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Micromachining of Advanced Materials

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ABSTRACT

Trend of miniaturization of products and consequently its components today's world can be evident in almost every Engineering field. To achieve requirements imposed by miniaturization micromachining proving to be satisfying manufacturing techniques. In recent years, advanced materials with unique metallurgical properties such as super alloys, composites and ceramics have been developed to meet the demands and satisfy the needs of extreme applications. While these materials with properties like harder, tougher, brittle, less heat sensitive and more resistant to corrosion and fatigue, they are also difficult to machine. Advanced materials are being widely used these days not only in the aerospace, defense and automotive. Therefore, the machining of difficult-to-machine materials is an important issue in the field of micromachining. Micromachining plays a very important role in miniaturization of parts used in aerospace (cooling holes in jet turbines blades), micro holes in fuel injection system of automotive, micro probes and micro needle for bio-medical application etc. Thus micromachining is important field in developed machining. This paper summarizes some of the micro machining technologies such as micro-electrical discharge machining, electro chemical micro machining, micro-laser assisted machining, and abrasive slurry jet Micro-machining, micro ultrasonic machining, and micro electron beam machining. Literature identifies that micro machining greatly influences machining of hard materials. Micromachining has great advantages in machining of hard materials in non-conventional machining as well as in conventional machining such as micro-mechanical milling, chemical etching, and micro-detonation of striking arc machining. The present overviews and analysis various requirements of micromachining and the effective utilization in the micromachining domain for further strengthening.

Keywords: Advanced material, Micromachining, Applications, Types, Analysis.

I. INTRODUCTION

In today's high-tech engineering industries, the designer's requirement for the component are stringent. To unbind the limits and increasing their capability of imagination to design a great product micromachining promises us the solution to complex products. Extraordinary properties of materials such as high Strength, high heat resistant, high hardness, brittleness, high ductility etc. demand different machining than the conventional machining to meet the application quality and demand. Complex 3D component with tight tolerances say, turbine blade. Miniature features filters for biomedical researchers, food processing and textile industries having a few tens of micrometer as diameter and thousands in numbers. Nano level surface finish on complex geometries which are impossible to achieve by any traditional methods say, thousands of turbinated cooling holes in a turbine blade, making and finishing of microfluidic channels in the electrically conducting and non-conducting materials say, glass, quartz , ceramics. Such features on a component can be achieved only through the advanced manufacturing processes in general and advanced machining processes in particular.

II. NEED FOR ADVANCED MATERIALS AND THEIR MACHINING

Final finishing operations in production of precise parts is always an important owing to their most critical, labor intensive and least controllable nature. In the world of Nano technology, remarkable high precision finishing processes are of utmost importance and are the need to compensate present manufacturing scenario. The need for high precision in manufacturing was felt by manufacturers worldwide to when they had to improve interchangeability of components, improving quality control and longer wear/fatigue life of products. Among the difficult to machine materials, super alloy is high performance alloy, it has outstanding mechanical strength and resistance to creep at high temperature, good surface stability, and corrosion and oxidation resistance. A super alloy's basic alloying element is normally nickel, cobalt, or nickel-iron. General applications are in the aerospace industry, industrial gas turbine and marine turbine, e.g. turbine blades for hot sections of jet engines, and bimetallic engine valves that are used in diesel and automotive applications. Composites materials are materials which are made from two or more constituents materials with significantly different physical or chemical properties, that when combined, produce a material with characteristics different from the individual components. These materials are stronger, lighter or less expensive when compared to traditional materials. Composite materials are generally used for buildings, bridges and structures such as boat hulls, swimming pool panels, race car bodies, shower stalls, bath tubs, storage tanks, imitation granite and cultured marble sinks and counter tops. The most advanced examples perform routinely on spacecraft in demanding environments. Some examples of composites are Composite building materials such as cements, concrete, Reinforced plastics such as fiber-reinforced polymer, Metal Composites, Ceramic Composites. Ceramic materials are inorganic, non-metallic materials made from compounds of a metal and a non-metal. Ceramic materials may be crystalline or partly crystalline. They are formed by the action of heat and subsequent cooling. Clay was one of the earliest materials used to produce ceramics, as pottery, but many different ceramic materials are now used in domestic, industrial and building products.

Although a clear distinction is sometimes not possible, it is generally accepted that micromachining techniques can be put into the following four categories.

- Bulk micromachining
- Surface micromachining
- Micro-molding processes
- Non-lithography based localized micromachining

Some of these (the first two, in particular) are derived from the microelectronic processes while the others are either miniaturized versions of the macro-scale processing techniques or techniques newly conceived for micro-scale manufacturing. In bulk micromachining, the structures are carved out of a substrate by chemical or physical etching methods.

In surface micromachining, thin layers (a few microns thick, usually up to three or four microns) of materials are sequentially deposited and etched to create multi-layer stacks of desired geometry. In micro-molding processes, as the name implies, a micro mold is made and it is then used to create microstructures made of different materials including metals, ceramics, plastics, etc., in addition to semi-conductor materials. The fourth category is a “grab-bag” of all the remaining techniques that do not fit into the first three. Most of them do not use lithography and hence that qualification fits them well. Before describing these processes, it is useful to list commonly used

MEMS materials and microelectronic processes.

III. MEMS MATERIALS

1) Silicon:

Single crystal silicon (SCS) and glass (Pyrex, in particular) were the materials used in the early days of MEMS in the seventies of the 20th century. Silicon is the choice material of MEMS even today. In addition to SCS, polycrystalline silicon (often abbreviated as poly) is also widely used now. Silicon is, as is well known, an excellent semi-conductor material. As explained in detail in the seminal paper* by Kurt Petersen, silicon is also an excellent mechanical material. More importantly, the fabrication processes for silicon are well developed. An added attraction is that microelectronics can be tightly integrated with the micromechanical structures. Thus, naturally, it became the popular structural material for MEMS.

Both SCS and poly can be used as …

- A resistor (if appropriately doped with boron or phosphorous)
- A conductor (if appropriately doped with boron or phosphorous)
- A mechanical structural layer (poly is used in surface micromachining and SCS in bulk machining)
- A piezo resistor

2) Silicon dioxide (SiO_2):

The silicon dioxide is most commonly used in micro fabrication. It can be grown thermally or deposited using chemical vapor deposition (CVD). It has different names as indicated below.

PSG: if the deposited SiO_2 is phosphorous doped, it is called phosphor silicate glass (PSG).

BSG: if the deposited SiO_2 is boron doped, it is called borosilicate glass (BSG).

BPSG: if the deposited SIO_2 is doped with both phosphorous and boron, it is called BPSG or

LTO: (low temperature oxide): if it is done at low temperatures.

SiO_2 can be used as …

- A mask for silicon etching
- A mask for selective doping
- An electrical insulator (it is essentially a dielectric layer)
- A part of the structure itself
- As a sacrificial layer

It is usually etched with hydrofluoric acid (HF). Potassium hydroxide (KOH) also etches it but very slowly to the extent that it can be used as masking layer to etch silicon with KOH.

3) Silicon nitride (Si_3N_4):

Silicon nitride is an extremely useful material as a good dielectric (insulating) material layer. It is deposited using silane (SiH_4) or ammonia (NH_3) using chemical vapor deposition. It can be wet etched using boiling phosphoric acid (H_3PO_3 mixture), but is generally patterned using plasma “dry” etching.

It is used as …

- A passivation layer for water and alkali ions.
- A mask for etching other materials
- A dielectric (insulator)
- A mask for selective oxidation of silicon part of the structure itself

Usually, silicon nitride layers thicker than 200 nm have a tendency to crack due to the high tensile stresses they develop during their processing.

4) Silicon carbide (SiC) -

Silicon carbide is extremely hard and resistant to chemical attack. It is also useful as a dielectric material. It can be deposited using PECVD technique or grown in situ. Case Western Reserve

University and others are working on SiC based MEMS technology. It is used in high temperature applications such as the micron-size turbine-compressor engine being developed at

MIT where high-strength materials are needed.

5) Ceramics, polymers, and metals -

Recent trends in the MEMS field indicate that silicon and its compounds are not the only materials that can serve as structural materials for micro applications. Ceramics, polymers

(Especially with the advent of *soft lithography*), and metals are increasingly used in MEMS.

These materials have many functional, performance-related, and economical advantages over silicon. However, processing techniques are yet to be completely worked out. A polymer called

PDMS (poly dimethyl siloxane) and a photoresist material called SU8 have become popular in recent years.

Next, we list the generic microelectronic processes and then consider all the above materials that can be micro machined using these and other processes.

IV. MICROELECTRONIC FABRICATION PROCESSES -

Deposition of thin films enables depositing thin layers of different materials on top of previously patterned layers.

Selective etching using masks enables selective removal of material from deposited layers. This is what we mean by *patterning* of a layer.

Doping changes properties, mainly the electrical resistivity, by adding “impurities”. It is needed for microelectronic fabrication much more than for micromachining. But doping also helps in creating “etch stops” wherein chemical etching can stop at surface located at a desired depth without having to time the etch exactly.

Photolithography is used to define the masks. This is the key element in micro manufacturing. It defines the patterns for the selective etching to work. It is explained a little more in the next section.

Oxidation and epitaxial growth are used for growing some materials such as Silicon Dioxide (SiO2) and silicon with a particular crystal orientation.

Bonding has many forms: wafer to wafer bonding; bonding between different materials; and bonding of a chip to a packaging substrate, etc.

Die bonding and wire bonding for packaging enable interfacing the microchip with the external macro connectors.

Micromachining techniques use several of the above techniques of microelectronic fabrication.
Some of the important ones will be briefly described here starting with photolithography.

1) Photolithography

A photo-polymer called photoresist (PR) is the basis for photolithography. If a layer needs to be patterned, that is, if we want to remove material from a layer selectively, we need to create a masking layer to define the windows through which to etch. The photoresist itself can be used as a mask in some cases when it can withstand the process etching, but usually another masking layer is used. The windows in the masking layer are opened using the photolithography technique. The masking layer is patterned in the following manner. First, we lay a thin layer of the photoresist by spinning the wafer after pouring a small amount of the liquid photoresist on top of the masking layer. It is called *spin-casting*. Spinning helps spread the thin layer of photoresist uniformly. It is then baked in an oven to harden it. The photoresist layer is then exposed to ultra violet (UV) light through a mask.

Mask is usually a glass plate with a chromium pattern. The “windows” through which to etch the masking layer are defined in this mask. Emulsion masks can also be used. They are cheaper but do not last long. If it is one-time use, even a laser-printed pattern on an overhead transparency can be used as a mask!

The UV exposed regions of the photoresist change properties via de polymerization. Next, the photoresist layer is developed. This is done by spraying a solution called photoresist developer. If the photoresist is of the positive type, the UV exposed regions will dissolve in the development process. If it is of the negative type, the UV exposed regions will remain while the unexposed regions will get dissolved. This is how a masking layer is patterned using the photolithography technique. Masks themselves are made using the same photolithography technique described above or using a direct-write technology such as laser-writing or electron beam-writing. The photolithography technique works as follows. A quart plate coated with a chrome layer and a photoresist is exposed through a rectangular window which can be stepped across the plate (i.e., scanned on the entire area of the plate). The size and the orientation of the window can be changed. This allows an entire mask pattern to be exposed through a sequence of step-and-repeat operations wherein the window size, its orientation and location are changes. These are dictated by the mask layout, which is simply a set of overlapping boxes of different sizes and orientations. They need to overlap to ensure that there are no gaps among them. The figure on the left shows how a sector of an annulus is exposed by way of several rectangular boxes. Each box is separately exposed in the step-and-repeat procedure.

In the direct writing using a laser beam or an electron beam, the photoresist material is removed or depolymerized by scanning the beam as per the mask layout. Here, the curved features can be written as such, as opposed to getting them via a set of rectangles that are rotated as needed.

2) **Soft lithography**: It is akin to imprinting, embossing and rubber-stamping. A stamping mold is made of a plastic material, which is then used to create patterns on various substrates, including the curved ones. As the name implies, it is suitable for soft materials. In conjunction with PDMS, soft lithography for micro-fluidic applications has become very popular lately.

V. ETCHING:

After covering the layer to be etched with a masking layer and opening the windows in the masking layer using photolithography, the next step is to remove the material through the windows in the masking layer. There are two broad types of etching: wet etching and dry etching.

1) Wet etch:

Wet etching typically implies immersing the masked wafer in a liquid bath of a chemical etchant. It can be isotropic or anisotropic.

1. **Isotropic etch**: It etches uniformly in all directions at more or less the same rate.
2. **Anisotropic etch**: It etches at different rates in different directions leading to somewhat complicated patterns which are exploited to define shapes for micromechanical and microelectronic structures. For silicon, for instance, HNA (a mixture of HF, nitric acid, and acetic acid) etch gives isotropic etching. KOH, TMAH, and EDP are two examples of anisotropic etching of silicon. KOH: Potassium hydroxide. EDP: Ethylene Diamine Pyrochatechol. TMAH: Tetramethyl amoonium hydroxide. The above chemicals etch SCS at different rates in different directions. As we discussed above, this has to do with the density of silicon atoms in different crystallographic planes. The (110) plane has fewer atoms, (100) a few more, but a (111) plane is the most dense among all three. Another reason for anisotropic etch rates is how many atoms on the surface have one or two dangling bonds. In (100) and (110) planes, there are two dangling bonds on the surface while (111) plane's atoms have one dangling bond. Consequently, (111) plane has much slower etch-rate: it has a lot more bonds to break and a lot more atoms too. This orientation dependent etch rate creates interesting shapes. In particular, for a (100) wafer a feature aligned with (110) direction under-etches at the edges of the mask by an angle of 54.74° . This under-etching along the edges leads to the creation of (111) planes. Doping (diffusing silicon with say Boron) helps contain etching so that it can be used to create etch-stops or as "sacrificial" regions. This can be exploited to define patterns by selective doping.

2) ECE: Electrochemical etch. Silicon is etched by forming bonds with OH- (hydroxyl groups) and dissolving the resultant oxide. In ECE, the OH- are supplied electrically to enhance the etching process.

3) Lift-off patterning: It is convenient material removal technique when selective etchants or plasmas are not available for a material. It is usually used for metals. It is similar to the way stencils are used. The photoresist later takes the role of the stencil. After the photoresist layer is patterned, the material is deposited. So, part of the material is deposited on the photoresist and part on the layer beneath where we want to have the material. When the photoresist layer is stripped away, akin to removing the stencil, the unwanted material is removed.

4) Etch stops – As can be imagined, etching will continue until the silicon wafer is taken out of the etchant solution. We need to stop it when a desired depth of etching is reached. A way to stop the etch is by timing it as needed. It is difficult to do in practice when accuracy is critical. Hence, etch-stop layers are used. A heavily p-doped (p+, more *holes* as opposed to more *mobile electrons*) layer can act as an etch stop. For the doping agents (phosphorous or boron) need to be diffused or ion implanted to the desired depth from the side of the wafer that is opposite to the etching side. Alternatively, an n-doped later under an applied electrical field can also be used as an etch-stop. This is called electrochemical etch-stop technique.

5) **Dry etch –** Where there is no immersion of the masked wafer into a solution to affect an etch.

6) **Plasma/Reactive Ion Etching:**

—Here the external energy in the form of radio frequency (RF) power drives chemical reactions.

—Ions are accelerated towards the material to be etched enhancing the etching reaction in the direction of travel of ions.

—It is anisotropic, but is not limited by crystal planes.

—up to 10-15 microns of depth can be etched this way.

7) **RIE:** Reactive Ion Etching (what is described above)

Deep RIE (or DRIE):

—A modification of the RIE to achieve up to 1 mm of depth of etch.

—It works by alternative RIE with a polymer deposition on the exposed side walls.

—Formation of the polymer on the horizontal layer is prevented by an applied bias voltage.

—This is a very useful technique for carving deep features in MEMS. Two companies that market a DRIE machine are: STS (surface technology systems, Redwood City, CA) and Plasma-Thermo, St. Petersburg, FL (unless they are bought over by other companies, which is very common these days).

8) **Vapor-phase dry etching**: XeF2 (xenon fluoride) vapor etches Si under a pressure of 1 torr. It is a non-plasma process.

9) **Lift-off patterning**: This is used for metal layers. Here the unwanted metal is lifted-off along with the photoresist layer when PR is developed. The PR layer is deposited on top of a masking layer that is patterned and is dissolved after the lift-off. The metal is evaporated onto the patterned masking layer and the lift-off technique is used.

VI. THIN FILM DEPOSITION

There are a number of techniques for creating a thin layer of deposit over the entire wafer.

1) **PVD:** Physical vapor deposition. The material is evaporated or vaporized and is made to cover the wafer uniformly such that the thickness can be controlled too. Filament evaporation, electron beam (E-beam) evaporation, and flash evaporation are some examples.

2) **Sputtering:** Sputtering is achieved by bombarding a target with energetic ions and knocking off the atoms from a target material and transporting them to the wafer where they get deposited.

3) **CVD:** Chemical Vapor Deposition. In this process, thin films are formed by depositing the gaseous phase material directly on the surface. The gaseous phase is created through thermal decomposition and/or chemical reaction. There are LPCVD (low pressure CVD) and PECVD (plasma enhanced CVD).

4) **Epitaxy**: CVD process is used to deposit silicon on the silicon wafer surface. The silicon wafer acts as a seed crystal under appropriate conditions and the single crystal silicon layer is grown on the wafer from the silicon obtained from the CVD deposit. There are VPE (vapor phase epitaxy), LPE (liquid phase epitaxy),

and MPE (molecular phase epitaxy). Epitaxial growth can be used to fill in small pits with crystalline silicon using the deposition process. Ordinary CVD will have polycrystalline silicon deposit but not crystalline silicon with desired orientation.

5) **Eletro plating**: Used commonly for depositing metal films. Metal ions from an electroplating solution get attracted to the base that is maintained at negative potential.
6) **Electroless plating**: The deposition of metal ions is induced chemically rather than electrically.
7) **Spin casting**: This is normally used for photoresists and other polymeric materials that have suitable viscosity. The solution is applied on the wafer and the wafer is spun at high speed. Centrifugal forces, surface tension, and viscous forces act together to spread the solution uniformly over the wafer. It works well with thin layers. It is then baked to harden the material.

VII. BONDING

1) **Anodic bonding:** Silicon to glass bonding is an example. Glass and silicon are brought together and a voltage is applied between them at high temperatures. The sodium ions present in the glass such as Pyrex help glass conduct them when it is at high temperatures. Oxide formed from silicon merges with the glass and forms a bond.
2) **Silicon fusion bonding:** This is a silicon to silicon bonding between two polished wafers.

—hydroxyl (OH-) groups must be present (boiling the wafers in HNO3 helps)

—done at 300º – 800º C temperature

—hydroxyl groups bond to each other resulting in a bond that will make the two wafers indistinguishable after bonding.

3) **Adhesive bonding**: It is common to bond silicon to other materials using epoxies.
4) **Eutectic bonding:** Sometimes, an intermediate layer (e.g., a metal) is used to bond two silicon wafers. When heated, the sandwiched metal layer forms a eutectic creating a strong bond. Usually gold is used for eutectic bonding of silicon.
5) **Planarization:**

Multi-layered structures, especially when surface micromachining is used, lead to complicated topographies. So, an intermediate planarization step is often needed to flatten the top layer. This simplifies the geometry of the subsequent layers. Planarization can be done in many ways. Three methods are described below.

6) **CMP**: This acronym stands for chemical mechanical polishing. It is basically a micro equivalent of the grinding process. As the name implies, a polishing abrasive slurry is applied and the wafer is rotated at the required speed in as in grinding.
7) **Resist etch back**: Here, a dummy layer of etch able photoresist is applied to achieve a flat surface and it is etched along with the layer beneath at the same rate.
8) **Polymer filling**: Just like varnishing a floor with multiple coats, a polymer is applied first to fill all the troughs and then more is applied to ensure a flat layer. It is not suitable if further process steps are done at high temperatures.

VIII. NON-LITHOGRAPHY BASED LOCALIZED MICROMACHINING

Micromachining to create micron-sized structures came into existence with microelectronic fabrication (photolithography, in particular) as the basis. But it does not have to be that way; many researchers are exploring non-lithography alternatives. A big advantage of photolithography is batch-processing and it is accompanying economic incentive when the volume of products is very large. A serial-process like macro-scale milling or drilling is not likely to be economical. But some specialized applications may justify even a serial process. For exploratory purposes, especially in the academic and industrial research labs, the no lithography processes are very attractive. A few processes of that kind are listed below. Some remove material and others add material.

IX. LOCAL MATERIAL REMOVAL METHODS

1) Real micromachining:

With diamond tool tips and precision machine stages, it is possible to turn, mill, and drill micronized features. There is field called precision-machining. Usually, metals, glasses, and ceramics suit this kind of machining and its large cutting forces. But some polymers also have been used.

Mechanical punching with a die could also lead to batch processing.

2) Micro-EDM:

In electro-discharge-machining (EDM), an electric field is applied between the tool and the work piece. It creates a spark and vaporizes the material locally and thus enabling the cutting. It is suitable only for electrically conducting materials.

3) Abrasive cutting:

Abrasive cutting is simply like sand-blasting: particles hit the surface at high velocities. For example, alumina (Al2O3) particles can remove material locally when ejected through an orifice at the location where the material is to be removed. Compressive air can also be used for such micromachining as in water-jet cutting.

4) Laser machining:

Laser can locally remove material using photolytic or pyrolythic techniques. Excimer lasers (KrF, ArF, or XeCl of 248 nm, 193 nm, or 308 nm wavelength) use photo lithic technique in the sense that they mechanically ablate the material. On the other hand, longer wavelength lasers

(ND: YAG (1064 nm) and CO2 (10.6 um)) thermally ablate the material and are called pyro lithic processes. With these, heat affected zone is a problem. In both categories, batch-processing using a mask are possible if the lasers have sufficient energy.

5) FIB milling:

In Focused Ion Beam (FIB) milling, energetic ions impinge on the surface to mill out the material.

Usually Gallium source is used to produce the ions. The spot size of the ion beam can be as small as 10 nm. By using assistive gases that chemically attack the material, the rate of material removal rate can be increased. Even then, this technique is very slow. But it is very precise. It is often used in electronic chip repair.

X. LOCAL MATERIAL-ADDITIVE PROCESSES:

1) Micro-stereo lithography:

It is just like its macro-scale cousin: a liquid polymer is selectively cured with a laser at the precise locations by a scanning method, and the structure is built-up layer by layer.

2) Electrochemical deposition:

A microelectrode with a sharp tip near a conductive surface causes a chemical reaction in a plating solution to take place. This enables deposition of material where the tip is placed. By scanning the tip over the region of interest, structures of desired shape can be created.

3) Ink-jet type deposition:

Liquid-dispensing as in ink-jet printing and subsequent drying can be used for layer-by-layer micro-deposition to create 3-D microstructures of the desired shape.

4) FIB deposition:

Focused ion beam can also be used to deposit material at the desired location. A precursor gas is laid down as a thin layer. The impinging of the ions will cause the chemical reaction to take place, the resultant of which is the deposition of the material at the right place. Very complex 3-D structures of multiple materials (within the same structure) can be created using this technique. Like FIB-milling, it is slow. But one can justify its use in chip repair where the value added is high even though it is slow.

5) Laser-assisted CVD:

Just like FIB-deposition, a laser can also be used in conjunction with CVD to add material at the right location. There are many more materials and many more techniques. Laser micromachining, EDM (electro discharge machining), abrasive power machining, chemical mechanical polishing (CMP), thermo migration, ion-beam milling (IBM), etc. are some of these techniques. There are plenty of books and papers and websites for the interested reader. Currently there is a lot of interest in polymers, ceramic and bio-based materials.

6) Packaging:

Packaging is an essential and often cost-limiting component of MEMS fabrication. It is needed for the following reasons: Thermal management – how do we remove the heat generated in the device? Mechanical support – how do we mount the micro machined device onto a macro part? Electrical connections – for power supply as well as signal input/output.

Fluidic connections – how do we attach fluidic fittings for intake/outtake in microfluidic applications? Protection from noise and damage. It is cost-limiting because, even when a micro device may be cheap but connecting it to the environment it is supposed to work in proves to be expensive, the overall cost goes up. It is often said that assembly and packaging cost account for more than 60% of the cost of a MEMS product. Some of the packaging techniques, again, mostly coming from the microelectronic field, are:

A. **Bonding** – already discussed above.

B. **Dicing** – where a wafer is cut into little chips. Done with a diamond saw usually.

C. **Wire/ball bonding** – a very popular technique to make electrical connection using gold wires.

D. **Flip-chip** – where mechanical structures on chip over which an electronic chip is attached in the flipped orientation. The solder bumps enable connection between them structurally and electrically. This enables the separation of mechanical and electronic components.

E. **Hybrid integration** – Some techniques have been developed so that both mechanical and electronic components can be built on the same chip but in separated portions. Sandia labs has developed a very nice technique of this type where the mechanical structures are fabricated in one half of the wafer at a slightly lower level (achieved with prior etching of one half), and the CMOS (complementary metal oxide semiconductor) electronic process is on the higher level with an overhang enabling the interconnection between the two halves.

XI. CONCLUSION

Finally we have concluded that Micro machining is the need of hour and hence has an unlimited applications only to the limit of a designer’s mind. The Micro Electro-Mechanical Systems that require complex machining and fabrication processes involved in MEMS elements are discussed briefly and put forward their advantages. We have also understood the material removal processes involved, etching methods and the advanced deposition techniques related to Micro machining.

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