MEMS Applications Overview

Primary Knowledge
Participant Guide

Description and Estimated Time to Complete

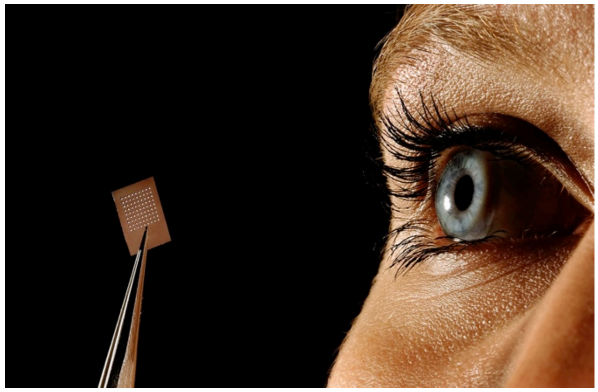
MEMS Applications Overview provides a brief summary of MEMS devices already on the market. It also discusses the various fields in which MEMS are used and the possibilities for MEMS in these fields.

Estimated Time to Complete
Allow approximately 45 minutes

Introduction

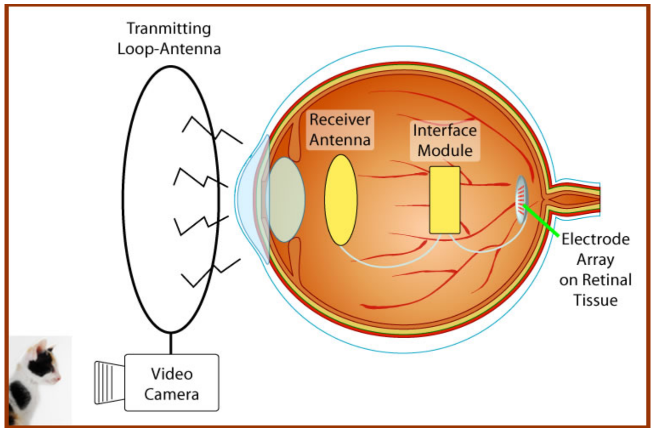
Microelectromechanical systems (MEMS) are very small devices or groups of devices that can integrate both mechanical and electrical components. MEMS can be constructed on one chip that contains one or more micro-components and the electrical circuitry for inputs and outputs of the components. The components include different types of sensors, transducers, actuators, electronics and structures (e.g., gears, sliding mirrors, diaphragms). Each type of component is designed to interface with an input such as light, gas molecules, and a specific type of radiation, pressure, temperature, or biomolecules.

MEMS can consist of a combination of devices in various scales: nano, micro, and macro. An example of a MEMS that encompasses the macro, micro and nano scales is the artificial retina prosthetic. A component of this device is shown in the photograph below.



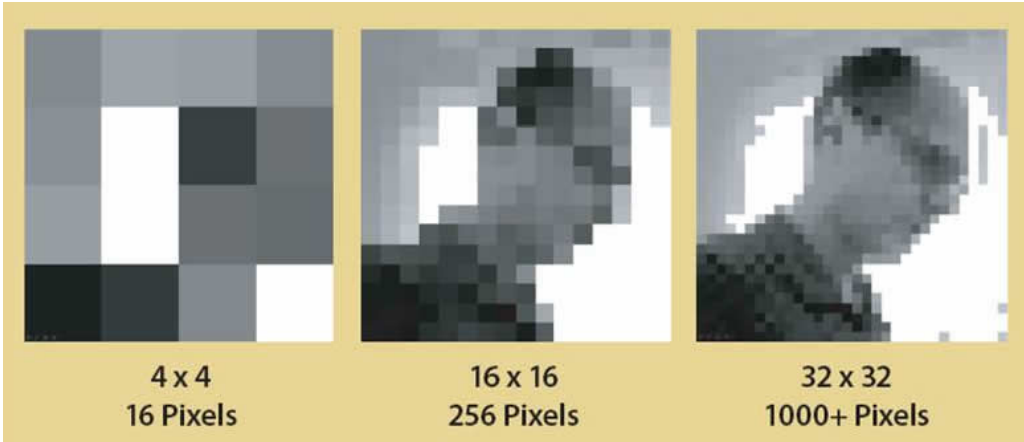
Prototype of a MEMS Retina Implant
[Photo by Randy Montoya. Courtesy of Sandia National Laboratories]

The component is a micro-electrode array used as a retina implant. The array mimics the task of the photoreceptor cells in the retina. These cells are destroyed in diseases such as age-related macular degeneration and retinitis pigmentosa (RP). This microarray interfaces with external components (a camera and microprocessor). The implant is placed on the retina inside (*in vivo)* the eye. The camera and microprocessor are contained within a pair of glasses worn by the blind person. This micro-system is referred to as a retinal prosthesis.



Here's how the retinal prosthesis works *(refer to the graphic above)*:

- The camera captures the image and sends it to the microprocessor.
- The microprocessor translates the image into an electrical signal.
- A transmitter sends the electrical signal to the retina implant (microarray) via a receiver and interface module.
- The electrical signal stimulates the electrodes on the microarray.
- This causes the array to emit pulses that travel along the retinal neurons, through the optic nerve and to the brain.
- The brain translates these pulses into flashes of light, which the brain uses to make the equivalent of low-resolution images. (The more electrodes in the array, the better the image.)
- Watch this animation of how this works. https://youtu.be/Bi_HpbFKnSw



Images generated by the DOE-funded Artificial Retinal Implant Vision Simulator devised and developed by Dr. Wolfgang Fink and Mark Tarbell at the Visual and Autonomous Exploration Systems Research Laboratory, California Institute of Technology.
[Printed with permission.]

The images above show what a patient with a MEMS retinal prosthesis should see. Increasing the number of electrodes in the retina array results in more visual perceptions and higher resolution vision. In 2007 six patients were successfully implanted with the first prototype Model 1 device or Argus I™ containing 16 electrodes (16 pixels - left picture). The Argus II™ (256 pixels-middle picture) is currently being tested in phase two of clinical trials. The third model (1000+ pixels – right picture) is under development and trials are projected for 2011.[1]

Update – On May 4, 2011, Argus reported the results of the Phase II clinical trial of Argus II. All of the 30 patients being test showed significant improvements in visual ability – from finding doorways to identifying up to eight different colors. One patient was able to read at a rate of 10 wpm. *Medical News Today. 05/04/11.*

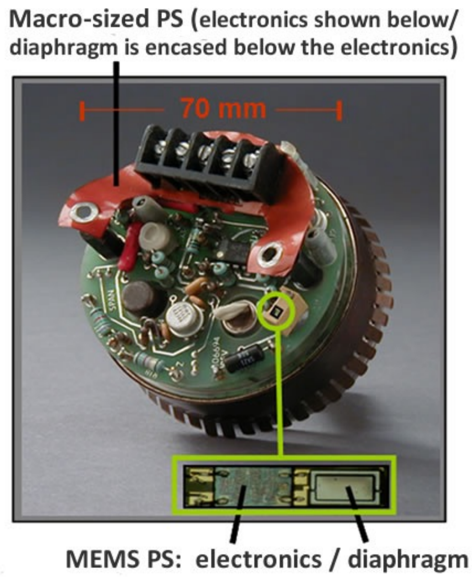
This device has now been approved for commercialization in Europe and the United States.

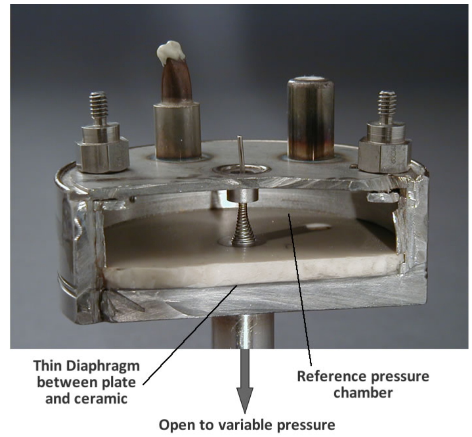
New applications for MEMS are being realized every day. Currently, MEMS are being built as micro-sized devices for applications in the medical field, aerospace, environmental, food industry, automobile industry, and consumer products, just to name a few. A single MEMS can consist of a few components to millions of components and the components can be mixed and matched to address a specific application. Because of this versatility, MEMS applications are practically unlimited.

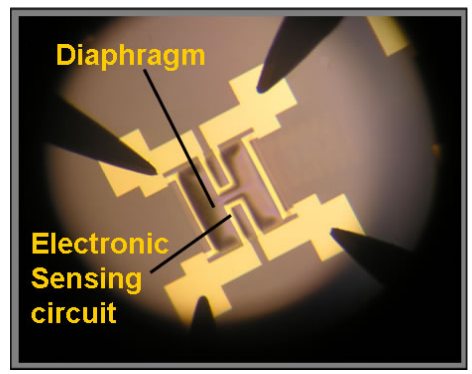
There are still challenges in the fabrication of MEMS for applications such as RF (radio frequency) devices, optical and chemical devices, and fluidics. However, due to the development of new processes, materials, and equipment, these challenges are being addressed and many have been overcome.

This unit will introduce several applications of MEMS within various fields.

Macro vs. Micro







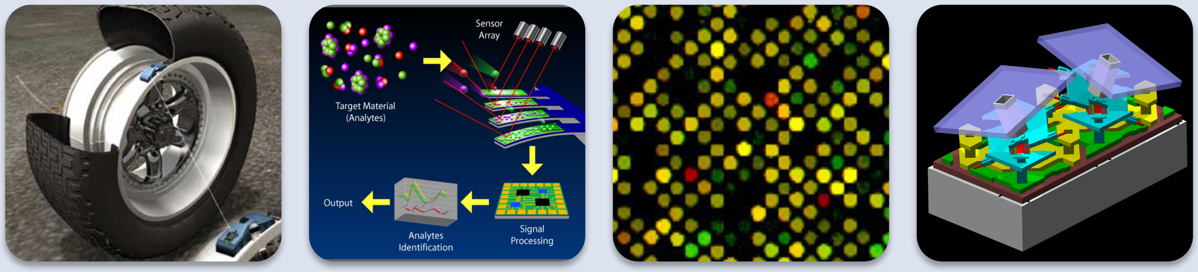
Macro diaphragm gauge (left) and diaphragm (upper right) compared to MEMS gauge (right picture bottom) and MEMS diaphragm (lower right)
[Macro PS Photo courtesy of Bob Willis. MEMS diaphragm courtesy of UNM/MTTC]

An equivalent of a MEMS device at the macro scale is the diaphragm gauge used to measure pressures and pressure changes. Such a gauge consists of a mechanical component (the diaphragm) and electrical components with an input and output voltage(s). As the diaphragm moves due to changes in pressure, an output voltage proportional to the change in pressure is generated. Reduce the size of the diaphragm and the related electrical components, place them all on the same microchip, and you have a microelectromechanical system or MEMS. The above photographs compare the macro pressure sensor to the MEMS sensor (left picture) and the diaphragms (right pictures).

Objectives

- State three fields in which MEMS devices are being used
- State three applications of MEMS devices in the automobile industry
- State three applications for MEMS in the medical field

What are MEMS?



Sense
- Movement
- Vibration
- Pressure
- Light
- Temperature
- Mass

Think
- Collect information
- Analyze data
- Interpret data
- Make decisions
- React to change

Communicate
- Send information
- Provide outputs
- Transmit data
- Provide warnings

Act
- Respond to changes
- Move devices
- Transmit light and fluids
- Transport particles

Microelectromechanical systems (MEMS) are devices that can sense, think, act and communicate. MEMS redirect light, pump and mix fluids, and detect the presence of molecules, heat, pressure or motion (all of which have been done for years in a macro scale). Through the miniaturization of these macro-sized devices and the ability to fabricate micro-sized devices in large numbers, the costs of manufacturing have decreased.

A MEMS's small size allows it to be incorporated into a vast array of products. It can be included as a component of an integrated circuit or embedded into materials during manufacturing. Such characteristics permit the construction of more complicated systems and expand the potential applications of MEMS.

MEMS are wide-ranging in their applications and construction. There can be one microdevice or element on a single chip or millions of devices or elements on a single chip. The interaction of these components working together makes up a microelectromechanical system or MEMS. MEMS elements work independently as a solitary device or work together in large arrays or combinations in order to perform complicated tasks.

A Note on Terminology

In the literal sense, MEMS means MicroElectroMechanical Systems - any microsystem that integrates both electrical and mechanical components on the same chip. However, as terms sometimes do, MEMS has evolved to refer to any microdevice or microsystem that is made using one of the typical microfabrication technologies. This includes not only microelectromechanical, but also microfluidics, micro-optics or any system made, at least in part, at the microscale.

Another term that represents all types of microsystems is MicroSystems Technology or MST. MST is all encompassing. It includes any device, system or component fabricated at the microscale. MST is not widely used in the United States. MEMS is the more common term and is used synonymously with MST.

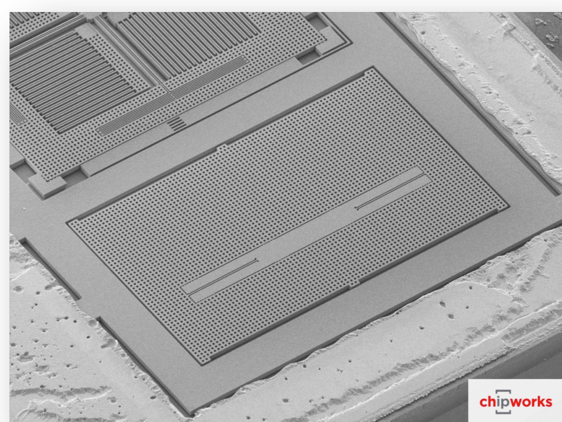
Therefore, as a note, the MEMS acronym is used for all microscale devices and systems discussed in this unit and other units developed by SCME.

Applications of MEMS

Today, applications for MEMS have been developed in several fields where miniaturization is beneficial:

- Consumer products
- Gaming
- Aerospace
- Automotive
- Biomedical
- Chemical
- Optical displays
- Wireless and optical communications
- Fluidics

Examples of MEMS devices include pressure sensors, transducers, accelerometers (inertial sensors), micromirrors, miniature robots, flow sensors, fluid pumps, microdroplet generators, and optical scanners. The automotive industry was one of the first industries to commercially embrace MEMS devices in the '90's with the accelerometer – a MEMS device used to sense a sudden change in velocity causing the activation of a crash (or air) bag *(see picture right)*.



3-axis High-Performance Micromachined Accelerometer
(Each accelerometer senses movement in one direction. The two, top left, are for x &y, while the accelerometer at the bottom is for z.)
[Image courtesy of Chipworks]

Other automotive applications currently in use or coming soon include sensors for monitoring tire pressure and fuel pressure, "smart" sensors for collision avoidance and skid detection, "smart" suspension for sport utility vehicles to reduce rollover risk, automatic seatbelt restraints and door locking, vehicle security, headlight leveling, and navigation. [1]

MEMS Sensors

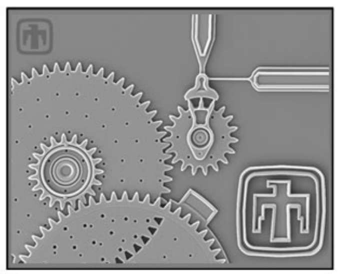
A major application for MEMS is as sensors. [2] Three primary MEMS sensors are

- pressure sensors,
- chemical sensors, and
- inertial sensors (accelerometers and gyroscopes).

MEMS sensors can be used in combinations with other sensors for multisensing applications. For example, a MEMS can be designed with sensors to measure the flow rate of a liquid sample and at the same time identify any contaminates within the sample.

In addition to sensors, MEMS consist of pumping devices, gear trains, moveable mirrors (see SEM images above), miniature robots, tweezers, tools and lasers. These devices have found numerous applications with various fields such as biomedical, optical, wireless networks, aerospace, and consumer products. Several of these applications are discussed in the following sections.

Mirror (popped-up)



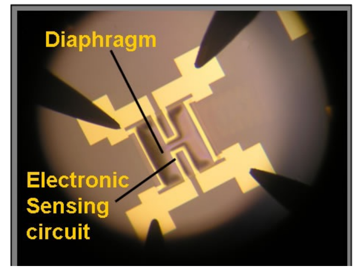
Gear Train

Courtesy of Sandia National Laboratories
SUMMiT™ Technologies, www.mems.sandia.gov

Let's start our exploration of MEMS by looking at some applications for MEMS pressure sensors.

MEMS Pressure Sensors

MEMS pressure sensors are designed to measure absolute or differential pressures. They typically use a flexible diaphragm as the sensing device as seen in the picture to the right. One side of the diaphragm is exposed to a sealed, reference pressure and the other side is open to an external pressure. The diaphragm moves with a change in the external pressure. MEMS pressure sensors are specified to work in a variety of ranges, depending on the design and application. There are MEMS pressure sensors that can measure pressures near 0 ATM or as high as 10 ATM or ~150 psi.



MEMS Pressure Sensor [Courtesy of the MTTC, University of New Mexico]

A couple of challenges that have been met in the design of MEMS pressure sensors are signal conversion and the use of MEMS in diverse environments. MEMS can convert physical quantities such as air flow and liquid levels into pressure values that are measured by an electronic system. This design quality has enhanced the versatility of MEMS sensors.

The characteristic of MEMS that incorporates several devices on one chip allows them to be used in a variety of environments. MEMS pressure sensors are used in conjunction with other sensors such as temperature sensors and accelerometers for multisensing applications or other components. For example, a MEMS pressure sensor mounted inside a tire includes a special filter supplies only dry air to the sensor's diaphragm.[3]

Applications of MEMS Pressure Sensors

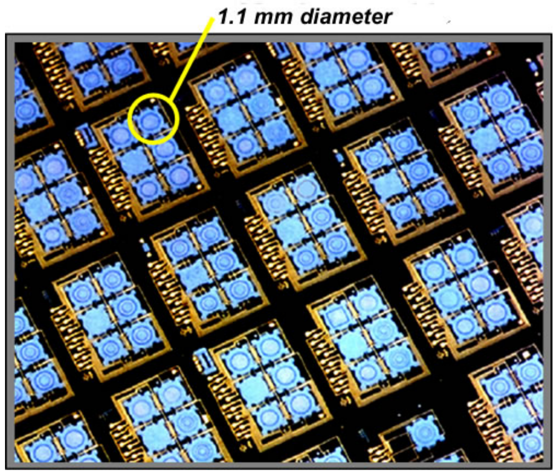
In the automotive industry, MEMS pressure sensors monitor the absolute air pressure within the intake manifold of the engine. MEMS are also being designed to sense tire pressure, fuel pressure, and air flow.

In the biomedical field, current and developing applications for MEMS pressure sensors include blood pressure sensors *(see photo)*, single and multipoint catheters, intracranial pressure sensors, cerebrospinal fluid pressure sensors, intraocular pressure (IOP) monitors, and other implanted coronary pressure measurements. The picture shows three blood pressure sensors on the head of a pin. These sensors were developed by Lucas NovaSensor in 1990's to measure blood pressure and provide an electrical output representative of the pressure. Today's blood pressure sensor can fit through the hole at the head of a needle. RF elements are incorporated into these MEMS devices allowing the sensors to transmit their measurements to an external receiver.

MEMS Blood Pressure Sensors on the head of a pin. [Photo courtesy of Lucas NovaSensor, Fremont, CA]

MEMS pressure sensors are also incorporated into endoscopes for measuring pressure in the stomach and other organs, infusion pumps for monitoring blockage, and noninvasive blood pressure monitors.
Applications of MEMS pressure sensors within the biomedical field are numerous.

More Current and Future Applications



Barometric Pressure Sensors (Photo courtesy of Khalil Najafi, University of Michigan)

Other current and future applications for MEMS pressure sensors:

- Barometric pressure sensors *(see figure above)* - used in wind tunnels and for weather monitoring applications. [3]
- Heating, Ventilating and Air Conditioning (HVAC) industry - MEMS pressure sensors can replace conventional pressure differential switches in home furnaces thus improving efficiency ratings and safety. [4]
- Air flow sensors used to monitor and maintain the air flow for optimum comfort.
- "Smart Roads" - A system where millions of MEMS sensors are incorporated into the roads. These sensors would gather and transmit information about road conditions. This information would be used to identify which roadways are given priority for repair.[5]
- Smart Dust is a network of micro-sized wireless MEMS sensors that communicate with each other through tiny transmitters. Smart dust sensors (such as MEMS pressure sensors) could be scattered around a building, a piece of property, embedded in clothing, or in road beds.[6]

What are some other applications and fields for MEMS pressure sensors?

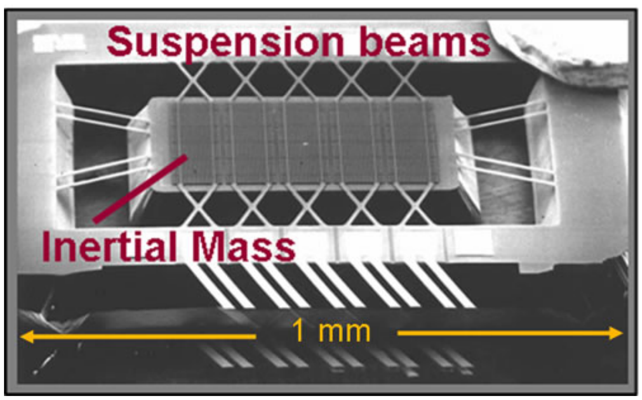
MEMS Inertial Sensors

Newton's First Law of Motion (also referred to as the law of inertia) states, "An object at rest tends to stay at rest and an object in motion tends to stay in motion with the same speed and in the same direction unless acted upon by an unbalanced force." When an external force causes an at rest object to move or a moving object to change speed or direction, then that object's inertia is affected. MEMS inertial sensors are designed to sense a change in an object's inertia, to convert, or transduce inertial force into a measurable signal.[9] They measure changes in acceleration, vibration, orientation and inclination. This is done through the use of micro-sized devices called accelerometers and gyroscopes.

MEMS inertial sensors can be found in navigation devices, anti-shake systems for high-magnification video cameras, airbag deployment systems, the Apple iPhone, pacemakers, and stabilization systems. MEMS inertial sensors are one of the fastest growing segments of the MEMS market. "Driven by accelerometer applications like the Apple iPhone and the Nintendo Wii, and by the coming legislation requiring stability-control systems in all vehicles, these devices have moved out of industrial segments and into consumer ubiquity."[8]

MEMS Accelerometers

Like pressure sensors, MEMS accelerometers are devices that can be used in a variety of sensing applications due to their simplicity and versatility.

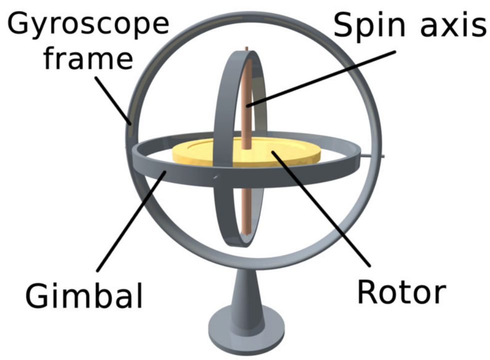


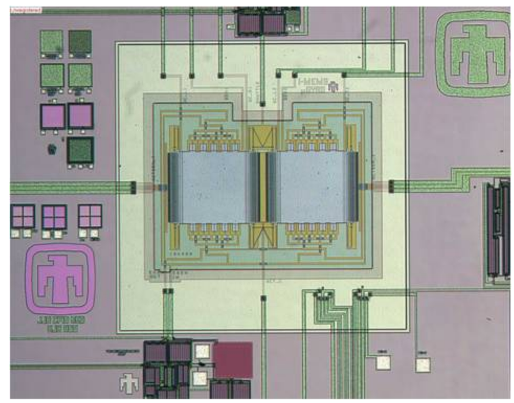
MEMS Out-of-Plane Accelerometer [Photo courtesy of Khalil Najafi, University of Michigan]

The simplest MEMS accelerometer sensor consists of an inertial mass suspended by springs *(see SEM image above)*. Forces affect this mass as a result an acceleration (change in velocity – speed and/or direction). The forces cause the mass to be deflected from its nominal position. As with the movement of the pressure sensor's diaphragm, the deflection of the mass is converted to an electrical signal as the sensor's output. [2]

MEMS Gyroscope

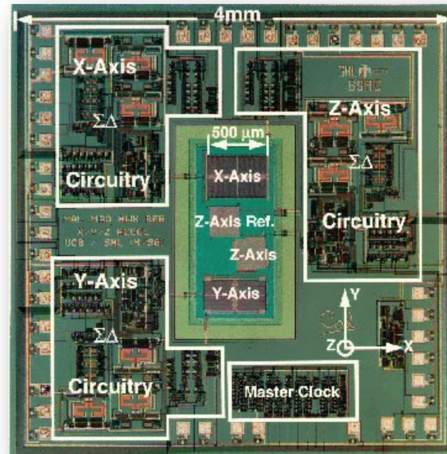
A gyroscope is generally a spinning wheel or disk with a free axis allowing it to take any orientation *(below left)*. Some MEMS gyroscopes use a vibrating structure rather than the traditional rotating disk to determine orientation *(see bottom right)*. This is possible based on the physical principle that a vibrating object (proof mass) tends to keep vibrating in the same plane as its support rotates. As the plane of oscillation rotates, the vibrating gyroscope or transducer is affected due to the Coriolis effect (the tendency for any moving body on or above the earth's surface, (e.g., an ocean current or an artillery round), to drift sideways from its course because of the earth's rotation.[10])





MEMS Vibrating Gyroscope - A type of inertial sensor
[Photo courtesy of Sandia National Laboratories]

MEMS Inertial Sensors in Automobiles



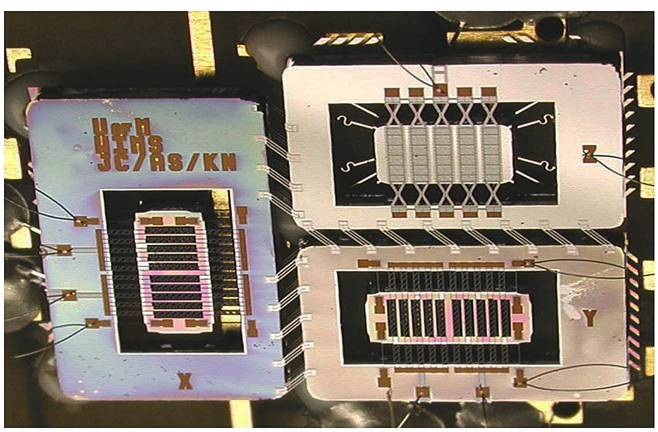
3-axis Accelerometer for airbag deployment [Courtesy of Sandia National Laboratories]

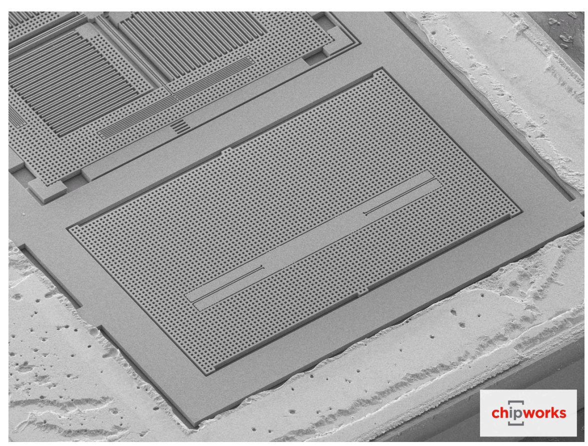
One of the most traditional applications of MEMS devices is the use of inertial sensors in automotive airbag deployment. The type of inertial sensor used in air-bags is an accelerometer or shock sensor. The airbag deployment MEMS developed by Sandia National Laboratories (*see 3-axis accelerometer)* contains three accelerometers – one for each direction (x, y, z) – and the circuitry for each direction.

The accelerometers used in the original airbags were relatively large and bulky with the electronics mounted near the airbag. The cost of these earlier airbag sensors was over $50.[11] As you can see from the picture, today's MEMS integrate the accelerometer and the electronics on a single chip (about the dimensions of a sugar cube), at a cost between $5 to $10.[9] These sensors provide a quicker response to rapid deceleration and more reliable functionality.[2]

Improvements in the area of shock or crash sensors include the ability of the sensor to detect where a person is sitting and to use the physical characteristics of that person to determine how the airbag will be deployed (the amount of force is required based on the size and position of the occupant).

Below shows how the technology of the 3-axis of accelerometer has improved from three discrete sensors (left) to having all three sensors integrated into one chip (right). In both cases, movement in the x and y directions are sensed by two in-plane accelerometers (left – bottom two; right – top two) and movement in the z-direction by an out-of-plane accelerometers (left – top right; right – bottom center). *[Integrated 3-axis accelerometers courtesy of Chipworks]*





Below are several other applications of MEMS inertial sensors in the automotive industry:

- "Smart" sensors for collision avoidance and skid detection[2]
- "Smart" suspension for sport utility vehicles to reduce rollover risk[2]
- Automobile diagnostics
- Automobile navigation
- Antitheft system
- Headlight leveling and positioning
- Rollover detectors
- Active suspension

Applications for MEMS Inertial Sensors

Other applications for MEMS inertial sensors:

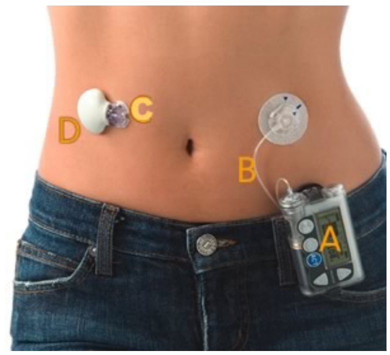
- Motion and shock detection - MEMS "shock sensors" are placed inside packages designated for shipping. They are used to monitor any type of damage that occurs while the package is in transit. When integrated with another MEMS device, they also monitor the time it takes to ship the package to the customer. When an RF MEMS is incorporated into the shock sensor, the collected data can be transmitted to external tracking systems.[5]
- Vibration detection and measurement – Example: Devices that measure frequency and amplitude, and create a vibration signature
- Measurement of tilt and inclination – Example: Compasses that can be read in any position or inclination
- Anti-theft devices mounted in cars, computers, briefcases and other mobile devices
- Home security devices mounted in windows, doors, ceilings and other places as deemed necessary by the homeowner
- Computer screen scrolling and zooming devices (when interfaced with the appropriate software)
- Gaming devices for portables and PC's - Example: The motion of the hand is sensed, eliminating the need for a mouse (e.g. Wii controllers)
- Image stabilizer for video cameras, digital cameras and mobile phones
- Remote monitoring of the physical movements and out-of-building mobility of people in assisted living or living at home.[12]

What are some other applications for MEMS inertial sensors?

Biomedical Applications for MEMS

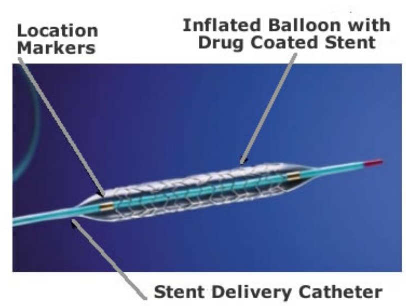
In addition to the medical pressure sensors already discussed, there are several applications for MEMS in the medical field. MEMS devices used in biological applications are called bioMEMS. These systems often require the use of biocompatible materials or biological molecules to avoid rejection by the host organism. Below is a partial listing of bioMEMS for medical applications:

- The precise dispensing of small amounts of liquids (amounts as minute as a picoliter and flow rates of as low as a few microliters per minute) found in needleless injectors, nebulizers, insulin pumps, and drug delivery systems.
- Sub-dermal glucose monitors that not only monitor one's glucose levels, but also deliver the necessary amount of insulin. The picture to the right of the *MiniMed Paradigm 522* shows a diabetic patient wearing a chemical sensor (C) that measures the blood glucose and a transmitter (D) that sends the measurement to the a computer in (A). (A) also contains a micropump that delivers a precise amount of insulin through the cannula (B) to the patient. This is a continuous bioMEMS monitoring and drug delivery system that has eliminated the traditional finger pricks for blood samples that diabetics have to do daily.



MiniMed Paradigm[R] 522 insulin pump, with MiniLinkTM] transmitter and infusion set. (Printed with permission from Medtronic Diabetes)

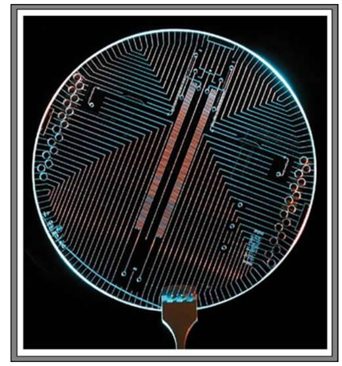
- MEMS tweezers or miniature robot arms that move, rotate, cut and place molecules, sort cells and proteins, and manipulate organelles and DNA inside a living cell.[5]
- Miniature surgical tools that incorporate sensing and measuring devices.
- Medical diagnostics (glucose monitoring, blood analysis, cells counts and numerous others).
- Biosensing devices used to measure biomolecular information (cells, antibodies, DNA, RNA enzymes)
- Medical stents inserted into previously blocked arteries to open and maintain a clear channel for blood flow *(see Stent Delivery Catheter to right)*. There devices are coated with a nanocoating of a drug that is slowly released into the bloodstream over time. This prevents a re-narrowing of the artery and future procedures.



TAXUS Express Drug-Eluding Stent Developed by Boston Scientific Corporation [Image Source: FDA]

- DNA microarrays used to test for genetic diseases, medicine interaction, and other biological markers.
- DNA duplication devices such as the Polymerase Chain Reaction (PCR) system that takes a miniscule bit of DNA, amplifies it and produces an exact duplication.

Clinical Laboratory Testing



The picture to the right shows a lab-on-a-chip (LOC). This device literally takes the laboratory testing of biomolecular samples (e.g. blood, urine, sweat, sputum) out of the typical medical lab and places it in the field and even at home. Using microfluidics and chemical sensors, this MEMS or bioMEMS can simultaneously identify multiples analytes (substances being analyzed). An example of a home LOC is the home pregnancy test. This bioMEMS uses a reactive coating that identifies a specific protein found in the urine of pregnant women.

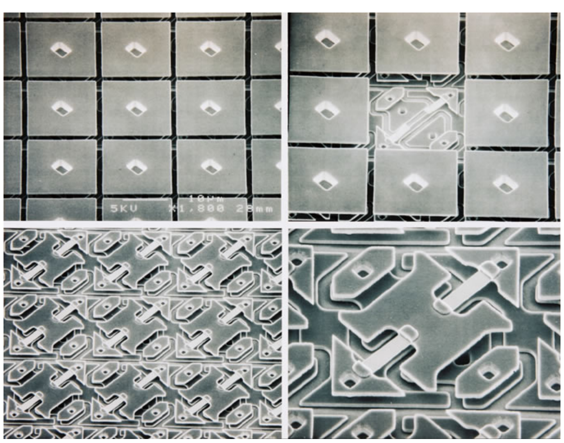
Lab-on-a-chip (LOC)
Printed with permission. From Blazej,R.G.,Kumaresan,P. and Mathies, R.A. PNAS 103,7240-7245 (2006).

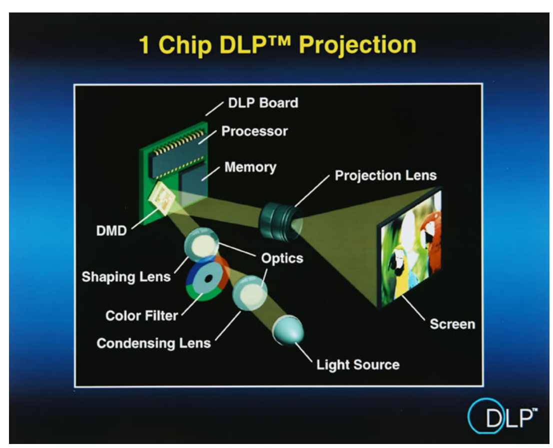
The applications of MEMS in the medical field are unlimited. What are a few more possibilities?

Optical Applications for MEMS

Optical MEMS have already been quite successful in display technologies. This success is rapidly growing with the innovations of high definition (HD) displays.

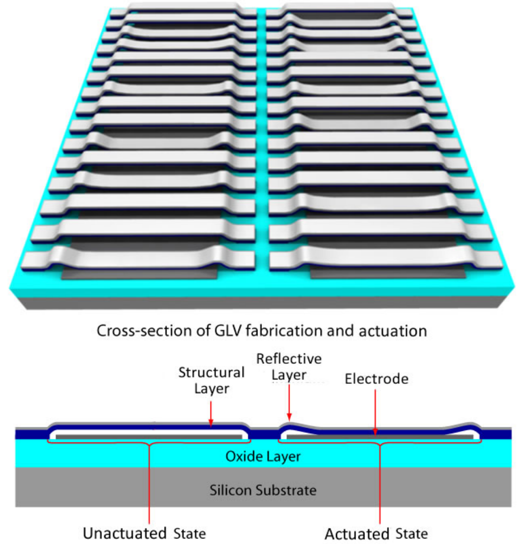
Texas Instrument's Digital Mirror Devices (DMD) have been used for several years in a variety of projection systems including video projection and digital cinema. The technology is called digital light processing or DLP^{TM}, a trademark owned by Texas Instruments, Inc. A DMD is an array of micromirrors *(see figure of DMD array below and left)*. Each micromirror (between 5um and 20um per side) is designed to tilt into (ON) or away from (OFF) a light source. The mirror tilts when a digital signal energizes an electrode beneath the mirror. The applied actuator voltage causes the mirror corner to be attracted to the actuator pad resulting in the tilt of the mirror. When the digital signal is removed, the mirror returns to the "home" position. In the ON position, the mirror reflects light towards the output lens. In the OFF position, the light is reflected away from the output optics to a light absorber within the projection system housing. . One mirror can be turned OFF and ON over 30,000 times per second.





Levels of a DMD Array (left) and How a DLP system works (right).
[Images Courtesy of Texas Instruments]

The GLV (Grating Light Valve) device *(shown above)* developed by Silicon Light Machines, is another micro optical based system. This microdevice consists of an array of silicon nitride ribbons coated with aluminum. A set of four ribbons (two fixed and two moveable) produce a 20 µm square pixel. The ribbons are held "up" by the tensile strength of the material (silicon nitride and aluminum). The moveable ribbons are "moved" up and down electrostatically. Variable voltages applied to the electrodes pull the ribbons down variable distances. For projection devices, red, green, and blue laser light is passed across the array as the ribbons move up and down. The position of each ribbon determines how much light is diffracted or reflected to a lens. When no voltage is applied, the tensile strength of the ribbon will allow it to snap back.[16,17]



Grating Light Valve – Top view and side view showing actuated and unactuated states

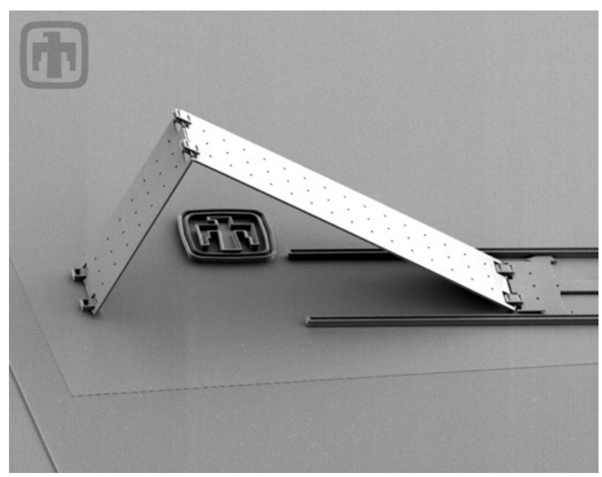
Both of these systems (DLP and GLV) are considered types of spatial light modulators (SLMs) which modulate (redirect) light to create high definition imaging from digital signals.

MEMS micromirror arrays are often the key components used in spatial light modulators or SLM's. These devices are used in high definition display systems as well as optical switching networks. Optical micromirror arrays transmit optical information without going through the timely and costly signal conversion process of optical to electronic and back to optical. The micromirrors can act as switches that direct light from a fiber optic to another fiber optic or to a specific output port by moving up and down, left to right or swiveling to a desired position. This requires the individual mirrors to be actuated, supported on a movable mount or stage, and integrated into a digital network.

The scanning electron microscope image to the right shows a popped-up micromirror. Notice the hinge allowing for the different angles needed to direct light in different directions. Also notice the track that assists in positioning the mirror at the correct angle.

Other optical applications of MEMS:

- Projection displays (GLV's and DLP's)
- Tunable lasers and filters
- Spatial Light Modulators (SLMs)
- Variable optical attenuators
- Optical Spectrometers
- Bar code readers
- Maskless lithography



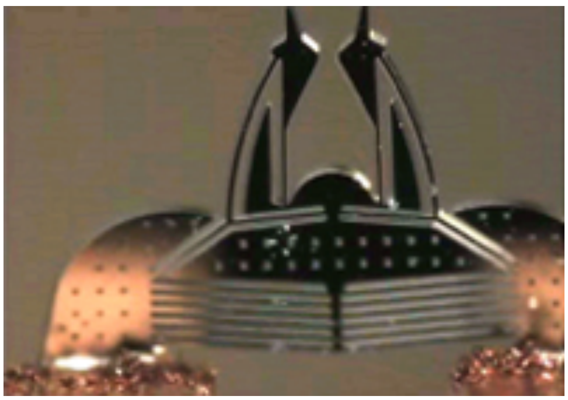
MEMS Pop-up mirror for optical applications [Image Courtesy of Sandia National Laboratories SUMMIT™ Technologies, www.mems.sandia.gov]

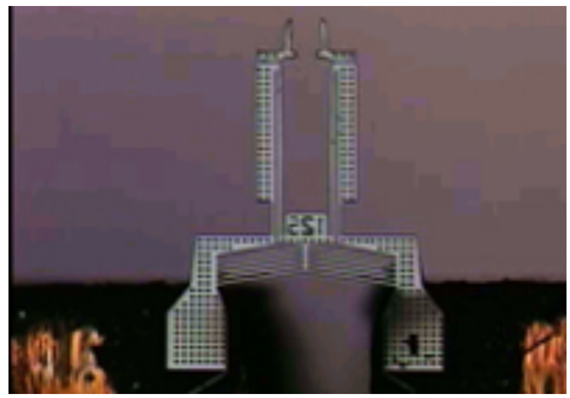
Additional Applications for MEMS

Below are a few more applications for MEMS:

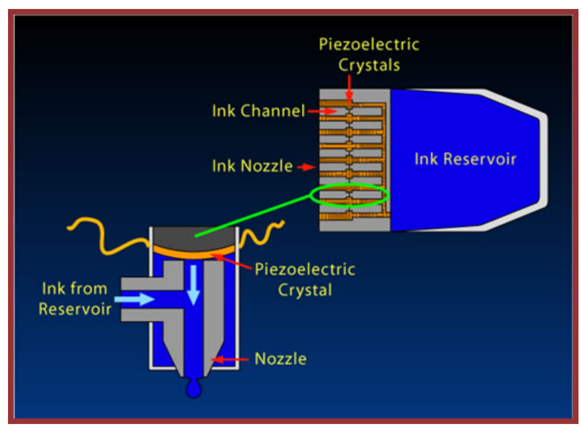
- RF devices – Small variable devices such as switches, tunable capacitors, phase shifters resonators, inductors, filters and variable antennas.
- Fuel delivery systems – Sensors within systems for aircraft and spacecraft that can control propellant motion (or slosh)
- Coating applications – Devices that compensate for coating problems such as adhesion and surface tension.
- Microgrippers – Grippers or tweezers used in a variety of fields to clasp, pick up, and move micron to nanosize components. The microgrippers (50 microns thick), developed by Zyvex Corporation, pick and place other microdevices in an automated microassembly process. The gripper on the left opens to 100 microns. The gripper on the right opens to 125 microns.[18]

[Images printed with permission © 2002 Zyvex]





- MEMS nozzles and pumps for inkjet printers (microfluidics) – Piezoelectrics or bubble jet based injection methods meeting the demand for higher and better resolution printing (smaller droplets). The graphic below illustrates a piezoelectric print head. When a voltage is applied across the piezoelectric crystal, a minute amount of ink is released into the nozzle.



MEMS-based InkJet Print head

Matching Activity (Answers provided)

Match the following MEMS devices with their applications.

		Device		Application
	1	Pressure Sensor	A	Camera stabilizer
	2	Inertial sensor	B	Home pregnancy test
	3	Micropump	C	Road repair projections
	4	Micromirror	D	Inkjet printers
	5	Chemical Sensor	E	Projection Display

Food For Thought

Thinking of your home or workplace – what application could be converted to a MEMS?

What type of MEMS would best suite this application?

Summary

The automotive industry and inkjet printer technology were some of the first widespread applications for MEMS. Since then, MEMS have found applications in wireless communications, biomedical, aerospace, and consumer products (to name a few). The potential uses for MEMS are endless.

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Glossary

Accelerometer - A device that uses a suspended inertial mass to measure acceleration.
Antibody - A specific subset of proteins made in response to an antigen (a foreign substance) as part of the immune response.
BioMEMS - MEMS systems with applications for the biological / analytical chemistry market.
Deoxyribonucleic acid (DNA) - A long linear polymer formed from nucleotides and shaped like a double helix; associated with the transmission of genetic information.
Digital Light Processing (DLP) - A micromirror display technology commercialized by Texas Instruments. Each image pixel in a large array is represented by an electrostatic driven MEMS Mirror. This reflective technology is far brighter than transmission LCD technology.
Digital Mirror Device (DMD) - A microdevice consisting of a number of mirror elements with variable light reflection angles adapted to change reflection angles of illuminated light according to

image signals. The purpose is to reflect only the signal light required for forming an image toward a projection lens system used as image display means (light valve). The DMD is the heart of the DLP (digital light processing) projector.
DNA Microarray - A bioMEMS array that has tens of thousands of single stranded DNA (ssDNA) probes that can detect and identify ssDNA from samples being tested.
Electromechanical - Pertaining to a mechanical device, system, or process which is electrostatically or electromagnetically actuated or controlled.
Grating light valve - The basic technology of a projection system. In MEMS, multiple ribbon-like structures, representing a pixel or image point, reflects incidental light.
Gyroscope - A device used to detect angular momentum, consisting of a spinning mass, typically a disk or wheel, mounted on a base so that its axis can turn freely in one or more directions, maintaining its orientation regardless of any movement of the base. A type of accelerometer.
Integrated circuits - An electronics circuit consisting of a large number semiconductor devices and passive components manufactured on a substrate of semiconductor material such as silicon.
MEMS - Micro-Electro Mechanical Systems – microscopic devices such as sensors and actuators, normally fabricated on silicon wafers.
Organelle - A discrete structure of a cell having specialized functions. An organelle is to the cell as an organ is to the body.
Piezoelectric - A material that generates an electric charge when mechanically deformed. Conversely, when an external electric field is applied to piezoelectric materials they mechanically deform.
Polymerase Chain Reaction (PCR) - A laboratory technique that can amplify the amount of DNA from a tiny sample to a large amount within just a few hours. PCR can take one molecule and produce measurable amounts of identical DNA in a short period of time.
Pressure sensor - A device that measures pressure or a change in pressure.
Resonator - A device or system that exhibits resonance or resonant behavior.
RF (radio frequency) - Refers to alternating voltages and currents having frequencies between 9 kHz and 3 MHz.
Ribonucleic acid (RNA) - A polymer consisting of a long, usually single-stranded chain of alternating phosphate and ribose units with the bases adenine, guanine, cytosine, and uracil bonded to the ribose.
Spatial light modulator (SLM) - An object that imposes some form of spatially-varying modulation on a beam of light. (See grating light valves and maskless photolithography).
Transducer - A substance or device that converts input energy of one form into output energy of another.

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