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Micro Electro-Mechanical Systems and VLSI Implementation

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Abstract

With the fabrication process and different materials of microelectronics, Micro Electro-Mechanical Systems (MEMS) technology combines mechanical and electrical components. Beyond this, MEMS fabrication pursues system miniaturization, multiplicity and microelectronics. Depending on MEMS, increasing pocket systems and palm systems appear in daily lives. To exploit new technologies for controlling these systems drives force for the development of MEMS.

MEMS have the similar fabrication process with Very Large Scale Integration (VLSI) systems. However, there are specific differences between VLSI and MEMS. MEMS design will require modifications from VLSI design methodologies. In this article, the difference of these two design methods is presented, and integration MEMS with Application Specific Integrated Circuits (ASIC)/VLSI is explained.

Keyword

MEMS, Micro Electro-Mechanical, Miniaturization, Multiplicity, Microelectronics.

1. MEMS Introduction

MEMS, or more simply, micro-machines are micron-scale devices and tools. MEMS technology makes it possible to develop micromechanical structures together with microelectronic circuitries (Lin, 2001). With the use of this technology, it is possible to

combine detectors, actuators, vibrators, and many more mechanical structures with electronics in micro world. MEMS are used in industrial, automotive, defense, life sciences, and consumer applications (Global Information, Inc).

The fabrication methods for MEMS are derived from VLSI microelectronics industry. That is: on silicon wafer selectively etching away parts of the wafer and add new structural layers to form MEMS devices (Sio , 2002). MEMS is an interdisciplinary field combining electrical engineering, mechanical engineering, materials science, physics and chemistry. And miniaturization, multiplicity and microelectronics are key characteristics in all MEMS fabrication approaches.

2. MEMS Design

There are plenty of common ground between MEMS and VLSI. MEMS design is developed from VLSI. VLSI is designed by a highly developed structured method. VLSI design is based on a set of routine design rules; process variations will not bring many changes in the performances of fabricated devices. Without knowing the details of the fabrication, a full level of description of a VLSI device is specified. The methodology of separation the structure and design in VLSI led to revolutionary reductions in design and prototyping costs. But MEMS have to meet each desired mechanical properties which closely related to precise process specification, some modifications from VLSI design methodologies are made for use in MEMS design (Antonsson et al., 1996).

VLSI devices can be designed from a standard library and manufactured from a relatively small set of primitives. MEMS devices have a much larger set of required primitives and their standard library is incomplete. Because many different devices are integrated into MEMS, it is difficult to interconnect different parts and built small libraries for every part.

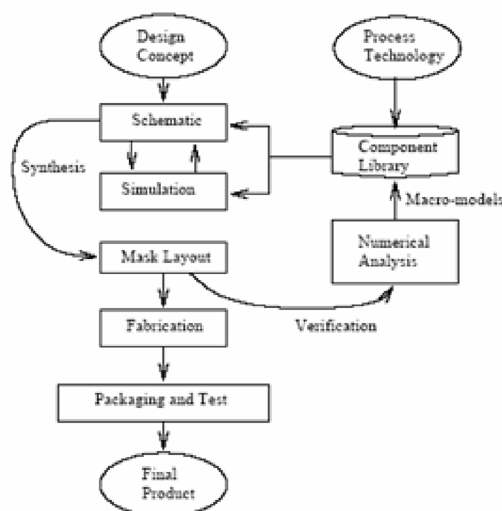

Figure 1: MEMS design flow

The structured design method for MEMS is shown in Fig. 1 which is guided by VLSI design methodologies and fabrication processes.

2.1 Synthesis

In VLSI, Hardware Description Language (HDL) (Verilog, VHDL, SystemC etc.) is used to describe the designed system, while languages for describing MEMS do not exist. MEMS HDL language will be formed and standardized through developing VLSI design language. The components in VLSI occur in a single energy domain, while in MEMS, the components of the system work in multiple energy domains: electrical, mechanical, thermal, chemical, magnetic etc. So MEMS synthesis methods are required to start with a multi-energy domain schematic and create component shapes (Antonsson et al., 1996).

2.2 Simulation

There are a large number of different processes and structures in MEMS, so finding a simulator which can accurately and flexibly simulate is required. That will reduce design cost and quicken process simulations. Because existing VLSI tools have not been fully integrated in MEMS, a study of expending existing simulators to MEMS processes should be undertaken.

2.3 Mask Layout

Nowadays, 2-dimention (2-D) geometry is used to describe the mask in VLSI. VLSI design and fabrication can be separated. In MEMS, since most MEMS have 3-D nature and much more complicated than VLSI, design and fabrication have to be integrated. According to design requirements to decide which mask should be fabricated.

3. MEMS fabrication

3.1 Characteristics of MEMS Fabrication Technologies

No matter which method is used to simulate, synthesis and design MEMS, all MEMS fabrication process has these characteristics: miniaturization, multiplicity and microelectronics (Gabriel 1998).

Miniaturization is a trend for all IC/MEMS fabrication. There are many advantages from miniaturization. Miniaturization enables to product compact, quick-response devices. When sensors are relatively small and light, a high operating frequencies and bandwidths are

achieved, also this make heat absorbed and released smaller. The next revolution for MEMS miniaturization is NEMS, Nanoelectromechanical Systems (Polla, 2005).

Multiplicity refers to the batch fabrication in MEMS process which provides two important advantages. First, multiplicity helps to reduce the unit cost of MEMS devices, since batch fabrication makes it possible to easily, quickly and simultaneously fabricate thousands or millions of components as one component. The other one is multiplicity provides the additional flexibility in the design of interconnected multi-domain MEMS.

Microelectronics technology provides the intelligence to MEMS and allows MEMS to merge micromechanical structure into a chip.

3.2 Fabrication Methods

MEMS fabrication process comes from VLSI process, so VLSI fabrication technology is the primary basis for developing MEMS process. VLSI fabrication technology has these major steps, film growth, doping, and lithography, etching and packaging. So far some new process technology suitable for MEMS has been developed corresponding to MEMS properties.

Bulk micromachining is an etching procedure which can fabricate 3-D structures. It selectively removes materials (Fig. 2) (Madou).

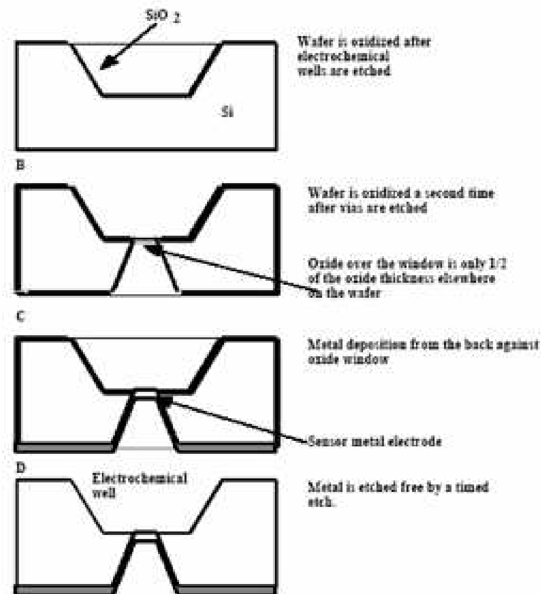

Figure 2: MEMS Bulk micromachining

While wafer bonding permits an additional material to be attached to a bulk substrate. Combining these two, 3-D complex microstructures can be constructed.

Surface micromachining is different with bulk micromachining. Some complex multi-components integrated micromechanical structures are fabricated by surface micromachining. Alternating sacrificial material layers are deposited on the substrate, surface

micromachining erases specific parts of a device in the sacrificial material layer without attacking the structural parts (Fig. 3) (Earthlink).

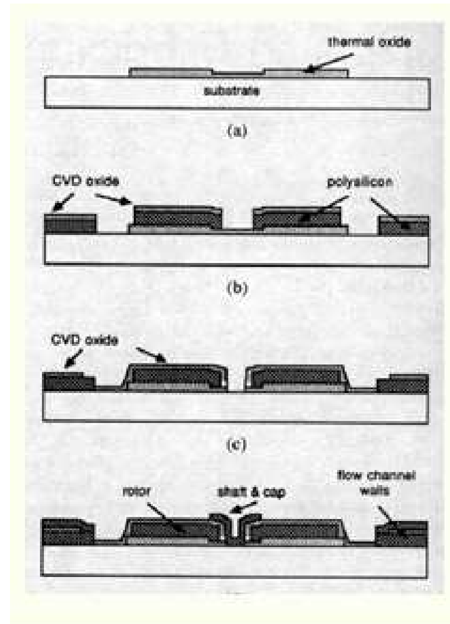

Figure 3: surface micromachining

High-aspect ratio micromachining is use in photolithographic processes, which generate hundreds of microns to centimeters thick photo resists layers (CSA).

4. Integration MEMS with ASIC/VLSI

The demand for low-cost MEMS is a driving force for integration ASIC/VLSI design with MEMS system design. At wafer level, either in 2-D domain or in 3-D domain, MEMS and ASIC/VLSI are integrated by wafer bonding technology. The wafer-bonding process provides electrical connections between the CMOS and MEMS wafers. However, integration limits the temperature budget of post processing, the task to minimize consumption and maximum functionality is undergoing (Gaddi et al., 2005) (Chowdhury, 2002).

5. Conclusion

In summary, MEMS is often considered as a bridge between VLSI and macro mechanics. It offers an opportunity to apply VLSI structured design methods and VLSI fabrication process to mechanical systems. Although MEMS technology faces many challenges such as lacking advanced simulation tools for MEMS design and immature process for MEMS fabrication, MEMS is still a huge market. Future MEMS will be developed with grater functionality, higher electronic-mechanical integration. In turn, future

MEMS will be driven to find new materials, system design methods, fabrication techniques and packaging tools.

Reference

CSA, URL: http://www.csa.com/discoveryguides/mems/overview.php

Dennis Polla (2005), "NEMS: The Next Revolution in Miniaturization".

Earthlink Inc. URL: www.earthlink.net

Erik K. Antonsson etc. (1996), "Structured Design Methods for MEMS". A workshop sponsored by the National Science foundation, California Institute of Technology, USA.

Marc Madou, "Miniaturization Science – V", MEMS Workshop.

Global Information, Inc. "Nanotechnology/MEMS".

Kaigham J. Gabriel (1998), "Microelectromechanical systems (MEMS) tutorial**".** *Test Conference*, Proceedings, International.

Liwei Lin (2001), **"**Curriculum development in microelectromechanical systems in mechanical engineering". Education, IEEE Transactions on. Volume 44, Issue 1.

MEMS and Nanotechnology Clearinghouse, URL: www.memsnet.org

Roberto Gaddi, Antonio Gnudi, Eleonora Franchi etc. (2005), "Reconfigurable MEMS-enabled LC-tank for multi-band CMOS oscillator", *Microwave Symposium Digest*, IEEE MTT-S International.

Sazzadur Chowdhury, M. Ahmadi, G. A. Jullien, and W. C. Miller (2002), "A MEMS Socket System for High Density SOC Interconnection". *Circuits and Systems, ISCAS 2002*, IEEE International Symposium on.

Wannok Sio (2002), "MEMS (Microelectromechanical System)**"**

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