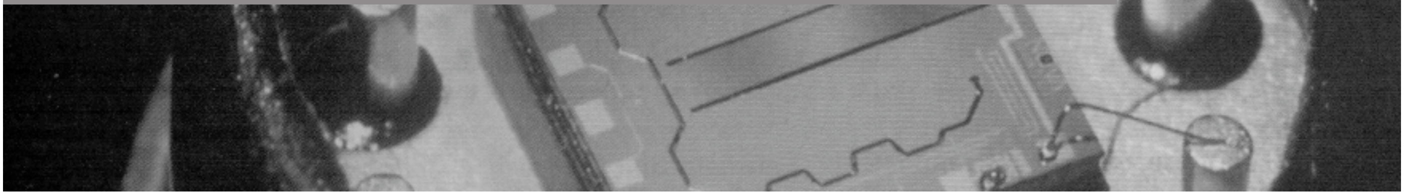
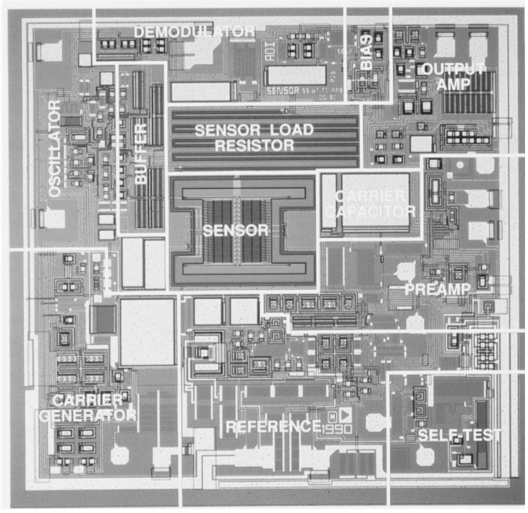
Introduction to MEMS



What are Mems

MEMS is the acronym for MicroElectroMechanicalSystem and describes a very small device with expanded functionality compared to microelectronics. Mechanical structures are used to interact with the environment to allow sensing or act. The term MEMS is often used in combination with prefixes or alterations to describe the integration of other functionality, like RFMEMS (Radio Frequency), BioMEMS (mostly microfluidics) or MOEMS(optical microsystems).



Monolithic integrated accelerometer form Analog Devices

The first developments that can be considered as Microsystems were made in the 1970s like the compact disc or LC Displays. Also the fundamental processes like anisotropic etching of silicon and the LiGA process were developed at this time. This opened up the path for first the academic successes in the 1980s and than the commercial ones in the 1990. Microsystems can be found today in almost every commercial sector, Information and communication, in entertainment, automotive and avionic, as well as medical and health related applications. But the military is still one of the biggest sectors for potential applications.

MEMS are always systems that consist of different components with three major functions: input, processing and output. This is what differentiates a micro system from a micro structure, and so therewith allowing interactions with the environment. And so this different components can be manufactured separately (modular integration) or all on one substrate (monolithic integration) as shown above. [1]

What kind of MEMS are they

A microsystem can be classified by the functionality of the system, sensor, actor or processing unit. But it is common to classify by the kind of components it consists of.

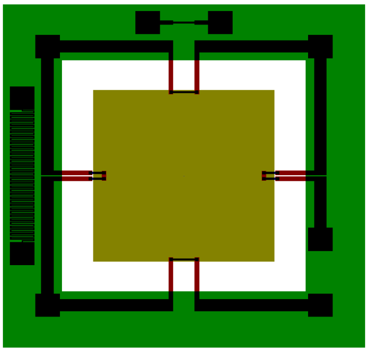
functionality	components	examples
electronics	*microelectronic components*	logic, memory, mixed signals
	RF microstructures	antennas, transformers, passive components
mechanics	*micro sensor*	pressure, acceleration, momentum, temperature, flux
	micro actuator	micro relays, pumps, valves,
	micro fluidics	reactors, dosing systems, separator
	micro acoustics	transducer, filter, signalling,
optics	*micro optics*	fibre optics, mirror arrays, spectrometer
chemistry/ biology	*micro chemistry/ biology*	Analyse

How MEMS are made

The typical MEMS are made out of single crystal Silicon discs. These discs are made by pulling a circling start crystal out of a moulded Silicon bath. The rod which was manufactured will than be sliced, lapped and polished. This ensures a bulk material of constant quality.

The typical silicon processing for MEMS is based on the lithography used in micro electronics. A photo mask is necessary for every step in the process that requires selective exposure. The mask can be positive of or negative depending on the chosen resist. The process flow looks always like this:

1. superimpose photoresist
2. expose photoresist
3. develop photoresist
4. etch or modify uncovered material OR growth of a new layer within the resist
5. resist stripping
6. optional: removal of sacrificial layer(s)
7. optional: deposit a layer onto the whole surface
8. go to 1



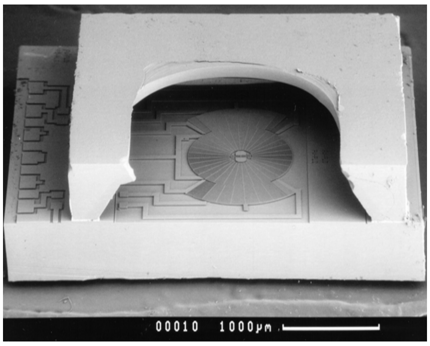
4 layer mask for a bulk micro machined pressure sensor

To achieve a simple system like a pressure sensor it is necessary to repeat this flow 17 times. This pressure sensor is a good example of Silicon Bulk machining. Some structures are formed on the surface of the wafer and than the mechanical structure is formed by modifying the wafer itself - the so called bulk material [2]

The other way to make MEMS from silicon is surface micro machining. In this case the mechanical structure is formed by:

1. depositing and structuring a sacrificial layer,
2. depositing and structuring of a poly silicon layer,
3. removing of the sacrificial layer,

Generally, an accelerometer is often manufactured using this approach. A normal accelerometer is formed by cantilever with a weight at the end.



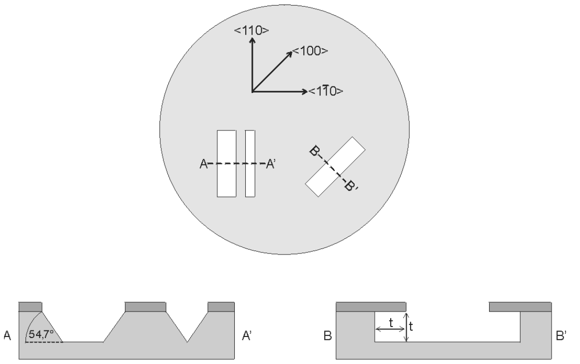
Surface micro machined Gyroscope

Another widely used technology is LiGa. LiGa is the German acronym for Lithography, electroplating (Galvanoformen), molding (Abformen). In the beginning it was just possible by utilising high energy x-rays to expose a PMMA resist. This resist was covering a conductive seed layer which made it possible to electroplate in the mould and so electroform large 2.5D metallic structures. The electroplated structure is than removed from the wafer and becomes a mould itself for micro injection moulding. This gives the possibility to make many parts in a relatively cheap way. The biggest disadvantage is the necessity of a synchrotron to generate the x-rays.

Today UV LiGA uses coherent UV light and a negative resist like SU-8; which is commonly used to achieve similar structures ("Poor mans LiGA"). The drawback with this method is the relative low resolution because of the long UV light wavelength.

Why is silicon still used for MEMS

Silicon is still the material of choice against all odds. The main reasons therefore are the very good mechanical properties, the possibility for embedded electronics and the anisotropic atomic crystalline structure. This causes also non uniform etch rates. The rates between the (100) plane and the (111) is from 100:1 up to 400:1, depending on the temperature. That means the (111) plane can be considered as a natural etch stop. The natural etch stops combined with artificial stops make structures possible that cannot be achieved with outer isotropic materials. All this possibilities give the device designer perfect ways to integrate his ideas in one monolithic design. [1]



Standard anisotropic etch geometry

And if he is part of a developer team for a semiconductor manufacturer he will have all the equipment to make the device at his fingertips. That explains why the big players in the MEMS market are mostly semiconductor companies.

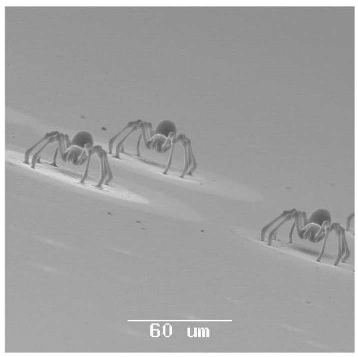
Will we see home grown MEMS in the near future

The manufacturing of MEMS is still a large scale batch process. Even a small cleanroom with the necessary facilities to run one process chain for silicone is between 5 and 10 million €. And such a process has an intrinsic inflexibility to design changes, as they are costly and difficult.

Errors are really costly too, so this which makes it unavoidable to manufacture tremendous quantities to produce just cost-covering.

The industry experiences the same problems at the moment with a drift in the market for tailored solutions. "Responsive manufacturing" is the weapon to face this new development. That means that production capabilities must be build that allow producing a product cost-effectively in a "Batch of one".

In MEMS this is even more difficult than in other industries because everything is based on one material. The academic community is constantly trying to develop new processes with new materials to enable manufacturing by smaller players without heavy financially resources.



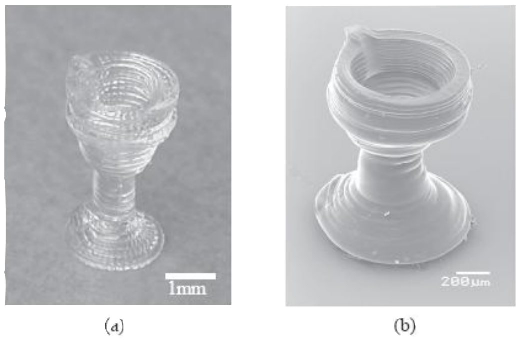
STL generated spider models made from Resin at the LTZ Hannover

And this is where fabbing takes its place in future home grown MEMS development. A fabber is basically a 3D-Manufactuing device that allows the user to manufacture physical free form objects. The most ideas are based on rapid prototyping/manufacturing of 3D structures. The additive modelling generates 3D structures by successive adding materials at the right place. The most rapid prototyping technologies are working with this approach like stereo lithography and fused deposition modelling. Electro deposition or chemical vapour deposition are also considered as additive modelling. The superiority of this method compared to subtractive methods is due to the fact that less waste is produced and the design space is not predestined.

Different concepts out of the rapid prototyping have proven themselves as capable of producing microstructures. The stereo lithography (STL) for example uses a liquid epoxy resin with a photo active linker as material. This resin is locally cured by writing with a laser beam onto the liquid level. The cured layer sticks to the vertical moveable stage. This stage then is sunk further into the resin so that liquid resin will cover the object and the next layer can be cured by the Laser. No support structures are necessary. The laser centre in Hannover, Germany has demonstrated they can produce micro parts with this technology. [3]

Based on a similar idea as the STL is the Selective Laser Sintering (SLS). Metal, polymer or ceramic powder are selectively fused together by the laser. The biggest advantage is the different material which can be used. [4]

Fused Deposition Modelling (FDM) uses a standard Cartesian robot to extrude liquefied thermoplastic onto the working stage. The working material can be changed at any time during the process. A support material is needed for overhanging structures. Recent research has shown that this method is also capable of manufacturing micro parts, as well as form part out of LTCC-like materials. [5]



Wineglasses from Nagoya University, (a) is 4mm high, (b) is 1500 µm high

Best technologies for MEMS

The Manufacturing of MEMS needs a high degree of accuracy, which can be only provided by STL, SLS and FDM. The condition for a variety of different materials cannot be satisfied by stereo lithography, which is the most accurate process at the moment (<1µm). The need of the selective laser sintering for a high power laser makes it not commonly affordable. That leaves Fused Deposition Modelling as the method of choice.

Fabbing can also be used by its own or in combination with other techniques. The most processes have been already described before or don't need any explanation. By using FDM and different material a large variety of MEMS can be formed. Further more there are new or hybrid technologies, which needs to explained in more detail.

Plating mould forming (soft lithography)

Electroforming of metallic parts was utilising a patterned photoactive resist onto conductive surface as mould for the electroplating process. This process requires usually a several facilities and steps. Direct deposition of a polymer by FDM or syringe deposition reduces these steps to deposition of the mould, electroplating itself and optional removing the mask and seed layer. [6]

Piezo ceramic FDM process

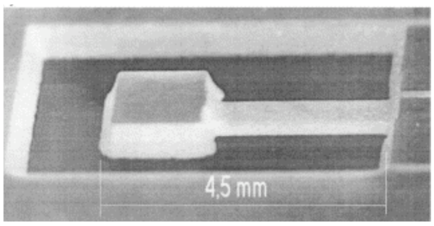
The deposition of ceramic containing polymer can be used to produces 3D-ceramic structures. As proposed by Safari and Danfarth. LTCC (low temperature co-fired ceramic) is a ceramic compound in a polymer matrix. It is then fired at 850 °C. [5]

Local plating nozzle

It was shown that special nozzles can be used to deposit metal in a defined area. They used a double nozzle with inlet and outlet to render a drop of electrolyte between the nozzle and the surface. And so the plating can take place just in the area, which is covered with electrolyte.

Powder blasting

A subtractive method which could allow cheap and fast processing of mesoscale Microfluidic chips is the powder blasting method. Thereby a polymer substrate is covered with a metallic mask. Then the open areas of the substrate are exposed to a stream of a few microns big alumina particles. This particle stream erodes with a different rate, so that it can form 2.5D structures cheap and easily.



Picture of an accelerometer beam realised in two steps by powder blasting from the two substrate sides

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[3] “Metal and polymer microparts generated by laser rapid prototyping “ by Neumeister, A.; Czerner, S.; Ostendorf, A.In: 4th international congress on laser advanced materials processing, 16.-19. Mai 2006, Kyoto. Paper No. 050873

[4] "Selective Laser Micro Sintering with a Novel Process" by Horst Exner, Peter Regenfuss, Lars Hartwig, Sascha Klötzer, Robby Ebert.

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[6] “ Fabrication of PLGA scaffolds using soft lithography and microsyringe deposition” by Giovanni Vozzi, Christopher Flaim, Arti Ahluwalia and Sangeeta Bhatia, BiomaterialsVolume 24, Issue 14, , June 2003, Pages 2533-2540.