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ASURVEYONMEMSFABRICATIONTECHNOLOGY

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***Abstract*-MicroelectronicMechanicalSystems(MEMS)isthetechnology which enables greater power and supreme complexity in asmall,singlesystem.MEMStechnologyisessentiallyverymicromachines ,miniature mechanical devices driven by electricity.MEMSdevices combineelectroniccircuitrywith mechanical structures toproduce different results. These devices are created with silicon chipsusingwell-established,very-large-scaleintegrationandcomplementarymetal-oxidesemiconductor(CMOS)foundryprocesses. In this paper many fabrication techniques and applicationsof MEMS are discussed in order to integrate number of operations ina singlesystem.**

Keywords-
MEMS,Bulkmicromachining,SufacemicromachininfHifhaspectratio,LIGA..

I.INTRODUCTION

MEMS and nanotechnology are the two terms thatdealswithmicrominiaturizedobjects,whichareentirelydifferent.TheMEMStechnologydealswiththeinventingdevicesthatarecalculatedinmicrometers,whereasnanotechnology deals with manipulating atoms at the nanometerlevel. The one main criterion of MEMS is that there are someelementshavingsometypeofmechanicalfunctionalitywhethe rornottheseelementscanmove.ThetermusedtodefineMEMSwhichvariesindifferentpartsoftheworld.IntheUnitedStatesthey are usually called as MEMS, while in other parts of theworld they are called “Microsystems Technology” or “micromacheineddevices”.

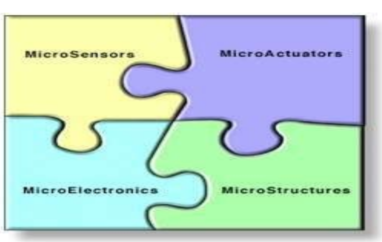


Fig1:componentsofMEMS

The functional components of MEMS are microstructures, microsensors,microactuators,andmicroelectronics[18].Themostimportantelementsarethemicrosensorsandmicroactuators.Microsensorsandmicroactuatorsarecategorizedas“transducers”, which converts energy from one form to another.Whereasmicrosensorsaretheonethatconvertsameasuredmechanical signal into an electrical signal. From past few years,many of the researchers and developers have demonstrated largenumberofmicrosensorsforeverypossiblesensingmodalitywhichincludesvariousparameterssuchas,temperature,pressure,inertial forces, chemical species, magnetic fields, radiation, andmany more. Noticeably, many of these micro machined sensorshave excellently demonstrated performances exceeding those oftheir macroscale counterparts. For example, the micromachinedversion of a pressure transducer usually outperforms a pressuresensor made using the most accurate macroscale level machiningtechniques. There is not only the performance of MEMS devicesexceptional, but their method of production leverages the samebatch fabrication techniques utilised in the IC industry – that cantranslate into low per-device production costs, and many otheradvantages.Itisnotonlypossibletoachievestellardeviceperformance, but to do so at a relatively low cost level. Notsurprisingly, silicon based discrete microsensors were quicklycommerciallyexploitedandthemarketsforthesedevicescontinuetogrowat aexponentialrate.

Theexistingliteraturecontainsseveralreviewsofimportanttechnologies for thefabrication of MEMS(by BruceK et al 7, Hongyi Yang et al 8 and Kenichi Takahata 9).SeveralreviewarticlesonfabricationtechnologiesforMEMShavealsobeenpublished20-25.

Incontrasttopreviouswork,thepresentpaperprovidesa comprehensive,up-to-date overview and comparison of theavailabletechnologiesforfabricationofMEMS.EstablishedandemergingtechnologiesforthefabricationofMEMSarereviewed, analyzed and categorized in a coherent manner, andtheapplications ofMEMSproductsisdiscussed.

MEMSFabricationTechniques

MEMS fabrication is an exciting endeavor due to the customizednature of process technologies and the extremely diversity ofprocessing capabilities. Nowadays, many fabrication techniquesareused.Basicallyto fabricateaMEMSdevicemorethanoneofthese techniques is used[18]. The three important features thatmustbeconsideredin MEMSfabrication techniquesare:

1. Miniaturization – The miniaturization allows the fabrication ofcompact and quick response devices. It is one of the trend tomanufactureeversmallermechanical,opticalandelectronicprodu cts and devices. It is also way to improvise the heat andmasstransferbytwocombinedeffects.Oneofthemisthediffusion distance within the reactor is much lower and anothereffect is the interfacial area per unit reactor volume is larger. Theminiaturization of mobile phones, computers and vehicle enginedownsizing aresomeof theexamples.

Miniaturization of the physical systems is not only justscalingdowndevicecomponentsinsizes.Somephysicalsystems either cannot be scaled down easily, or cannot be scaled down atall.Thusforanengineer,Scalinglawsbecometheveryfirstthingthat would do in the design of MEMS and Microsystems. One ofthe types of Scaling law is, Scaling in Geometry i.e., the scalingofphysical sizeofobjects andthesecondlawis scalingofPhenomenologicalBehaviouri.e.,scalingofbothsizeandm aterialcharacterizations.

2. Multiplicity – The multiplicity is the ability of the fabricationtechniques, inherent in semiconductor processes, that results inthousands ormillions ofunits concurrently.Multiplicity alsocalledasbatchfabricationinherentinphotolithographic-basedMEMSprocessing,isasimportantasminiaturization.Itprovide stwo major advantages to electromechanical devices and systems.Multiplicitymakesitpossibletofabricatetenthousand oramillion MEMS ccomponents as easily and quickly as one.Thesecond,equallyimportantadvantageofmultiplicityisthefle xibility in the design of massively parallel, combined withelectromechanical systems. This multiplicity characteristic hasalready been exploited in the development and demonstration ofa digital micromirror display. In an array about the size of twopostage stamps, over a million mirrors-each the size of a whitebloodcell-collectivelygenerateacomplete,high-resolutionvideoimage.

***3.* Microelectronics-** The microelectronics refers to provide themerger of sensors, actuators and logic in a unit, so that feedback(intelligent) mechanisms canbeimplements. Thus, eithertheminiaturizationorthemultiplicitycharacteristicsofMEMS couldnotbecompletelyexploitedwithoutmicroelectronics.Themicr oelectronics with MEMS devices results in the latter withintelligence and allows closed-loop feedback systems, localizedsignalactuatorarrays.Theremarkableinvestmentthathasb een made into microelectronics materials andprocessing, and theexpertise built up in this field, is helping the development ofMEMSdevices.

TofabricateMEMScombinethefirsttwofeatures,bothinheritedfrom the semiconductor IC(integrated circuit) domain such asoxidation, diffusion, ion implantation, LPCVD, sputtering, etc.,withasophisticatedmicromachiningprocesses.Someofthetech niquesarediscussed below.

A) ICFabrication

MEMSfabricationisdevelopedfromICfabrication.AsICfabrication technology is having many advantages like low cost,high reliability and performance, these techniques and materialsare implemented in MEMS fabrication[16]. This process is theusual technique which is used to manufacture typical integratedcircuits. The IC fabrication consists in the application of thefollowing steps, normally many times during the manufacturing.Theprocessbeginswithapolishedsilicon–thesubstrate-waferthatundergoesthese steps.

- **Thinfilmgrowth**.Tobuildactiveandpassivecomponents, athinfilmisneededtobedepositedonthewafer. The type of film may includes epitaxial silicon,silicondioxide(SiO_2),siliconnitride(Si_3N_4)polys ilicon,ametal andothers.

- **Doping**. To control the conductivity of the wafer atdifferent locations, impurities like boron, phosphorous,etc.willbeaddedbythermaldepositionorioni mplantation.
- **Lithography and etching**. Using masks designed toproducecertainpatternsonthewaferandusingaphotosens itive chemical called photo resist a pattern isgeneratedandtransferredtothewafer.Thephotolithograp hymethodisusedtoeitheraddimpuritiesor to etch the wafer in selected locations. The Etching isa process which is used to selectively remove unwantedregions of the thin film or substrate in order to delineateand shape the components. There are two modalities ofetching:wet anddryetching.

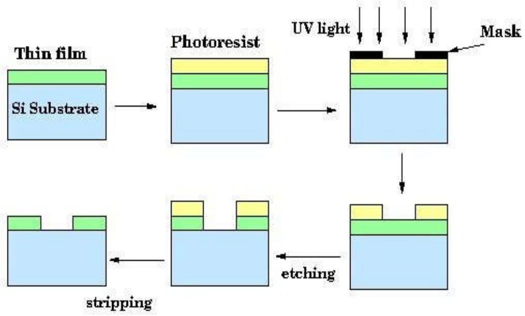


Figure2:showsthemainstepsof theICfabricationprocess.

TheMEMS fabricationis still differentfromIC fabricationatsomeaspects.Theyare:

1. Unconventional Materials – The MEMS fabrication includesmany varietyof materials. Other than conventional materials usedin IC fabrication, MEMS fabrication uses other materials also.MEMS fabrication can also be made from quartz, ceramics, andpolyamideetc.

2. LackofStandardProcesses- ICfabricationshavesomecertainstandard processes, that can be used to implement all kinds ofcircuit functions. For example, by using the bulk micromachiningmethod,pressuresensorsandinkjetprintingnozzles arefabricated, and by using the surface micromachining method,airbagaccelerometersandmicromirrorprojectionarraysare fabricated. As of now there is no library of design rules availableforMEMS

3. FeatureSize- TheFeaturesizeofMEMSfabricationisusuallylarger than IC fabrication. Thus when IC fabrication feature sizehasbeenshrinkedto25nm,thesmallestfeaturesofMEMSdevices are still in 0.5um to 1um range. This leads to cheapermaskcostwhencomparedtoICfabrication.

4. MechanicalProperties- MEMSfabricationconsidersthemechanicalpropertieslikeresiduest ress,density,young'smodulusetc.muchmorethanICfabrication.Be causetheneedofMEMSfabricationis tomakemicromachines, wemore careabouttheirmechanicalproperties,specificallyformaterialformi ng the structures. The properties include Young's modulus,yield strength, density, residual stress and stress gradients, andlong termstabilityofthese properties.

5. Unique Unit Processes - MEMS fabrication inherits many ofunit processes from IC fabrication, however, it also has somespecificrequirements.MEMSfabricationutilizesthesamephot olithography, wet and dry etch, oxidation, diffusion, LPCVD,andsputterdepositionsameasICfabrication.Forimprovisin g mechanical performance like high sensitivity and better signal tonoise ratio, MEMS fabrication needs much deeper etch, and muchthicker depositionofmaterials (high aspectratio).

6. LessLayers– WhencomparedtotheICfabrication,numberoflayers in MEMS fabrication is usually less. Some of the MEMSprocessescanbemuchsimplerthantheICfabrication.Thisisd uetotheinterconnectionneedinMEMS deviceislessthan IC.

7. Front/Back Side Processing – Someof the MEMS devices needtobeprocessedonbothfrontsideandbacksidewhileICfabricatio n is focused on one side of the wafer. For example, thePressuresensorneedsetchingonthebacksidetomakecavityandm embraneanddopingonthefrontsidetobuildthepiezoresistorson the membrane, and the front-backside process alignment isrequired.

8. MEMSPackageStress– TheThermalandmechanicalpropertiesofpackagearethetwoimport antparameterstoMEMSfabrication. The package stress can leads to the deflection andstress. MEMS structures and therefore change the device behaviorwhile IC is less affected by mechanical stress. There are alsodifferencesinMEMSpackaging,whether wafer-ordie-level.

9. Severalordersofmagnitudedifferenceinwafervolume

10. Qualification of Process After process and design lockdown,to transition to volume production, the process must be qualifiedbyStatisticalQualityControl&StatisticalProcessControl,(SQC/SPC)implementation.

TofabricateMEMS,wementionthisbefore;alongwiththebasicIC fabrication methods, it is needed to add a micromachiningprocess involving the selective removal of silicon or the additionofotherstructurallayers.Someofthewidelyusedmicromach iningmethods arediscussed below.

MEMSfabricationtechniques

1. **Bulkmicromachining**
2. **Surfacemicromachining**
3. **WaferBonding**
4. **Highaspectratio MEMSfabricationtechniques**
    a. **DeepreactiveionetchingofSilicon**
    b. **Deepreactiveionetchingofglass**
    c. **LIGA**
    d. **Hotembossing**

5. **LowcostMEMSfabricationbyInjectionMolding**

1. BULKMICROMACHINING

The oldest micromachining technology is bulk micromachining.This technique is used to selectively remove substrate to shapemechanical components. It can be accomplished using chemical(wet etch) or physical means (dry etch), with chemical meansbeing far more widely used in the MEMS industry as it canprovidehighselectivityandhighetchrate.[20]Bysimplychangin g the chemical composition of the etching liquid, theselectivity andetchratecanbe altered.

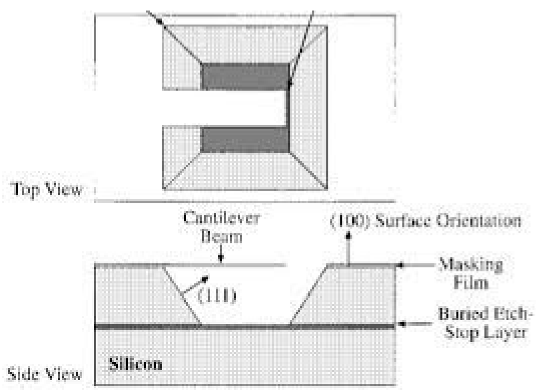


Fig3:BulkMicromachiningTechnique

StepsofMEMsFabricationusingBulkMicromachining:

1. Circuitdesigning

The first step involves the circuit design and drawing of the circuitusing software like PSpiceorProteus.

2. Simulation

Thesecondstepinvolvesthesimulationofthecircuitandmodeling using CAD (Computer-Aided Design) which is used todesign the photolithographic mask which consists of the glassplatecoatedwith chromiumpattern.

3. Photolithography

Third step involves photolithography. In this step, a thin film ofinsulating material like Silicon Dioxide is coated on the siliconsubstrate, and over this, another layer called organic layer whichissensitiveto UVraysisdepositedusingspincoatingtechnique. Then the photolithographic mask is placed in contact with theorganic layer. The whole wafer is then subjected to ultravioletradiation, which allows the pattern mask to be transferred to theorganiclayer.Theuncoveredoxideontheexposedphotoresistisre moved using HCl acid. The remaining photo resist is removedusing hot Sulphuric acid and the resultant is an oxide pattern onthesubstrate,whichisusedasamask.

4. Etching

Afterphotolithographythis stepinvolvestheremovaloftheunused silicon or etching. This step involves the removal of a bulkofthesubstrateusingeitherwetetchingordry etching.

In wet etching, the substrate is immersed in a liquid solution of achemicaletchant,whichetchesoutorremovestheexposedsubstrate either equally in all directions (isotropic etchant) or aparticular direction(anisotropicetchant).

So, there are two types of wet etching in bulk micromachining:isotropicwetetchingandanisotropicwetetching.In isotropicwetetching, the etch rate is not dependent on the crystallographicorientationofthesubstrateandtheetchingproceedse quallyinalldirection. The isotropic wet etching is almost always performedwith vigorous stirring of the etchant solution. Commonly usedetchants are HNA (Hydrofluoric acid, Nitric acid, and Aceticacid)andKOH(Potassium Hydroxide).

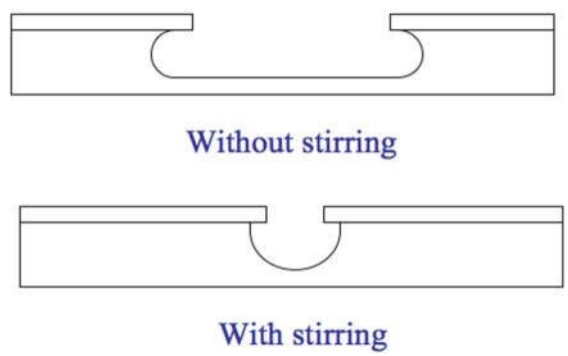


Figure4:representationofetchprofile,withandwithoutstirring, using anisotropicwetchemicaletchant

Franssila S , has described that ,for all etching process it requiresa masking material to be used, with preferably a high selectivityrelativetothesubstratematerial.Forisotropicwetsiliconet chingcommonlyusedmaskingmaterialincludesilicondioxideand silicon nitride.The frequently used masking material is siliconnitrideasithavingloweretchrate.

The substrate material's dopant concentration is controlled byTheetchrateofsomeisotropicwetetchantsolutionmixtures.Forexample: the commonly used mixture of HC2H3O2:HNO3: HFintheratioof8:3:1willetchhighlydopedsilicon(>5x1018atoms/cm3) at a rate of 50 to 200 microns/hour. Theetchrateselectivitywithrespecttodopantconcentrationisdependentonsolutionmixture.

Figure 5 below is an illustration of some of the shapes that arepossible using anisotropic wet etching of <100> oriented siliconsubstrates including an inverted pyramidal and a flat bottomedtrapezoidal etch pit. The shape of the etch pattern is primarilydetermined by the slower etching <111> planes. Figures 5a and5bareSEMphotographsofasiliconsubstrateafterananisotropic wet etching. Figure 5a shows a trapezoidal etch pit that has beensubsequently diced across the etch pit and Figure 5b shows thebackside of a thin membrane that could be used to make a pressuresensor. It is important to note that the etch profiles shown in theFigures are only for a <100> oriented silicon wafer; substrateswithothercrystallographicorientationswillexhibitdifferentshapes. Occasionally, substrates with other orientations are usedinMEMSfabrication,butgiventhecost,leadtimesandavailability,thevastmajorityofsubstratesusedinbulkmicromachininghave<100>orientation

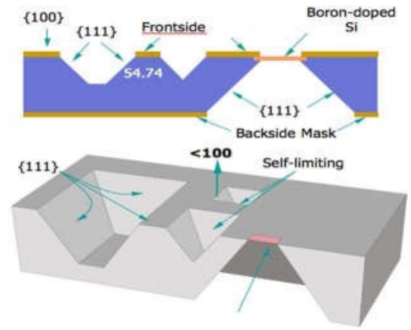
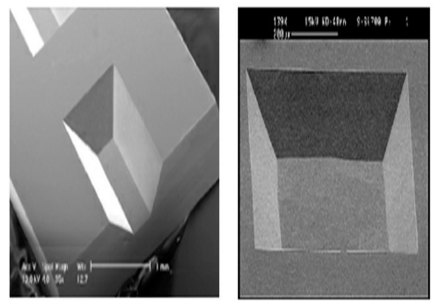


Figure5:Illustrationofshapeoftheetchprofilesofa <100>orientedsiliconsubstrateafterimersioninananisotropic wetetchant solution



Figures 5a and 5b: SEMS of a <100> oriented siliconsubstrateafterimmersioninananisotropicwetetchant.

Etchant	Etchrate (110) µm/min	AR {100}/{111}	EtchMasks	Etchstop	Maincharacteristics
KOH	1,4	400	Si_3N_4,SiO_2	B>10^{20}/cm^3	Fastest, greatestselectivity,makes verticalsidewalls
EDP	1,25	35	SiO_2,Si_3N_4, Ta,Au,Cr,Ag,Cu	B~7×10^{19}/cm^3	Lotsofmasks, lowestBorondopingetchstop,lowAR
TMAH	1	30	Si_3N_4	B~4×10^{20}/cm^3	Smoothsurface, slowetchrate,lowAR

Table1. Basicpropertiesofcommonanisotropicetchants

5. Multiplayerwaferformation

In this step , to produce a multilayered wafer or a 3D structure,there is a necessity of joining two or more wafers. To form thisstructure, fusion bonding is used. The fusion bonding involvesdirectbondingbetween thelayersorby using anodicbonding.

Figure6. Waferbonding

1. SURFACEMICROMACHINING

The surface micromachining is a popular technology which isused to construct the structural components for MEMS usingthin film layers. The bulk micromaching process builds thecomponentswithinasubstratewhereas,surfacemicromachining builds on top of the substrate[32]. This involves a sequence ofstepsasshownbelow.

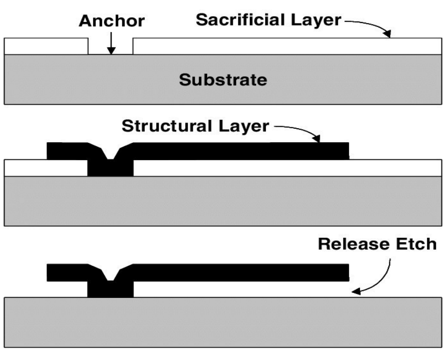


Fig7:Surfacemicromachiningprocess

ManufacturingofCantileverStructureusingSurfaceMicromachining

The first step involves the deposition of thin-film material to actas a temporary mechanical layer onto which the actual devicelayers are built; using a low-pressure chemical vapour depositiontechnique.Thislayerprovideselectricalisolationwhichis asacrificiallayer.

The second step involves the deposition and patterning of thethin-film device layer of material which is referred to as thestructural layer; which can be a phosphor silicate glass, used toprovidea structuralbase.

Thethirdstepinvolvesetchingofthelayerusingthedryetchingtechnique.Dry etchingtechniquecanbereactiveion etching.

T**hefourthstep**involvesthechemicaldepositionofphosphorus-dopedpolysilicontoformthestructural layer.

Thefifthstepinvolvesdryetchingorremovalofthetemporary

layertoreleasethemechanicalstructurelayerfromtheconstraintofthe underlyinglayer

The sixth step forms the required structure by removing the oxidelayer andspacerlayer.

An illustration of a surface micromachining process is shown inFigure 8. In the figure shown an oxide layer is deposited andpatterned where this oxide layer is temporary and is commonlycalled as the sacrificial layer. Subsequently, a thin film layer ofpolysilicon [33] is deposited and patterned and this layer is thestructural mechanical layer. Now the polysilicon layer is free tomove asacantileverbyremoving the sacrificiallayer.

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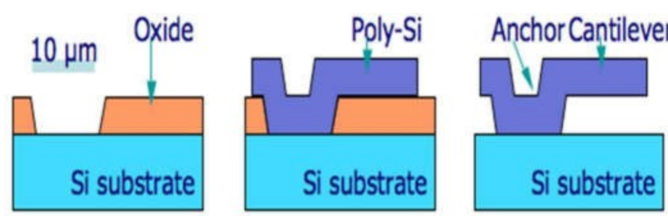


Figure8:Illustrationofasurfacemicromachiningprocess.

The PSG sacrificial layer is most commonly used for surfacemicromaching and material combination. To release this deviceandtoremovethePSGsacrificiallayer,Hydrofluoricacidisused as an etchant. In the deployment of crash airbag, the analogdevices integrated with MEMS accelerometer device is used forthefabricationbyusingtheprocesscalledsurfacemicromachining. The SEMs images of two surface micro machinedpolysiliconMEMSdeviceareasshown infigure9 and10.

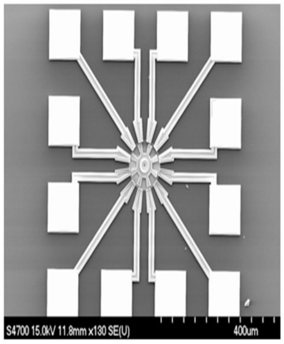


Figure 9: Polysilicon micromotor fabricated using asurfacemicromachiningprocess.

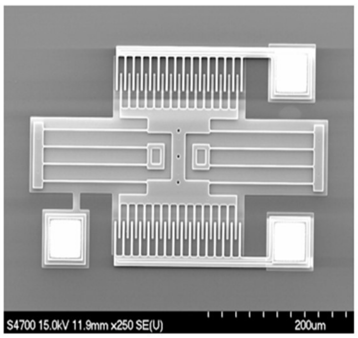


Figure10:Polysiliconresonatorstructurefabricatedusingasurfacemicromachiningprocess

Thefigure11illustratespolysiliconsurfacemicromachiningprocess.Thecomplexityofthesurfacemachining process is determined by the number of structuralandsacrificiallayers.[33]Twostructurallayersallowformation of free moving mechanical gears, springs, sliders,etc. The main advantage of surface micromachining over bulkmicromachining is that many different devices can be realizedusing common fabrication process. By changing patterns on thephotomasklayoutsdifferentdevicesarebeingfabricatedsimultaneously on the same substrate. For that reason, thesurface micromachining process is often referred to as an ICprocess that allows formation of multilayer structures usuallywithtwotofivepolysiliconlevels.

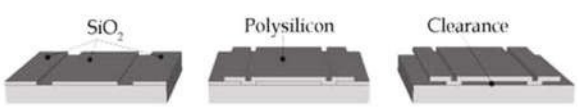


Figure11. PolysiliconsurfacemicromachiningOften,itis

desirabletofabricatestructuresthickerthan those achievable using polysilicon. An alternativemicromachiningprocessuseslithographicexposureofthick photoresist, followed by electroplating to build on chip highaspect ratio 3D structures. In the LIGA(lithography, electroplating and molding) process synchrotron radiation is used asthe exposure source that can achieve feature heights of the orderof500µm.cheaperalternativesuseexcimerlasersorUVmask alignersthatachievefeatureheightsoftheorderof200µmand20µm, respectively. Parts are usually plated in nickel afterremoval of the resist as illustrated in Figure 12.The releasedmetal layer can be used in various applications including opticalMEMSdevices.

Thepolysiliconsurfacemicromachining processisasdepictedinfigure 11. By knowing the number of structural and sacrificiallayers, the complexity of surface machining is determined [33].Byusingthecommonfabricationprocess,manydifferentdevicescanberealized.Thisisthemainadvantageofsurfacemicromaching over bulk micromachining. The different devicesare fabricated simultaneously on the same substrate, by changingthepatternsonthephotomasklayouts.Thussurfacemicromachiningmethodissimilar to thatofICfabricationmethod.

For optical MEMS devices, and many more other applications thereleased metal layer can be used. The figure 12, illustrates thepartsthatareusuallyplatedinnickelafterremovaloftheresist.

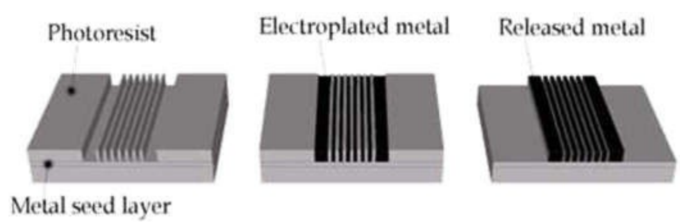


Figure12. Metalmicromachining

Based on BSOI i.e., bonded silicon on insulator standards,more reproducible properties than polysilicon are formed byusing suspended single crystal Si structures, with lower stress.By thermal process, Si wafer is bonded to an oxidized Sisubstrate. Figure 13 shows, the bonded layer which is structuredbybdeep reactive ion etching which has high etch rates andanisotropy to form very deep features with almost verticalsidewalls. And by removing the buried oxide , movable partscanbemade.

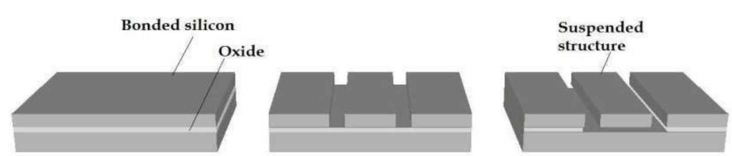


Figure13. Deepreactiveionetching(DRIE)ofbondedsilicon-on-insulator(BSOI)

The Si micro molding techniques allows DRIE such asHexSil process, to be developed. These Trenches are of afraction of millimeter deep. To fill these trenches, a sacrificialoxide layer is deposited that is followed by the polysiliconstructural layer. By releasing the polysilicon, deep suspendedstructuresaremadeasshownin Figure14.

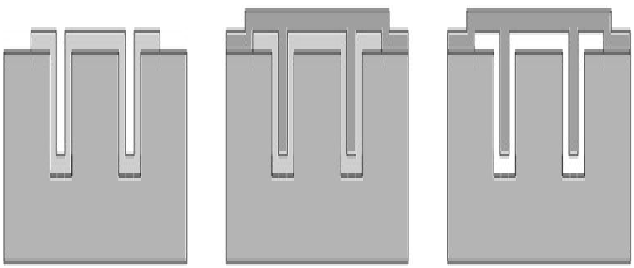
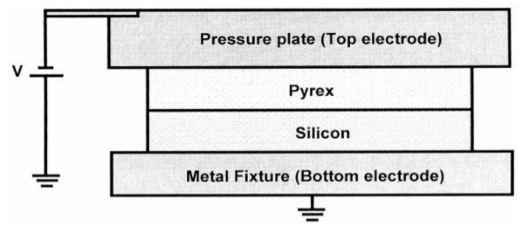


Figure14. HexSilprocess

1. **WAFERBONDING**

TheresearcherZhengCui,hasexplainedthat,Waferbondingisatechniqueofadheringtwomirror-polishedwafersofanymaterialsatroom temperaturewithoutapplyinganymacroscopicgluing layer or external force. The bonding is achieved throughVander Waals force. When compared to metal bondingcovalentlyorironicallybondsolids,Waferbondingachieved atroomtemperature is usually relatively weak. Thus heat treatment ofbonded wafers is the best solution to strengthen the bonds acrossthe interface. Thus Wafer bonding is a micromachining methodthat is analogous to welding in the macro scale world and involvesthe joining of two (or more) wafers together to create a multi-wafer stack.

K.N Bhat et al has said that, this technique play a key role in thepresentdaysiliconbulkmicromachiningforMEMSbasedsensors andactuators.Alongwiththewetordryetchingtechniques,thewaferbondingtechniquecanbeusedtorealize(1)themembranesofthickness whichwillbediffersfrommicronstoseveralmicrons,thatisapplicableforpressuresensors,(2)complicated3Dstructuresforaccelerometersand(3)multilayereddevicestructuressuchasmicropumpformicro fluidicandbiomedicalapplications,and(4)withtheLIGAprocessthat cancompetehighaspect ratiostructures



Basically thereare3 types ofbonding:director fusionbonding; field-assisted or anodic bonding; and bonding using an intermediate layer. Inorder to be the wafer bonding successful and free of voids allbondingmethodsrequiresubstratesthatareveryflat,smooth,andclean. The general process of the wafer bonding follows a threestep sequence,andconsist of surface preparation, contacting andannealing,even though the process conditions used for all thethreebondingtechniquesvary.Withahighcontentofsodium,anodic bonding involves bonding a silicon wafer and aglass wafer. By applying a high voltage in the range 500 -1000 Vand temperature maintainedaround450°C,

theanodicbondingiscarriedout,andtoattractNA+ions tothenegativeelectrodewherethey areneutralized

Fig15:Silicon–glassanodicbondingarrangement

Asiliconwaferis bondedtoaPyrex7740waferinanodicbonding, using an electric field and elevated temperature prior tobonding.Thetwowaferscanbepre-processedandcanbealignedduringthebondingprocedure.Pyrex7740hasahighconcentrationofNa+ions,thisisthemechanismbywhichanodicbondingworks.Thenegativechargeatglasssurfaceiscreatedby applying a positive voltage to the silicon wafer which drives theNa+ ions from the Pyrex glass surface. The Anodic bonding is awidely usedtechniqueforMEMSpackaging.

2. *HIGH-ASPECT RATIO MEMS FABRICATIONTECHNOLOGIES*

a. ***DeepReactiveIonEtchingofSilicon***

The Deep reactive ion etching or DRIE is a new fabricationtechnologythathasbeenwidelyadoptedbytheMEMS.Forsilicon substrates this technology enables very high aspect ratioetches. The depth of the etch on the sidewalls can range fromhundreds to thousands of microns into the silicon surface andetched holes arenearlyvertical[28].

Toalternatelyetchthesiliconanddepositanetchresistantpolymer layer on the sidewalls,the etchant of dry, high densityplasma etch is used. On the sidewalls as well as on the bottom ofthe etch pit, the protective polymer layer is deposited but theanisotropy of an etch removes the polymer at the bottom of theetch pit. DRIE systems are single wafer tools. For DRIE etchingPhotoresist can be used as a masking layer [29]. The selectivitywith photoresist is about 75 to 1and oxide is about 150 to 1. Duetoloadingeffectsinthesystem,withlargerexposedareasetchingat a much faster rate compared to smaller exposed areas theprocessrecipedependsontheamountofexposedsilicon.

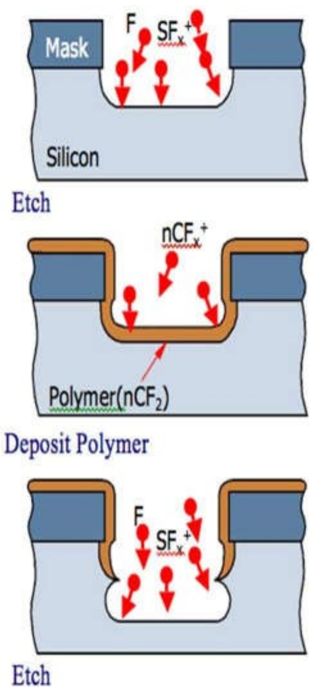


Figure16:Illustrationofhowdeepreactiveionetchingworks

Figure 17 is a SEM of a MEMS component fabricated usingDRIE and wafer bonding. This device was made using an SOIwafer wherein a backside etch was performed through the handlewafer, stopping on the buried oxide layer, and a front side DRIEwasperformedontheSOIdevicelayer.Toreleasethemicrostructure to freely move, the buried oxide was removed.Figure 18 uses DRIE technology which is a cross section SEM ofasiliconmicrostructurefabricated

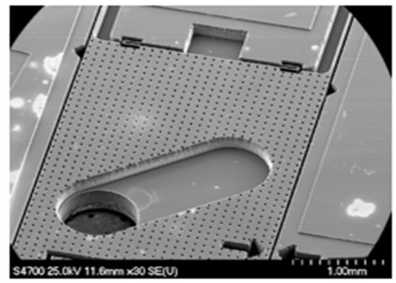


Figure17:SEMofaMEMSdevicefabricatedusingtwosidedDRIE etchingtechnologyon anSOIwafer.

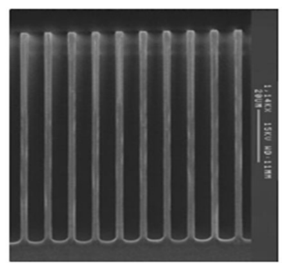


Figure 18: SEM of the cross section of a silicon waferdemonstratinghigh-aspectratioanddeeptrenchesthatcanbefabricatedusingDRIEtechnology.

a. **DeepReactiveIonEtchingof Glass**

ThistechnologyhasbeengaininginpopularityinMEMSfabrication with high aspect ratios for Glass substrates which canalsobeetcheddeepintothematerial.Theetchingrangeisbetween 250 and 500 nm per minute for high aspect ratio glass.The metal or a polysilicon can be used as a mask depending onthedepthofthephotoresist.

b. ***LIGA***

TheLIGAisanotherhighaspectratiomicromachiningtechnologywhichisaGermanacronymfor“LithographyGalvanoformingAdforming.”Onasinglesubstratethistechniqueinvolveslithography,electroplating,andmoulding

[27]. It requires the use of synchrotron generated x-ray radiationand it isprimarily anon-siliconbasedtechnology.

c. HotEmbossing

By raising the temperature of the polymer just above its glasstransitiontemperature,polymerissoftenedwherehotembossingis essentially the stamping of a pattern on it [1]. The variety ofways including micromachining from silicon, LIGA, andmachining using a CNC tool,the stamp is used to define thepattern in the polymer. For defining micro-channels and wellsforfluidicdevices,hotembossingtechniqueismajorlyused

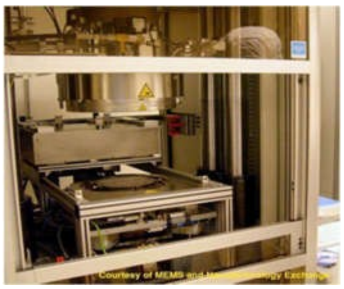


Fig19:Photographofahotembossingplatformduringuse.(Courtesyof theMNXatCNRI).

3. LowcostMEMSfabricationusinginjectionmolding

By using printing and injection moulding, the MEMS fabricationoflarge-areadeviceswithlowcapitalinvestment,withoutavacuumprocess,andlowerproductioncostsiscarriedout.Henceforth for the fields where manufacturing cost was an criteriasuch aslighting,thistechnologyisapplied.

Toproduceintegratedcircuits,includingvacuumprocesses,conventional commercial MEMS devices which uses fabricationtechniqueswithsemiconductormanufacturingsystems. Theproduction costs are high due to vacuum-based processes for theresinswhichisusedtoformpatternsontomovingmicrostructures. The resins get harden immediately after moldinjection thus it is difficult to form and thin MEMS structuressuch assprings andcantilevers.

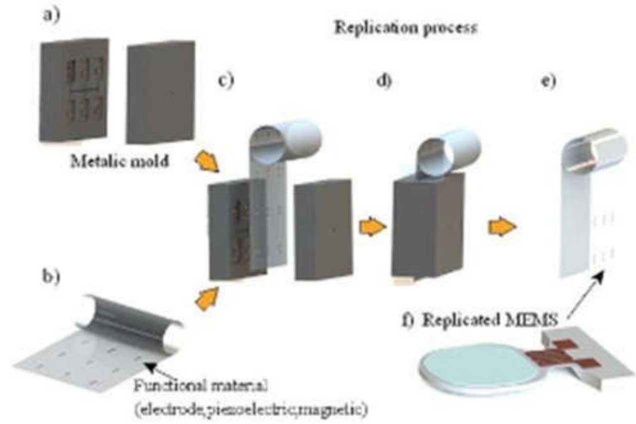


Figure 20: MEMS fabrication processes by printing and injectionmolding

The printed MEMS functional layers can be changed accordingto the desired purpose of the MEMS device — from accelerationsensorsandgassensorstopowergenerationdevices.This represents low cost MEMS fabrication in the sectors where costsare currently high. The AIST highlights is in light distributioncontrol of LED lighting is one of the example. MEMS-basedactivelightdistributioncontroldevicesoffersthenewopportunitiesforthisnewMEMSfabricationtechnology,though,could produce low-cost large MEMS devices (larger than severalmmacross).Byimprovingthearrangementoftheopticalsystem,the signal processing, and the control circuit it expands the rangeofthe lightdistribution.

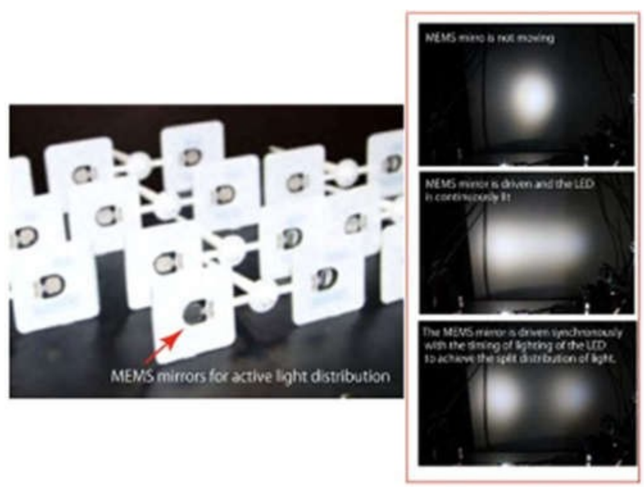


Figure21:MEMSmirrorsforactivelightdistributionfabricated.

The left figure shows fabrication by using only printing andinjection molding , and the right figure shows examples of theresulting light Distributionpatterns.

APPLICATIONSOFMEMS

There are plenty of applications for MEMS[37]. MEMS combinesthe fields such as biology and microelectronics. And many newMEMSandNanotechnologyapplicationswillcomeintoexistence, expanding beyond that which is currently identified orknown.

MEMS technology finds wide applications in the below generaldomains

Automotive domain: The following are some of the deviceswhereMEMSiswidelyapplicableinthisdomain.

- AirbagSystems
- VehicleSecuritySystems
- IntertialBrakeLights
- HeadlightLevellingRolloverDetection
- AutomaticDoorLocks
- ActiveSuspension

Consumer domain: The following are some of the deviceswhereMEMSiswidelyapplicable inthisdomain

1. Appliances
2. SportsTrainingDevices
3. ComputerPeripherals
4. CarandPersonalNavigationDevices
5. ActiveSubwoofers

Industrial domain: The following are some of the deviceswhereMEMSiswidelyapplicable in thisdomain

1. EarthquakeDetectionandGasShutoff
2. MachineHealth
3. ShockandTiltSensing

Military: ThefollowingaresomeofthedeviceswhereMEMSiswidely applicablein thisdomain

1. Tanks
2. Planes
3. EquipmentforSoldiers

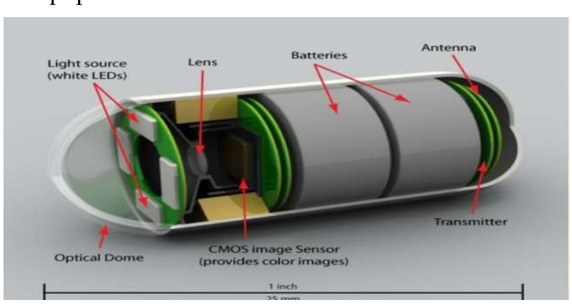


Fig22:PillCamforDiagnosticapplications

Biotechnology: ThefollowingaresomeofthedeviceswhereMEMSiswidelyapplicableinthisdomain

1. PolymeraseChainReaction(PCR)MicrosystemsforDNAamplification and identification
2. MicromachinedScanningTunnellingMicroscopes(STMs)
3. Biochipsfordetectionofhazardouschemicalandbiologicalagents.
4. Microsystemsforhigh-throughputdrugscreeningandselection

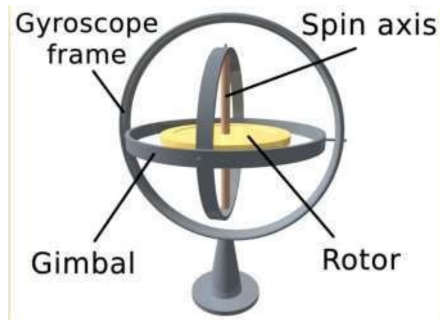


Fig23:MEMSgyroscopes

MEMSdevices:

Fewexamplesofreal MEMSproductsare,

1. AdaptiveOpticsforOphthalmicApplications
2. OpticalCrossConnects
3. AirBagAccelerometers
4. PressureSensors
5. MirrorArraysforTelevisionsandDisplays
6. HighPerformanceSteerableMicromirrors
7. RFMEMSDevices
8. DisposableMedicalDevices
9. HighForce,HighDisplacementElectrostaticActuators
10. MEMSDevicesforSecureCommunications

Fig24:MEMMStirepressuresensor

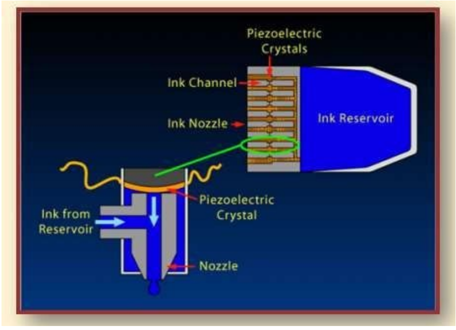


Fig25:MEMS-basedInkJetPrinthead

CONCLUSION

TheMEMSfabricationtechniquesareiscontinuouslydevelopingtill date,inthispapermanydifferentmethodshasbeensummarised . this survey and listing of all current methods maychannelizetheresearchersto understandthedevelopmentpathofall fabrication techniques since from years ago on single paper.Thisendeavour maybelievetobeabest source tounderstandthewidenessofMEMSfabricationtechniques.Italsoclearlydifferentiate the IC fabrication technique with MEMS fabrication.Theworkalsoinvolvestheclearlistofallapplicationsof MEMS.Wecanconcludethecurrentpaperassurveyguideonallfabricationtechniques.

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