MEMS : A Smart System of Modern Era

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1. Introduction

MEMS or Micro Electro Mechanical Systems are the microscopic structures integrated onto silicon that combine mechanical, optical and fluidic elements with electronics. Though a MEMS device is of the size of a sand grain, these devices are complex machines that enable chips to become intelligent. They act as the most direct links between digital electronics and the physical world, allowing the integration of electronics and mechanical systems on a single chipset. First developed in the 1970s and then commercialized in the 1990s, MEMS make it possible for systems of all kinds to be smaller, faster, more energy-efficient and less expensive. These general microsystems can directly interact with the real world, and thus they are expected to have the most widespread impact on the application domains. The impact of MEMS is not just limited to reducing overall size, cost, weight, and power dissipation. They open up new market opportunities and enhance the overall accuracy and performance of the systems by making formation of large arrays of distributed microsystems and tansducers feasible.

2. Configuration of MEMS

In a typical MEMS configuration, integrated circuits (ICs) provide the "thinking" part of the system while MEMS complement this intelligence with active perception and control functions. Microelectronic integrated circuits can be thought of as the "brain" of a system and MEMS augments this decision-making capability with "eyes" and "arms", to allow microsystems to sense and control the environment. MEMS are usually divided into two categories - those devices that detect information, called microsensors, and another that can respond to information, or act, called actuators. Sensors gather information from the environment through measuring mechanical, thermal, biological, chemical, optical and magnetic phenomena. The electronics part of the system then processes the information derived from the sensors and through some decision making capability direct the actuators to respond by moving. positioning, regulating, pumping and filtering, thereby controlling the environment for some desired outcome or purpose.

3. MEMS Technology

MEMs devices are extremely small - for example, MEMS have made possible electrically-driven motors smaller than the diameter of a human hair - but MEMS technology is not primarily about size. MEMS is also not about making things out of silicon, even though silicon possesses excellent material properties. Instead, MEMS is a new manufacturing technology, a way of making complex electromechanical systems using batch fabrication techniques similar to those used for integrated circuits such as thin-film deposition and growth, photolithography, etching and micro-machining. These techniques are increasingly being used to make MEMS and NEMS (Nano Electro Mechanical Systems) structures that are mechanical in nature. This technology can be thought of as an enabling technology, one that helps develop new measurement tools that can measure the physical world more precisely and can unite these electromechanical elements together with electronics. It is the integration of mechanical elements, sensors, actuators and

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electronics on a common silicon substrate through microfabrication technology. While the electronics parts of the system 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. 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 chip at a relativly low cost.

MEMS promises to revolutionize nearly every product category by bringing together silicon-based microelectronics with micromachining technology, making possible the realization of complete systems-on-a-chip. MEMS is an enabling technology allowing the development of smart products, augmenting the computational ability of microelectronics with the perception and control capabilities of microsensors and microactuators and expanding the space of possible designs and applications. The nature of MEMS technology and its diversity of useful applications make it potentially a far more pervasive technology than even integrated circuit microchips. MEMS blurs the distinction between complex mechanical systems and integrated circuit electronics. Historically, sensors and actuators are the most costly and unreliable part of a macroscale sensor-actuator-electronics system. MEMS technology allows these complex electromechanical systems to be manufactured using batch fabrication techniques, improving the reliability of the sensors and actuators to equal those of integrated circuits.

4. Applications

First MEMS product was the airbag sensors for the cars and was introduced during the 1980s. Since then the technology has grown very rapidly. MEMS technology is currently used in low or medium-volume applications. Already the world's smallest motors have rotors that are less than the diameter of a human hair. These motors are powering optical switches, valves and airbag deployment sensors.At present MEMS are most commonly found as sensors in automobile airbags, but the devices are making extensive inroads into defense, traffic control, communications systems and biotechnology.

4.1 Accelerometers

MEMS accelerometers are quickly replacing conventional accelerometers for crash air -bag deployment systems in automobiles. The conventional approach uses several bulky accelerometers made of discrete components mounted in the front of the car with separate electonics circuit near the air-bag; MEMS technology has made it possible to integrate the accelerometer and electronics part onto a single silicon chip at a much lower cost. These MEMS accelerometers are much smaller, more functional, lighter, more reliable and are produced for a fraction of the cost of the conventional macroscale accelerometer elements.

4.2 Smart dust

Scientists have created "smart dust" where millions of miniscule MEMS sensors are spread over a military site and communicate information to humans or computers ready to interpret possible troop movements.

4.3 Smart road

"Smart roads" would have MEMS devices embedded in them, conveying information about the roadway, traffic and accidents to automobile-mounted global positioning systems, allowing drivers to avoid problems and alerting highway workers to areas that are potential troublespots.

4.4 Communication

High frequency circuits will benefit considerably from the advent of the RF-MEMS technology. Electrical components such as inductors and tunable capacitors can be improved significantly compared to their integrated counterparts if they use 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. In addition, the mechanical switch as developed by several research groups, *is a key component with huge potential in various* microwave circuits. The demonstrated samples of mechanical switches have quality factor much higher than anyting previously available. Reliability and packaging of RF-MEMS components seem to be the two critical issues that need be solved before they receive wider acceptance by the market.

4.5 Fiber optic network

An important new application of MEMS devices is in fiber optic networks. At the micron level, MEMS-based switches route light from one fiber to another. Such an approach enables a truly photonic (completely light-based) network of voice and data traffic, since switching no longer requires conversion of light signals into digital electronic signals and then back to optical. While many of the key applications for MEMS devices require them to perform like valves of pumps, the functionality developed for optical networks typically revolves around MEMS-based micromirrors. Micromirrors are the fundamental micro mechanical components for optical crossconnect switches that switch light frequencies from one set of fibers to another. This process includes an input / output port, an actuator and a mirrored surface. When voltage is applied to the actuator, it causes the mirror to move and direct the light to a specific output port. The mirror then remains static until the light path needs to be redirected.

MEMS switches include both mechanical and microfluidic types. Mechanical switches, which currently seem to offer the most reliable and flexible approach, are based on an array of micromachined mirrors that range in quantity from hundreds to thousands on a single chip. This is important because switching using optical-eletrical-optical (OEO) conversion can often cause substantial bottlenecks, preventing the realization of truly broadband networks. But MEMS and micromachined devices can be used as more than switches in the optical network. Additional applications include active sources, tunable filters, variable optical attenuators, and gain equalization and dispersion compensation devices. These mirror-based switches are also classified as either two-dimensional, where they move up and down or left and right, or three dimensional, where they can swivel in a broad range of movement.

MEMS-based switches must be extermely reliable to meet the standards and requirements of optical telecommunications networks - they must remain in precise position over millions of operations, and they must be designed to meet stringent environmental specifications involving temperature and vibration. However, there is a high degree of confidence that mechanical MEMS devices can meet requirements, as similar devices based on the same manufacturing processes have proven to be exceedingly robust in the automotive, military and aerospace industries.

A typical example of an optical network application is add-drop multiplexing, especially in metropolitan area networks. Though non-MEMS-based devices may range from 32 or 64 ports to 1,000 ports, a number of companies are looking at lower port, scalable solutions which offer immediate anufacturability with high yields, robustness and cost-effective batch process technology. Both the metropolitan and access areas of the network have high volume requirements and may be the best opportunity to capiatalize on the optical network while proving the value of MEMS. The result is an end-to-end photonic network which is more reliable and cost-effective, and which has minimal performance drop-off. However, the development of an all-optical network has been complex and challenging due to the integration of optics, mechanics and electronics.

4.6 Biotechnology

MEMS technology is enabling new discoveries in biotechnology such as the Polymerase Chain Reaction (PCR) microsystems for DNA amplification and identification, micromachined Scanning Tunneling Microscopes (STMs), biochips for detection of hazardous chemical and biological agents, and microsystems for high-throughput drug screening and selection.

5. Limitations of MEMS Technology

Though the smart products using MEMS devices are expected to create new opportunities for perceiving and controlling our work and life environments, some of the obstacles preventing the wider adoption of MEMS are as follows.

5.1 Limited Options

Most companies who wish to explore the potential of MEMS technology have very limited options for prototyping or manufactuing devices, and have no capability or expertise in microfabrication technology. Few companies will build their own fabrication facilities because of the high cost. A mechanism giving smaller organizations responsive and affordable access to MEMS fabrication is essential.

5.2 Fabrication Knowledge

Currently the designer of a MEMS device requires a high level of fabrication knowledge in order to create a successful design. Often the development of even the most mundane MEMS device requires a dedicated research effort to find a suitable proces sequence for fabricating it. MEMS device design needs to be separated from the complexities of the process sequence.

5.3 Packaging

The packaging of MEMS devices and systems needs to improve considerably from its current primitive state. MEMS packaging is more challenging than IC packaging due to the diversity of MEMS devices and the requirement that many of these devices be in contact with their environment. Currently almost all MEMS development efforts must target a new and specialized package for each new device. Most companies find that packaging is the single most expensive and time consuming task in their overall MEMS product development program. As for the components themselves, numerical modeling and simulation tools for MEMS packaging are virtually non-existent. Approaches which allow designers to select from a catalog of existing standardization packages for a new MEMS device without compromising performance would be beneficial.

'Unless man increases in wisdom, increase in knowledge will result in increase in sorrow.'

\- Bertrand Russel