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Review on Micro Electro Mechanical Systems

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ABSTRACT

MEMS acronym for Micro Electro Mechanical System is one of the booming technology that has paved its way in current engineering & technology. This paper includes the explanation of simple MEMS system and its applications.

KEYWORD: *Mems, miniaturized systems, micro systems, micro fabrications, mems functionality*

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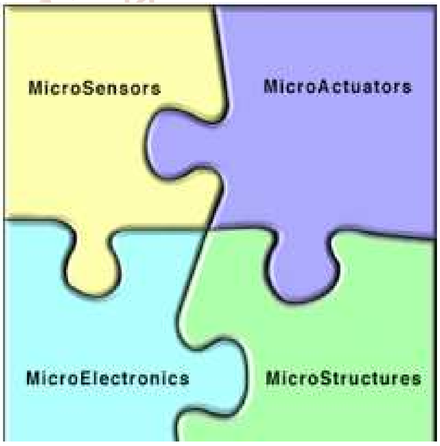
I. INTRODUCTION

Micro-Electro-Mechanical Systems, or MEMS, is a technology that in its most general form can be defined as miniaturized mechanical and electro-mechanical elements (i.e., devices and structures) that are made using the techniques of micro fabrication. The critical physical dimensions of MEMS devices can vary from well below one micron on the lower end of the dimensional spectrum, all the way to several millimetres [1]. Likewise, the types of MEMS devices can vary from relatively simple structures having no moving elements, to extremely complex electromechanical systems with multiple moving elements under the control of integrated microelectronics. The one main criterion of MEMS is that there are at least some elements having some sort of mechanical functionality whether or not these elements can move.

While the functional elements of MEMS are miniaturized structures, sensors, actuators, and microelectronics, the most notable elements are the micro sensors and micro actuators. Micro sensors and micro actuators are appropriately categorized as “transducers”, which are defined as devices that convert energy from one form to another. In the case of micro sensors, the device typically converts a measured mechanical signal into an electrical signal.



II. Developments

More recently, the MEMS research and development community has demonstrated a number of micro actuators including: microvalves for control of gas and liquid flows; optical switches and mirrors to redirect or modulate light beams; independently controlled micromirror arrays for displays, microresonators for a number of different applications, micropumps to develop positive fluid pressures, microflaps to modulate airstreams on aerofoils, as well as many others. Surprisingly, even though these micro actuators are extremely small, they frequently can cause effects at the macroscale level; that is, these tiny actuators can perform mechanical feats far larger than their size would imply [2]. For example, researchers have placed small micro actuators on the leading edge of aerofoils of an aircraft and have been able to steer the aircraft using only these microminiaturized devices.

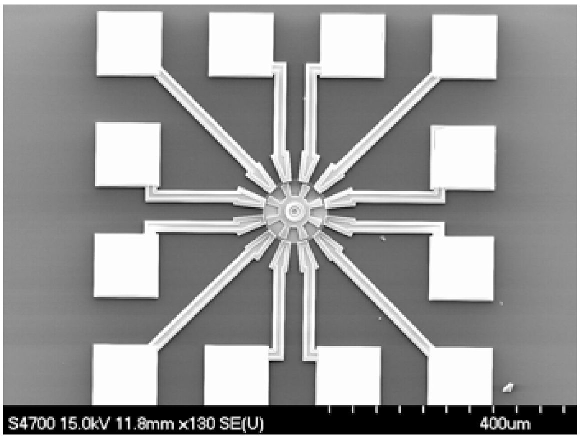


Fig: Asurface micromachined electro-statically-actuated micromotor fabricated. This device is an example of a MEMS-based micro actuator.

III. Purpose

The real potential of MEMS starts to become fulfilled when these miniaturized sensors, actuators, and structures can all be merged onto a common silicon substrate along with integrated circuits (i.e., microelectronics). While the electronics are fabricated using integrated circuit (IC) process sequences (e.g., CMOS, Bipolar, or BICMOS processes), the micromechanical components are fabricated using compatible "micromachining" processes that selectively etch away parts of the silicon wafer or add new structural layers to form the mechanical and electromechanical devices. It is even more interesting if MEMS can be merged not only with microelectronics, but with other technologies such as photonics, nanotechnology, etc. This is sometimes called “heterogeneous integration.” [3]

While more complex levels of integration are the future trend of MEMS technology, the present state-of-the-art is more modest and usually involves a single discrete micro sensor, a single discrete micro actuator, a single micro sensor integrated with electronics, a multiplicity of essentially identical micro sensors integrated with electronics, a single micro actuator integrated with electronics, or a multiplicity of essentially identical micro actuators integrated with electronics. Nevertheless, as MEMS fabrication methods advance, the promise is an enormous design freedom wherein any type of micro sensor and any type of micro actuator can be merged with microelectronics as well as photonics, nanotechnology, etc., onto a single substrate [4].

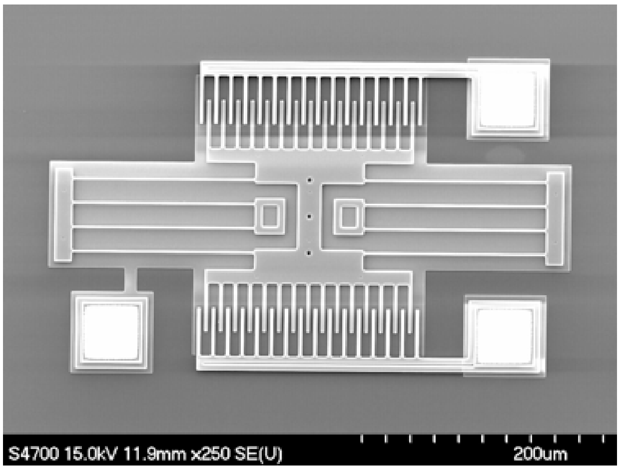


Fig: A surface micromachined resonator fabricated. This device can be used as both a micro sensor as well as a micro actuator.

This vision of MEMS whereby micro sensors, micro actuators and microelectronics and other technologies, can be integrated onto a single microchip is expected to be one of the most important technological breakthroughs of the future. This will enable the development of smart products by augmenting the computational ability of microelectronics with the perception and control capabilities of micro sensors and micro actuators. Microelectronic integrated circuits can be thought of as the "brains" of a system and MEMS augments this decision-making capability with "eyes" and "arms", to allow microsystems to sense and control the environment. Sensors gather information from the environment through measuring mechanical, thermal, biological, chemical, optical, and magnetic phenomena. The electronics then process the information derived from the sensors and through some decision making capability direct the actuators to respond by moving, positioning, regulating, pumping, and filtering, thereby controlling the environment for some desired outcome or purpose. Furthermore, because MEMS devices are manufactured using batch fabrication techniques, similar to ICs, unprecedented levels of functionality, reliability, and sophistication can be placed on a small silicon chip at a relatively low cost. MEMS technology is extremely diverse and fertile, both in its expected application areas, as well as in how the devices are designed and manufactured. Already, MEMS is revolutionizing many product categories by enabling complete systems-on-a-chip to be realized.

Nanotechnology is the ability to manipulate matter at the atomic or molecular level to make something useful at the Nano-dimensional scale. Basically, there are two approaches in implementation: the top-down and the bottom-up. In the top-down approach, devices and structures are made using many of the same techniques as used in MEMS except they are made smaller in size, usually by employing more advanced photolithography and etching methods. The bottom-up approach typically involves deposition, growing, or self-assembly technologies. The advantages of Nano-dimensional devices over MEMS involve benefits mostly derived from the scaling laws, which can also present some challenges as well.

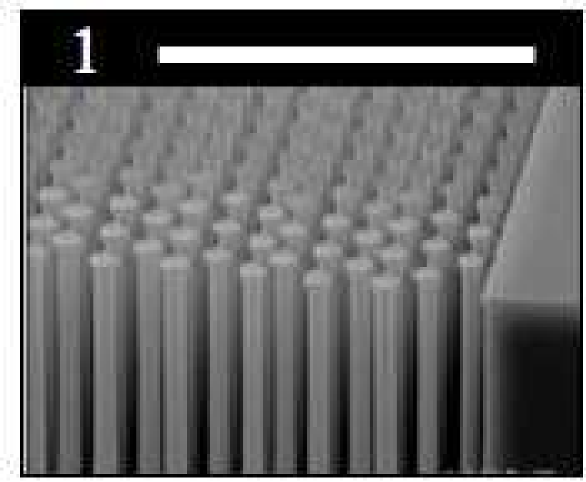


Fig: An array of sub-micron posts made using top-down nanotechnology fabrication methods

IV. Applications:

There are numerous possible applications for MEMS and Nanotechnology. As a breakthrough technology, allowing unparalleled synergy between previously unrelated fields such as biology and microelectronics, many new MEMS and Nanotechnology applications will emerge, expanding beyond that which is currently identified or known. Here are a few applications of current interest:

Biotechnology

MEMS and Nanotechnology is enabling new discoveries in science and engineering such as the Polymerase Chain Reaction (PCR) microsystems for DNA amplification and identification, enzyme linked immunosorbent assay (ELISA), capillary electrophoresis, electroporation, micromachined Scanning Tunnelling Microscopes (STMs), biochips for detection of hazardous chemical and biological agents, and microsystems for high-throughput drug screening and selection.

Medicine

There are a wide variety of applications for MEMS in medicine. The first and by far the most successful application of MEMS in medicine (at least in terms of number of devices and market size) are MEMS pressure sensors, which have been in use for several decades. The market for these pressure sensors is extremely diverse and highly fragmented, with a few high-volume markets and many lower volume ones. Some of the applications of MEMS pressure sensors in medicine include [5]:

The largest market for MEMS pressure sensors in the medical sector is the disposable sensor used to monitor blood pressure in IV lines of patients in intensive care. These devices were first introduced in the early 1980's. They replaced other technologies that cost over $500 and which had a substantial recurring cost since they had to be sterilized and recalibrated after each use. MEMS disposable pressure sensors are delivered pre-calibrated in a sterilized package from the factory at a cost of around $10.

MEMS pressure sensors are used to measure intrauterine pressure during birth. The device is housed in a catheter that is placed between the baby's head and the uterine wall. During delivery, the baby's blood pressure is monitored for problems during the mother's contractions.

MEMS pressure sensors are used in hospitals and ambulances as monitors of a patient's vital signs, specifically the patient's blood pressure and respiration.

The MEMS pressure sensors in respiratory monitoring are used in ventilators to monitor the patient's breathing.

MEMS pressure sensors are used for eye surgery to measure and control the vacuum level used to remove fluid from the eye, which is cleaned of debris and replaced back into the eye during surgery

Special hospital beds for burn victims that employ inflatable mattresses use MEMS pressure sensors to regulate the pressure inside a series of individual inflatable chambers in the mattress. Sections of the mattress can be inflated as needed to reduce pain as well as improve patient healing.

Physician's office and hospital blood analysers employ MEMS pressure sensors as barometric pressure correction for the analysis of concentrations of O_2, CO_2, calcium, potassium, and glucose in a patient's blood.

MEMS pressure sensors are used in inhalers to monitor the patient's breathing cycle and release the medication at the proper time in the breathing cycle for optimal effect.

MEMS pressure sensors are used in kidney dialysis to monitor the inlet and outlet pressures of blood and the dialysis solution and to regulate the flow rates during the procedure.

MEMS pressure sensors are used in drug infusion pumps of many types to monitor the flow rate and detect for obstructions and blockages that indicate that the drug is not being properly delivered to the patient.

The contribution to patient care for all of these applications has been enormous. More recently, MEMS pressure sensors have been developed and are being marketed that have wireless interrogation capability. These sensors can be implanted into a human body and the pressure can be measured using a remotely scanned wand. Another application are MEMS inertial sensors, specifically accelerometers and rate sensors which are being used as activity sensors. Perhaps the foremost application of inertial sensors in medicine is in cardiac pacemakers wherein they are used to help determine the optimum pacing rate for the patient based on their activity level. MEMS devices are also starting to be employed in drug delivery devices, for both ambulatory and implantable applications. MEMS electrodes are also being used in neuro-signal detection and neuro-stimulation applications. A variety of biological and chemical MEMS sensors for invasive and non-invasive uses are beginning to be marketed. Lab-on-a-chip and miniaturized biochemical analytical instruments are being marketed as well.

Communications

High frequency circuits are benefiting considerably from the advent of RF-MEMS technology. Electrical components such as inductors and tenable capacitors can be improved significantly compared to their integrated counterparts if they are made using MEMS and Nanotechnology. With the integration of such components, the performance of communication circuits will improve, while the total circuit area, power consumption and cost will be reduced. In addition, the mechanical switch, as developed by several research groups, is a key component with huge potential in various RF and microwave circuits. The demonstrated samples of mechanical switches have quality factors much higher than anything previously available. Another successful application of RF-MEMS is in resonators as mechanical filters for communication circuits.

Inertial Sensing

MEMS inertial sensors, specifically accelerometers and gyroscopes, are quickly gaining market acceptance. For example, MEMS accelerometers have displaced conventional accelerometers for crash air-bag deployment systems in automobiles. The previous technology approach used several bulky accelerometers made of discrete components mounted in the front of the car with separate electronics near the air-bag and cost more than $50 per device. MEMS technology has made it possible to integrate the accelerometer and electronics onto a single silicon chip at a cost of only a few dollars. These MEMS accelerometers are much smaller, more functional, lighter, more reliable, and are produced for a fraction of the cost of the conventional macroscale accelerometer elements. More recently, MEMS gyroscopes (i.e., rate sensors) have been developed for both automobile and consumer electronics applications. MEMS inertial sensors are now being used in every car sold as well as notable customer electronic handhelds such as Apple iPhones and the Nintendo Wii.

MEMS fabrication is an extremely exciting endeavour due to the customized nature of process technologies and the diversity of processing capabilities. MEMS fabrication uses many of the same techniques that are used in the integrated circuit domain such as oxidation, diffusion, ion implantation, LPCVD, sputtering, etc., and combines these capabilities with highly specialized micromachining processes.

Bulk Micromachining

The oldest micromachining technology is bulk micromachining. This technique involves the selective removal of the substrate material in order to realize miniaturized mechanical components. Bulk micromachining can be accomplished using chemical or physical means, with chemical means being far more widely used in the MEMS industry.

A widely used bulk micromachining technique is chemical wet etching, which involves the immersion of a substrate into a solution of reactive chemical that will etch exposed regions of the substrate at measurable rates. Chemical wet etching is popular in MEMS because it can provide a very high etch rate and selectivity [6]. Furthermore, the etch rates and selectivity can be modified by: altering the chemical composition of the etch solution; adjusting the etch solution temperature; modifying the dopant concentration of the substrate; and modifying which crystallographic planes of the substrate are exposed to the etchant solution.

There are two general types of chemical wet etching in bulk micromachining: isotropic wet etching and anisotropic wet etching. In isotropic wet etching, the etch rate is not dependent on the crystallographic orientation of the substrate and the etching proceeds in all directions at equal rates. In theory, lateral etching under the masking layer etches at the same rate as the etch rate in normal direction. However, in practice lateral etching is usually much slower without stirring, and consequently isotropic wet etching is almost always performed with vigorous stirring of the etchant solution. Figure 1 illustrates the profile of the etch using an isotopic wet etchant with and without stirring of the etchant solution.

Any etching process requires a masking material to be used, with preferably a high selectivity relative to the substrate material. Common masking materials for isotropic wet silicon etching include silicon dioxide and silicon nitride. Silicon nitride has a much lower etch rate compared to silicon dioxide and therefore is more frequently used.

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