# AN INTRODUCTION TO MEMS

Engineering PRODUCT design

# Contents

## What is MEMS?

MEMS stands for microelectromechanical system. It is also known by other affiliated names such as microsystems technology (MST) or micromachines. MEMS is an umbrella term for a wide range of microfabrication designs, methods and mechanisms that involves realising moving mechanical parts at microscopic scale. (Figure 1)

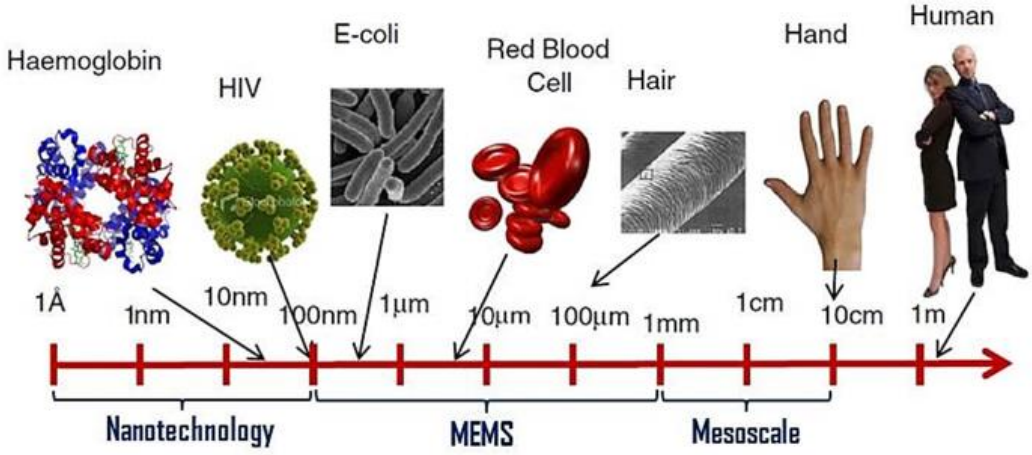


*Figure 1 MEMS microscopic scale*

In a nutshell, MEMS is concerned with transforming the traditional bulky mechanical systems into miniature, better performing and highly mass producible alternatives, analogous to what the integrated circuit and semiconductor technologies have done to the electrical and electronics systems. (Figure 2)



## What are the uses of MEMS?

MEMS are used in a wide range of sensors, actuators, generators, energy sources, biochemical and biomedical systems and oscillators.

Some examples of MEMS applications include:

- sensors such as MEMS accelerometers, MEMS gyroscopes, MEMS pressure sensors, MEMS tilt sensors and other types of MEMS resonant sensors
- actuators such as MEMS switches, micro-pumps, micro-levers and micro-grippers
- generators and energy sources such as MEMS vibration energy harvesters, MEMS fuel cells and MEMS radioisotope power generators

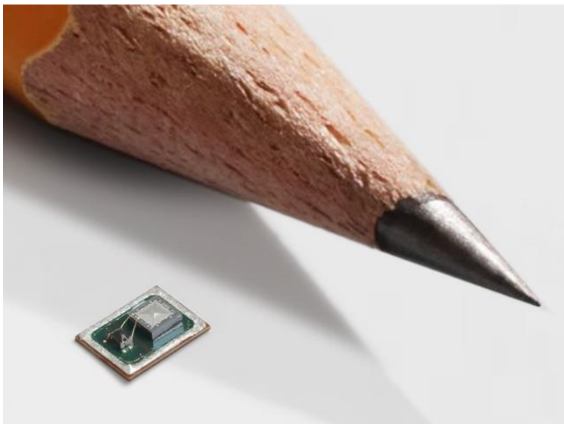

*Figure 2 MEMS microphones (credit:vespermems.com)*

- biochemical and biomedical systems such as MEMS biosensors, lab-on-chips, and MEMS air microfluidic and particulate sensors
- MEMS oscillators for accurate time keeping and frequency control applications

*Figure 3 MEMS optical switch (credit:ethw.org)*

At an even smaller nanometre scale, the fabrication technology morphs into nanoelectromechanical system (NEMS). Furthermore, where MEMS is integrated with other technologies, various combinatory embodiments can take form, such as, bioMEMS where biochemical and biomedical systems are realised on microfabricated devices, micro-opto-electro-mechanical system (MOEMS) or OptoMEMS where optical systems such as micro-mirrors are integrated to manipulate or sense light at the microscopic scale, radio frequency microelectromechanical system (RFMEMS) typically involves close integration with semiconductor microelectronics to provide RF transduction and switching capabilities.

## Technological advancement of MEMS

The first laboratory demonstration of MEMS devices came about in the 1960's in the form of a MEMS pressure sensor. Academic research gained momentum in the 1980's, while the commercial development and manufacturing took off in the 1990's. Today, everyone carries MEMS devices on themselves in the form of smartphones, smart watches and fitness trackers. In the past, an aeronautic gyroscopic system used to determine roll, pitch and yaw in the cockpit of aircrafts weighed several kilograms and measured several inches in length, whereas nowadays, MEMS gyroscopes in our smartphones weigh less than a milligram and is equivalent in size to a grain of sand. With miniaturisation in size, also comes significant reduction in manufacturing cost and improved scales of economy. This is like the continued miniaturisation and reduction in cost seen in the semiconductor industry.

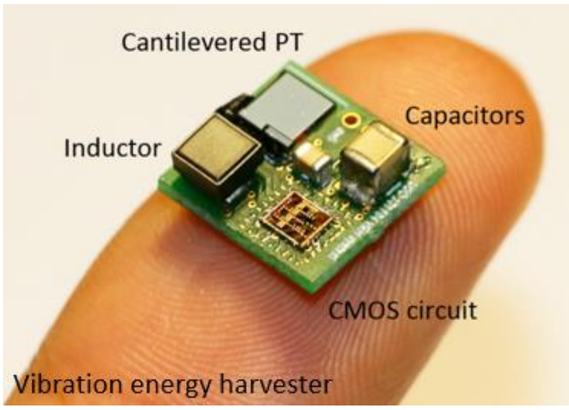


*Figure 4 MEMS Vibration energy harvester*

Furthermore, MEMS devices also offer lower power consumption and higher sensitivity that traditional mechanical counterparts simply cannot physically achieve. For instance, a MEMS resonating strain gauge consumes micro-watts of power while offering sensitivity in the nano-strain range. This compares with the hundreds of milli-watts of power consumption for conventional foil strain gauges that can only measure down to a few microstrains at the best. Another example is that conventional microbalances are limited to a precision of a few tens to a few hundreds of micrograms whereas MEMS microbalances can get down to picograms or even femtograms of resolution.

## Advantages and disadvantages of MEMS

### Advantages of MEMS

- Extremely scalable in manufacturing, resulting in very low unit costs when mass produced
- MEMS sensors possess extremely high sensitivity
- MEMS switches and actuators can attain very high frequencies
- MEMS devices require very low power consumption
- MEMS can be readily integrated with microelectronics to achieve embedded mechatronic systems
- Scaling effects at microscopic levels can be leveraged to achieve designs and dynamic mechanisms otherwise not possible at macro-scales

### Disadvantages of MEMS

- Very expensive during the research and development stage for any new MEMS design or devices
- Very expensive upfront setup cost for fabrication cleanrooms and foundry facilities
- Fabrication and assembly unit costs can be very high for low quantities. Therefore, MEMS are not suitable for niche applications, unless cost is not an issue
- Testing equipment to characterise the quality and performance can also be expensive

## How are MEMS made?

MEMS are classically micromachined from silicon. Various types of silicon wafers exist, and silicon can be doped to varying levels of conductivity. Additional functional materials can be added to provide various capabilities, such as electrode layers or piezoelectric layers. MEMS design and fabrication involves a series of steps and cycles, which can be summarised into:

- Design, modelling and simulation (using analytical, numerical, CAD and FEA methods)
- Layout and wafer tape-out (using Layout Editor)
- Starting wafer substrate (such as silicon, glass, quartz, stainless steel, plastics)
- Microfabrication process (cycling through the following steps until desired design is achieved)
    - Additive (material deposition: chemical vapour, sputtering, evaporation, oxidisation)
    - Pattern (masks, photolithography, contact lithography, projection lithography)
    - Subtractive (material etching: wet chemical, dry ion or plasma, DRIE)

- Die dicing (laser, diamond saw, plasma etch)
- Wire bonding (to connect to interface circuitry)
- Packaging and encapsulation (hermetic seal, plastic/ceramic/metal seal, wafer-level packaging)

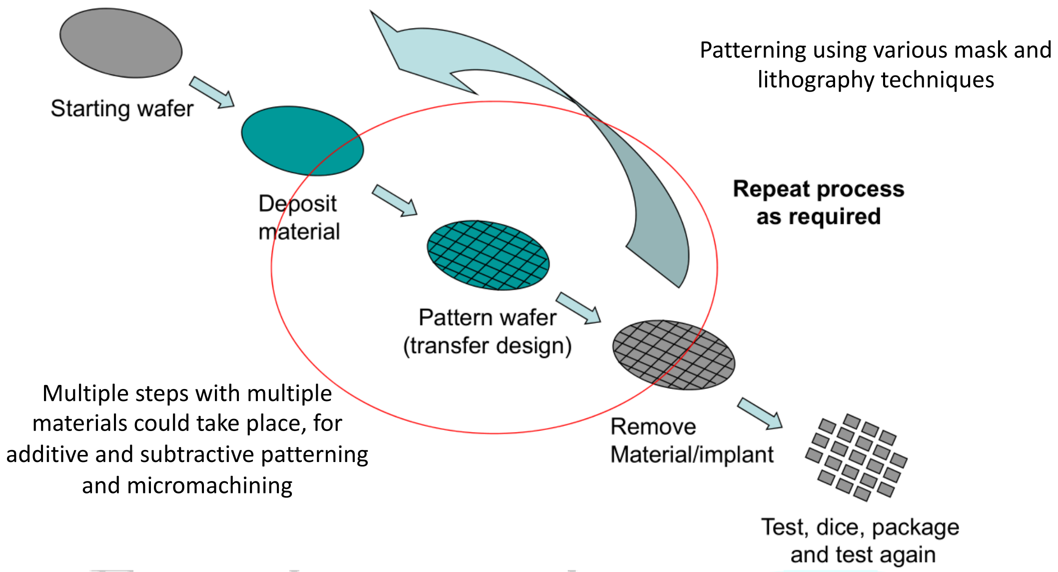


*Figure 5 MEMS manufacturing steps*

## Types of MEMS transducers

In order to interact with the world, MEMS devices can employ various types of transduction mechanisms. Usually, these are mechanical-to-electrical transducers and vice versa, so that we can control the MEMS devices and their interactions with the mechanical world through interface circuits. Additionally, a number of other types of transducers can also be used to interact with chemical, light, magnetic, RF (Radio Frequency) and other domains.

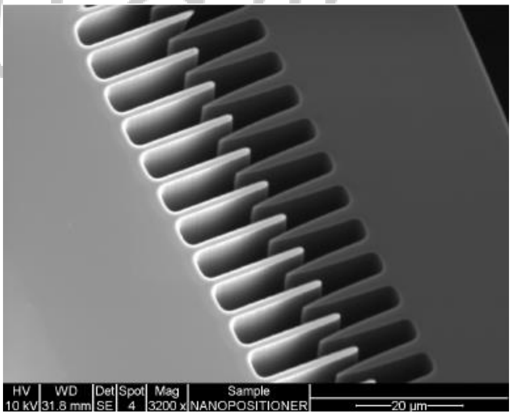


*Figure 6 electrostatic comb drive in a MEMS device*

Conventionally, electrostatic is the most popular transducer in silicon MEMS. This is because no additional specialist material is required and micromachined silicon can be doped to provide conductivity. By establishing an electric field across a pair of capacitive parallel plates, an electrostatic force can be sustained. When mechanical motion changes the distance between the parallel plates, an electrical signal can be measured across the parallel plates. Alternatively, by applying a dynamic electrical signal, the parallel plate can be actuated. Comb finger designs are very popular amongst MEMS electrostatic transducers in order to maximise the capacitive surface area of the transducer.

In the past decade, piezoelectric transducers are also becoming more popular in MEMS design as fabrication technology for micromachining piezoelectric materials have improved. Typically, MEMS-compatible piezoelectric materials include alunimum nitride (AlN), zinc oxide (ZnO), sol-gel lead zirconate titanate (PZT), thinned bulk PZT, and various combinations of niobates. As the fabrication technology further matures, more functional materials can potentially be integrated with silicon micromachining processes.

Some of the main transducers used in MEMS include:

- Electrostatic
- Piezoelectric
- Ferroelectric
- Electromagnetic
- Triboelectric
- Magnetostriction
- Magnetic
- Radio-frequency (RF)
- Thermal (temperature gradient or temperature fluctuation)
- Optic (light energy or light signals)
- Chemical (micro-fluidics)
- Biological and biomedical

## References and recommended reading


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