Abstract: This paper describe about the Mems (micro electro mechanical system) and the emerging Nano technology. The procedure of manufacturing, fabrications of Mems is described with its application. Nanorobots in specific for design and research in present and future is discussed.

1 Introduction:

Micro-Electro-Mechanical Systems, or MEMS, is a technology with most general form can be defined as miniaturized mechanical and electromechanical 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 millimeters. 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 term used to define MEMS varies in different parts of the world. In the United States they are predominantly called MEMS; while in some other parts of the world they are called “Microsystems Technology” or “micro machined devices”.

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

Nano electro mechanical systems, or NEMS, are characterized by small dimensions, where the dimensions are relevant for the function of the devices. Critical feature sizes may be from hundreds to a few nanometers. New physical properties, resulting from the small dimensions, may dominate the operation of the devices, and new fabrication approaches may be required to make them. Microelectronics fabrication technologies are driving relentlessly to manufacture smaller transistors packed with increasing density on integrated circuit chips. The economic driving forces for this miniaturization are strong and have driven transistor minimum feature sizes down to the 100-nm regime.

The fabrication and manufacturing of the Mems and Nems as explained in detailed in upcoming sections.

2 Mems Fabrication:

One of the basic building blocks in MEMS processing is the ability to deposit thin films of material. In this text we assume a thin film to have a thickness anywhere between a few nanometers to about 100 micrometer. The film can subsequently be locally etched using processes described in the Lithography and Etching sections are as follows later in this paper[6].

2.1 Chemical Vapor Deposition (CVD)

In this process, the substrate is placed inside a reactor to which a number of gases are supplied. The fundamental principle of the process is that a chemical reaction takes place between the source gases. The product of that reaction is a solid material with condenses on all surfaces inside the reactor.

The two most important CVD technologies in MEMS are the Low Pressure CVD (LPCVD) and Plasma Enhanced CVD (PECVD). The LPCVD process produces layers with excellent uniformity of thickness and material characteristics. The main problems with the process are the high deposition temperature (higher than 600°C) and the relatively slow deposition rate. The PECVD process can
operate at lower temperatures (down to 300°C) thanks to the extra energy supplied to the gas molecules by the plasma in the reactor. However, the qualities of the films tend to be inferior to processes running at higher temperatures. Secondly, most PECVD deposition systems can only deposit the material on one side of the wafers on 1 to 4 wafers at a time. LPCVD systems deposit films on both sides of at least 25 wafers at a time. Fig 1 shows the hot-wall LPCDV reactor.

2.2 Electrodeposition:

This process is also known as "electroplating" and is typically restricted to electrically conductive materials. There are basically two technologies for plating: Electroplating and Electroless plating. In the electroplating process the substrate is placed in a liquid solution (electrolyte). When an electrical potential is applied between a conducting area on the substrate and a counter electrode (usually platinum) in the liquid, a chemical redox process takes place resulting in the formation of a layer of material on the substrate and usually some gas generation at the counter electrode.

In the electroless plating process a more complex chemical solution is used, in which deposition happens spontaneously on any surface which forms a sufficiently high electrochemical potential with the solution. This process is desirable since it does not require any external electrical potential and contact to the substrate during processing. Unfortunately, it is also more difficult to control with regards to film thickness and uniformity. Figure 2: shows typical setup for Electrodeposition.

2.3 Physical Vapor Deposition (PVD):

PVD covers a number of deposition technologies in which material is released from a source and transferred to the substrate. The two most important technologies are evaporation and sputtering. PVD comprises the standard technologies for deposition of metals. It is far more common than CVD for metals since it can be performed at lower process risk and cheaper in regards to materials cost. The quality of the films is inferior to CVD, which for metals means higher resistivity and for insulators more defects and traps. The step coverage is also not as good as CVD.

2.3.1 Evaporation:

In evaporation the substrate is placed inside a vacuum chamber, in which a block (source) of the material to be deposited is also located. The source material is then heated to the point where it starts to boil and evaporate. The vacuum is required to allow the molecules to evaporate freely in the chamber, and they subsequently condense on all surfaces. This principle is the same for all evaporation technologies, only the method used to the heat (evaporate) the source material differs. There are two popular evaporation technologies, which are e-beam evaporation and resistive evaporation each referring to the heating method. In e-beam evaporation, an electron beam is aimed at the source material causing local heating and evaporation. In resistive evaporation, a tungsten boat, containing the source material, is heated electrically with a high current to make the material evaporate. Many materials are
restrictive in terms of what evaporation method can be used (i.e. aluminum is quite difficult to evaporate using resistive heating), which typically relates to the phase transition properties of that material. Figure 3 shows the typical system for e-beam evaporation of materials.

![Typical system for e-beam evaporation of materials](image)

Fig 3: Typical system for e-beam evaporation of materials.

### 2.3.2 Sputtering

Sputtering is a technology in which the material is released from the source at much lower temperature than evaporation. The substrate is placed in a vacuum chamber with the source material, named a target, and an inert gas (such as argon) is introduced at low pressure. A gas plasma is struck using an RF power source, causing the gas to become ionized. The ions are accelerated towards the surface of the target, causing atoms of the source material to break off from the target in vapor form and condense on all surfaces including the substrate. As for evaporation, the basic principle of sputtering is the same for all sputtering technologies. The differences typically relate to the manner in which the ion bombardment of the target is realized. Figure 4: shows the typical RF sputtering system.

![Typical RF sputtering system](image)

Fig 4: Typical RF sputtering system.

### 2.4 Lithography

Lithography in MEMS context is typically the transfer of a pattern into a photosensitive material by selective exposure to a radiation source such as light. A photosensitive material is a material that experiences a change in its physical properties when exposed to a radiation source. If a photosensitive material is selectively exposed to radiation (e.g. by masking some of the radiation) the pattern of the radiation on the material is transferred to the material exposed, as the properties of the exposed and unexposed regions differ.

#### 2.4.1 Photolithography

Photolithography, also termed optical lithography or UV lithography, is a process used in micro fabrication to pattern parts of a thin film or the bulk of a substrate. It uses light to transfer a geometric pattern from a photo mask to a light-sensitive chemical "photoresist", or simply "resist," on the substrate. A series of chemical treatments then either engraves the exposure pattern into, or enables deposition of a new material in the desired pattern upon, the material underneath the photo resist. For example, in complex integrated circuits, a modern CMOS wafer will go through the photolithographic cycle up to 50 times. Some basic process of Photolithography is Cleaning, Preparation, Photoresist application, Exposure and developing.

#### 2.4.2 Electron beam lithography

Electron beam lithography (often abbreviated as e-beam lithography) is the practice of scanning a beam of electrons in a patterned fashion across a surface covered with a film (called the resist), ("exposing" the resist) and of selectively removing either exposed or non-exposed regions of the resist.
The purpose, as with photolithography, is to create very small structures in the resist that can subsequently be transferred to the substrate material, often by etching. It was developed for manufacturing integrated circuits, and is also used for creating nanotechnology architectures.

2.4.3 Ion beam lithography

Ion beam lithography is the practice of scanning a focused beam of ions in a patterned fashion across a surface in order to create very small structures such as integrated circuits or other nanostructures. Ion beam lithography has been found to be useful for transferring high-fidelity patterns on three-dimensional surfaces. Ion beam lithography offers higher resolution patterning than UV, X-ray, or electron beam lithography because these heavier particles have more momentum. This gives the ion beam a smaller wavelength than even an e-beam and therefore almost no diffraction. The momentum also reduces scattering in the target and in any residual gas. There is also a reduced potential radiation effect to sensitive underlying structures compared to x-ray and e-beam lithography.

3 Mems Manufacturing

MEMS fabrication is an extremely exciting endeavor 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.[5]

3.1 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. 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 5 shows Illustration of the etch profile, with and without stirring, using an isotropic wet chemical etchant.

![Illustration of etch profile](image)

With stirring

Without stirring

The much more widely used wet etchants for silicon micromachining are anisotropic wet etchants. Anisotropic wet etching involves the immersion of the substrate into a chemical solution wherein the etch rate is dependent on crystallographic orientation of the substrate. The mechanism by which the etching varies according to silicon crystal planes is attributed to the different bond configurations and atomic density that the different planes exposed to the etchant solution. Wet anisotropic chemical etching is typically described in terms of etch rates according to the different normal crystallographic planes, usually <100>, <110>, and <111>. In general, silicon anisotropic etching etches more slowly along the <111> planes than all the other planes in the lattice.
and the difference in etch rate between the different lattice directions can be as high as 1000 to 1. It is thought that the reason for the slower etch rate of the <111> planes is that these planes have the highest density of exposed silicon atoms in the etchant solution, as well as 3 silicon bonds below the plane, thereby leading to some amount of chemical shielding of the surface.

### 3.2 Surface Micromachining

Surface micromachining is another very popular technology used for the fabrication of MEMS devices. There are a very large number of variations of how surface micromachining is performed, depending on the materials and etchant combinations that are used. However, the common theme involves a sequence of steps starting with the deposition of some thin-film material to act as a temporary mechanical layer onto which the actual device layers are built; followed by the deposition and patterning of the thin-film device layer of material which is referred to as the structural layer; then followed by the removal of the temporary layer to release the mechanical structure layer from the constraint of the underlying layer, thereby allowing the structural layer to move. This oxide layer is temporary and is commonly referred to as the sacrificial layer. Subsequently, a thin film layer of polysilicon is deposited and patterned and this layer is the structural mechanical layer. Lastly, the temporary sacrificial layer is removed and the polysilicon layer is now free to move as a cantilever.

Some of the reasons surface micromachining is so popular is that it provides for precise dimensional control in the vertical direction. This is due to the fact that the structural and sacrificial layer thicknesses are defined by deposited film thicknesses which can be accurately controlled. Also, surface micromachining provides for precise dimensional control in the horizontal direction, since the structural layer tolerance is defined by the fidelity of the photolithography and etch processes used. Other benefits of surface micromachining are that a large variety of structure, sacrificial and etchant combinations can be used; some are compatible with microelectronics devices to enable integrated MEMS devices. Surface micromachining frequently exploits the deposition characteristics of thin-films such as conformal coverage using LPCVD. Lastly, surface micromachining uses single-sided wafer processing and is relatively simple. This allows higher integration density and lower resultant per die cost compared to bulk micromachining.

![Fig 6: Illustration of a surface micromachining process.](Image)

One of the disadvantages of surface micromachining is that the mechanical properties of most deposited thin-films are usually unknown and must be measured. Also it is common for these types of films to have a high state of residual stress, frequently necessitating a high temperature anneal to reduce residual stress in the structural layer. Also, the reproducibility of the mechanical properties in these films can be difficult to achieve.

### 3.3 Wafer Bonding

Wafer bonding is a micromachining method that is analogous to welding in the macroscale world and involves the joining of two (or more) wafers together to create a multi-wafer stack. There are three basic types of wafer bonding including: direct or fusion bonding; field-assisted or anodic bonding; and bonding using an intermediate layer. In general, all bonding methods require substrates that are very flat, smooth, and clean, in order for the wafer bonding to be successful and free of voids.

Direct or fusion bonding is typically used to mate two silicon wafers together or alternatively to mate one silicon wafer to another silicon wafer that has been oxidized. Direct wafer bonding can be performed on other combinations, such as bare silicon to a silicon wafer with a thin-film of silicon nitride on the surface as well.

As mentioned, wafer bonding is analogous to welding in the macroscale world. Wafer bonding is used to attach a thick layer of single crystal silicon onto another wafer. This can be extremely useful when it is desired to have a thick layer of material for applications requiring appreciable mass or in applications where the material properties of single crystal silicon are advantageous over those of thin-film LPCVD materials. Direct wafer bonding is also used to fabricate Silicon-On-Insulator (SOI) wafers having device layers several microns or more in thickness.
4 Nems as Nano robots

Nanorobotics is concerned with: 1) design and fabrication of nanorobots with overall dimensions at or below the micrometer range and made of nanoscopic components; 2) programming and coordination of large numbers (swarms) of such nanorobots; and 3) programmable assembly of nanometer-scale components either by manipulation with macro or micro devices, or by self-assembly on programmed templates or scaffolds[1].

Nanorobots have overall dimensions comparable to those of biological cells and organelles. This opens a vast array of potential applications in environmental monitoring for microorganisms and in health care [1]. Nanorobots, Nanomachines, and other Nano systems discussed in this paper are objects with overall sizes on the order of a few micrometres or less in all three spatial directions, and which are assemblies of nanoscopic components with individual dimensions 1–100 nm.

4.1 CNT’s as building blocks for Nanorobots:

The well-defined geometry, exceptional mechanical properties, and extraordinary electric characteristics, among other outstanding physical properties of CNT (see Table 1) qualify them for potential applications in Nano electronic circuits, Nanoelectromechanical systems (NEMS) and nanorobotic systems. For nanorobotic, some of the most important characteristics of nanotubes include their nanometer diameter, large aspect ratio (10–1000), terapascal scale Young’s modulus, excellent elasticity, ultra small interlayer friction, excellent field-emission properties, various electric conductivities, high thermal conductivity, high current carrying capability with essentially no heating, sensitivity of conductance to various physical or chemical changes, and charge induced bond-length change. CNTs can serve in nanorobotic systems as structural elements, tools, sensors, and actuators.

CNTs can serve directly as functional elements of nanodevices. The first example of such a device – a nanotube probe for an atomic force microscope (AFM). In the device, a multiwalled CNT (MWNT) was manually assembled onto a commercially available Si cantilever. Further developments improved the construction technique through direct chemical vapor deposition (CVD), controlled assembly, and picking up a tube from vertically aligned single-walled CNTs (SWNTs) grown from planar substrate surfaces. Nanotube tweezers have been constructed with two nanotubes on a glass fiber and driven by the electrostatic interaction between them.

<table>
<thead>
<tr>
<th>Property</th>
<th>Item</th>
<th>Data</th>
<th>Potential applications in nanorobots</th>
</tr>
</thead>
<tbody>
<tr>
<td>Geometrical</td>
<td>Layers</td>
<td>Single/multiple</td>
<td>Structures, probes, grippers/tweezers, scissors</td>
</tr>
<tr>
<td></td>
<td>Aspect ratio</td>
<td>10–1000</td>
<td></td>
</tr>
<tr>
<td></td>
<td>Diameter</td>
<td>≤0.4 nm to &gt;3 nm (SWNTs)</td>
<td></td>
</tr>
<tr>
<td></td>
<td></td>
<td>≤1.4 nm to &gt;100 nm (MWNTs)</td>
<td></td>
</tr>
<tr>
<td></td>
<td>Length</td>
<td>Several micrometres (up to centimetres)</td>
<td></td>
</tr>
<tr>
<td>Mechanical</td>
<td>Young’s modulus</td>
<td>&lt;1 T (steel 0.2 T)</td>
<td>Actuators, bearings, syringes, switches, memories</td>
</tr>
<tr>
<td></td>
<td>Tensile strength</td>
<td>85 GPa (steel 2 GPa)</td>
<td>Actuators, bearings, syringes, switches, memories</td>
</tr>
<tr>
<td></td>
<td>Density</td>
<td>1.39–1.4 g/cm³ (Al 2.7 g/cm³)</td>
<td>Actuators, bearings, syringes, switches, memories</td>
</tr>
<tr>
<td></td>
<td>Interlayer friction</td>
<td>Ultralow friction</td>
<td>Actuators, bearings, syringes, switches, memories</td>
</tr>
<tr>
<td>Electronic</td>
<td>Conductivity</td>
<td>Metallic/conducting</td>
<td>Diodes, transistors, switches, logic gates</td>
</tr>
<tr>
<td></td>
<td>Correct carrying capacity</td>
<td>&lt;1 T V⁻¹ (C₉1 GPa/cm)</td>
<td>Diodes, transistors, switches, logic gates</td>
</tr>
<tr>
<td></td>
<td>Field emission</td>
<td>Acoustic phonons at 1–3 V</td>
<td>Diodes, transistors, switches, logic gates</td>
</tr>
<tr>
<td>Electromechanical</td>
<td>Piezoresistivity</td>
<td>Positive/negative</td>
<td>Deformation/displacement sensors</td>
</tr>
<tr>
<td>Thermal</td>
<td>Heat emission</td>
<td>&gt;6 W/K (Diamond: 2 W/K)</td>
<td>Circuits, sensors, thermal actuators</td>
</tr>
</tbody>
</table>

Table 1: Properties of CNT.

4.2 Nano assembly of CNTs:

Random spreading, direct growth, fluidic self-assembly47, transfer printing, and dielectrophoretic (DEP) assembly have been used for positioning as-grown nanotubes or other nanostructures on electrodes for the construction of electronic devices, or NEMS generally, in some type of regular array.

The process used to build the nanostructure array is as follows. First, the bottom nanoelectrode layer (15 nm Cr/45 nm Au) is defined on a Si substrate, which is covered with a 500 nm insulating oxide. The nanoelectrode layer is formed by defining patterns in bilateral resist (PMMA/PMAA) using electron-beam lithography, followed by metal deposition and lift-off. The electrodes are 300 nm wide and are separated by 350 nm gaps. Next, carbon-based nanomaterials are deposited onto the electrodes by coupled ac-dc DEP.

For this step, the nanomaterials are suspended and sonicated in ethanol to insure homogeneity. The chip is then immersed in a reservoir containing the suspension and a composite ac-dc electric field is applied with a high frequency function generator. After about 100 s, the chip is removed from the
reservoir and rinsed in clean ethanol. Finally, it is blown dry with a nitrogen gun. This assembly process realizes structures that aid in investigating and characterizing the electrical and mechanical properties of these novel nanomaterials. More importantly, the capability of assembling disparate nanomaterials using the same technique would enable their integration into complex nanostructures in realizing integrated NEMS and other nanosystems.

5 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:

5.1 Medicine:
- 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.
- 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 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.
- Physician’s office and hospital blood analyzers employ MEMS pressure sensors as barometric pressure correction for the analysis of concentrations of O2, CO2, calcium, potassium, and glucose in a patient's blood.

5.2 Communications:

High frequency circuits are benefiting considerably from the advent of RF-MEMS technology. Electrical components such as inductors and tunable 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.

5.3 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 Tunneling Microscopes (STMs), biochips for detection of hazardous chemical and biological agents, and microsystems for high-throughput drug screening and selection.

6 Nano good or bad:

The Grey goo (alternatively spelled gray goo) is a hypothetical end-of-the-world scenario involving molecular nanotechnology in which out-of-control self-replicating robots consume all matter on Earth while building more of them. The term was first used by molecular nanotechnology pioneer Eric Drexler in his book Engines of Creation (1986).

The researchers doing the research in present need to keep in the mind that future protection is more important to control the Nanites which can be self-replicate it.

7 Conclusion:

The Micro electro mechanical system (Mems) fabrication and the manufacturing and application are well explained with evolution of the Nano technology specifically the fabrication of Nanites (Nano robots) is described.
8 Reference:


