REVIEW: MICROCANTILEVER FABRICATION TECHNOLOGY

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Abstract—Microelectromechanical systems or MEMS are integrated micro devices or systems combining electrical and mechanical components. The fast development of MEMS technology has brought many great ideas and development of physical, chemical and biological sensors. Microcantilevers are the most simplified device of MEMS. Moreover, the technology has been developed in the last few years for the fabrication of microcantilever as a sensing device. The sensing action essentially is the deflection of the cantilever beam. Conventional methods for fabricating micro-cantilevers are centered either etching in glass and silicon or using lithography. Given the emerging importance of microcantilever sensor, it is instructive to review the fabrication technology, and to examine new developments in the field.

Keywords— Microelectromechanical, microcantilever, Fabication technologies, substrate, planar technologies, Photolithography, etching, Surface micromachining, High-aspect-ratio micromachining, LIGA, laser micromachining, Replication Techniques,Micromoulding, hot embossing, Injection moulding.

I. INTRODUCTION

The past decade has seen the wide exploration of Microelectromechanical systems (MEMS) as an important area of technology. One of the most flexible mechanical sensor systems is the microcantilever based sensor. They have been developed for the applications such as gas, temperature, pressure, biological and force sensors. Furthermore, by reducing the dimensions of the sensor to the nanometer scale, the sensor can become faster, cheaper and more sensitive.

Micro cantilever has been used to monitor different processes by various means of transduction such as temperature, mass, electromagnetic field, and surface stress. Microcantilever deflection is one of the unique transduction mechanisms of microcantilever sensors. The technology is based upon the changes in the deflection property induced by environmental factors in the medium in which a microcantilever is immersed. It has been observed that microcantilevers bend upon the specific binding of species in the environment due to an adsorption induced surface stress change [1]. The cantilever bending can be detected by different read-out methods, such as optical reflection, piezoresistive, interferometric, piezoelectric and capacitive [2-7]. Any one of these methods is chosen for implementation based on the application. Most of the detection methods require extra hardware for detection and sensing along with the electronics, hence, the size of the assembly becomes bigger. These methods are costly, require highly sophisticated circuits for measurements and a very precise mechanical alignment or require additional material layers, which is usually difficult in the semiconductor manufacturing. Microcantilevers are generally made from a material called polycrystalline silicon which is a common material also used to make integrated circuits. Frequently, polycrystalline silicon is doped with other materials like germanium or phosphate to enhance the materials properties. Sometimes, copper or aluminum is plated onto the polycrystalline silicon to allow electrical conduction between different parts of the MEMS devices. Polymers possess a great variety of material characteristics (e.g., mechanical flexibility, optical transparency, biocompatibility, chemical stability, *etc.*) enabling them to be used in diverse applications such as micro fluidic systems and bio-implantable systems. Because of continuous development of the manufacturing industry of polymers, they can be produced in huge volumes. However, due to lack of electrical conductivity in most polymers, its application is been limited to a structural component. Often, polymer-based MEMS devices require conductive elements to electrically control or collect signals from systems. Since MEMS-based sensors require feature sizes on the micro scale, conductive fillers of polymer nanocomposite typically have feature size on the nanometer scale, so that the conformity of microstructures could be ensured. Common nanofillers include carbon nanotubes, carbon black (nanoscaled carbon particles), metal particles and flakes [8].

II. FABRICATION TECHNOLOGIES

MEMS encompass the process-based technologies used to fabricate tiny integrated devices and systems that integrate functionalities from different physical domains into one device. Such devices are fabricated using a wide range of technologies, having in common the ability to create structures with micro- and even nanometer accuracies. The products range in size from a few micrometers to millimeters. These devices (or systems) have the ability to sense, control and actuate on the micro scale, and generate effects on the macro scale.

A. Substrates

Silicon is still by far the most commonly used substrate in microelectronics and microtechnology, particularly by the semiconductor industry. For microcantilever the most popular substrate is silicon for the following reasons:

1) Silicon is abundant, inexpensive, and can be processed to unparalleled purity.
2) Silicon's ability to be deposited in thin films is very amenable to MEMS.
3) High definition and reproduction of silicon device shapes Using photolithography are perfectly suited to achieve high Levels of precision and repeatability.
4) It allows fabrication with high quality and high volumes in efficient semiconductor facilities.

The sensitivity of the sensor depends on Young's modulus of the structural material, thickness of the cantilever as well as on the gauge factor of the piezoresistor. UV patternable polymers Such as SU-8 have a very low Young's modulus compared to the silicon-based materials. Polymer microfabrication methods are becoming increasingly important as low-cost alternatives to the silicon or glass-based MEMS technologies. Polymer hot embossing and injection molding are replication methods applicable to micro replication of a diversity of materials and microstructures. Due to its ease of fabrication, low cost and great variety of functionalities, polymer has become an important material in micro fabrication. MEMS devices with polymer as the structure material have found applications in various fields, especially in Bio MEMS and optical MEMS.

B. Planar technologies

The planar technologies are mostly based on semiconductor technologies like photolithography, sputtering, evaporating, Low Pressure Chemical Vapour Deposition (LPCVD), Plasma Enhanced Chemical Vapour Deposition (PECVD), wet and dry etching, and chemical mechanical planarisation. To those technologies some specific MEMS technologies are added like bulk and surface machining; wafer bonding; backside alignment, Deep Reactive Ion Etching (DRIE) etc.

5) Photolithography

Photolithography is the photographic technique to transfer copies of a master pattern, usually a circuit layout in IC applications, onto the surface of a substrate of some material (usually a silicon wafer).For example, the substrate is covered with a thin film of some material, usually silicon dioxide (SiO2), in the case of silicon wafers, on which a pattern of holes will be formed. A thin layer of an organic polymer, which is sensitive to ultraviolet radiation, is then deposited on the oxide layer; this is called a photoresist. A photomask, consisting of a glass plate (transparent) coated with a chromium pattern (opaque), is then placed in contact with the photoresist coated surface. The wafer is exposed to the ultraviolet radiation transferring the pattern on the mask to the photoresist which is then developed in a way very similar to the process used for developing photographic films. The radiation causes a chemical reaction in the exposed areas of the photoresist of which there are two types; positive and negative (see figure 1).

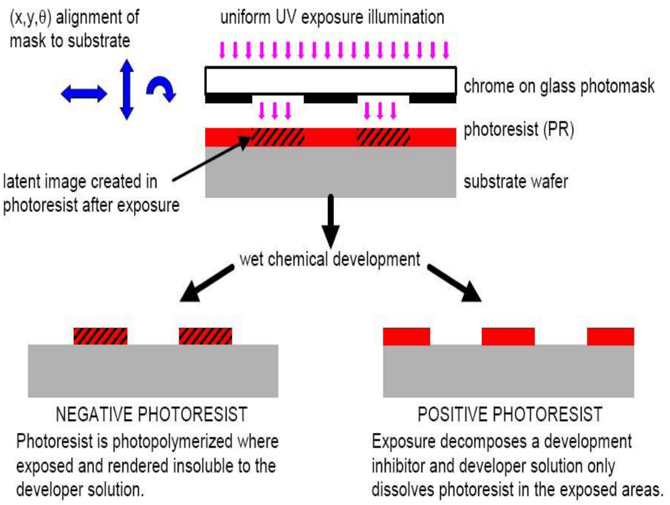

Figure: 1 Negative and positive photoresist

6) Etching

In bulk and surface micromachining silicon etching is an important step. Not only for creating the base structures like trenches and cavities, but also for the final release of the membranes, cantilevers or free hanging masses in surface micromachining. This final release etching or sacrificial etching involves the undercutting by etching of a structure.

a) Wet etching

Wet etching describes the removal of material through the immersion of a material (typically a silicon wafer) in a liquid bath of a chemical etchant. These etchants can be isotropic or anisotropic. Isotropic etchants etch the material at the same rate in all directions, and consequently remove material under the etch masks at the same rate as they etch through the material; this is known as undercutting (Figure 2 a and b). Etch rates can slow down and in some cases (for example, in deep and narrow channels) they can stop due to diffusion limiting factors. However, this effect can be minimized by agitation of the etchant, resulting in structures with near perfect and rounded surfaces (Figure 2 b).

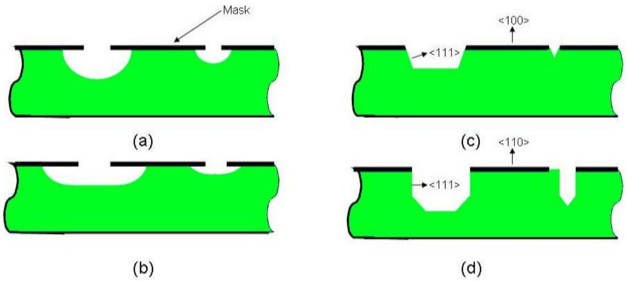

Figure: 2 Isotropic etching with (a) and without (b) agitation, and anisotropic etching wet etching of (100) and (110) silicon (c and d)

Dopant levels within the substrate can affect the etch rate by KOH, and if levels are high enough, can effectively stop it. Boron is one such dopant and is implanted into the silicon by a diffusion process. This can be used to selectively etch regions in the silicon leaving doped areas unaffected, for instance to control the thickness of a silicon membrane.

b) Dry itching

Dry etching relies on vapour phase or plasma-based methods of etching using suitably reactive gases or vapours usually at high temperatures. The typical etch rates are 1 to 3 µm/min and it is commonly used for release etch. The other is Reactive Ion Etching (RIE) which utilizes additional energy in the form of radio frequency (RF) power to drive the chemical reaction. Energetic ions are accelerated towards the material to be etched supplying the additional energy needed for the reaction; as a result the etching can occur at much lower temperatures (sometimes room temperature or even lower). The MEMS process Deep Reactive Ion Etching (DRIE) is a much higher-aspect-ratio etching method. It involves an alternating process of high-density plasma etching (as in RIE) and protective polymer deposition to achieve greater aspect ratios.

7) Surface micromachining

Surface micromachining involves processing above or in the top layers of the substrate, the substrate only using as a carrier on which to build. Material is added to the substrate in the form of layers of thin films. The process usually involves films of two different materials: a structural material out of which the free standing structure is made (generally polycrystalline silicon or polysilicon, silicon nitride or aluminum) and a sacrificial material, deposited wherever either an open area or a free standing mechanical structure is required (usually an oxide, but also resist or metals are used).

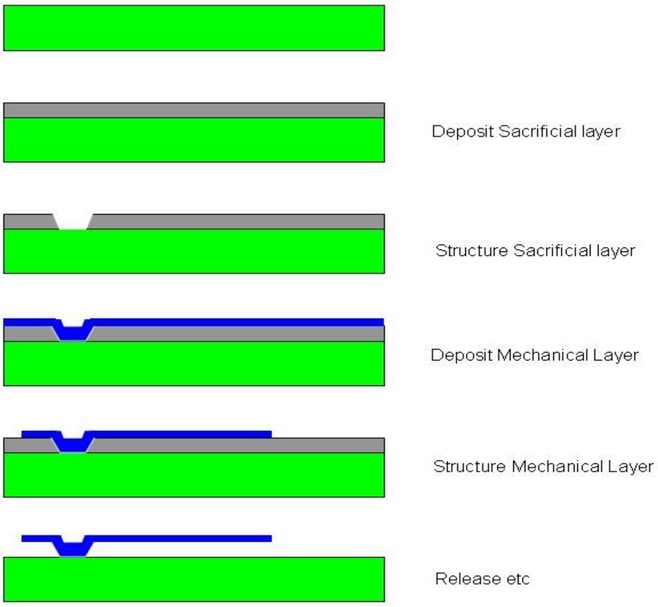

Figure 3 Basic process flow surface micromachining process

In the above example shown in Figure 3, a sacrificial layer of oxide is deposited on the silicon substrate surface using a pattern and photolithography. A polysilicon layer is then deposited and patterned using RIE processes to form a cantilever beam with an anchor pad. The wafer is then wet etched to remove the oxide (sacrificial) layer releasing the beam. More complex MEMS structures can be made using several structural polysilicon and sacrificial silicon dioxide layers, including sliding structures, actuators and free moving mechanical gears.

8) Bulk micromachining

Bulk micromachining starts with the deposition of a masking layer on both sides of the wafer, mostly LPVCD low stress silicon nitride. In the most simple process, this mask is then structured and the wafer is subsequently etched in KOH etch. Depending on the mask pattern cantilevers of free hanging silicon nitride layers, cavities, membranes and wafer through holes are formed (see Figure 4).

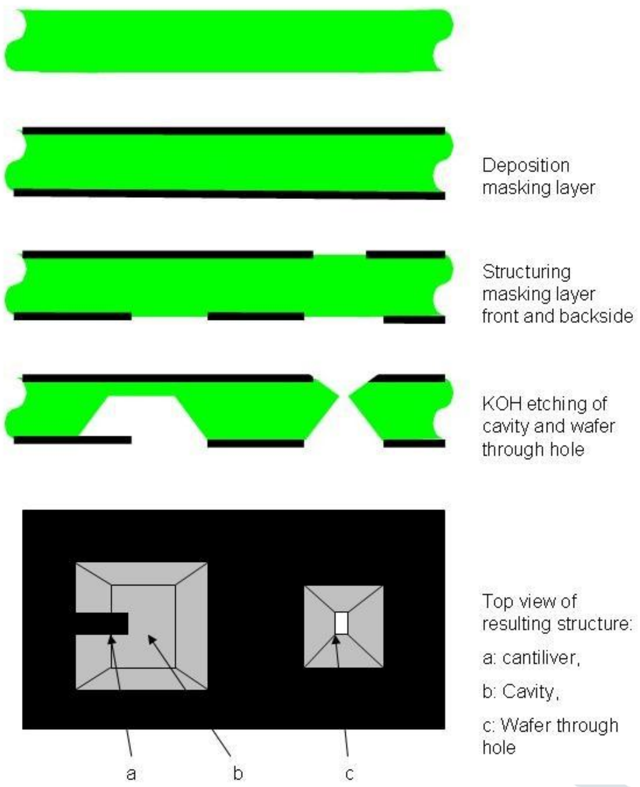

Figure 4 Basic process flows Bulk Micromachining process

C) 3-D Technologies

Polymers are increasingly used, especially in area where there is a high price pressure, like in the market for disposables. Polymers are in general cheaper to produce, but only for large numbers and they lack the thermal and mechanical stability of silicon and glass. Polymer fabrication can be divided in direct fabrication, often using some kind of radiation to pattern the polymers, and replication technologies using moulds.

9) High Aspect Ratio Micromachining and LIGA

High-aspect-ratio micromachining (HARM) is a process that involves micromachining as a tooling step followed by injection moulding or embossing and, if required, by electroforming to replicate microstructures in metal from moulded parts. It is one of the most attractive technologies for replicating microstructures at a high performance-to-cost ratio and includes techniques known as LIGA. Products micromachined with this technique include high aspect ratio fluidic structures such as moulded nozzle plates for inkjet printing and microchannel plates for disposable micro titre plates in medical diagnostic applications. The materials that can be used are electro-formable metals and plastics, including acrylate, polycarbonate, polyimide and styrene.

LIGA is an important tooling and replication method for high-aspect-ratio microstructures. The technique employs X-ray synchrotron radiation to expose thick acrylic resist of PMMA under a lithographic mask. The exposed areas are chemically dissolved and, in areas where the resist is removed, metal is electroformed, thereby defining the final product or the tool insert for the succeeding moulding step. LIGA is capable of creating very finely defined microstructures up to 1000 µm high. LIGA provides a radically new way to produce small precise micromachined parts at relatively low cost.

10) 3-D Lithography

In general, most photo-resist and photo-epoxy materials in micro lithography employ a strategy that results in a two-dimensional pattern printed in a material with the same pattern (or exact reverse) of the light image used to expose that material. In this way, planar photolithography can directly transfer two-dimensional images into materials used for micro- and nano-technology processing. However, for three-dimensional structures, the fabrication procedure can be much more complex because it might include multiple layer deposition, lithography and etching processes.

A three-dimensional micro fabrication technique that uses a unique class of light-activated molecules to selectively initiate chemical reactions within polymers and other materials could provide an efficient way to produce complex structures with sub-micron features. Known as "two-photon 3-D lithography," the technique could compete with existing processes for fabricating micro fluidic devices, photonic band gap structures, optical storage devices, photonic switches and couplers, sensors, actuators, micro machines - and even scaffolds for growing living tissue. It is not however (yet) a mainstream technology.

11) Laser Micromachining

Most laser micromachining processes are serial and hence insufficiently fast for cost effective MEMS fabrication. Nonetheless, such techniques have their use in specialty micromachining or in fabricating moulds. Excimer laser micromachining is, particularly, used for the micromachining of organic materials (plastics, polymers etc.). Applications include machining lubrication or air channels in bearings, machining variable shape nozzles for ink jet devices, machining channels, reservoirs and elements for micro-fluidic, bio-medical and photonic devices.

12) Replication Techniques

Other micro-replication techniques besides LIGA can be used to generate a pre-form for the tool insert. These include laser ablation, ultra-violet (UV) lithography and mechanical micromachining, which include electric discharge machining (EDM) and diamond milling. EDM is a relatively new approach that uses machine shop production techniques and offers the capability to make parts out of most conductive materials. Unfortunately, as a spark erosion technique, it is slow and not ideal for batch processing but has found many applications for MEMS prototype production.

The most common materials used to replicate are: polydimethylsiloxane (PDMS), polymethylmethacrylate (PMMA), polycarbonate (PC) and polystyrene (PS), but many other materials are used. Replication technologies are perfectly suitable to produce large numbers of relatively simple components with fine structures. Integration with electronics or into complex devices is not always straightforward.

c) Micromoulding

In such techniques, a monomer or a low molecular weight polymer is applied to the mould. The monomer solution is polymerized or the low molecular weight polymer is cross linked by curing. Hereafter the master is released and can be reused. Curing can be done by heat or light. Often the masters are made with LIGA and PDMS is used as moulding material. As organic solvents swell PDMS easily, epoxy is used as an alternative. As epoxy sticks to the master, anti sticking layers like Teflon must be used.

d) Hot Embossing

Hot embossing involves pressing a hard structured surface against a soft polymeric surface at elevated temperature. After sufficient holding and cooling times, the hard surface is removed leaving its impression upon the polymeric substrate. This technique has been used to produce microvalves, microsensors, diffraction gratings, and optical devices [9-11]. It can also be used to pattern thin thermoplastic resists coated onto hard substrates which links molding to lithography (thus called nanoimprint lithography). In principle every thermoplastic material can be used for embossing.

e) Injection Moulding

Injection molding appears to be one of the most efficient processes for the large-scale production of thermoplastic polymer micro-parts [9]. It is a subset of the injection molding process, where a polymer melt is forced into a cavity, allowed to cool, and removed to produce a part that has the same general shape as the cavity. Micromolding has been used to create a slew of different parts including micro-fluidic devices and micro-pumps for biological applications. Once a mold insert is available, several thousand parts can be molded with modest effort. Micro-patterns on the mold can be replicated into the molded device too, making it possible to integrate different dimensions and topographies into one single tool [12].

Of the discussed replication technologies, injection moulding is the fastest, but higher temperatures and pressures have to be used. The disadvantage lies in the cost and time needed to create the mould.

III. CONCLUSION

The variety and diversity of MEMS products is huge. Each of these product groups relies on its own, often unique, technology. Contrary to the semiconductor industry, the MEMS industry does not show such a generic technology platform that can be shared. Still, when studied in detail, some general trends become clearer and it is possible to define, at least in general terms, the principle technology developments that underpin microcantilever fabrication. MEMS fabrication uses high volume IC style batch processing that involves the addition or subtraction of two dimensional layers on a substrate (usually silicon) based on photolithography and chemical etching. As a result, the 3-D aspect of MEMS devices is due to patterning and interaction of the 2-D layers. Additional layers can be added using a variety of thin-film deposition and bonding techniques as well as by etching through sacrificial “spacer layers”.

“Real” 3-D technologies include high-aspect-ratio micromachining (HARM), such as LIGA (a German acronym from Lithographie, Galvanoformung, Abformung translated as lithography, electroforming and moulding,; but also conventional macro scale manufacturing techniques such as injection moulding, are all good for producing three dimensional shapes and objects, but limited to low complexity products.

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