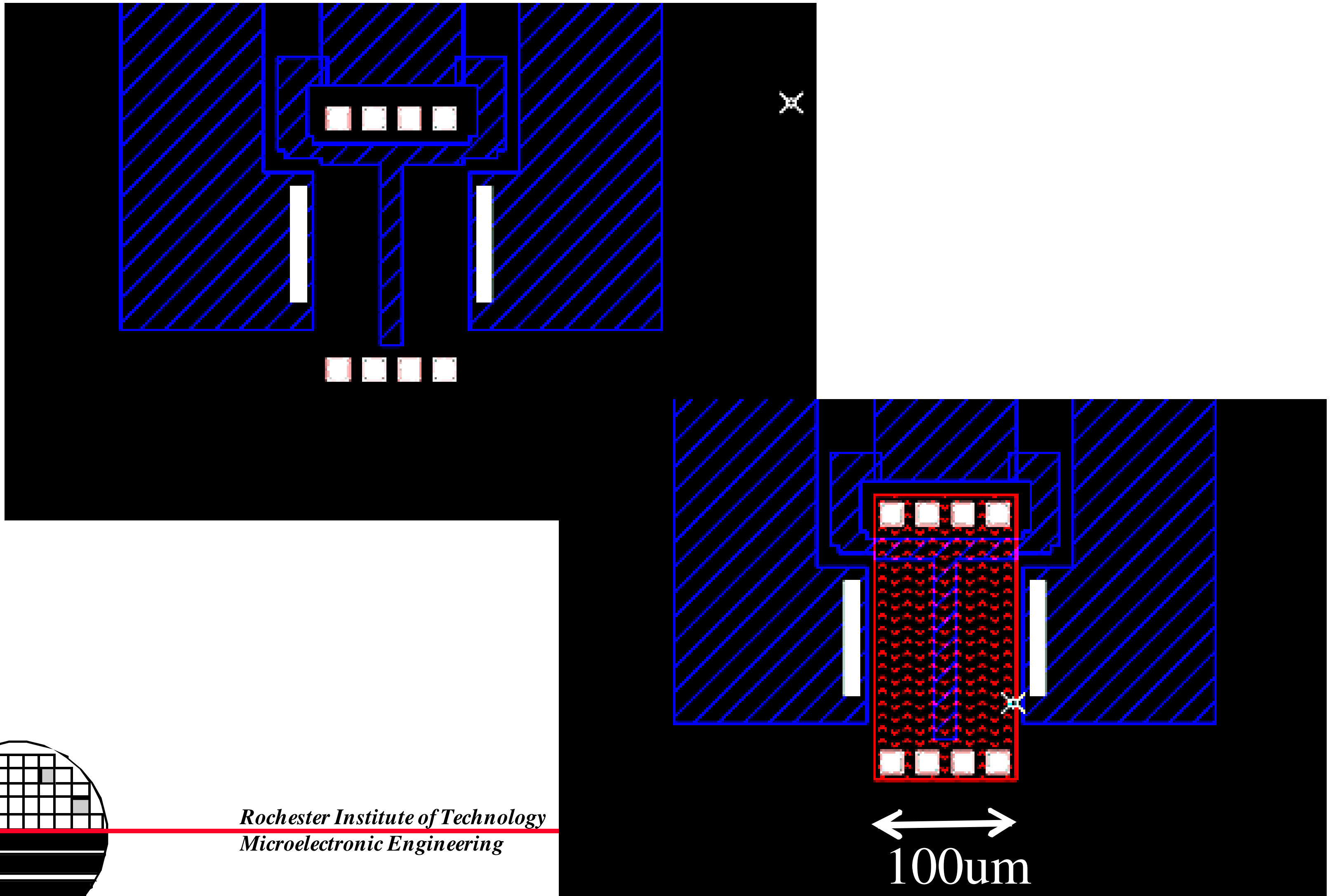


5TH VERSION CMOS Compatible Tiny Pressure Sensor

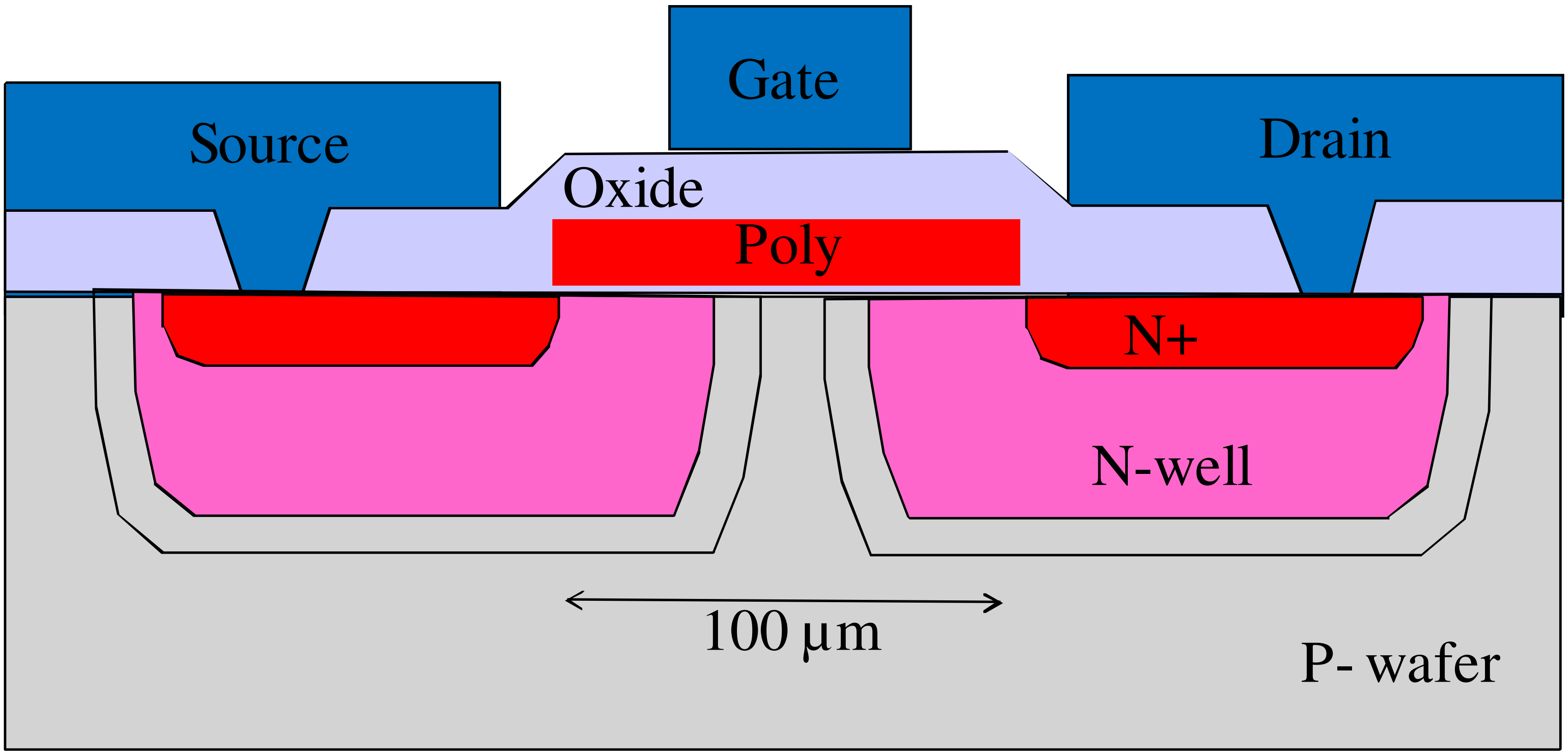




5TH VERSION CMOS Compatible Tiny Pressure Sensor

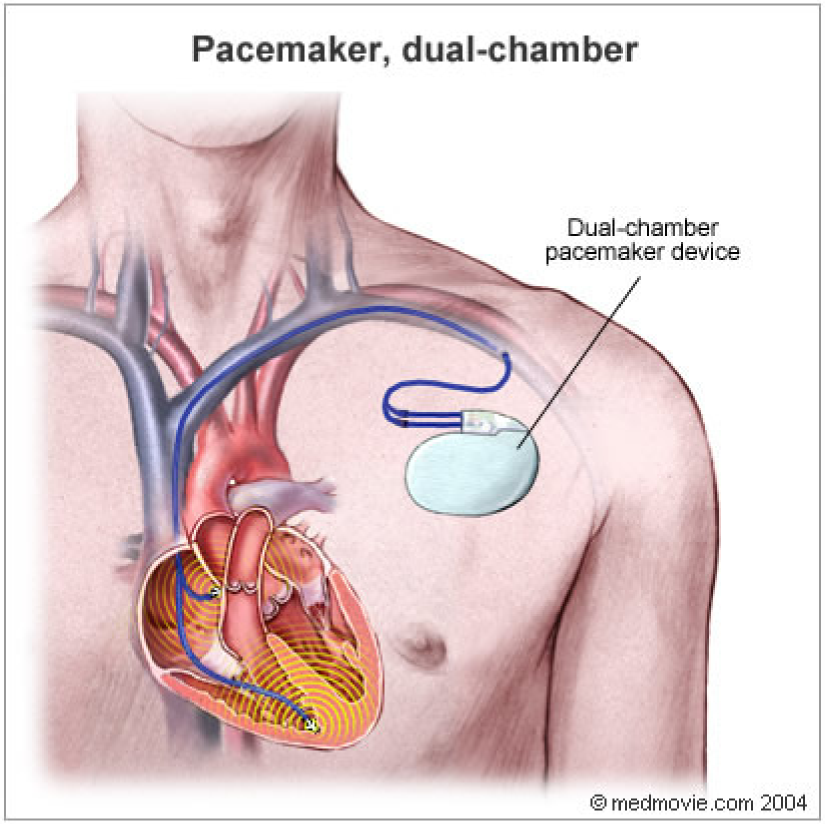


5^{TH} VERSION CMOS Compatible Tiny Pressure Sensor



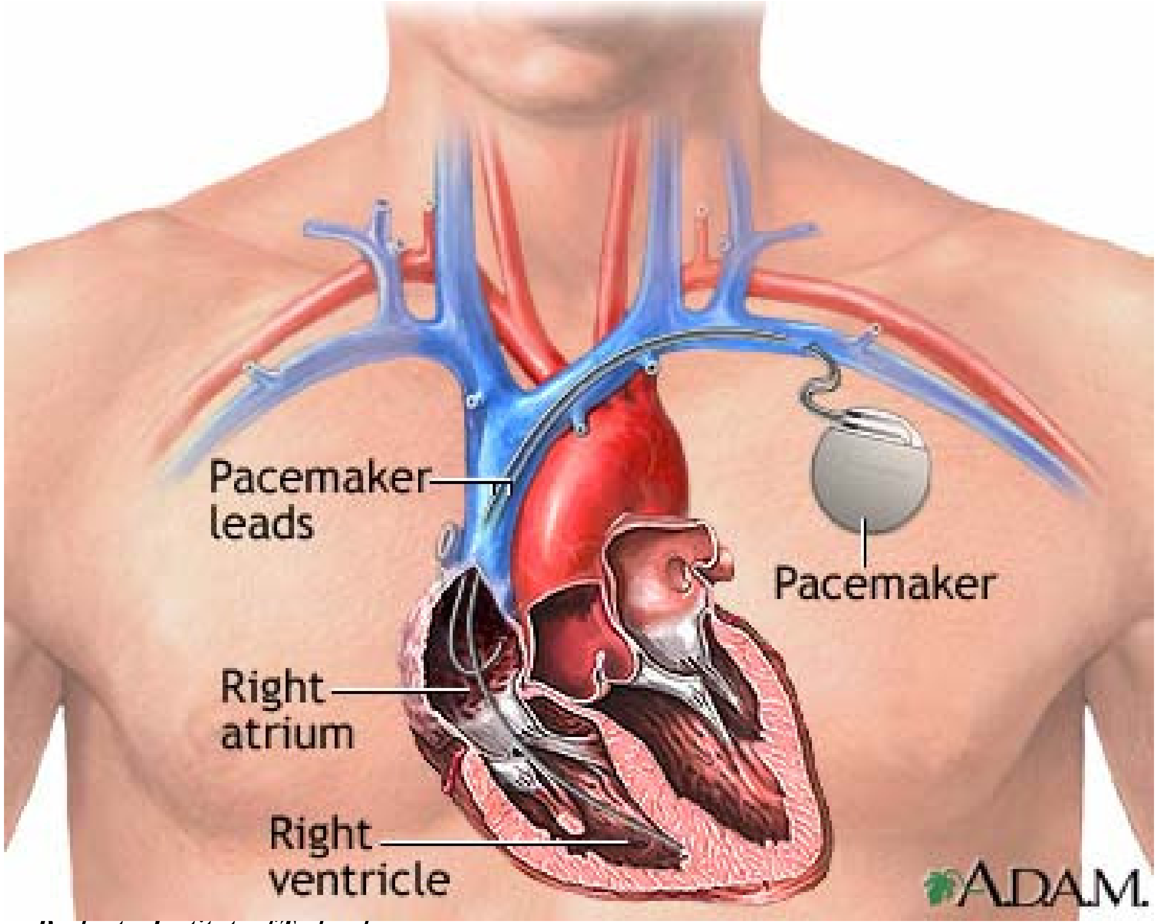
XeF_2 etch can remove poly leaving an air gap creating a pressure sensitive oxide diaphragm

HEART PACEMAKER AND DEFRIBULATION



http://www.bostonscientific.com/templatedata/imports/multimedia/CRM/pro_pacemaker_us.jpg

FUNCTIONAL DIAGRAM

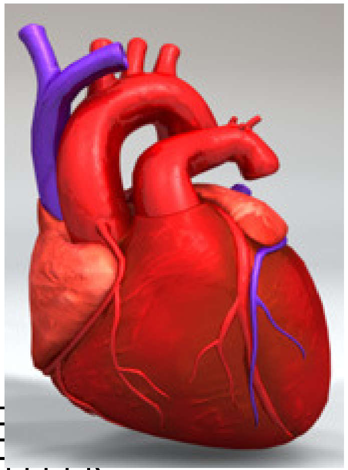


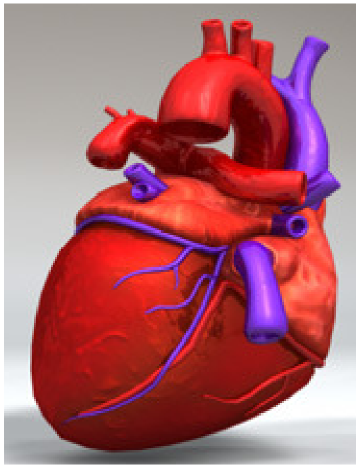
http://apps.uwhealth.org/health/adam/graphics/images/en/19566.jpg

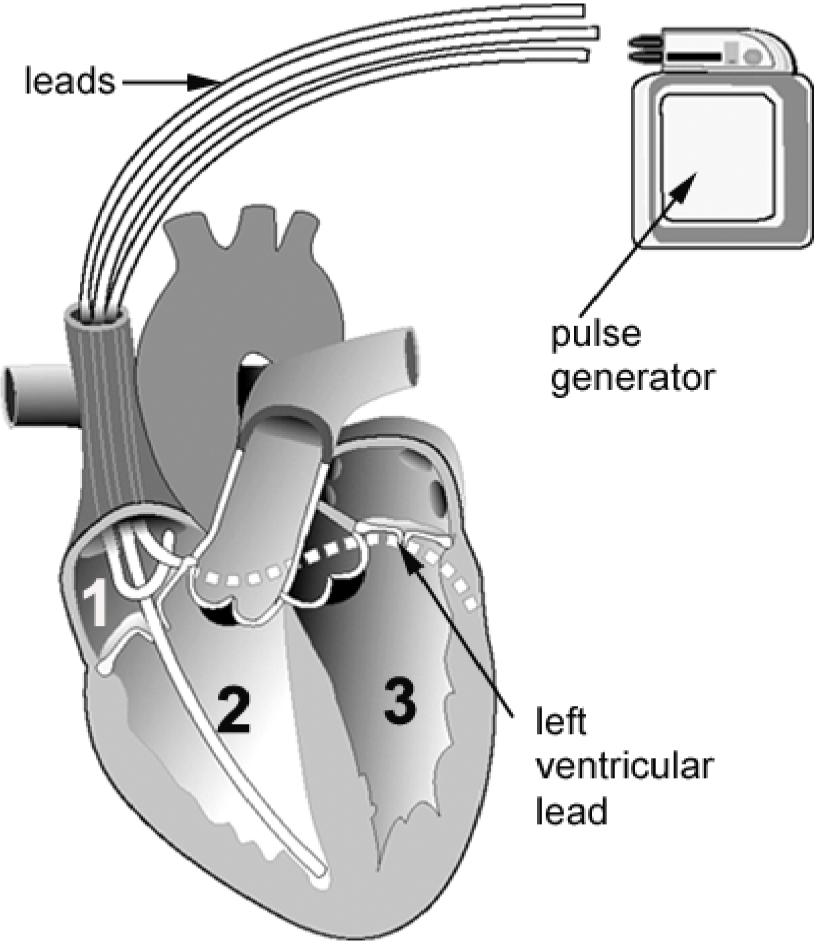
ADDITIONAL ANATOMICAL POINTS TO CONSIDER

1. Leads in the right ventricle will be in direct contact with the heart wall

2. Leads in the left ventricle are fed through the pulmonary vein and remain unattached







http://www.3dscience.com/Animations/Heartbeat_AntCut.php

http://www.infomat.net/infomat/focus/health/health_curriculum/images/heart.gif

HEART WALL MOVEMENT SENSOR

We want to make a device that can sense the movement of the wall of the heart. This will help in adjusting the synchronization of the heart muscle response to the electronic pulses from a pacemaker.

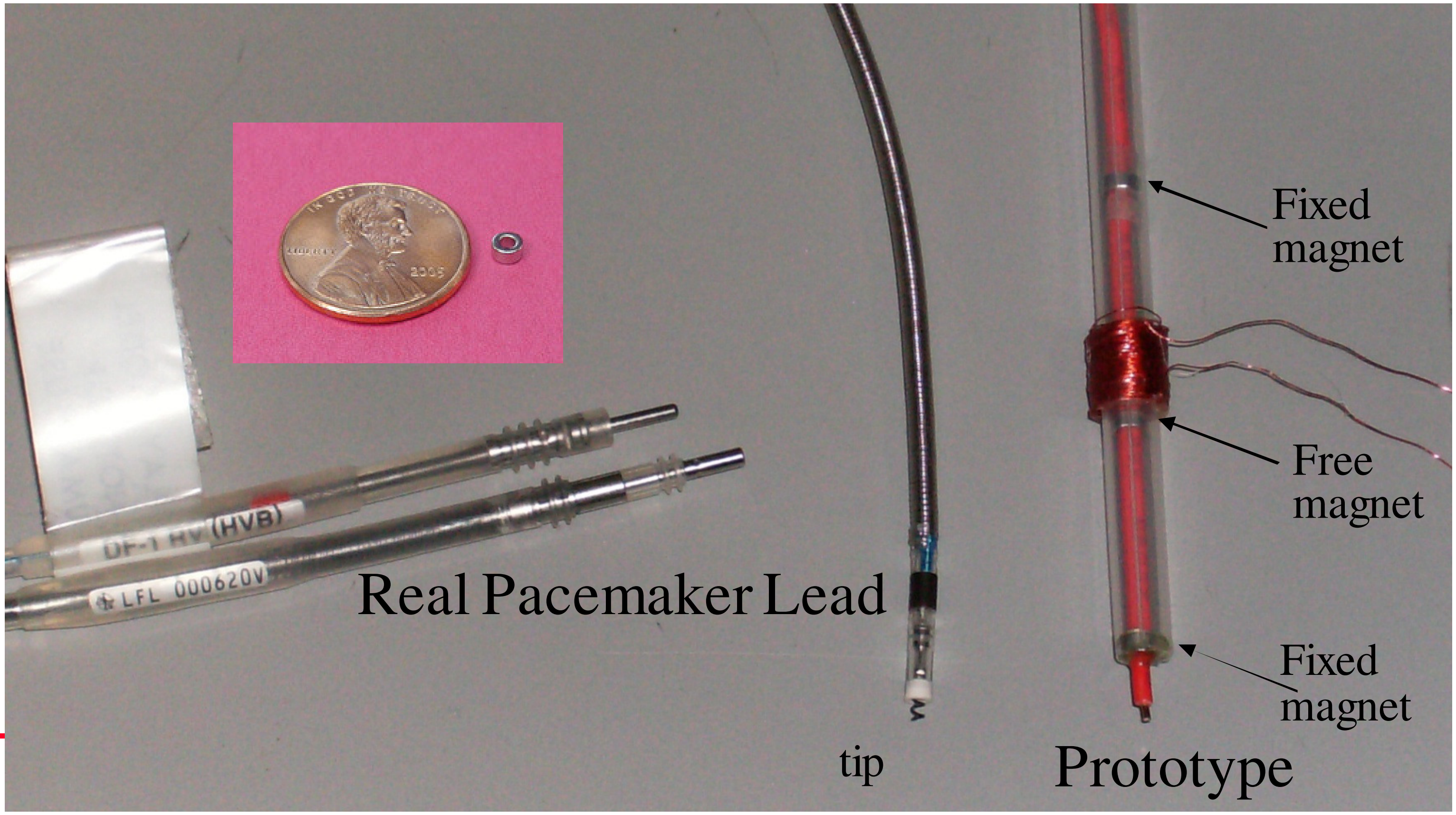
A sensor based on Faraday's principal of electromagnetic induction is proposed. A magnet and the coil have to move relative to each other. Such a sensor measures velocity and creates an output voltage.

A coil wrapped around the pacemaker lead, near the tip, will move with the movement of the heart wall where it is attached. Inside the lead a magnet is levitated in a position near the coil then any movement of the coil will cause a changing magnetic field and an output voltage.

The magnet's inertia holds it in place, momentarily, as the coil moves. We levitate the free magnet in between two fixed magnets with like poles towards each other creating a restoring force. The magnets are donut shaped and a small wire through the hole prevents the free magnet from flipping thus enabling the restoring, levitation, action to work.

DESIGN APPROACH

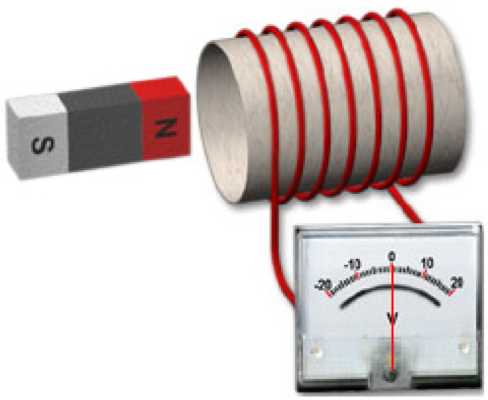
The middle magnet is free and its inertia keeps it stationary (momentarily) when the tip moves. The two end magnets are fixed and oriented with like poles facing the free magnet providing a restoring force to return the free magnet near the coil. The red wire goes through the center of the donut shaped free magnet preventing it from flipping.



FARADAY PRINCIPLE OF ELECTROMAGNETIC INDUCTION

Faraday's Magnetic Field Induction Experiment

When Michael Faraday made his discovery of electromagnetic induction in 1831, he hypothesized that a changing magnetic field is necessary to induce a current in a nearby circuit. To test his hypothesis he made a coil by wrapping a paper cylinder with wire. He connected the coil to a galvanometer, and then moved a magnet back and forth inside the cylinder.



Click and drag the magnet back and forth inside the coil.

When you move the magnet back and forth, notice that the galvanometer needle moves, indicating that a current is induced in the coil. Notice also that the needle immediately returns to zero when the magnet is not moving. Faraday confirmed that a moving magnetic field is necessary in order for electromagnetic induction to occur.

http://micro.magnet.fsu.edu/electromag/java/faraday2/

MAGNETS

http://www.kjmagnetics.com/

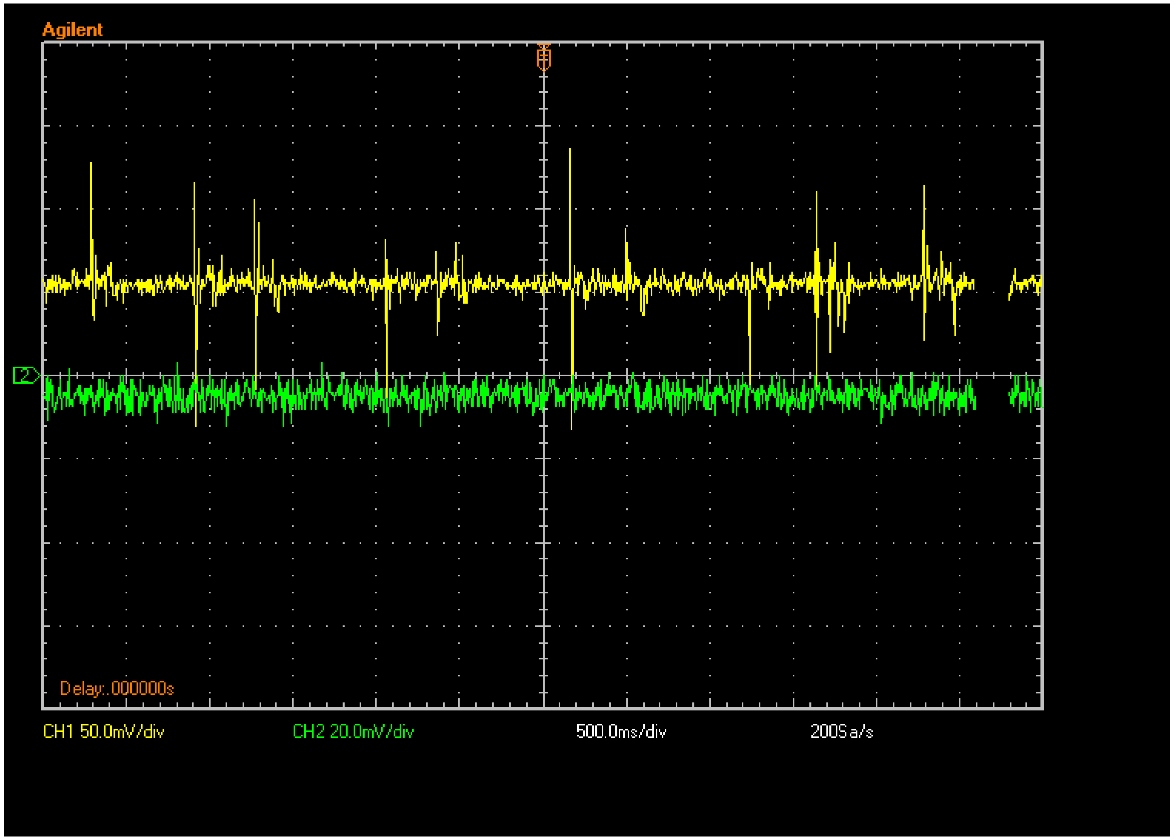
R211

- Dimensions: 1/8" od x 1/16" id x 1/16" thick
- Tolerances: ±0.001" x ±0.001" x ±0.002"
- Material: NdFeB, Grade N42
- Plating/Coating: Ni-Cu-Ni (Nickel)
- Magnetization Direction: Axial (Poles on Flat Ends)
- Weight: 0.00249 oz. (.0707 g)
- Pull Force: 0.45 lbs
- Surface Field: 1515 Gauss
- Brmax: 13,200 Gauss
- BHmax: 42 MGOe

Tiny rings!

R211: 1 for $0.14

TEST RESULTS



Signal Amplified x100

Signal no amplification

REFERENCES

1. "Emerging Prostheses Attempt Vision Restoration", R&D Magazine, June 2004.
2. Boston Retinal Implant Project, www.bostonretinalimplant.org
3. Optobionics Corporation, www.optobionics.com
4. Biology, 3rd Edition, Neil A. Campbell, Benjamin/Cummings Publishing Co. Inc.
5. Boston Scientific Co.

HOMEWORK – MEMS PROBES

1. Search for other applications of MEMS electrodes in biology. Summarize, in your own words, and list your references.