MEMS Fabrication methodology used to Design Non-Invasive Bio-Nano-Sensor to detect Diabetics

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Abstract

MEMS- micro-electro-mechanical-system. MEMS demand is increasing and can be applicable and useful in various domains of life such as Automotive, electronics, Medical, Communication, and Defense. This article is focused on microfabrication process and its use to Design Bio-Nano-sensor to detect blood glucose level

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1. INTRODUCTION

MEMS fabrication methodologies are described in following steps:

1. Photolithography
2. Material for Micromachining
   a. Substrate – use of silicon
   b. Additive films and materials
3. Bulk Micromachining
   a. Wet etching
   b. Dry etching
4. Surface Micromachining
5. HARM
   a. LIGA
   b. LASER micromachining
6. CAD
7. Assembly and system Integration
8. Packaging.

1] Photolithography:

It is photographic technique to convert copies of master pattern i.e circuit layout in IC application onto the surface of substrate. Substrate is a thin film converted with material like silicon dioxide (SiO₂). In case of silicon wafers on which a pattern of holes will be formed as shown in fig[1]- on this oxide layer which is sensitive to UV radiations is deposited called as photoresist. A photo mask, i.e glass plate coated with chromium pattern is placed in contact with photoresist coated surface. Wafer is exposed to UV radiations transferring the pattern on mask to the photoresist which is then developed. Radiation caused in photoresists exposed area are of two types:

   a) Positive photoresists → strengthened by UV radiation and
   b) Negative Photoresists → weakened by UV radiation.

Fig [1]. Photoresist and silicon dioxide patterns following photolithography [1].
On developing, the rinsing solution removes either the exposed area or unexposed area of photosites leaving pattern bare. The resultant is either positive or negative image of original pattern. HCL acid is used the pattern serves as a mask for processing steps.

2) Material for Micromachining

a) Substrate: -

Silicon is used as substrate widely used because:

1. Silicon is found in plenty amount, less costly and
2. Its ability to be deposited in thin films is very amenable to MEMS
3. High definition and reproduction of silicon device shapes using photolithography are perfect for high levels of MEMS precision.
4. Silicon microelectronics are batch fabricated.

Other materials semiconductors like fermanium(Ge), Gallium arsenide(GaAs) are used and non-semiconductor- like metals, glasses, quartz, crystalline, insulators, ceramics, and polymers are used.

a) Aditive films and materials:

- silicon - single crystal, polycrystalline and amorphous
- silicon compounds (SixNy, SiO2, SiC etc.)
- metals and metallic compounds (Au, Cu, Al, ZnO, GaAs, IrOx, CdS)
- ceramics (Al203 and more complex ceramic compounds)
- organics (diamond, polymers, enzymes, antibodies, DNA etc.) [2]

3) Bulk Micromachining

It involves elimination of bulk substrate generally considered as a subtractive process that uses Wet etching method or dry etching method. Such as ion etching (RIE) to create large pits, grooves and channels.

a) Wet Etching:

It uses silicon and quartz material. It can be considered the removal of material through immersion of a material like silicon wafer in liquid bath chemical etchant. Etchant can be anisotropic or isotropic.

I) Isotropic Etchant:

It etch the material at same rate in every direction. This is called undercutting as shown in fig[2-a] and fig[2-b]. HNA mixture of hydrofluoric acid(HF),Nictic acid(HNO3) and acetic acid(CH3COOH)[2][c]

II) Anisotropic Etchant:

Etched at particular refered direction and potassium hydroxide(KOH) is used and its safe too. As shown in fig[2-c]and fig[2-d].[3][c]

Fig [2]. Isotropic etching with (a) and without (b) agitation, and anisotropic wet etching of (100) and (110) silicon (c and d respectively) [3]

b) Dry Etching:

It relies on vapour phase or plasma based method of etching. The commonly used MEMS is RIE which uses additional energy i.e RF power for chemical reaction. Because of which etching carried out in room temperature or lower temperature above 1000OC

Deep Reactive Ion etching (DRIE) is Higher aspects ratio etching method shown in fig: [3]. [4, 5]
4) Surface Micromachining:
Next level to substrate is considered as base layer. Surface micromachining is layer next to substrate. Materials are added to substrate in form of thin films. These layers are structural layers / acts as spacers; removed after words they are known sacrificial layers. Hence the process contains two different materials;
   i) A structural Material: from this free standing structure is made like polycrystalline si, polysilicon, aluminum …
   ii) Sacrificial Material: deposited wherever open area/ free standing mechanical structure is needed like oxide is usually used for deposition.
The success depends on above two steps which give correct behavior and reliable fabrication MEMS. This is called stiction. Stiction is defined as structural element either to substrate or adjacent elements. Levels of complexity MEMS is shown in fig [4].In order for complex and larger MEMS structures, micro machined silicon wafer can be bonded with other material; this process is called as Fusion Bonding.

![Fusion Bonded Layer](image)

Fig [4]. Formation of sealed cavity using fusion bonding

5) HARM- High-Aspects-Ratio-Micromachining:-
It considers micromaching as a tooling step after injection moulding or embossing if required by electroforming to replicate microstructure in metal. This contains LIGA techniques. LIGA – a german acronym from Lithographie, Galvanoformung, abformung translated as Lithography, electroforming and mouldingsjown in fig [5].

![LIGA Process](image)

Fig[5]. The LIGA process

a) LIGA:
This techiques contains X-ray synchrotron radiation to expose thick acrylic resist of PMMA under lithograhic Mask. The exposed area ac chemically dissolved and in area material is removed( electroformed metals), then definning the tools insert for next moulding steps i.e making microstructures upto to 1000 micrometer high. Little modification. i.e. X-ray synchrotron facility combines LIGA features and surface micromachining removing the need for exposure to x-ray been developed and called as SLIGA i.e Scarificial LIGA[6]
Other techiques like LASE ablation, UV lithography, and mechanical micromachining which will contain electric discharge machining EDM and Diamond milling.

b)LASER Micromachining
As LASER Micromaching processes are not parallel and not fast enough, for MEMS fabrication it is not considered.

6) Computed Aided design(CAD)
CAD is used for designing of photolithographic mask, mask design, CAD and finite element Analysis (FEA) are important simulation tools for design of MEMS application.the draw back is- no adequate software availlble till date to design tools to fully model, analyse, and simulate MEMS microstructures. Some examples of software present are
   a) MEMCAD- system give layout and process, 3-D geometry, anlyze performance, sensitivity to manufacturing and design variations
   b)MEMS Pro- to simulate growth / deposition, implantation/ diffusion and etchsteps in MEMS fabrication process.
   c)Intellisuite- Simulate design, 1-D, 2-D,3-D geometry shaped, performances……
   d) Conventor- just similar to Intellisuite
e) COMSOL Multiphysics – it is tool which provides an excellent platform that allows us to examine all physics within one easy-to-use environment and optimize system operation before we start building prototypes. This provides simulation environment facilitates all the steps of modelling process.

Defining geometry
Meshing
Specifying required physics
Solving
Then visualizing results

As COMSOL Multiphysics offers – a single, integrated solution than can address the widest range of application. Even designing a nano-bio-sensor for medical detection, diagnosis purpose.[7]

Hence for this research topic” COMSOL Multiphysics” tool is selected to serve the purpose to detect level of glucose in blood.

7] Assembly and System Integration:
Fig[6] depicts the same procedure used to fabricate MEMS and IC’s.

but to create MEMS the most challenging fact is the integration between miniature mechanical system and electronic interface to have effective production of MEMS device it is needed to integrate the complex mechanical structures with microelectronics- electrical system on a single chip shown in fig[7].

For example: airbag accelerometerfig[8] and disposable blood pressure sensor fig[9]. benefits of integration is done then they are smaller, faster, less costly, inexpensive, low power consumption, and highly sensitive system.

Fig[8] Analog Devices – 1993 Saab was the first automobile company to include MEMS accelerometers to trigger airbags.[8]

Fig[9]-Disposable sensors use MEMS transducers to measure changes in blood pressure. Photo courtesy of Motorola, Sensor Products Div., Phoenix, AZ.
8] Packaging:
It is important phase because operations of MEMS depend on this phase only. Various problems are faced depicted in fig [10],[9]

![Packaging](image)

Fig [10]. Schematic illustration of the packaging role of a MEMS micro sensor [9].

Package should:

a) Provide protection and be robust to its operating environment
b) Allow for environmental access and connections to physical Domain (Optical fibers, fluid feed lines etc.)
c) Minimize electrical interference effects from inside and outside device
d) Dissipate the heat with land high operating temperature as needed
e) Minimize stress from external loading…. Etc

Designing Bionanosensor by using above steps:

![Layer Structure](image)

Fig [11] Schematic diagrams of layer structure of the MEMS based Ultrasonic Transducer

Use of COMSOL 4.3a software is used. using an ultrasonic transducer, the glucose levels of human blood can be determined. MEMS based acoustic biosensing transducer is based on the piezoelectric technology which exploits the nature and properties of the propagating ultrasonic wave in blood medium of various densities. The biologically sensitive elements are combined with physical transducer to make biosensors, which are mostly used as analytical devices. This is done to discern specific compounds from a biological environment. Using an ultrasonic transducer with which the glucose levels of humans can be determined by studying the variation of amplitude with density of blood sample with glucose and it can be calibrated and compared to determine the sugar level. Piezoelectric materials are employed because they offer a high pressure per density ratio for the actuator, high stability in hostile environment and chemically they are very stable. For making ultrasonic transducers and piezoelectric actuators, it is desirable to have high electromechanical coupling coefficients, relatively large dielectric constant and large piezoelectric coefficient [10]. Large electromechanical coupling coefficient makes the transducer to achieve a broader bandwidth, whereas, larger dielectric constant makes the electric impedance matching between the transducer and its driving power supply easier for small sized transducers, such as MEMS [11].

Fabrication process of ultrasonic transducer MEMS
In general, MEMS based Ultrasonic Transducer is fabricated using surface micromachining technology, processing is done on the surface of the silicon wafer by means of thin-film depositions, thin-film etching, and photolithography. The design, modeling with process fabrication of piezoelectric micro-machined ultrasonic transducers. [12] The possible layer structure of MEMS based ultrasonic transducer is shown in Fig [11]. The micro electronic circuit layer just below the substrate is the circuit that would be employed for supplying the input and interprets the output for this study. This microelectronic layer is fabricated separately and assembled using the layer bonding technique. [13]

Conclusion:
In this article a detail procedure of for MEMS based fabrication methodology is given. Simultaneously a Design for Bio-Nano-sensor is illustrated which is non invasive in nature to detect Diabetics. Still work is currently carried out to give better performed results

References

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