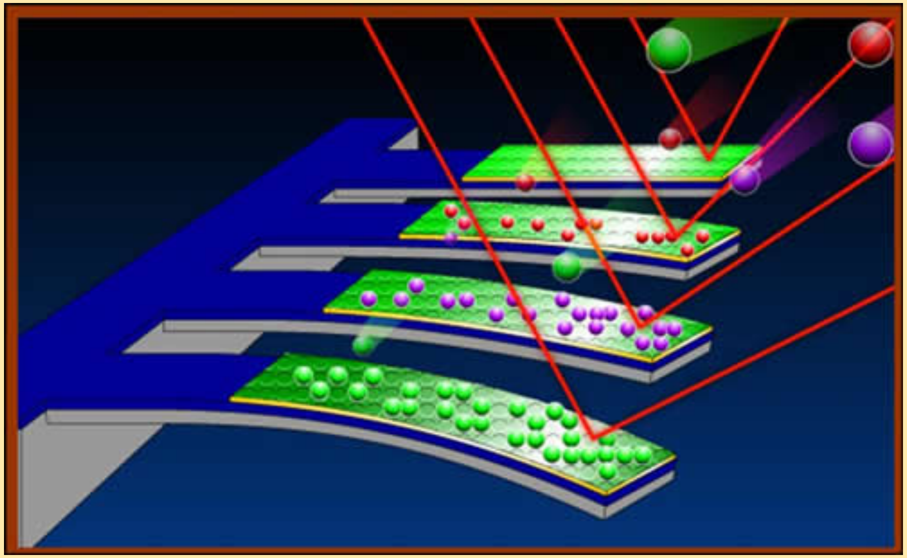
MICROCANTILEVER APPLICATIONS OVERVIEW



SCME
Southwest Center for Microsystems Education

Microcantilevers Learning Module

Unit Overview

The microcantilever is a widely used component in MEMS (microelectromechanical systems).

Its flexibility and versatility make it a popular component for applications in a number of fields.

This unit discusses many of these applications.

Objectives

- Discuss four different applications in which microcantilevers are used.
- Discuss the advantages and limitations of microcantilevers compared to macrocantilevers.

Introduction

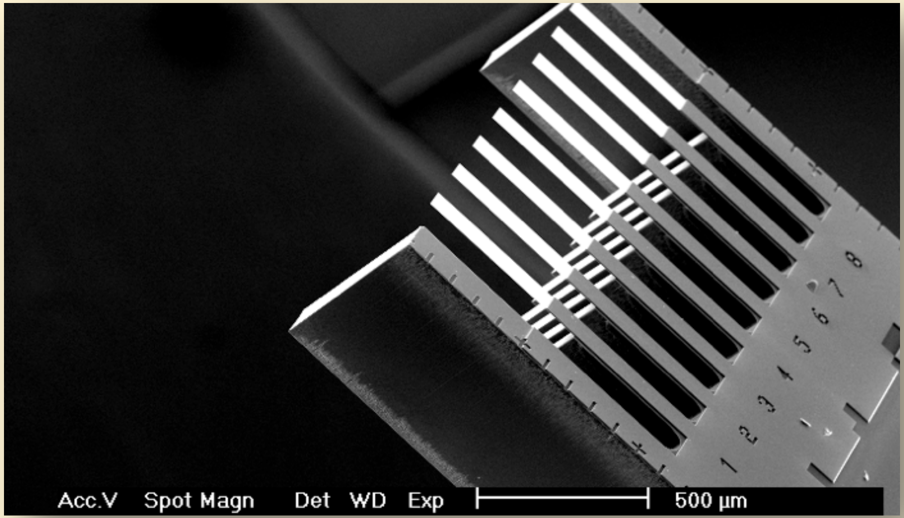
A cantilever is a suspended beam, supported at only one end. Aircraft wings, balconies, diving boards, and free standing radio towers are types cantilevers.

Cantilevers come in all sizes. Macrocantilevers range in length from a few meters to hundreds of meters.

Microcantilevers are a few micrometers to several hundred micrometers in length.

Types of Cantilevers

Microcantilever Applications



Scanning Electron Microscope (SEM) image of a Cantilever Sensor Array These cantilevers were developed by the Swiss Nanoscience Institute for proteomic and genomic applications.

[Image courtesy of Dr. Christoph Gerber, Institute of Physics, University of Basel]

Microcantilevers are used as sensors, transducers, probes, needles, transport mechanisms, and switches for many tasks.

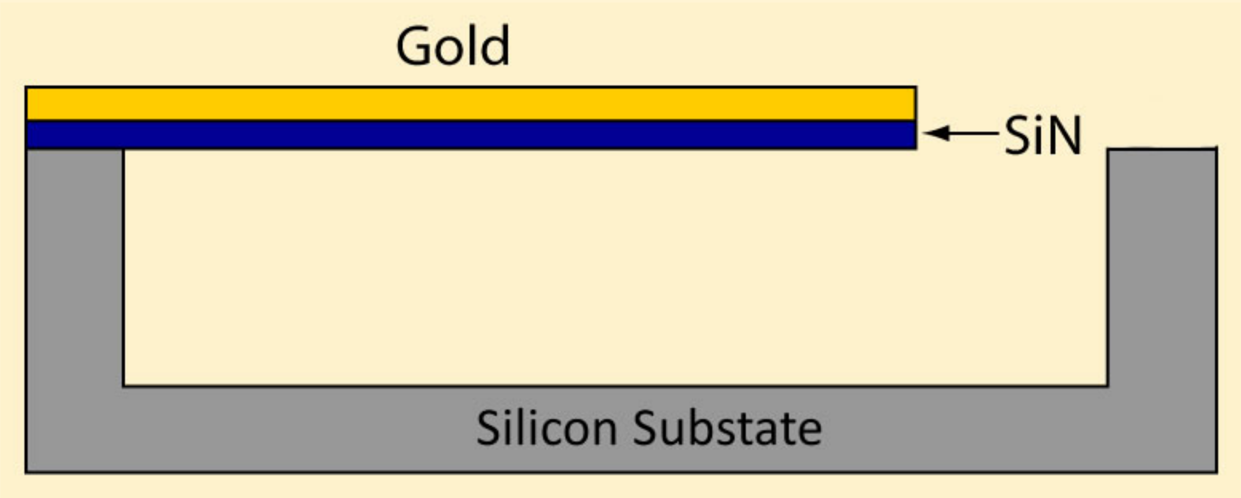
- Detect physical, chemical, and biological particles
- Penetrate tissue in therapeutic and diagnostic applications
- Sensors to detect nano-size particles on a surface
- Memory storage devices

Cantilever-based MEMS

Current applications of cantilever-based MEMS:

- Biomedical Applications (BioMEMS)
- pH sensors
- Therapeutics
- Atomic Force Microscopes (AFM)
- Read/Write storage devices
- Environmental Monitoring
- Food Production and Safety
- RF Switching

Microcantilever Materials



Cantilever Beam of silicon nitride (SiN) coated with a gold layer

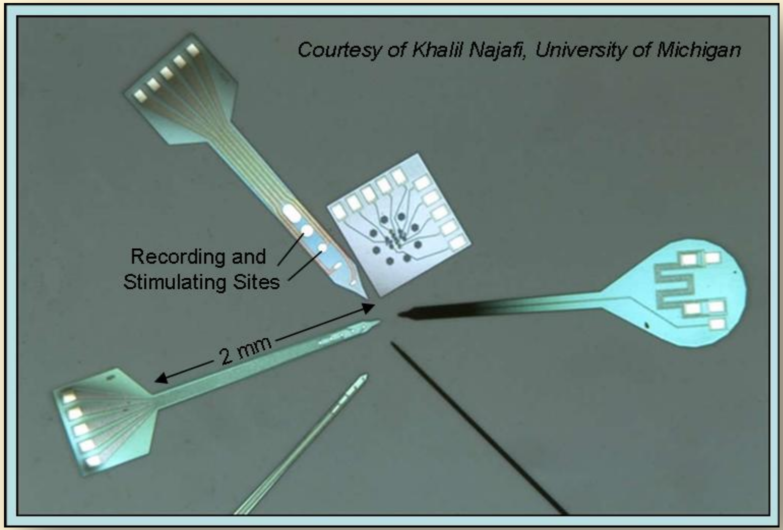
- Microcantilevers are fabricated from various materials, most commonly from silicon, silicon nitride (SiN), and polymers.
- Application of the cantilever determines the coating or subsequent layers.
- Type of material and physical dimensions are determined by the cantilever's application and operational requirements.

Application vs. Stiffness

Probes and needles need to be stiff enough to penetrate tissue without bending.

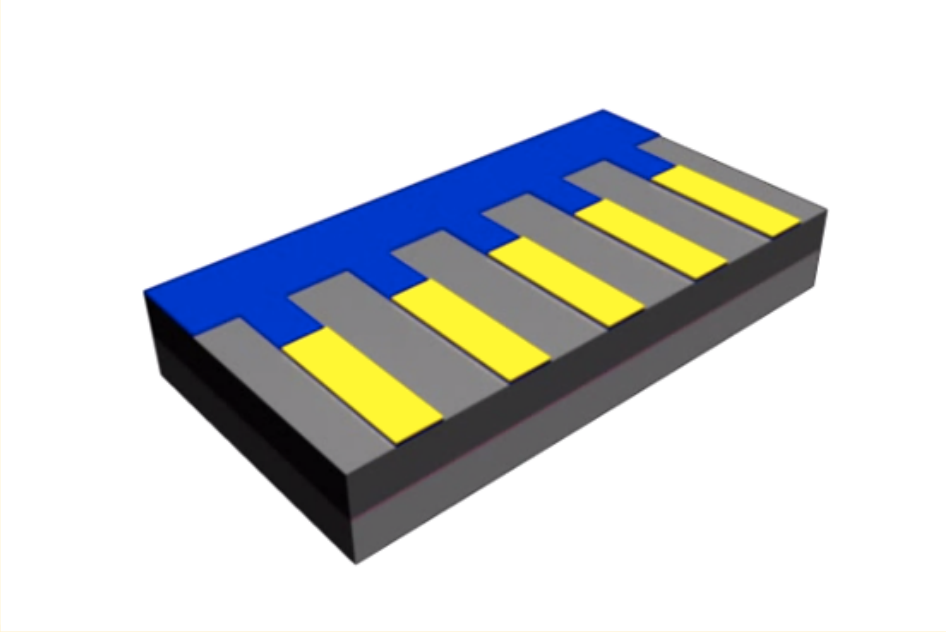
Resonators, and latches need to be stiff enough so as not to oscillate too easily or flex due to weak ambient forces.

Cantilever sensors, transducers and switches need more flexibility.



Probes with MEMS sensors at the probe tips

Microcantilever Fabrication



(Click on graphic to start YouTube animation.)

Fabricated using both bulk and surface micromachining.

In each process, a solid structure is released from the crystal silicon to create a free-standing beam, anchored at one end.

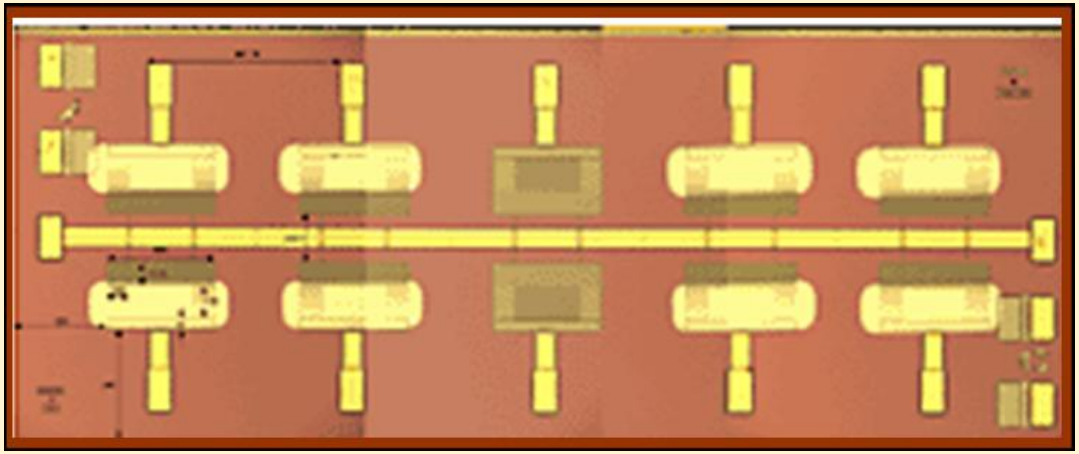
Micromachining processes allow for the fabrication of a single cantilever or an array of cantilevers.

Microcantilever Characteristics

This popularity of the microcantilever in MEMS is due several characteristics which include the following:

- Ability to render measurable mechanical responses quickly and directly
- Sensitivity to a miniscule amount of external force or stimuli
- Low power consumption
- Capability to fabricate a high density array with simultaneous responses to different stimuli – each cantilever in the array is individually functionalized.

Microcantilevers as Sensors



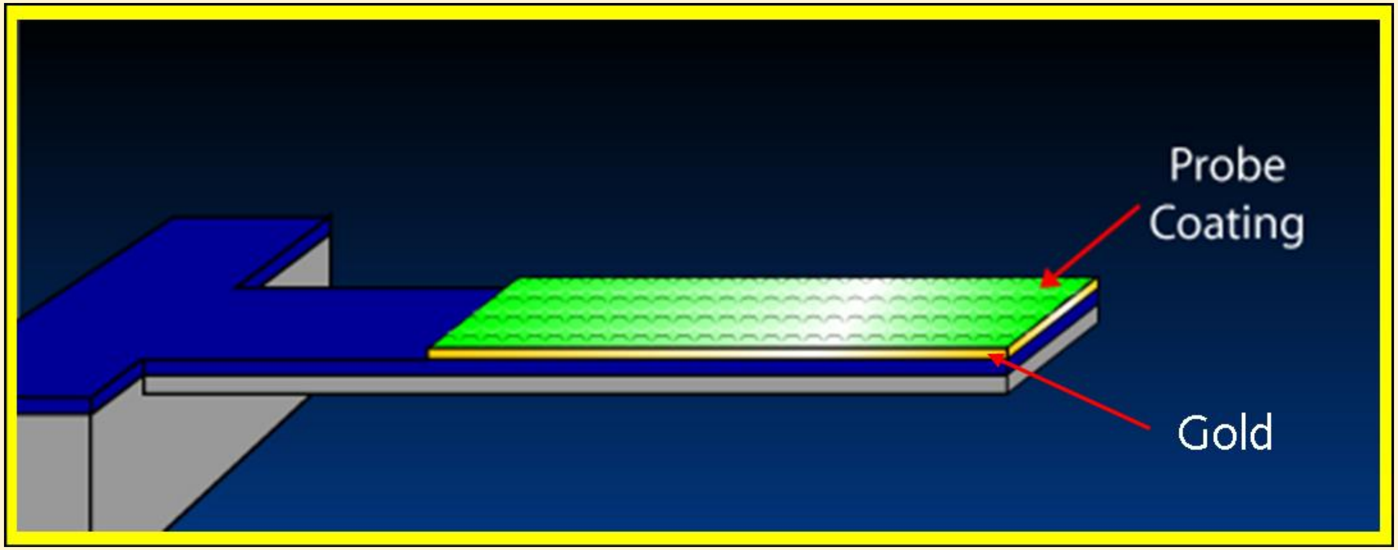
Eight cantilevers coated with palladium-nickel films. Two reference cantilevers left uncoated) [University of California at San Diego project, headed by Michael Sailor, a professor of chemistry and biochemistry.]

Sensors are the most versatile applications of MEMS.

MEMS sensors can be either a micro or nano-sized device.

Their size allows them to interface with integrated circuits on the same chip in order to provide analysis and feedback.

Sensor Coating



Probe Coating (A chemically sensitive material that absorbs select analytes in a sample)

To sense the presence of a certain particle or analyte, microcantilevers are coated (functionalized) with a chemically sensitive material or probe coating.

The type of material can provide for a high degree of specificity in detecting certain particles or "analytes" within a sample (e.g. The Enose (electronic nose).

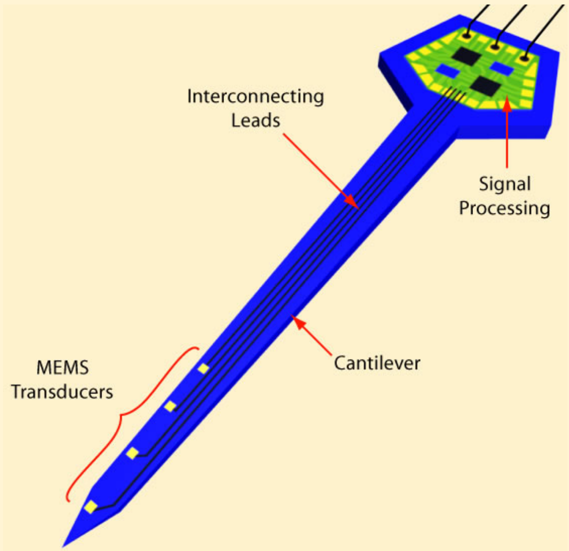
Properties of Measurement

As sensors, microcantilevers rely on their flexibility or "spring constant" to create some type of measurable change when exposed to external stimuli.

The cantilever's reaction to an external stimulus is referred to as *mechanical stress*. This stress results in a change in one of the cantilever's mechanical or electrical properties:

- Angular deflection
- Resistivity
- Natural resonant frequency

Microcantilevers in Sensors



Single MEMS probe with electronics

Cantilever Array for Read/Write Memory
[Image courtesy of IBM]

Microcantilevers can be fabricated as a single device *(left figure)* or as several devices arrange in a sensor array *(right figure)*. Applications for cantilever-based sensor arrays are endless.

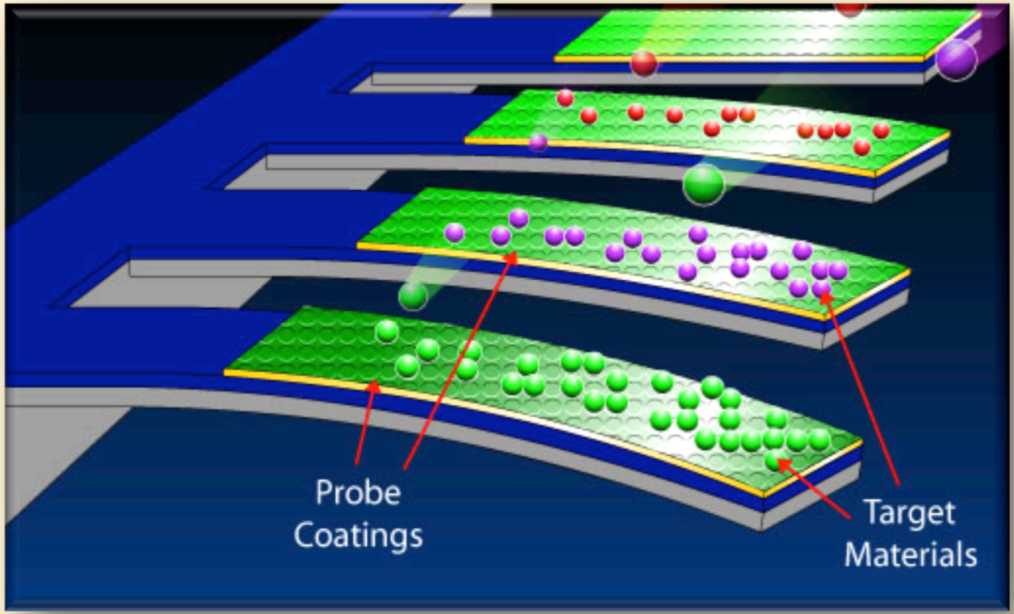
Chemical Sensor Arrays

A chemical sensor array (CSA) is designed to detect and measure the amount or concentration of one or more substances within a given sample or environment.

Examples:

- CSAs used in the medical field can identify the amount of a specific antibody or antibodies with a small blood sample.
- An artificial nose is a CSA used to recognize certain vapors and their concentrations.

Chemical Sensor Array



CSAs are chemically discriminating. An individual cantilever or a set of cantilevers can be designed to detect one and only one analyte within the sample OR an array can have numerous discriminating cantilevers allowing for the detection of several different analytes within the same sample *(see figure).*

Microcantilever Sensors and Sensor Arrays

- Gas leak detectors
- Detection and characterization of chemicals in liquid and gaseous states
- Biosensors (detect and measure antibodies, protein, enzymes, antigens, and DNA)
- Sensors for DNA hybridization and Protein binding
- pH sensors
- Biomolecular analysis

Advantages of Microcantilever Sensors

- Microscale size
- Ease of constructing many cantilevers in one array
- Ability to detect multiple analytes in one solution using one MEMS device
- Extremely high sensitivity and selectivity
- Flexibility of its working environment (air, vacuum, liquid)
- Wide dynamic range
- Low power consumption

Microcantilevers as Transport Devices

- As sensors, microcantilevers need some degree of flexibility in order to "bend" when exposed to its target.
- As a transport device, a microcantilever needs a higher degree of stiffness. However, for some transport applications, such as the Atomic Force Microscope cantilevers, some "bending capability" is still required.

Following are applications for cantilevers used as transport devices.

Cantilevers as Surface Probes: AFM

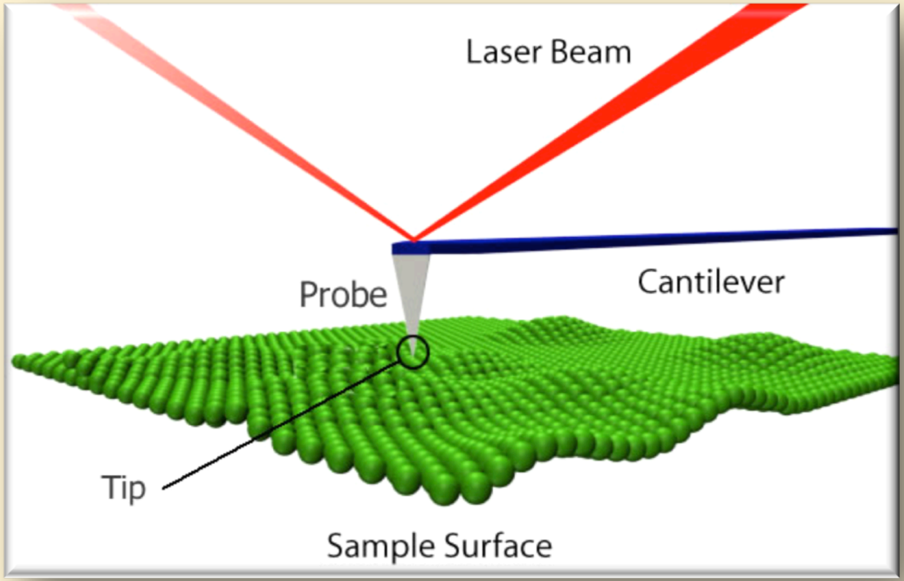
An Atomic Force Microscope (AFM) is a high-resolution scanning probe microscope.

As the sample moves in the x-y directions, the microcantilever “senses” the surface topography.

A laser is reflected off the top of the cantilever.

The z-motion of the cantilever changes the angular deflection of the laser.

These changes are detected and translated into a 3-dimensional representation of the sample surface.



AFM Cantilever and Probe Tip

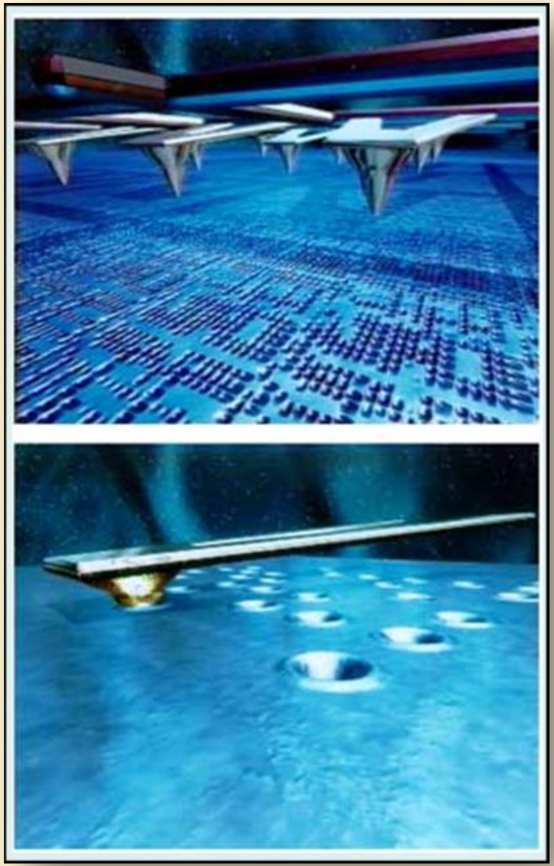
Read / Write Storage

In storage devices a microcantilever transports a probe over a polymer storage medium. The probe tips have a diameter of ~ 10 nm.

To *read, t*he tips detect the presence or absence of matter in the polymer film. To *write*, they move or displace matter a few nanometers in width *(see figure).*

It is projected that MEMS read/write storage devices will be able to store 1 Tbit/in^2 (1 Gbit/mm^2) of data in a unit the size of a postage stamp.

NOTE; Even though several prototypes of this device have been made, as of 2015 such devices are not commercially available. Following is a brief discussion of the IBM Millipede Prototype.



Close-up of read/write cantilevers showing displacement of matter in a polymer film. [Picture courtesy of IBM)

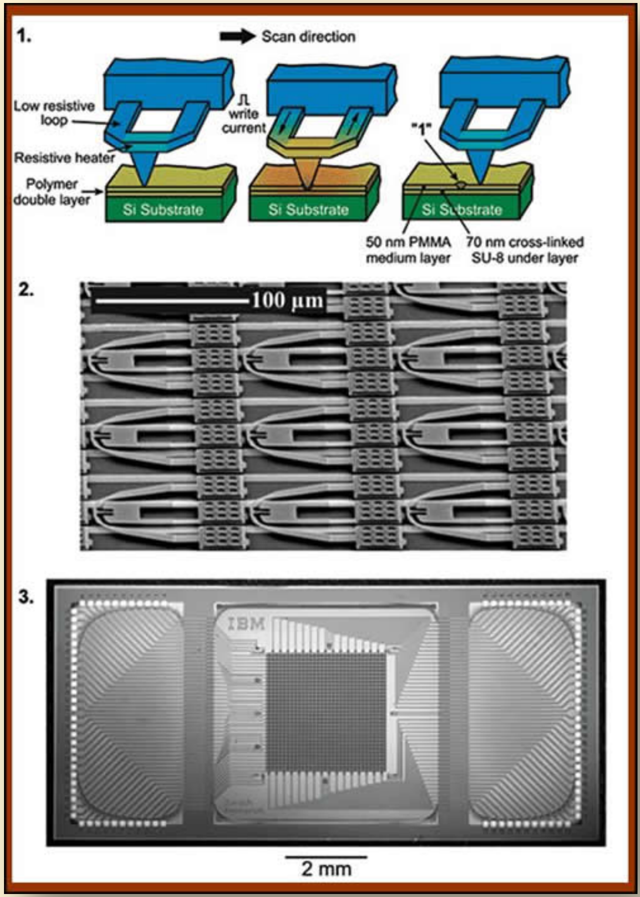
IBM Millipede Prototype

The Millipede consists of a micro-cantilever array positioned over a polymer film storage medium.

The most recent prototype (2005) consists of a 64 x 64 array of 4,096 cantilevers.

An electromagnetic actuation precisely moves the storage medium in the x-y directions.

Each probe tip reads and writes to a storage area of 100 μm x 100 μm.



IBM Prototype (32 x 32 array)
[Picture courtesy of IBM)

Millipede Videos

Millipede Array – Courtesy of IBM

Millipede Close Up – Courtesy of IBM

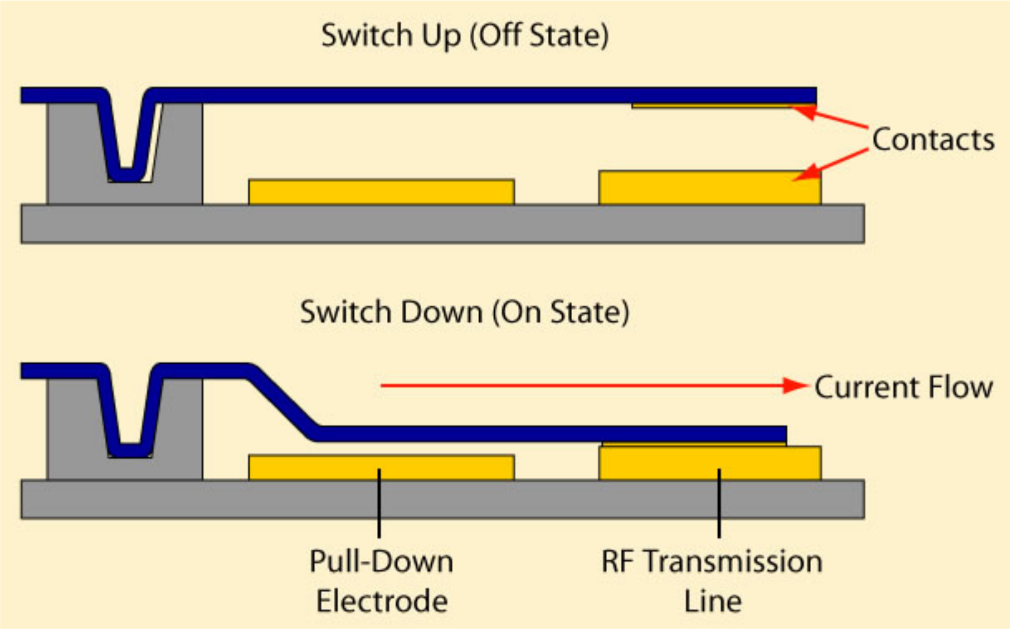
Microcantilevers as Switches

MEMS switches are typically broadband switches (can operate over a wide frequency range).

In theory, MEMS RF *(radio frequency)* switches can direct and control signals as high as 50 GHz and possibly higher.

Because of their low power consumption MEMS switches significantly increase the battery life of many handheld applications such as cell phones and PDAs.

A MEMS RF Switch



MEMS RF Switch

A MEMS RF switch is a metal microcantilever with a metal contact tip.

When a voltage is applied to the Pull-Down Electrode, the resultant electrostatic force pulls the cantilever contact towards the lower contact until the two come together.

Upon contact, the switch is closed.

Microcantilevers as Needles

A micro-needle takes a small blood sample (picoliters) by drawing blood flow via capillary force. Because of size, the injection is relatively painless.

Micro and nano-sized needles are used singly and in needle-arrays for drug delivery applications. *(image right)*

These needles can be made of silicon with each needle measuring 40 μm in diameter and 500 μm tall.

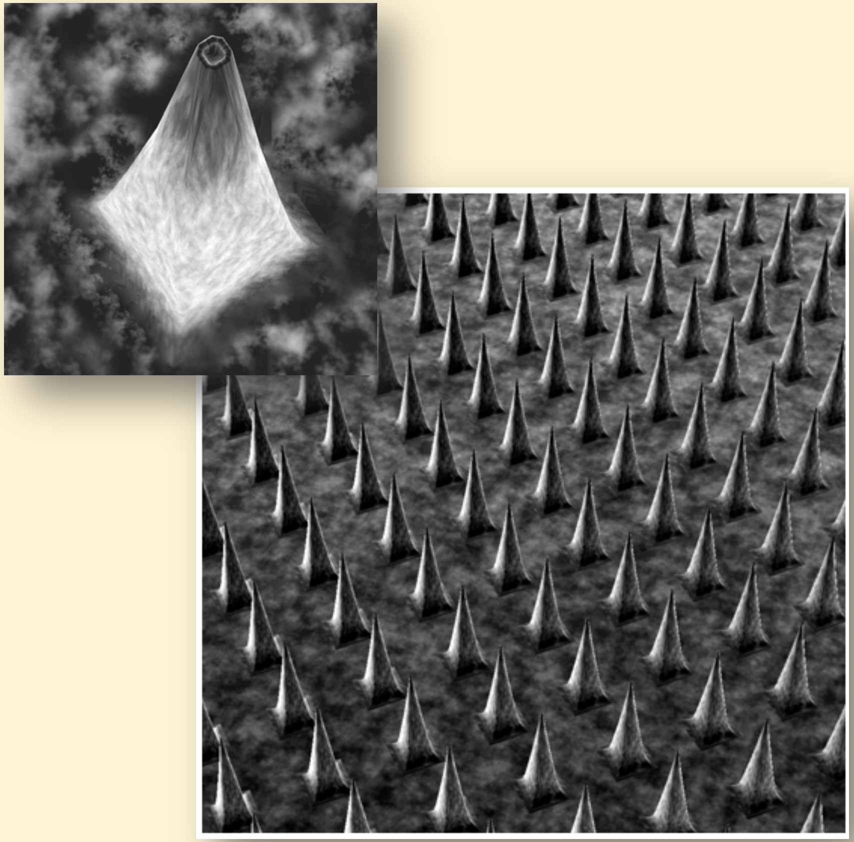


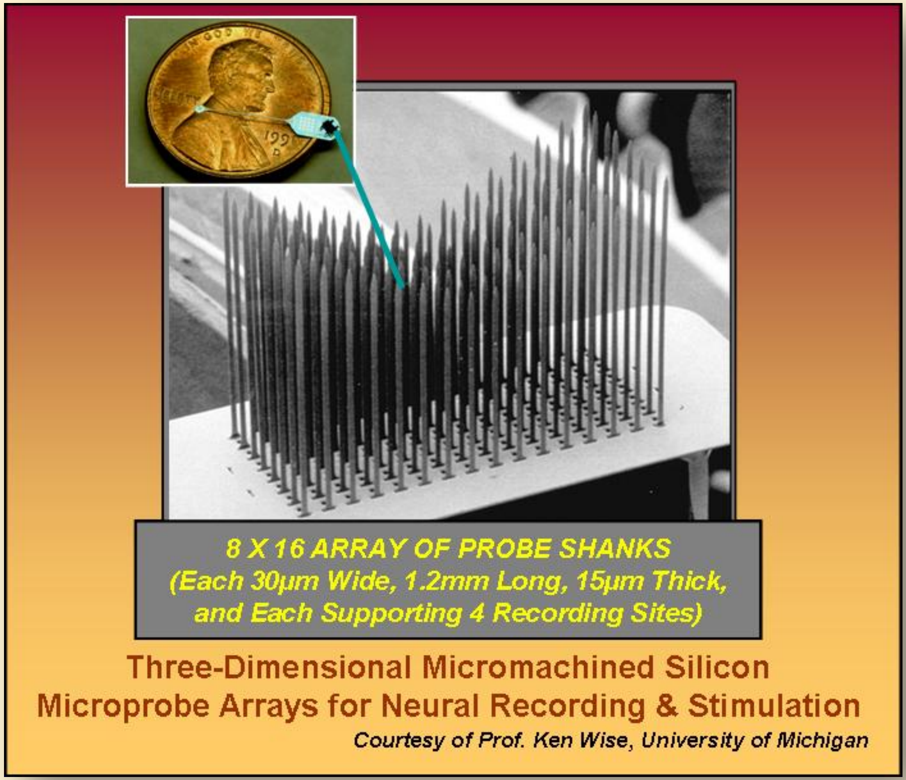
Illustration of a Microneedle array and a needle's tip that could be used as a Transdermal Drug Delivery System

Microcantilevers as Probes

Diseases such as Parkinson's and Alzheimer's have helped to mobilize research into using micro and nano-sized cantilevers as neural probes *(see figure)*.

Applications of Neural probes:

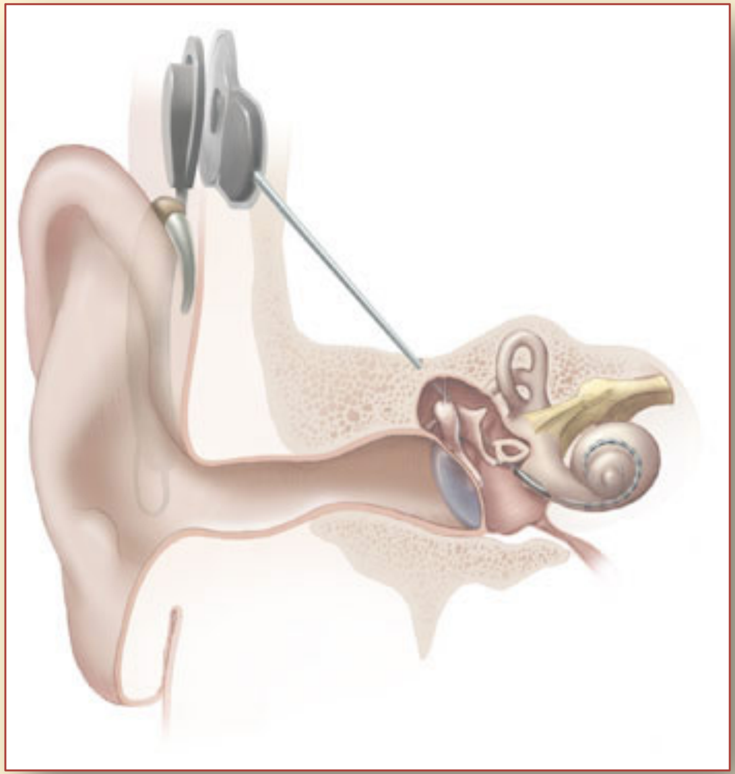
- Studying the central and peripheral nervous system
- Treating Neurological disease through the use of neural prostheses
- Studying the brain network



Cochlear Implant

For the hearing impaired, a Cochlear implant is a neuroprosthetic that allows a deaf person to hear noises never heard before. *(See diagram of Cochlear Implant)*

Neuroprosthetic devices have become one of the most important emerging technologies in biomedical engineering applications.



Cochlear Implant

[Image courtesy of National Institute of Health]

Let's Review

What appears to be one of the major applications for microcantilevers?

What are some possible applications of microcantilevers not discussed in this presentation?

How does application determine the stiffness of the cantilever?

Summary

Microcantilevers are used for many applications. The specific application determines the geometric shape of the cantilever, the material from which it is made, and its stiffness characteristics.

The microcantilever is the cornerstone component of a wide variety of MEMS including micro-chemical sensor arrays, atomic force microscopes, microswitches, and neural probes.

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