

MEMS – A New Technology for Digital Geophone Design

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ABSTRACT : Micro Electro Mechanical Systems or MEMS in short has opened a new era in nearly every product category by the integration of silicon-based microelectronics with micromachining technology. This has led to the creation of complete transducer systems on-a-chip. This technology has the capability of integrating computational ability of microelectronics with the control capabilities of microsensors and microactuators thereby scaling new designs and applications. That is, the role of microelectronic integrated circuits is as “brain” and that of microsensors and microactuators are as “eyes” and “arms” of a human body system - thereby integrating sensing, decision making and controlling parts to realize a complete system. Sensors respond to the information fed from the environment by measuring mechanical, thermal, biological, chemical, optical or magnetic signals. The associated electronic circuits then processes the information received from the sensors. The processed output runs through a decision making algorithm resulting in issue of command to the micro actuators. The actuators, in turn, respond accordingly by moving, positioning, regulating, pumping, and filtering thereby controlling the environment for some desired outcome or purpose. Because MEMS devices are manufactured using batch fabrication techniques similar to those used for integrated circuits, unprecedented levels of functionality, reliability, and sophistication can be placed on a small silicon chip at a relatively low cost.

BACKGROUND

Traditional Geophones used in Seismic Industry for detecting and recording seismic reflections in oil and Gas exploration, have come a long way with almost mature technology. Improvements in their various characteristics like sensitivity, distortion and noise factor, frequency response, size etc have almost reached saturation. Basically these geophones are inductive type moving coils and are sensitive to motion. Evolving of new technology has changed the scenario and opened up a new concept in the geophone design. MEMS based digital geophone was developed to provide performance and deployment enhancements needed to improve success ratio in energy exploration.

WHAT IS MEMS ?

Micro-Electro-Mechanical Systems (MEMS) is the integration of mechanical elements, sensors, actuators, and electronics on a common silicon substrate through microfabrication technology. While the electronics are fabricated using integrated circuit (IC) process sequences (e.g., CMOS, Bipolar or BICMOS processes), the micromechanical components are fabricated using compatible “micromachining” processes that selectively etch away parts of the silicon wafer or add new structural layers to form the mechanical and electromechanical devices. MEMS devices are extremely small, for example, MEMS has made possible electrically driven motors smaller than the diameter of a human hair. Not only the

size but also the improved device parameters make the MEMS technology distinct.

The focus now is on MEMS as a new manufacturing technology, a way of making complex electromechanical systems using batch fabrication techniques similar to those used for integrated circuits, and uniting these electromechanical elements together with electronics.

APPLICATIONS OF MEMS

MEMS is an extremely diverse technology that could significantly affect every product category of commercial and military interest. MEMS are already used for tasks ranging from in-dwelling blood pressure monitoring to active suspension systems for automobiles. The nature of MEMS technology and its diversity of useful applications make it potentially a much sought after technology than even integrated circuit microchips.

MEMS also blurs the distinction between complex mechanical systems and integrated circuit electronics. Historically, sensors and actuators are the most costly and less reliable parts of a macroscale sensor-actuator-electronics system. MEMS technology allows these complex electromechanical systems to be manufactured using batch fabrication techniques, increasing stability, reliability and scalability of the sensors and actuators to match that of integrated circuits. The performance of MEMS devices and

systems are much superior to macroscale components and systems.

There are numerous possible applications for MEMS. As a upcoming and breakthrough technology, leading unparalleled synergy between previously unrelated fields like Biology and Microelectronics, many new MEMS applications are emerging . Examples of real world MEMS devices are RF components for cell phones, miniature pressure sensors for blood pressure monitoring, DNA detectors on a chip, micro-mirror arrays for portable projectors, as well as inertial sensors for realistic computer gaming joysticks and wireless computer interfaces, etc.

Biotechnology

MEMS technology is enabling new discoveries in science and engineering fields. To name few of them ,

- a) Polymerase Chain Reaction (PCR) microsystems for DNA amplification and identification
- b) Micromachined Scanning Tunneling Microscopes (STMs)
- c) Biochips for detection of hazardous chemical and biological agents in the body
- d) Microsystems for high-throughput drug screening and selection etc.

Communications

In communication area , the design of high frequency circuits can be considerably improved with this emerging technology. Electrical components like – the fabrication of inductors and tunable capacitors can be improved significantly compared to their integrated counterparts if they are developed using MEMS technology. With the integration of such components, the performance of communication circuits will improve, while the total circuit area, power consumption and cost will be reduced. One more component that can be looked into, is the mechanical switch where already much research has been made and this is a key component with huge potential used in various microwave circuits. The mechanical switches developed using MEMS technology have quality factors much higher than anything previously available.

One more area of application is in Dense wavelength Division multiplexing (DWDM). Large number of data streams travelling in a single fibre needs to be routed in various

directions which can be achieved using microscopic mirrors. MOEMS (Micro-optoelectromechanical systems) technology as it is referred is used in the development of optical add/drop multiplexers, optical routers and switches. MOEMS narrows down the transitions between optical and electronic transmitters. Reliability and packaging components are the main two critical issues that requires further improvement for wider acceptance by the market.

Accelerometers

MEMS based accelerometers are on run replacing conventional accelerometers used in automobile industry for crash air-bag deployment systems. The conventional accelerometers are very bulky and are made of discrete components mounted in the front of the car with separate electronics near the air-bag. MEMS technology has made it possible to integrate the accelerometer and electronics onto a single silicon chip at a much lower cost. These MEMS accelerometers are much smaller, more functional, lighter, more reliable. Seismic survey is another area where improved versions of accelerometers can be deployed for data acquisition.

DIGITAL GEOPHONE AND ITS DESIGN

MEMS digital Geophone has basically two parts

1. Sensor part
2. Electronic part

The Sensor part includes silicon micro machined capacitive accelerometer and Electronic part includes signal processor, force feedback application related circuit with embedded software (ASIC – Application Specific Integrated Circuit) and A/D converter.

The sensor is basically composed of a moving inertial mass- the proof mass suspended by springs from the surrounding frame structure. The resonant frequency of this spring mass sensor system is in Kilo Hertz range which is much beyond the seismic frequency range; In traditional inductive type geophones, the resonant frequency is at lower end of seismic band. The upper and lower surfaces of the suspended mass have metallic deposits in order to make them conductive. Upper and lower wafer caps also have metallic deposits to work as variable capacitor between proof mass and cap wafers. Thus the MEMS assembly is composed of four individual silicon wafers, each wafer etched to form component structures and collectively bonded to form final

die assembly. This assembly (stand alone capacitive accelerometer) is integrated with ASIC to achieve the required performance. ASIC provides restoring feedback force to the proof mass to maintain its neutral position. That is, any seismic signal induces a change in capacitance. Opposite feedback charges are applied by the ASIC for maintaining the proof mass balance. The feedback charges are digitized by an internal sigma – delta A/D converter and taken out as digital signal.

FABRICATION OF DIGITAL GEOPHONE

There are many types of MEMS fabrication technologies. Broadly these are classified under three categories. 1. Bulk micromachining 2. Surface micromachining 3. HARM (High-aspect ratio micromachining)

In Bulk micromachining subtractive process is used. Here substrate is removed selectively to form the MEMS structure like cantilevers, holes, grooves, membranes etc.

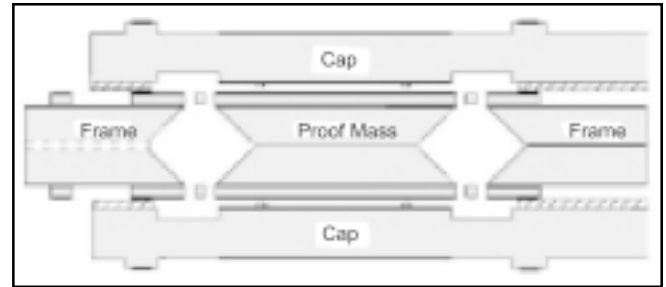
In surface micromachining additive process is used. Here, by depositing combinations of structural and sacrificial layers structures like gears, comb figures, cantilevers and membranes are formed.

In HARM (High-aspect ratio micromachining) the ultraviolet or x-ray lithography techniques are collectively used.

In the fabrication of digital Geophone, a three terminal variable capacitance sensor is processed using four six - inch double side polished single crystal silicon wafers. The two centre wafers are fusion bonded to form the proof mass, mass support frame and the centre electrode. The two outer wafers provide the outside electrodes and are metal thermo compression bonded to the mass frame. The two outer wafers provide the outside electrodes and are metal thermo-compression bonded to the mass frame. Etching the epitaxial layer on the outside surfaces of the proof mass wafers forms the silicon springs.

Metal is deposited on the bonded proof mass and caps to provide electrodes and electrical connections. The completed die is approximately 6.5mm x 5.5mm x 2mm. The completed sensor is housed in a custom ceramic package and is sealed in a vacuum.

The electronic part comprises of a custom, application specific CMOS integrated circuit (ASIC). The ASIC utilizes switched-capacitor technology and controls the sensor in a time-division multiplexed mode.



Cross Section of MEMS Accelerometer

The completed sensor and ASIC are mated to form a surface-mount assembly.

ADVANTAGES OF DIGITAL GEOPHONE

The benefits of MEMS technology in the development of digital geophone are :

- Direct digital output at the sensor
- Wide Bandwidth to resolve reservoir details
- High vector fidelity enable acquisition of data of unparalleled clarity
- Superior low and high frequency response
- Enable acquisition of cost effective multi component data
- Increased Operational efficiency
- Provides information about tilt against the vertical axis
- Achievement of in pact – 3C digital geophone in a single housing

A Comparison of a typical * MEMS based digital geophone and conventional Geophone

| Sl. No | Parameter | * Digital Geophone | Conventional Geophone |
|--------|---------------------|--------------------|----------------------------|
| 1 | Harmonic Distortion | 0.0027 % | 0.1 – 0.15 % |
| 2 | Vector Fidelity | 46 dB | 29 dB |
| 3 | 50/ 60 Hz pick up | No | Yes |
| 4 | Analog Leakage | No | Yes |
| 5 | Amplitude Response | Flat | Lower response below f_n |
| 6 | Phase response | Flat | + 90° centred on f_n |
| 7 | Frequency Response | 0 -500 Hz | 10 -240 Hz |
| 8 | Tilt Limits | None | + 10° |

- Typical Parameters of I/O make VectorSeis™ Geophone, courtesy: Published Technical literature.

CONCLUSION

Usage of the Digital Geophones in Seismic industry has already taken place to some extent. Being more reliable and scalable this technology has potential to add into the data quality in seismic exploration.

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