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ANALYSIS OF MICRO-ELECTROMECHANICAL SYSTEMS

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ABSTRACT

Micromachining and micro-electromechanical system (MEMS) technologies can be used to produce complex structures, devices and systems on the scale of micrometers. A micro-electromechanical system (MEMS) integrates miniaturized mechanical structures with electronics to extend the benets of planar integrated circuit technology to a broader class of systems. MEMS are a process technology used to create tiny integrated devices or systems that combine mechanical and electrical components. MEMS, an acronym that originated in the United States, is also referred to as Microsystems Technology (MST) in Europe and Micro machines in Japan. Emerging micromachining technology enables us to fabricate mechanical parts on the order of micron size. It provides us with micro-sensors and micro-actuators which facilitate the exploration of all areas of science. In this review paper, we will first briefly introduce Micro-Electro-Mechanical-Systems (MEMS) technology. Then, the applications of MEMS to flow control will be discussed. Initially micromachining techniques were borrowed directly from the integrated circuit (IC) industry, but now many unique MEMS-specific micromachining processes are being developed.

I. INTRODUCTION

MEM has been identified as one of the most promising technologies for the 21st Century and has the potential to revolutionize both industrial and consumer products by combining silicon based microelectronics with micromachining technology. In MEMS, a wide variety of transduction mechanisms can be used to convert real-world signals from one form of energy to another, thereby enabling many Despite only partial standardization and a maturing MEMS CAD technology foundation, complex and sophisticated MEMS are being produced. The integration of ICs with MEMS can improve performance, but at the price of higher development costs, greater complexity and a longer development time. A growing appreciation for the potential impact of MEMS has prompted many efforts to commercialize a wide variety of novel MEMS products. In addition, MEMS are well suited for the needs of space exploration and thus will play an increasingly large role in future missions to the space station, Mars and beyond.

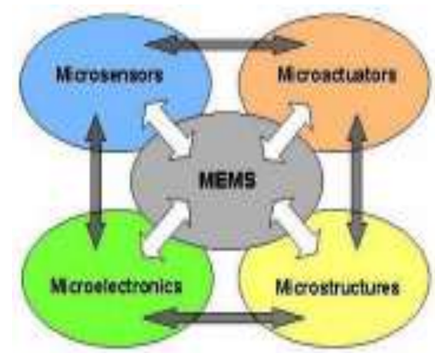

Figure 1. Schematic illustration of MEMS components.

In the most general form, MEMS consist of mechanical microstructures, micro-sensors, micro-actuators and microelectronics, all integrated onto the same silicon chip. This is shown schematically in Figure 1 Micro-sensors detect changes in the system's environment by measuring mechanical, thermal, magnetic, chemical or electromagnetic information or phenomena. Microelectronics process this information and signal the micro-actuators to react and create some form of changes to the environment.

Classifications

This section defines some of the key terminology and classifications associated with MEMS.
It is intended to help the reader and newcomers to the field of micromachining become familiar with some of the more common terms. Figure 3 illustrates the classifications of micro-systems technology (MST). Although MEMS is also referred to as MST, strictly speaking, MEMS is a process technology used to create these tiny mechanical devices or systems, and as a result, it is a subset of MST.

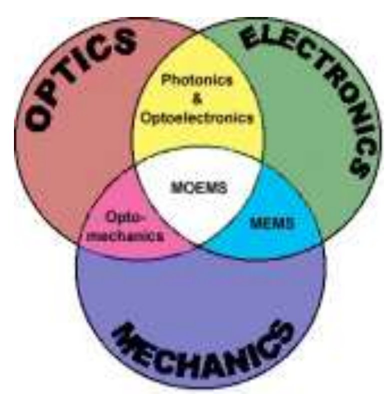

Figure 2. Classifications of micro-systems technology [3].

Micro-opto-electromechanical systems (MOEMS) is also a subset of MST and together with MEMS forms the specialized technology fields using miniaturized combinations of optics, electronics and mechanics. Both their micro-systems incorporate the use of microelectronics batch processing techniques for their design and fabrication. There are considerable overlaps between fields in terms of their integrating technology and their applications and hence it is extremely difficult to categories MEMS devices in terms of sensing domain and/or their subset of MST. The real difference between MEMS and MST is that MEMS tends to use semiconductor processes to create a mechanical part. In contrast, the deposition of a material on silicon for example, does not constitute MEMS but is an application of MST.

Transducer

A transducer is a device that transforms one form of signal or energy into another form. The term transducer can therefore be used to include both sensors and actuators and is the most generic and widely used term in MEMS.

Sensor

A sensor is a device that measures information from a surrounding environment and provides an electrical output signal in response to the parameter it measured. Over the years, this Information (or phenomenon) has been categorized in terms of the type of energy domains but MEMS devices generally overlap several domains or do not even belong in any one category.

These energy domains include:

Mechanical - force, pressure, velocity, acceleration, position Thermal - temperature, entropy, heat, heat flow Chemical - concentration, composition, reaction rate Radiant - electromagnetic wave intensity, phase, wavelength, polarization Reflectance, refractive index, transmittance Magnetic - field intensity, flux density, magnetic moment, permeability Electrical - voltage, current, charge, resistance, capacitance, polarization [4,5,6,7]

Actuator

An actuator is a device that converts an electrical signal into an action. It can create a force to manipulate itself, other mechanical devices, or the surrounding environment to perform some useful function.

II. LITERATURE & SURVEY

The history of MEMS is useful to illustrate its diversity, challenges and applications. The following list summarizes some of the key MEMS milestones [8].

1958 Silicon strain gauges commercially available, 1959 “There’s Plenty of Room at the Bottom” – Richard Feynman gives a milestone presentation at California Institute of Technology. He issues a public challenge by offering $1000 to the first person to create an electrical motor smaller than 1/64th of an inch. 1961 First silicon pressure sensor demonstrated, 1967 Invention of surface micromachining. Westinghouse creates the Resonant Gate Field Effect Transistor, (RGT). Description of use of sacrificial material to free micromechanical devices from the silicon substrate. 1970 First silicon accelerometer demonstrated. 1979 First micromachined inkjet nozzle. Early 1980’s: first experiments in surface micro machined silicon. Late 1980’s: micromachining leverages microelectronics industry and widespread experimentation and documentation increases public interest. 1982 Disposable blood pressure transducer 1982 “Silicon as a Mechanical Material” [9]. Instrumental paper to entice the scientific community – reference for material properties and etching data for silicon. 1982 LIGA Process 1988 First MEMS conference. Methods of micromachining aimed towards improving sensors.1992 MCNC starts the Multi-User MEMS Process (MUMPS) sponsored by Defense Advanced Research Projects Agency (DARPA) 1992 First micro machined hinge 1993 First surface micro machined accelerometer sold (Analog Devices, ADXL50) 1994 Deep Reactive Ion Etching is patented 1995 Bio-MEMS rapidly develops 2000 MEMS optical-networking components become big business.

III. FABRICATION METHOD

MEMS fall into three general classifications; bulk micromachining, surface micromachining and high-aspect-ratio micromachining (HARM), which includes technology such as LIGA (a NGerman acronym from Lithographie, Galvanoformung, Abformung translated as lithography, electroforming and moulding). The market for MEMS devices is still being developed but does not have the explosive growth of, for example, the IC industry in the 1970s. Despite MEMS being an enabling technology for the development and production of many new industrial and consumer products, MEMS design and fabrication processes are not readily partitionable and MEMS designers are thus required to be experts in many areas. Hence, there is a need for a more structured design methodology and supporting tool set for micro-electromechanical systems (MEMS) that promotes higher levels of abstraction and behavioral design. In addition, the majority of the organizations expected to benefit from this technology currently do not have the required capabilities and competencies to support MEMS fabrication. For example, telecommunication companies do not currently maintain micromachining facilities for the fabrication of optical switches. Affordable and receptive access to MEMS fabrication facilities is crucial for the commercialization of MEMS. Due to the highly integrated and interdisciplinary nature of MEMS, it is difficult to separate device design from the complexities of fabrication. Consequently, a high level of manufacturing and fabrication knowledge is necessary to design a MEMS device. Furthermore, considerable time and expense is spent during this development and subsequent prototype stage. In order to increase innovation and creativity, and reduce unnecessary ‘time-to-market’ costs, an interface should be created to separate design and fabrication. As successful device development also necessitates modelling and simulation, it is important that MEMS designers have

access to adequate analytical tools. Currently, MEMS devices use older design tools and are fabricated on a 'trial and error' basis. Therefore, more powerful and advanced simulation and modelling tools are necessary for accurate prediction of MEMS device behaviour. The packaging and testing of devices is probably the greatest challenge facing the MEMS industry. As previously described, MEMS packaging presents unique problems compared to traditional IC packaging in that a MEMS package typically must provide protection from an operating environment as well as enable access to it. Currently, there is no generic MEMS packaging solution, with each device requiring a specialized format. Consequently, packaging is the most expensive fabrication step and often makes up 90% (or more) of the final cost of a MEMS device.
Several other European initiatives supported by governments and the European commission have been coordinated: Europractice (Microsystems Service for Europe), NEXUS (Network of Excellence in Multifunctional Microsystems), aimed at enhancing European industrial competitiveness in the global marketplace, and Netpack, whose role is to drive the Development and use of advanced packaging and integration technologies. The networking of these smaller companies and organizations on both a European and a global scale is extremely important and necessary to lay the foundation for a formal standardization system.

IV. CONCLUSION

MEMS capacitive sensors, such as pressure sensors, accelerometers and gyroscopes have been one of the most successful examples of microsystem technology. The complexity and interdisciplinary nature of MEMS require educated and well-trained scientists and engineers from a diversity of fields and backgrounds. The current numbers of qualified MEMS-specific personnel is relatively small and certainly lower than present industry demand. Education at graduate level is usually necessary and although the number of universities offering MEMS-based degrees is increasing, gaining knowledge is an expensive and time-consuming process. Therefore, in order to match the projected need for these MEMS scientists and engineers, an efficient and lower cost education methodology is necessary.

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