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# APPLICATION OF MEMS INDUCTORS IN SENSORS AND RF COMPONENTS

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## ABSTRACT

*The design of sensors and RF components has increasingly made use of microelectromechanical systems (MEMS) technology or micromachining. The quality-factor of inductors on silicon and the reduction of substrate losses requires approaches as the use of MEMS technology. The MEMS technology had emerged from the conventional silicon processes with the aim to utilize the well-established microstructuring technology but to exploit the excellent mechanical rather than the electrical characteristics of silicon. Passive components, especially inductors, used often determine the size and performance of systems and current research efforts in MEMS aimed at performing these functions mechanically should make it possible to realize the entire transducer and RF transcever monolithic ally, reducing size, weight, cost and power.*

## 1. INTRODUCTION

Microsystem technology is the system integration technology by which physical/ biochemical signals are converted into electrical signals and electrical signals are processed, stored, communicated with a human on a single chip. It can be realized by combining the VLSI technology which makes the system think and communicate with the MEMS (Micro Electro Mechanical System) technology which makes the system sense and act. In these days, multimedia allows people to get exposed to more information.

While the intelligent human digital system has been faster and smaller, human interfaces have not. The demand for faster interfaces is increasing. Not only high performance but also miniaturization with low power and low noise become an important issue. Microsystem technology can satisfy these requirements. This is a core technology to create new applications and new markets in the future. Microsystem technology can be applied to many fields such as biochemical interfaces, communication applications, image/display, and storage devices. Interdisciplinary research program should be developed because microsystem research requires integration of various expertise such as electronics, mechanics, physics, chemistry, and biology. MEMS can sense (with sensors), communicate (with RF modules), think (with signal processing units) and act (with actuators). The Microsystem technology has a great market potential. There already exists a market for microsensors and actuators in the world.

Inductive components in the MEMS technology include actuators, electronic components [1]-[7] and sensors [8]-[11]. There is width application in these components, especially, in RF module high performance, have monolithic solenoid and spiral inductors, with great quality factor (Q-factor) and small resistance.

## 2. BRIEF OVERVIEW MEMS PROCESSES

This section contains a brief overview of some key micromachining processes, focusing on bulk and surface micromachining and LIGA process.

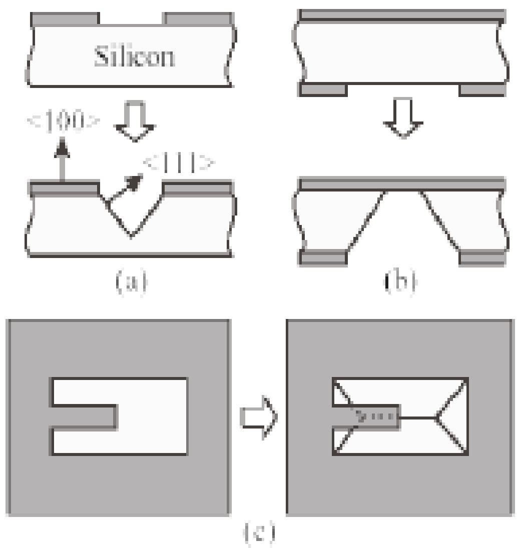
### 2.1. Bulk micromachining

As the name suggests, bulk micromachining is concerned with modification of the silicon substrate. Bulk micromachining is based largely on anisotropic etching. Etching is slowest along the <111> direction, while the relative etching speeds in other directions depend on the etchant and process conditions.

Anisotropic etching produces 3-dimensional features whose geometries are determined both by the mask pattern at the wafer surface and by the silicon crystal structure. For example, picture 1a shows the effect of anisotropic etching on a masked (100) silicon surface.

The etchant attacks the exposed regions of silicon as expected, but effectively stops wherever the slow-etching {111} planes become exposed. The result is a V-shaped opening in which the side-walls are defined (with crystallographic precision) by {111} planes. Bulk micromachining has been used to realize a wide range of devices, mostly physical sensors. Many of these devices incorporate two or more micromachined wafers, bonded together by fusion or anodic bonding; glass to silicon bonding is also widely used for encapsulation. Monolithic integration with electronics can be achieved by post-processing of CMOS wafers, and this is now highly developed.

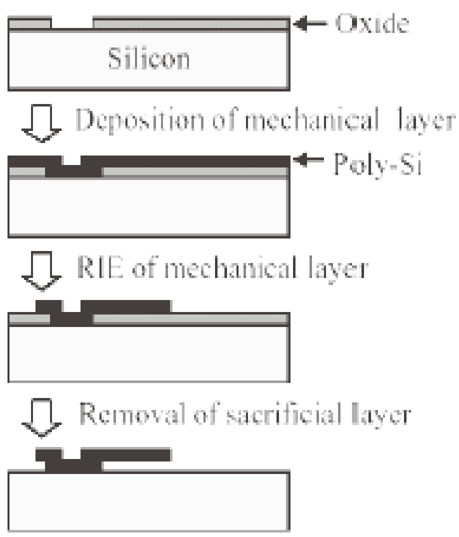
Pictures 1b and 1c show two of the most important applications of bulk micromachining: the formation of membranes and beams. An obvious drawback with anisotropic etching is that only a limited range of geometries can be produced, as dictated by the silicon crystal structure.



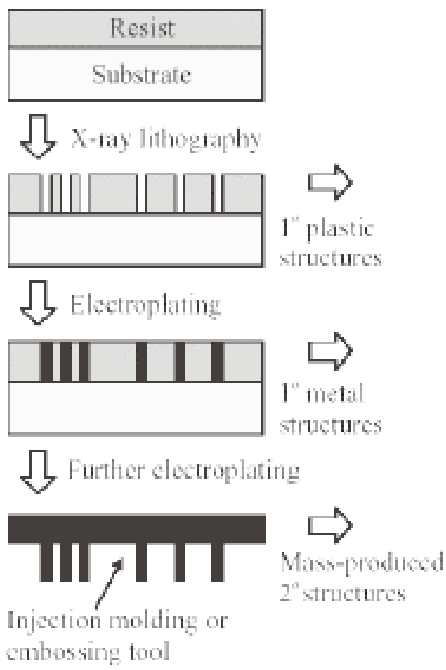

PICTURE 1. (a) ANISOTROPIC ETCHING
AND ITS APPLICATION TO (b) MEMBRANES AND (c) BEAMS.

## 2.2. Surface micromachining

Surface micromachining for MEMS was first developed at the University of California in the 1980s. This technique allows micromechanical structures with both fixed and moving parts to be fabricated on the surface of a silicon wafer by a series of deposition, photolithography and etching operations. Typically two materials are involved: (1) a mechanical material - usually poly crystalline silicon or silicon nitride - from which the mechanical structure is to be made, and (2) a 'sacrificial' material - usually silicon dioxide -which is eventually etched away to release the moving part.




PICTURE 2. A BASIC SURFACE MICROMACHINING PROCESS




PICTURE 3. THE LIGA PROCESS

Picture 2 shows a basic process for producing suspended polysilicon structures; more elaborate processes, involving two or more polysilicon layers, are also possible. The key materials in surface micromachining - polysilicon, silicon nitride, and silicon dioxide - are all present in CMOS processing, as are the required deposition and etching processes. Plasma etching, and in particular RIE *(reactive ion etching),* is used in preference to wet chemical etching because it can be highly directional even in non-crystalline materials, allowing high aspect-ratio structures to be defined; this is particularly important for electrostatic devices, where small interelectrode gaps are required to achieve appreciable driving forces. Surface micromachining has produced an impressive range of MEMS devices, including electrostatic sensors and actuators, micromotors, gear trains and mechanical linkages, and micro-optical components.

### 2.3. The LIGA process

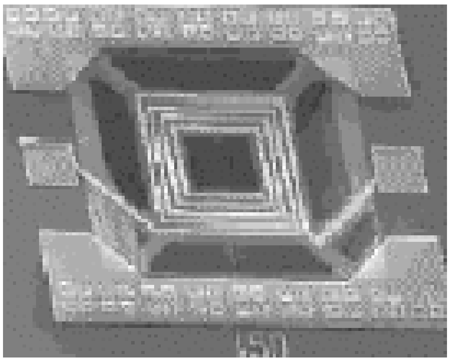
The LIGA process, shown in Picture 3, was developed in Germany during the late 1980s. The name LIGA is an acronym derived from the words Lithographie, Galvanoformung (electroplating) and Abformung (moulding), which describe the basic process steps. First, a thick layer of resist, supported on a metal (or metallised) substrate, is patterned using x-ray radiation from a synchrotron source. Because of the short wavelength of the radiation (typically around 3 Å), deep penetration into the resist can be achieved with negligible diffraction, allowing very tall structures (up to several urn) with high aspect ratios to be defined.

After development, the resist structure is replicated by an electroplating step in which the cavities in the resist are filled with a metal, usually nickel. By continuing the electroplating until a thick backing plate has grown over the entire surface, a tool for injection moulding or embossing can be made. This allows mass replication of the original or primary resist structure in either plastic or ceramic. In principle, further metal parts can also be made by electroforming of plastic replicas.

The key features of the LIGA process are its high precision, processing depth and aspect ratio (all made possible by the short wavelength of the radiation), together with its use of mass replication. The latter is important for two reasons. Firstly, the replication processes used allow structures to be realized in a wide range of materials. Secondly, deep x-ray lithography is expensive, and so for most applications large numbers of devices need to be produced from each primary resist structure in order for the process to be economically viable. The LIGA process has been used to fabricate a wide range of MEMS components at R&D level, including gears, motors and turbines, linear actuators, electrical microconnectors, planar inductors, passive optical components and accelerometers. Many of these devices have been manually assembled, because complex multi-level LIGA processes are difficult (though not impossible) to implement. Some of the most promising devices have involved a mixture of fabrication methods, with LIGA being used to fabricate only critical components.

## 3. INDUCTORS BASED ON MEMS

The ability of MEMS fabrication technologies to eliminate the substrate underneath passive structures, to elevate them over the substrate, or to enable high-aspect ratio/large cross-sectional area structures, places at the designer's disposal a large repertoire of techniques to help him combat the limitations of passive components.



PICTURE 4. A BULK-MICROMACHINED INDUCTOR [10]

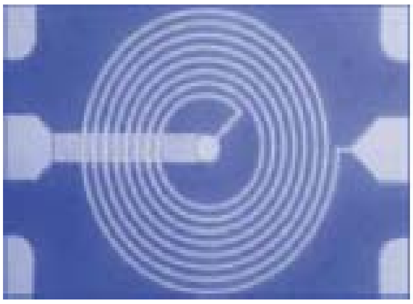
Bulk micromachining has been applied to drastically reduce the parasitics plaguing conventional on-chip planar inductors, and that contribute to their low quality factor (Q) and self-resonance frequency, with the particular aim of approaching the performance of their off-chip counterparts. Picture 4 shows an example of a bulk-micromachined inductor in which the substrate has been eliminated from underneath the spiral trace. Measured Q is in the range from 6 to 28 at frequencies from 6 to 18 GHz, with typical inductor values around 1nH.

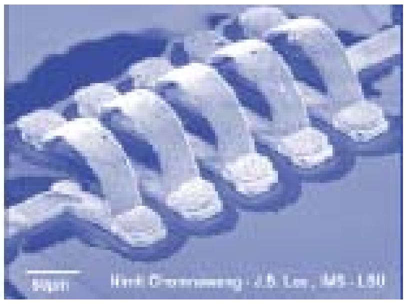

(a) (b)

PICTURE 5. SOLENOID-LIKE INDUCTORS [10].

Similarly, surface micromachining has been exploited to create solenoid-like inductors above the substrate. Picture 5 shows an example of such an approach. A quality factor of 25.1 at 8.4 GHz and an inductance of 2.3 nH were obtained, for inductor from picture 5.

Inductors are key elements determining the performance of tuned circuits, in particular, impedance matching networks, low noise amplifiers and voltage-controlled oscillators (VCO). Improving the gain, power dissipation or phase noise of these circuits has, in turn, led to incorporating MEMS-based on-chip inductors. Flat spiral inductors possible in today's CMOS processes have low Q due to losses from series resistance in the spiral, parasitic capacitance between turns, and parasitic coupling into the substrate. The inductor improves if the substrate is etched away below the inductor's spiral. This "bulk micromachining" improves the inductor enough to make it useful for cell phone applications. "Surface micromachining," a process that builds three-dimensional structures above the substrate, can build inductors with coils perpendicular to the substrate, avoiding parasitic losses to the substrate. Surface micromachining also creates inductors good enough for cell phone applications. Example two type inductors is shown in the picture 6a and 6b.





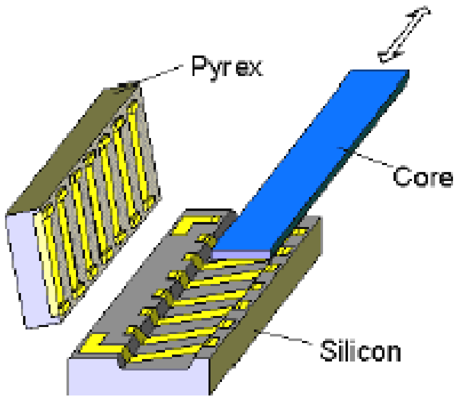
PICTURE 6.
(a) BULK MICROMACHINING REMOVES THE SUBSTRATE (DARK BACKGROUND) BEHIND THE INDUCTOR'S COIL, LEAVING FREE SPACE BELOW THE COIL
(b) SURFACE MICROMACHINING BUILDS THE INDUCTOR ABOVE THE SEMICONDUCTOR'S SURFACE [11]

Integrated planar inductors are fundamentally important to development of fully integrated magnetic MEMS devices. For most microactuator applications, microfabricated inductive components are required to have high inductance for generating large magnetic fields, as well as low resistance for high-current driving applications.

It is also important that these inductive components be fabricated with a low-cost reliable method. Because this is not an easy task, much research effort has been focused on this area. To date, several different planar inductors, including spiral-type, solenoid-type (also called bar-type), and meander-type have been developed to fit the needs of various applications. Spiral inductors are typically the simplest inductors to fabricate. Although spiral inductors often work very well as electronic components, there are some drawbacks to using these types of inductors in an actuator scheme. First, many turns are required to achieve high inductance. This not only increases the inductors's size, but also increases the coil resistance. Another drawback of the spiral inductor is that it is difficult to achieve a closed magnetic flux path. Solenoid-type inductors are typically better suited for applications involving actuation.

## 4. INDUCTORS BASED ON MEMS APPLICATIONS IN SENSORS AND RF COMPONENTS

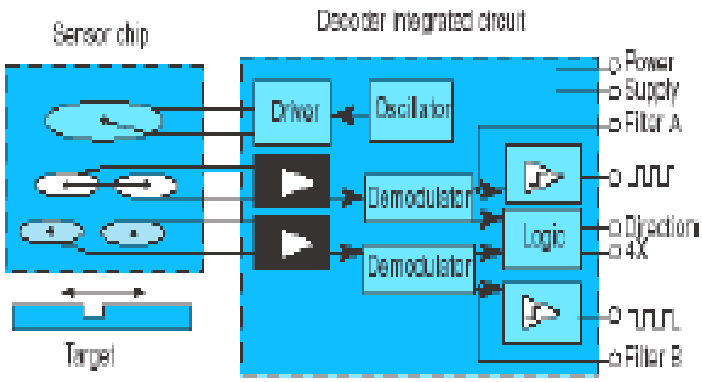
The structure of the sensor is shown in Picture 7. It consists of three parts, the upper and lower part of the coil, and the iron core.



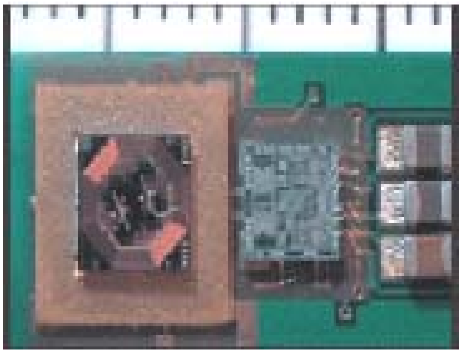

PICTURE 7. STRUCTURE OF THE MICRO COIL [12]

A full 3D coil can be build by connecting the two halves of the coil by flip chip bonding. The micro coil will be used as a sensor that measures the flexion of fingers. For this purpose several micro coils are mounted on a data glove. Though the coil is fabricated by means of silicon bulk micromachining it is possible to move an iron core through the coil without destroying the windings. The inductance of the full coil is 0.25 μH without core and 7.2 μH with core. The ohmic resistance has a value of 60 Q. A movement of the flexible core results in a change of inductance so that this micro coil can be used as a position sensor or an angular sensor.

Accurate, reliable position sensing is the backbone of many closed-loop control systems in robotics, automotive and industrial process industries, to name a few. Inductive sensor developed by the Swiss company CSEM. What makes this sensor interesting is that in principle it is similar to the variable differential transformer, with the coils micromachined on a chip. Picture 8 shows the sensor with its driver and decoder electronics encapsulated for protection. Picture 9 is a microscopic detail of the business end of the sensor.



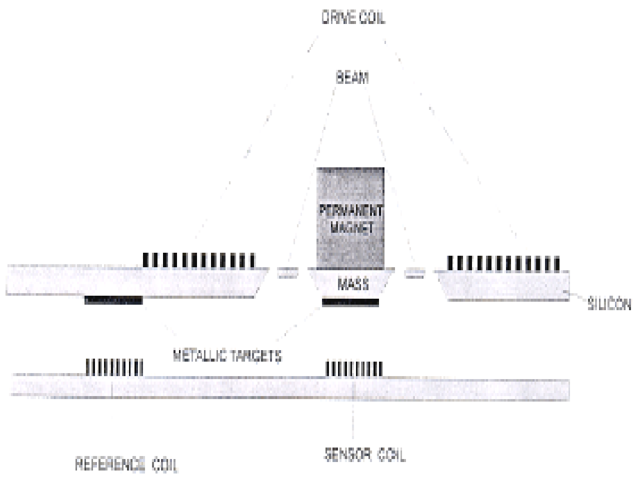

PICTURE 8. THE CSEM SENSOR DIAGRAM IS SIMPLE.
AN OSCILLATOR DRIVES THE EXCITATION COIL WHILE THE POSITION SIGNAL IS PICKED UP AND DECODED BY FOUR SERIES-PARALLEL SENSORS COILS [13].



PICTURE 9. MICROSCOPIC DETAIL OF THE SENSOR PART.
YOU CAN SEE THE LARGE OCTAGONAL EXCITATION COIL, WHICH IS ABOUT 3.8 mm ACROSS. THE FOUR SMALLER SENSING COILS BELOW IT ARE FAINTLY VISIBLE [13]

## 5. ADVANTAGES INDUCTIVE MICROMACHINING COMPONENTS

Friction and wear of components have been a major impediment in the development of active microelectromechanical systems (MEMS) devices like micromotors.




PICTURE 10. CROSS-SECTIONAL OF THE SILICON PLATFORM PLATE [14]

The coefficient of dynamic friction between the small smooth surfaces of the micromachined components has been estimated to be 0.2 to 0.5. Magnetically suspended levitated noncontact devices are highly desirable for active MEMS components.

The paper [14] describes MEMS component of the microsuspension system. The drive coil is electroplated around a highly compliant beam-mass structure, which is designed to allow large deflections along the vertical direction and to constrain movement in all other directions. A bulk NdFeB permanent magnet is mounted on the top of proof mass. Additionally, two identical thin metallic structures are fabricated on the bottom of the wafer. These metallic structures act as sensing targets for the inductive sensing coils.

Picture 10 schematically illustrates the cross-sectional view of platform plate. A planar gold coil is electroplated around the folded silicon boss structure. Gold was chosen as the preferred material for coils because it has an electrical conductivity comparable to Cu, is chemically inert (does not oxidize in atmosphere), has excellent thermal conductivity, and is easy to wire bond. Its excellent thermal conductivity ensures uniform heat flow from the coil to the underlying Si substrate. The metallic targets for position sensing are made of Ni, a soft magnetic material. The moving metallic target is placed on the backside of the proof mass, while the stationary target is attached directly to the platform plate. This stationary target is positioned sufficiently far from the beam mass structure to ensure that it is not influenced by the platform motion.

## 6. CONCLUSION

MEMS technologies give smaller, cheaper, and less power consuming components than traditional solid-state components and devices. MEMS are three-dimensional miniature devices or a collection of devices that combine both electrical and mechanical characteristics. These electromechanical subsystems can range in size from micrometers to millimeters and are fabricated with existing IC batch-processing techniques. While the microcosmic world of MEMS components can be measured in microns, its future market potential is estimated in the billions.

## ACKNOWLEDGMENT

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