Making Micro Machines

Activity 3 – MEMS Sensors Design

Participant Guide

Description and Estimated Time to Complete

MEMS: Making Micro Machines Learning Module supports the film of the same name produced and directed by Ruth Carranza of Silicon Run Production. The film introduces MEMS (microelectromechanical systems), applications, fabrication, and design. This learning module provides activities to encourage you to delve deeper into the topics introduced in the film and to demonstrate your understanding of the terminology and general concepts of MEMS.

This is the third of three activities in the learning module. This activity should be completed after viewing the third part of the film: Sensors and MEMS Design.

This activity consists of two parts:

- A **crossword puzzle** that tests your knowledge of the terminology and acronyms associated with MEMS sensors and the MEMS design process.
- **Post-activity questions** that ask you to demonstrate your understanding of MEMS sensors and the MEMS design process.

Estimated Time to Complete

Allow at least 30 minutes to complete this activity.

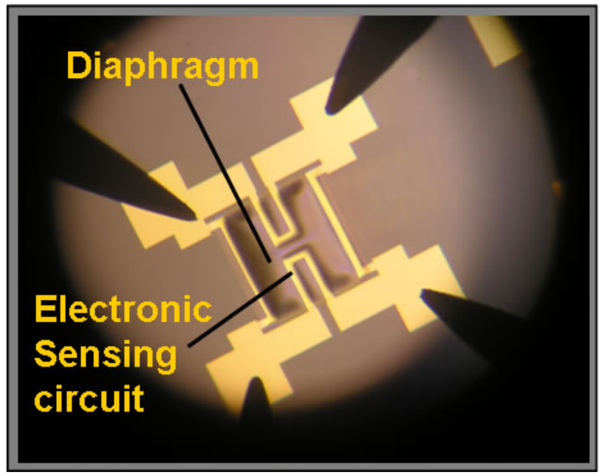
Introduction

Sensor components are critical in microelectromechanical systems (MEMS) and in MEMS applications. A MEMS sensor receives an input from the environment. It converts its input signal into a digital or analog electronic representation. For example, a type of MEMS chemical sensor monitors the change in mechanical stress on a microcantilever as a result of a chemical reaction occurring on a surface coating. The sensor responds to the change by producing an electrical output (change in resistance) that represents the amount of chemical reaction occurring on the microcantilever transducer surface.
Two common types of MEMS sensors are pressure sensors (which sense changes in pressure) and inertial sensors (which sense movement, acceleration and inclination).

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.

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. This movement is measured as a change in resistance due to additional strain on the piezoresistive elements fabricated onto the diaphragm. MEMS pressure sensors are specified to work over a variety of ranges, depending on the design and specific 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]

Applications of MEMS pressure sensors include the following areas:

- Automotive industry (e.g., measure tire pressure, fuel pressure, intake manifold pressure)
- Biomedical (e.g., measure blood pressure, intracranial pressures, pressure due to blockage in catheters and infusion pump systems)
- Environmental (e.g., measure barometric pressure, ocean pressures sensors, and pressures found within roads and bridges)
- Non-destructive testing (e.g., identify defects and cracks in materials)

MEMS Inertial Sensors

MEMS inertial sensors are designed to sense a change in an object's acceleration, vibration, orientation and inclination. MEMS inertial sensors include accelerometers and gyroscopes.

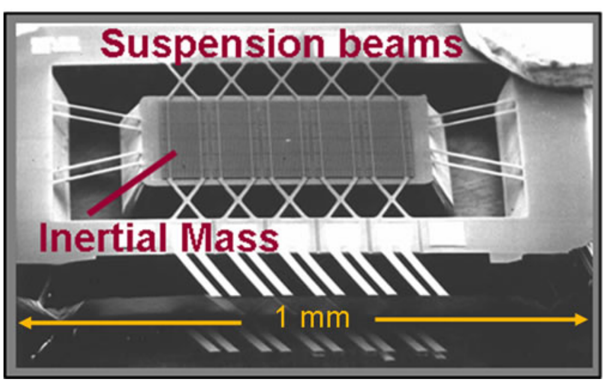
Acceleration is defined as a change in velocity (speed and/or direction). In order to accelerate an object, a force must be applied to that object. If an object changes velocity (accelerates), the object, including any imbedded MEMS inertial sensor, will experience a force acting on it. Hence, inertial sensors are used to measure force related variables such as inclination, orientation, vibration, changes in speed, direction and impact forces.

MEMS inertial sensors can be found in many applications including

- navigation devices,
- image stabilization systems for high-magnification video cameras,
- airbag deployment systems,
- the Apple iPhone,
- pacemakers, and
- stabilization systems found in washing machines.

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." *("MEMS-based inertial sensor is not your grandfather's gyroscope." Randy Torrence, Chipworks. Electronics, Design, Strategy News. December 2008.)*

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



MEMS 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 in 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. *("MEMS Targeting Consumer Electronics". EE Times. Gina Roos. September 2002.)*

MEMS Gyroscopes

Gyroscopes are used to either maintain orientation of a moving object, such as a spacecraft, or to monitor the orientation changes of an object. The classical gyroscope we are used to seeing consists of a spinning wheel or disk. The rotating object tends to maintain its axis in a fixed orientation. Think of a fast spinning top, the top axis tends to point in the same direction. Another example is that of a bicycle wheel – if you spin a bicycle wheel very quickly, the axis tends to point in the same direction. Vibrating systems can also act as a gyroscope. An example is a tuning fork device set into motion. The tines of the fork will vibrate within a plane of motion. This is based on the physical principal that a vibrating object (proof mass) tends to keep vibrating or oscillating in the same plane. MEMS gyroscopic based sensors have been made using both methods, spinning and vibrating structures. With these types of structures, changes in yaw, pitch and roll can be measured.

The third part of the film, MEMS: Making Micro Machines, shows you the process of designing MEMS sensors. There are many team members who work together and with the customer to achieve success of the project. Each team member contributes within the area of expertise but must also be multidisciplined enough to understand and communicate effectively with others in the team. The design process shown is typical of what is used in most MEMS design and fabrication organizations. As is obvious in this part of the film, having excellent communication skills is critical, this includes all aspects, listening, writing, reading and speaking.

Activity Objectives and Outcomes

Activity Objectives

- Identify the terms or acronyms associated with definitions related to MEMS, MEMS sensors, and MEMS design.
- Demonstrate your understanding of MEMS, MEMS sensors, and MEMS design by correctly answering the Post-Activity questions.

Resources

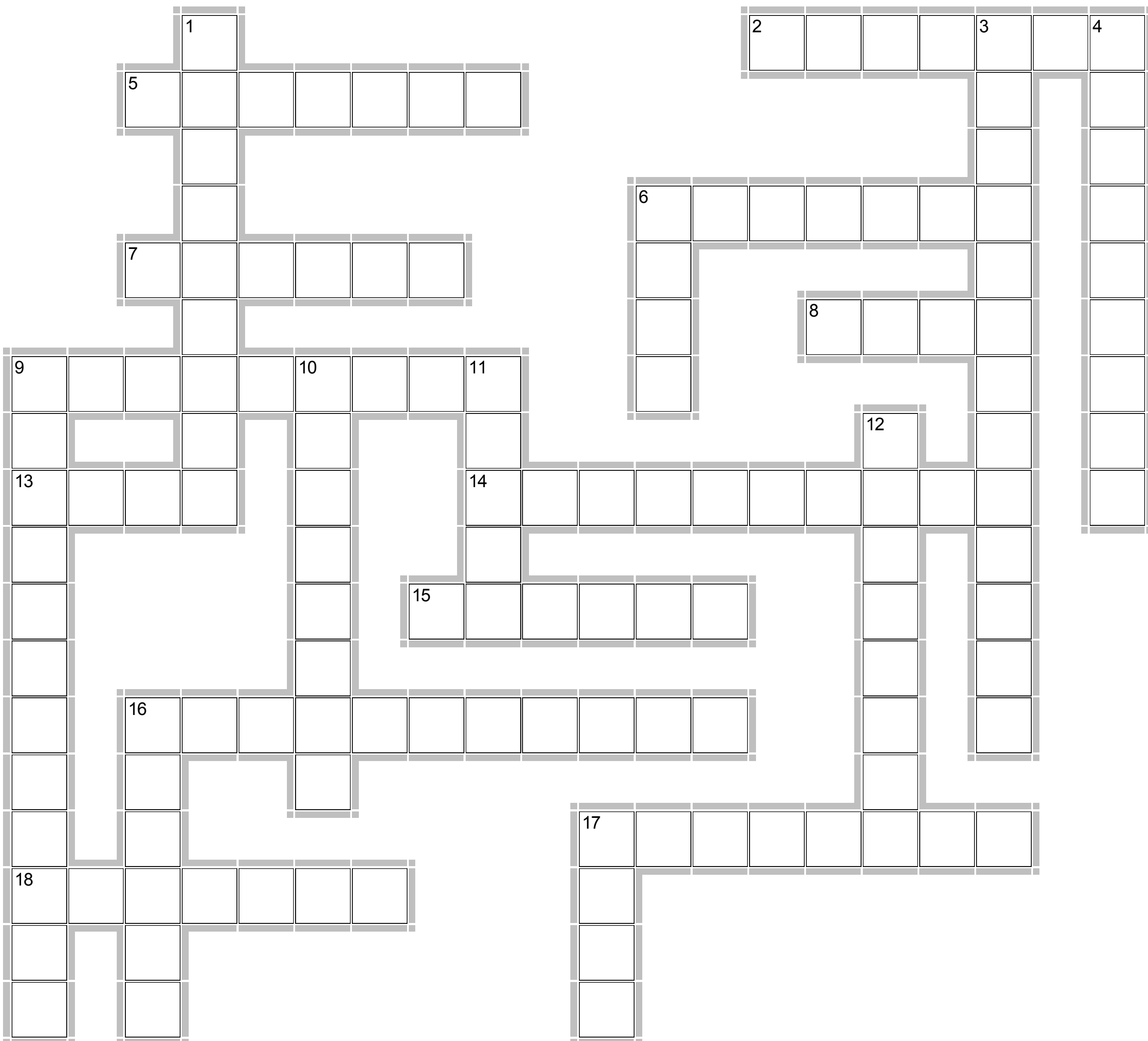
- MEMS: Making Micro Machines, an overview of microelectromechanical systems, produced and directed by Ruth Carranza of Silicon Run Production. 2009.
- "MEMS Applications". Southwest Center for Microsystems Education (SCME). 2009.
- "Sensors, Transducers, and Actuators." Southwest Center for Microsystems Education (SCME). 2009.

Documentation

1. Completed Crossword Puzzle
2. Questions and Answers to the Post-Activity Questions

Activity: MEMS Sensors Design Crossword Puzzle

Complete the crossword puzzles using the clues on the following page.



EclipseCrossword.com

Across

2. A change on the input of a sensor can create a change in capacitance which gets converted to _______________.
5. The ________ designer creates an architectural design and writes the specifications for the MEMS.
6. The design phase brings together the MEMS and the ASIC blocks to ____________ their performance and ensure results meet product specifications.
7. The ______ratio is the ratio of etch depth (or height) to its width.
8. The etch process that creates etch profiles with high aspect ratios.
9. A logical sequence of steps for solving a problem is called an ______________.
13. Each block of a MEMS design has a mathematical representation that consists of lines of equations, or ______.
14. A MEMS ______ ______ consists of various engineers, marketing and sales personnel.
15. It is the responsibility of the Microsystems Group to divide or to partition the components of the system into specific ________.
16. In an inertial sensor, the space between the mass and electrode is measured as an electrical _____________.
17. It is the responsibility of the mechanical design engineer to determine transducer _____________ limitations.
18. Deep Reactive _____ ______ or DRIE uses a process known as the Bosch Process to create deep, straight, etched walls.

Down

1. The MEMS inertial sensor that measures rotational movement is called a _________________.
3. A(n) _________ measures linear movement along the x, y, and z axes.
4. MEMS accelerometers use an __________ to sense mass movement and produce an electrical output representative of the movement.
6. The Application Specific Integrated Circuit designer is also called the _______ designer.
9. ___________ is defined as a change in velocity (speed and/or direction).
10. MEMS ________ sensors are designed to sense a change in an object's acceleration, vibration, orientation and inclination.
11. A virtual and sometimes physical _______ is constructed to test predictions and different situations.
12. A _______ or diaphragm is the moveable component in a MEMS pressure sensor.
16. Sensors are designed to monitor and detect _______ at the input.
17. In a MEMS accelerometer, a proof _____ moves when affected by an external force.

Post-Activity Questions

Based on what is in the film and the Introduction of this activity, answer the following questions:

1. What do MEMS inertial sensors sense?
2. What are two types of MEMS inertial sensors?
3. Name at least three applications of MEMS inertial sensors.
4. Name at least three applications of MEMS pressure sensors.
5. When designing a new MEMS, who determines the requirements (e.g., operating parameters, specifications)?
6. Why does it take a team of engineers (mechanical, electrical, systems, process and sometimes chemical, biochemical, etc.), marketing and sales experts to develop MEMS?
7. Virtual models and sometimes, macro-sized models, are constructed before a MEMS device is fabricated. What is the purpose of these models?
8. If you had to choose one of the roles highlighted in the film, which one would you choose? Which one is of most interest to you? Why? What sort of education do you think you would need to fill this role? What subjects should you focus on in school to acquire the necessary knowledge and skills?

Summary

One of the most common applications of MEMS is as sensors. MEMS pressure sensors and accelerometers were some of the first MEMS devices to make it to the market. These sensors are found in cars, planes, medical equipment, and gaming devices.

No matter what the device, all MEMS must go through a rigid design process before being sent to manufacturing. The design process involves engineers from several areas, all of which play an important role in the final design. By the time a MEMS device is sent to manufacturing, it has been tested, tweaked and retested many, many times to ensure that it meets the customer's requirements and specifications.

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