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Micro Machining For Micro Electro Mechanical Systems (MEMS)

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Abstract

This paper studies on micro fabrication methods for MEMS. Silicon micromachining has been a key factor for the vast progress of MEMS. Silicon micromachining refers to fashioning microscopic mechanical parts out of a silicon substrate or on a silicon substrate. Silicon micromachining comprises two technologies: bulk micromachining, in which structures are etched into silicon substrate and surface micromachining, in which the micromechanical layers are formed from layers and films deposited on the surface. Bulk micromachining and surface micromachining are the two major micromachining processes of silicon, and silicon wafer bonding is usually necessary for silicon microfabrication. LIGA and 3D microfabrications have been used for high aspect ratio and 3D-microstructure fabrication for MEMS.

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Keywords: Micro Machining; bulk micromachining; surface micromachining; LIGA; MEMS

1. Introduction

A Microelectromechanical system (MEMS) is the technology of very small mechanical devices with at least some of their dimensions in the micrometer range driven by electricity. Typical MEMS consist of components with a size of 1 to 100 µm – the whole MEMS device generally ranges in size from 20 µm to 1 mm. structure (Jaeger, R.C 1988). It usually consists of a central unit that processes data, the microprocessor and several components that interact with the outside such as e.g. pressure sensors, accelerometers or gyroscopes.

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Nomenclature

HAR	High aspect ratio
IC	Integrated chip
MEMS	Microelectromechanical system
µ	Micro
RIE	Reactive Ion Etching
SOI	silicon-on-insulator
UV	Ultraviolet

In the 1980s the MEMS fabrication was almost exclusively based on processes and materials borrowed from IC fabrication labs. In the 1990s additional techniques including moulding, plating, wet and dry etching and other technologies capable of manufacturing small devices were developed. To make new applications possible lots of quite exotic materials were integrated into the MEMS devices. For applications in the fields of medicine and biochemistry these materials include for example gas-permeable membranes, enzymes, biological cells, antibodies etc.

Micro fabrication is increasingly central to modern science and technology. Many opportunities in technology derive from the ability to fabricate new tvpes of microstructures or to reconstitute existing structures in down-sized versions. The most obvious examples are in microelectronics. Microstructures should also provide the opportunity to study basic scientific phenomena that occur at small dimensions: one example is quantum confinement observed in nanostructures. Although micro fabrication has its basis in microelectronics and most research in micro fabrication has been focused on microelectronic devices, applications in other areas are rapidly emerging. These include systems for microanalysis, micro-volume reactors, combinatorial synthesis, microelectromechanical systems (MEMS), and optical components

2. Materials used in MEMS fabrication

2.1 Silicon

Silicon is the material used to create most integrated circuits used in consumer electronics in the modern world. It is also an attractive material for the production of MEMS, as it displays many advantageous mechanical and chemical properties: Single crystalline silicon is an almost perfect Hookean material. This means that when silicon is bent there is virtually no hysteresis and hence almost no energy loss. This property makes it to the ideal material, where many small motions and high reliability are demanded, as silicon displays very little fatigue and can achieve service lifetimes in the range of billions to trillions of cycles (Petersen, K.E. 1982).

2.2 Polymers

Even though the electronics industry provides an economy of scale for the silicon industry, crystalline silicon is still a complex and relatively expensive material to be produced. Polymers on the other hand can be produced in huge volumes, with a great variety of material characteristics. MEMS devices can be made from polymers by processes such as injection moulding, embossing orstereolithography and are especially well suited to micro fluidic applications such as disposable blood testing cartridges.

2.3 Metals

Metals can also be used to create MEMS elements. While metals do not have some of the advantages displayed by silicon in terms of mechanical properties, when used within their limitations, metals can exhibit very high degrees of reliability. Metals can be deposited by electroplating, evaporation, and sputtering processes. Commonly used metals include gold, nickel, aluminium, copper, chromium, titanium, tungsten, platinum, and silver.

2.4 Ceramics

The nitrides of silicon, aluminium and titanium as well as silicon carbide and other ceramics are increasingly applied in MEMS fabrication due to advantageous combinations of material properties.

2.4 Other materials

Besides silicon also some metals and polymers can be used to form MEMS elements or functional layers. The common fabrication processes for metals such as gold, nickel, copper, titanium, silver and several more are electroplating, evaporation and sputter deposition. Polymeric MEMS can be produced by using injection moulding, embossing or stereo lithography. These MEMS devices are especially well suited to micro fluidic applications such as disposable blood testing cartridge.

3. Micromachining

• Photolithography
• Etching
• LIGA
• Mechanical Micromachining

4. Bulk micromachining

The term bulk micromachining comes from the fact that this type of micromachining is used to realize micromechanical structures within the bulk of a single-crystal silicon wafer by selectively removing (‘etching’) wafer material. The microstructures fabricated using bulk micromachining may cover the thickness range from submicron to full wafer thickness (200–500 μm), and the lateral size range from submicron to the lateral dimensions of a full wafer. Bulk micromachining technique allows to selectively remove significant amounts of silicon from a substrate to form membranes on one side of a wafer, a variety of trenches, holes, or other (Bryzek, J et al. 1994). Bulk micromachining technique can be divided into wet etching and dry etching of silicon according to the phase of etchants. Liquid etchants, almost exclusively replying on aqueous chemicals, are referred to as wet etching. Vapor and plasma etchants are referred to as dry etching.

For etching such thick silicon substrate, anisotropic wet etchants such as solutions of potassium hydroxide (KOH), ethylene diamine and pyrocatechol (EDP), tetramethylammonium hydroxide (TMAH), and hydrazine-water are used. These etchants have different etch rates in different crystal orientation of the silicon . Wet etching in mostcase is done from the back side of the wafer while the plasma etching is being applied to front side (Shaw, K W. et al 1994)

Etch process can be made selective by the use of dopants (heavily doped regions etch slowly) or may even be halted electrochemically (e.g., etching stops upon encountering a region of different polarity in a biased p–n junction). A region at which wet etching tends to slow down or diminish is called an etch-stop.

Wet etching occurs by dipping substrate into an etching bath or spraying it with etchants that may be acid or alkaline. Wet etching can either be isotropic etching or anisotropic etching depending on the structure of the materials or the etchants used (Aeidel, H,(1987). If the material is amorphous or polycrystalline, wet etching is always isotropic etching (Figure 1.a). During isotropic etching (etchants used are acid solution), resist is always undercut, implying that the deep etching is not practical for MEMS.

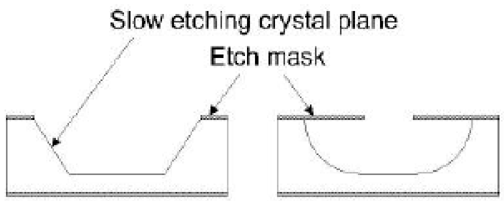

Figure .1: (a) Isotropical etching (b) Anisotropic etching

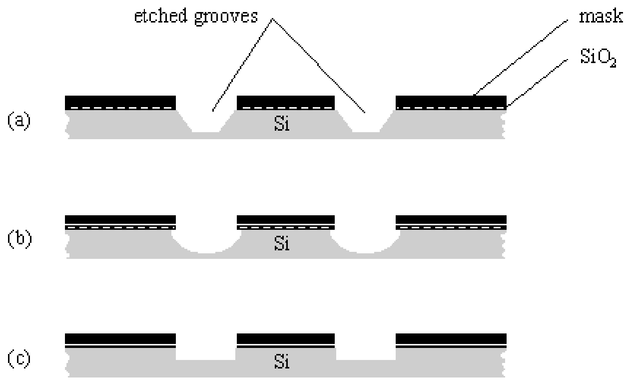

Figure 2: Etched grooves using (a) anisotropic etchants, (b) isotropic etchants, (c) Reactive Ion Etching (RIE)

5. Surface Micromachining

- selectivity of structural, sacrificial and substrate materials
- stress of structural material
- stiction

Most commonly used materials for surface micromachining:

- substrate: silicon
- sacrificial material: SiO_2 or phosphosilicate glass (PSG)
- structural material: polysilicon

Surface micromachining does not shape the bulk silicon but instead builds structures on the surface of the silicon by depositing thin films of 'sacrificial layers' and 'structural layers' and by removing eventually the sacrificial layers to release the mechanical structures (Figure 3). The dimensions of these surface micromachined structures can be several orders of magnitude smaller than bulk-micromachined structures. The prime advantage of surface-micromachined structures is their easy integration with IC components, because the wafer is also the working area for IC elements (Rai-choudhury, P, 1997). It should be noted that as miniaturization is immensely increased by surface micromachining, the small mass structure involved may be insufficient for a number of mechanical sensing and actuation applications.

Surface micromachining requires a compatible set of structural materials, sacrificial materials, and chemical etchants. The structural materials must possess the physical and chemical properties that are suitable for the desired application. In addition, they must have satisfactory mechanical properties, for e.g., high yield and fracture stresses, minimal creep and fatigue, and good wear resistance. The sacrificial materials must have good mechanical properties to avoid device failure during fabrication. These properties include good adhesion and low-residual stresses to eliminate device failure by delamination and/or cracking. The etchants to remove the sacrificial materials must have excellent etch selectivity and they must be able to etch off the sacrificial materials without affecting the structural ones. In addition, the etchants must have proper viscosity and surface tension characteristics.

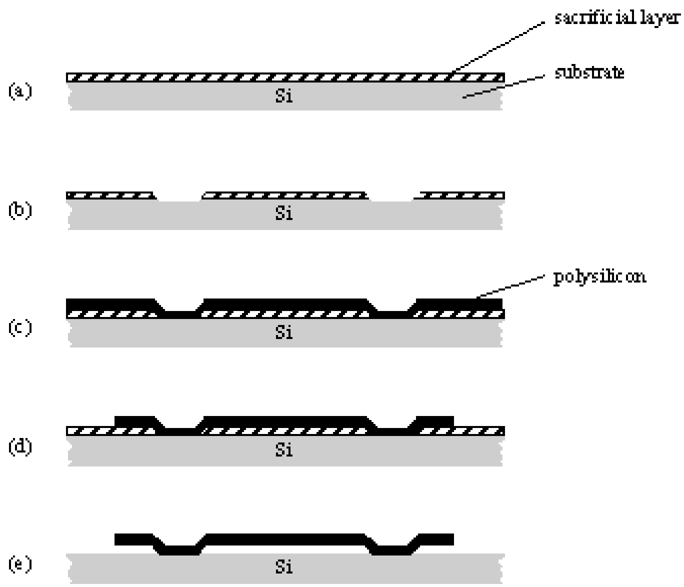

Figure 3: Basic surface micromachining process. (a) Spacer layer deposition. (b) Pattering of the spacer layer. (c) Deposition of the microstructure layer. (d) Patterning of desired structure. (e) Stripping of the spacer layer resolves final structure

Table 1. *Alternative materials*

Substrates	**Sacrificial**	**Structural**
Glass Plastic metals	Polymer Metals silicon nitride	Thin film silicon (a-Si:H, c-Si) silicon nitrides Silicon carbide Metals polymers bilayer composites

- Polysilicon deposited by LPCVD (T~600 ºC) usually has large stress
- High T anneal (600-1000 ºC) for more than 2 hours relaxes the strain

Low temperature, thin film materials has much less intrinsic stress

6.0 Wafer Bonding For MEMS

Silicon micromachining has limitations in forming complex 3D microstructures in a monolithic format; multichip structures are then proposed for advanced MEMS, in which wafer-to-wafer bonding is critical in the formation . The wafer bonding for MEMS can be categorized into three major types: anodic bonding, intermediate-layer bonding-assisted bonding, and direct bonding.

6.1 Wafer bonding- Anodic

- bring sodium contating glass (Pyrex) and silicon together
- heat to high temperature (200-500 ºC) in vacuum, air or inert ambient
- apply high electric field between the 2 materials (V~1000V) causing mobile + ions to migrate to the cathode leaving behind fixed negative charge at glass/silicon interface
- bonding is complete when current vanishes
- glass and silicon held together by electrostatic attraction between – charge in glass and + charges in silicon

The advantage of anodic bonding for MEMS is that the low temperature used can ensure the metalization layer (aluminum) to withstand this temperature without degradation.

6.2 Intermediate Layer-Assisted Bonding

This type of bonding for MEMS requires an intermediate layer, which can be metal, polymer, solders, glasses, etc., to fulfill the bonding between wafers.

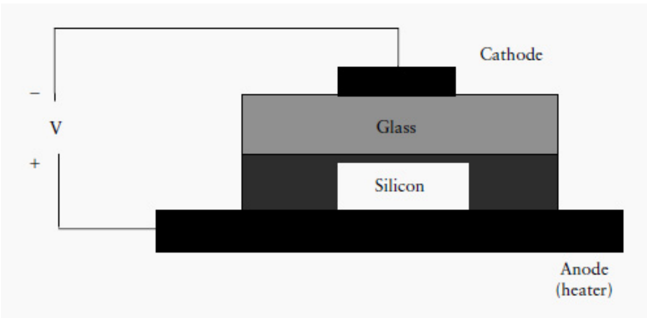

Figure.4: Anodic bonding

7. LIGA Process

7.1 Deep X-ray lithography and mask technology

Deep X-ray (0.01 – 1nm wavelength) lithography can produce high aspect ratios (1 mm high and a lateral resolution of 0.2 µm). X-rays break chemical bonds in the resist; exposed resist is dissolved using wet-etching process (Xia, Y et al. 1998).

7.2Electroforming

The spaces generated by the removal of the irradiated plastic material are filled with metal (e.g. Ni) using electro-deposition process. Precision grinding with diamond slurry-based metal plate used to remove substrate layer/metal layer

7.3 Plastic Molding

Metal mold from LIGA used for injection molding of MEMS structures

LIGA (Lithography,Electroforming,Molding) is a technique that combines X-ray (or synchrotron) lithography electroplating, and molding for fabricating microstructures with high aspect ratios and relatively large feature sizes (- 10 pm). Although the standard equipment for UV exposure can be adapted for this application, special optics and alignment systems are needed for structures thicker than 200 µm.

8. High aspect ratio (HAR) silicon micromachining

Both bulk and surface silicon micromachining are used in the industrial production of sensors, ink-jet nozzles, and other devices. But in many cases the distinction between these two has diminished. A new etching technology, deep reactive-ion etching, has made it possible to combine good performance typical of bulk micromachining with comb structures and in-plane operation typical of surface micromachining (Cohen, A, et al., 1999).While it is common in surface micromachining to have structural layer thickness in the range of 2 µm, in HAR silicon micromachining the thickness can be from 10 to 100 µm (Guckel, H, 1998). The materials commonly used in HAR silicon micromachining are thick polycrystalline silicon, known as epi-poly, and bonded silicon-on-insulator (SOI) wafers although processes for bulk silicon wafer also have been created (SCREAM). Bonding a second wafer by glass frit bonding, anodic bonding or alloy bonding is used to protect the MEMS structures. Integrated circuits are typically not combined with HAR silicon micromachining.

9. Applications

- Inkjet printers, which use piezoelectrics or thermal bubble ejection to deposit ink on paper.
- Accelerometers in modern cars for a large number of purposes including airbag deployment in collisions.
- Accelerometers in consumer electronics devices such as game controllers (Nintendo Wii), personal media players / cell phones (Apple iPhone, various Nokia mobile phone models, various HTC PDA models) and a number of Digital Cameras (various Canon Digital IXUS models). Also used in PCs to park the hard disk head when free-fall is detected, to prevent damage and data loss (Ahn, C H. et al. 1998)
- MEMS gyroscopes used in modern cars and other applications to detect yaw; e.g. to deploy a roll over bar or trigger dynamic stability control.
- Silicon pressure sensors e.g. car tire pressure sensors, and disposable blood pressure sensors.
- Optical switching technology which is used for switching technology and alignment for data communications.
- Bio-MEMS applications in medical and health related technologies from Lab-On-Chip to MicroTotalAnalysis (biosensor, chemosensor).

10. Conclusions

Microfabrication is growing in importance in a wide range of areas outside of microelectronics, including MEMS, microreactors, microanalytical systems and optical devices. Photolithography will continue as the dominant technology in the area of microelectronics for the foreseeable future.

Soft lithography offers a new strategy for microfabrication. Based on self-assembled Monolayers and molding of organic polymers, this set of techniques represents a nonphotolithographic methodology for forming micropatterns, microstructures and microsystems of different materials on a range of substrates.

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