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Study on MEMS Fabrication Techniques and Applications

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Abstract

MEMS is the acronym for Micro Electro Mechanical Systems. Micromachining has potential applications for large area image sensors and displays, but conventional MEMS technology, based on crystalline silicon wafers cannot be used. Instead, large area devices use deposited films on glass substrates. This presents many challenges for MEMS, both as regards materials for micro-machined structures and the integration with large area electronic devices. A new single crystal silicon Micro Electro Mechanical Systems (MEMS) fabrication process is proposed using proton-implantation smart-cut technique. Compared to conventional silicon on insulator (SOI) wafer fabrication processes for MEMS applications. The fabrication of free-standing high-carbon microstructures by soft lithographic techniques; these structures ranged in complexity from simple beams to complex, suspended deflectors. MEMS products are highly used in various fields like telecommunications, communications satellites, automotive, healthcare, in electronic devices and in many general applications.

Keywords: MEMS, Micromachining, Lithography, MOEMS, Nanotechnology.

Introduction

MEMS is the acronym for Micro Electrical Mechanical Systems.The beginning of MEMS technology dates back to the discovery of semiconductors at Bell Laboratories in the early1950s. Many consider their 1954 paper, announcing the discovery of piezoresistive effect in silicon and germanium, as the birth date of MEMS. A related acronym MOEMS stands for Micro OptoElectro Mechanical Systems and defines a subset of MEMS, that is, devices performing optical functions.

In Europe, MEMS is labeled Microsystems Technology (MST) and in Japan it is labelled Micromachines. The term MEMS evolved in the United States in the 1990s. Prior to that period the technology was labelled silicon micromachining. **M**icro **E**lectro Mechanical **S**ystems, the tiny mechanical devices that are built onto semiconductorchips and are measured in micrometers. In the research labs since the 1980s, MEMS devices began to materialize as commercial products in the mid-1990s. They are used to make pressure, temperature, chemical and vibration sensors, light reflectors and switches, as well as accelerometers for vehicle airbags, smartphones, tablets and games.

It defines mechanical structures fabricated with IC processing on (most often) silicon wafers.It is a highly miniaturized device or an array of devices combining electrical and mechanical components that is fabricated using integrated circuit (IC) batch processing techniques and can range in size from micrometers to millimetres (1mm=1000m)

Micro-Electro-Mechanical Systems (MEMS) is the integration of a number of microcomponents on a single chip which allows themicrosystem to both sense and control the environment. The components typically include microelectronic integr ated circuits (the “brains”), sensors (the “senses” and “nervous system”), and actuators (the “hands” and “arms”). MEMS defines the Technology; not specific products.This technology encompasses a collection of a variety of processes enabling three-dimensional shaping of wafers or stacks of wafers. While most of the applications use silicon wafers, many other materials have been used, including glass and quartz wafers.

As a result of batch manufacturing technology (using multiple devices photolithographically defined on a wafer), the cost of the single device depends on its size; wafer processing cost is fixed for a given process. The cost difference between a 1 × 1mm device

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and a 10 × 10mm device is 100 times, as the first device would yield about 16000devices on a 6-in diameter wafer, and the larger devicewould yield only about 160 devices on the same wafer.

MEMS and MOEMS

When optical components are included in a MEMS device, it is called a micro-opto-electro mechanical system (MOEMS). For example, adding a photonic sensor to a silicon chip constitutes a MOEMS device. Seemicromachine, MEMS mirror, DLP and optical switch.

MEMS Vs. Nanotechnology:

Sometimes MEMS and nanotechnology are terms that are used interchangeably, because they both deal with microminiaturized objects. However, they are vastly different. MEMS deals with creating devices that are measured in micrometers, whereas nano technology deals with manipulating atoms at the nano meter level.

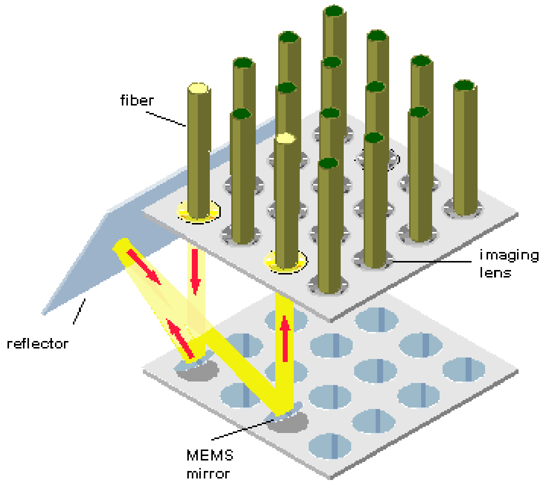

Fig.1 MEMS-based Optical Switch

In an all-optical switch,(Fig.1) MEMS mirrors reflect the input signal to an output port without regard to line speed or protocol. This technology is expected to be the dominant method for building photonic switches.

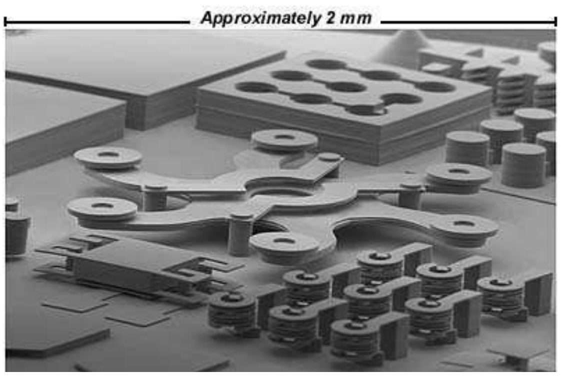

Fig. 2 Sample Micromachines

to accept CAD files as input, turning customer designs into micromachines much faster than traditional methods as shown in fig.2. EFAB Microfabrica's EFAB system was the first MEMS foundry process builds the devices one metal layer at a time. In this image, the square at the top is a microfluidics device with internal passageways used for a "lab on a chip." The multi-arm device (center) is a fuel injection nozzle. Bottom left is an accelerometer,and bottom right is an inductor used in RF circuits.

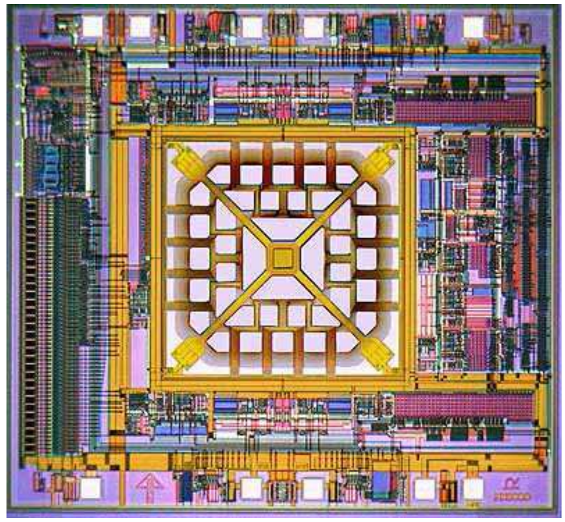

Fig. 3 MEMS-Based Accelerometer

MEMSIC's dual-axis thermal accelerator is a MEMS based semiconductor device that like air bubble in work conceptually a construction level as shown in fig.3. The square in the middle of the chip is a resistor that heats up a gas bubble. The next larger squares contain thermal couples that sense the location of the heated bubble as the device is tilted or accelerated.

A high level of interest in MEMS technology results from both business and technical factors.

Factors on the business side are given below:

- Multiple emerging markets for MEMS devices promise large financial gains. The cumulative venture capital industry investments into MEMS-based companies are estimated at over $1 billion as of 2003.
- In 1999, Business Week selected MEMS as one of the three technologies expected to fuel the growth of the economy in the twenty-first century. The other two were information technology and biotechnology.
- The IC industry created a solid technology infrastructure immediately availa ble for MEMS.

On the technical side, some of the multiple factors that contributed to making MEMS attractive are as follows:

- Potential for integration of devices with IC circuitry, to create integrated systems on a chip.
- Excellent mechanical properties resulting from extremely pure crystalline structure with a silicon content of 99.999% or better, resulted in no material fatigue or mechanical hysteresis. This makes silicon almost a perfect material for sensors. The mechanical properties are comparable to steel, see Table 1.
- Batch wafer processing technology, enabling lowcost, high volume production.
- Excellent lateral dimension control to submicron level.
- Available cutting edge IC processing equipment, offering easy transition to volume production.
- Available ultrapure (no mechanical fatigue) low-cost materials.
- Available sophisticated diagnostic and test equipment.
- Available design and simulation tools (software).
- Available high-volume IC packaging technologies.
- Available pool of educated silicon processing technologists

Another aspect of MEMS that adds to its attractiveness is its synergy with nanotechnology, which receives a high level of government funding worldwide. In many cases, MEMS can be used as a packaging vehicle for nano devices.

Fig.4 shows MEMS is the integration of mechanical elements, sensors actuators and electronics on a single common silicon substrate through microfabrication technology . These systems can sense, control and actuate on the microscale and function individually or in arrays to generate effects on microscale.

Size of mems components

(1) Size definition
1 micro =1 um =1/10-3 mm =1/10-6 m
1 nanometer =1 nm =1/10-3 um =1/10-9 m
1 Angstrom =1/10 nm =1/10-10 m

(2) Size comparison
Human hair ～100 um
Paper thickness ～100 um
Red blood cell, capillaries ～8um
Visible light～0.5 um
Tobacco smoke ～0.5 um
Bacteria ～5 um Virus ～0.1 um
IC elements ～0.2 um SARS: 0.01 ～0.05 um
Year 2010 IC production rule～0.07 um
Atomic spacing in solids～0.0003 um

(3) Size of MEMS/micromachines:
1 ～1000 um

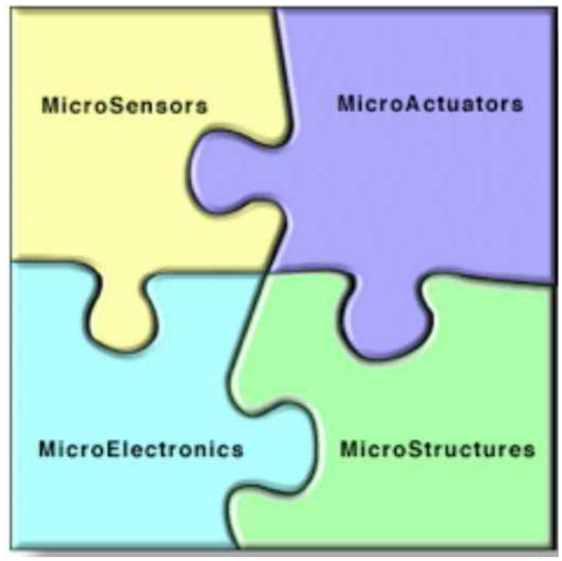

Fig.4 components of MEMS

MEMS Manufacturing Process

MEMS is a manufacturing technology, that is a new way of making complex Electro mechanical systems. This new manufacturing technology has several distinct advantages. First, MEMS is an extremely diverse technology that potentially could significantly impact every category of commercial and military products. Second, it blurs the distinction between complex mechanical systems and integrated circuit electronics. MEMS manufacturing involves the repetitive process of designing, fabrication, packaging and testing, as shown in Fig.5

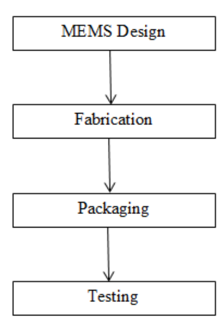

Fig. 5 MEMS manufacturing process

(A) Design:

There are software packages available for the design and simulation of MEMS devices.

(B) Fabrication:

The micromechanical components are fabricated using compatible "micromacihing" process.MEMS promises revolutionize nearly every product category by bringing together silicon-based microelectronics with micromachining technology. This makes possible of realization of complete systems –on-a-chip.

(C) Packaging:

MEMS packaging is an application-specific task. It accounts for the largest fraction of the cost of the MEMS device. Packaging should avoid transferring mechanical strain, heat, pressure, etc. to the device in the package. MEMS introduce new interfaces, processes and materials foreign to the IC packaging industry.

(D) Testing:

The testing of MEMS devices is more complex than that of ICs because of the integratedelectronic and mechanical character of MEMS. Since MEMS devices are manufactured using batch fabrication techniques, similar to ICs, unprecedented levels of functionality, reliability and sophistication can be placed on a small silicon chip at a relatively low cost.

Fabrication of MEMS

Micro engineering refers to the technologies and practice of making three dimensional structures and devices with dimensions in the order of micrometers. The two constructional technologies of micro engineering are microelectronics and micromachining. Microelectronics, producing electronic circuitry on silicon chips, is a very well developed technology. Micromachining is the name for the techniques used to produce the structures and moving parts of micro engineered devices.

One of the main goals of Micro engineering is to be able to integrate microelectronic circuitry into micro machined structures, to produce completely integrated systems (Microsystems). Such systems could have the same advantages of low cost, reliability and small size as silicon chips produced in the microelectronics industry

(A) Bulk Micromachining:

It is applied to a variety of etching procedures that selectively remove material, typically with a chemical enchants whose etching properties are dependent on the crystallographic structure of bulk material.

(B) Surface Micromachining:

It starts with wafer of material ,but unlike Bulk Micromachining where the wafer itself serves as the stock from which material is removed to define mechanical structures, in surface micromachining is the substrate—the working surface—on which multiple, alternating layers of structural and sacrificial layers are deposited and etched. Because of the laminated structural and sacrificial material layers the etching of material done by a process that is insensitive to crystalline structure, surface micromachining enables the fabrication of free-form complex and multi-component integrated electro mechanical structures, liberating the MEMS designer to envision and build devices and systems that are impossible to realize with bulk process. More than any other factor, it is surface micromachining that has ignited and is at the heart of the current scientific and commercial scientific activity in MEMS.

The components are typically integrated on a single chip using microfabrication technologies. The electronics, mechanical and electromechanical components are fabricated using technologies borrowed heavily, but not exclusively, from integrated circuit fabrication technology.

There are three principal steps:

- Deposition processes - thin films of material are placed on a substrate.
- Lithography - a patterned mask is applied on top of the films
- Etching processes - the films are etched selectively to provide relief following the mask outlines.

The fabrication of free-standing high-carbon microstructures by softlithographic techniques; these structures ranged in complexity from simple beams to complex, suspended deflectors. Microstructures of polymeric precursors (copolymers of furfuryl alcohol-phenol) to high-carbon solids were fabricated using polydimethylsiloxane (PDMS) molds. Carbonization of these microstructures under argon resulted in mass loss (up to 45%) and shrinkage (up to 20% linearly); the density increased to reach a plateau value of_1.5 g/cm^3 at _900°C. Microstructures pyrolyzed at 900°C were electrically conductive, with a conductivity of _10^{-2}Ωcm. Elementary microelectromechanical functions were demonstrated in these microstructures: electrostatic actuation induced deflection or vibrations of suspended structures. The measurement of the frequency of resonance of highcarbon cantilevered beams allowed the determination of Young's modulus for the solid: typical values were _15-20 GPa. The microelectromechanical properties of more complex structures (microresonators, light deflectors) were also determined.

Single crystal silicon MEMS fabrication based on smart-cut technique

A new single crystal silicon MicroElectroMechanical Systems (MEMS) fabrication process is proposed using proton-implantation smart-cut technique. Compared to conventional silicon on insulator (SOI) wafer fabrication processes for MEMS applications, this technology can potentially result in a significant substrate and processing cost reduction. A silicon layer with 1.79_m thickness has beenachieved over an oxidized 4-in silicon substrate using the proposed technique. TEM analyses of the silicon thin film reveal single crystal characteristics, which is attractive for potential integration of MEMS devices with microelectronics in the same structural layer. Implant-induced defect density in the silicon can be substantially reduced to a negligible level through high temperature annealing. Prototypesingle crystal silicon MEMS structures, such as cantilever beams and clamped–clamped micro-bridges with a typical length of a few hundreds of micrometers, have been successfully fabricated as demonstration vehicles for future micro-systems implementation

Fabrication of Free-Standing Metallic Pyramidal Shells

A technique for fabricating three dimensional , metallic , pyramidalmicrostructure s with base dimensions of 1-2 μm, wall thicknesses of _100-200 nm, and tip-curvature radius of _50 nm. The procedure begins with the fabrication of pyramidal pits in the surface of an n-doped silicon substrate. An electrically insulating surface layer of SiO_2 covers the regions outside the pits. These pits are patterned using either conventional photolithography or soft lithography and formed by selective anisotropic etching. The resulting topographically patterned silicon serves as the cathode for the selective electrodeposition of metal in the pyramidal pits. Removing the silicon template by etching generates free-standing, pyramidal, metallic microstructures.

Applications of MEMS

Telecommunications

Telecommunications has a broad array of applications, from micro relays for line card applications to complex multi frequency tunable systems for wireless communications. The integrated circuit industry is heading toward system on a chip (SOC), which seeks to integrate complete functionality on a single silicon substrate.

Communications Satellites

MEMS ***offer*** significant benefits for future satellite systems since they can realize various electrical and mechanical functions in a fraction of the size, weight, **and** power consumption of corresponding traditional “macro” systems. This makes these devices quite attractive in space applications, especially in commercial communications satellites, which ***are*** constantly **drivenby** increased capabilities, high levels of integration, miniaturization and cost reductions. Several applications of MEMS in satellite platforms ***are*** presently under consideration. This includes micro sensors, micro actuators, micro heat pipes for thermal management, propulsion, active conformable surfaces, etc. Applications of MEMS technology in microwave components **and** subsystems ***ore*** growing very rapidly.

Automotive

For the past six years, the automotive industry has used MEMS to sense and control a car’s relationship to its environment, most notably to sense acceleration.

Healthcare

Micro fabricated silicon pressure sensors for blood pressure monitoring, Respirators, Kidney dialysis equipment are some of the applications of MEMS in this field.

General Applications:

Pressure, temperature, chemical and vibration sensors, Light reflectors Switches Accelerometers (for airbags, pacemakers) , Micro actuators for data storage and read/write heads. All-optical switches storage devices etc are general applications of MEMS devices.

Conclusion

- A single crystal silicon MEMS fabrication technology has been demonstrated using proton-implantation smart-cut technique.
- The proposed technology, compared to conventional SOI wafer fabrication processes for MEMS applications, can potentially result in a significant substrate and processing cost reduction.
- Prototype cantilever beams and clamped–clamped micro-bridges have been successfully fabricated as demonstration vehicles for future micro-system implementations. Material analyses show that the transferred silicon layer reveals single crystal characteristics and exhibits a negligible defect density after high temperature annealing.
- These characteristics are critical for realizing high-performance MEMS sensors, actuators,

and potential system integration with microelectronics in the same structural layer.

- The less expensive softlithographic techniques that we have developed: a key element in these techniques is the availability of convenient, inexpensive methods for the preparation of polydimethysiloxane (PDMS) molds that are used throughout these techniques, and the use of these PDMS molds to generate microstructures in polymeric materials that are precursors to carbon solids.
- The PDMS molds were prepared as described previously, by casting PDMS on a photographically generated master.
- Free-standing metallic pyramidal shellsprocedure provides a route to fabricate metallic shells with a pyramidal structure, the tips of whichhave a radius of curvature of _50 nm.
- The uniformity of the template fabricated by photolithography or soft lithography ensures the uniformity in shape and size of the pyramidal shells.
- Pyramid-shaped microobjects are potentially useful for exploring bottom-up self-assembly.

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