Design and Fabrication Issues in MEMS

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Abstract - **Micro-electromechanical systems (MEMS) have recently become an important area of technology, building on the success of the microelectronics industry over the past 50 years. MEMS combine mechanical and electrical function in devices at very small scales. Examples include pressure sensors, accelerometers, gyroscopes and optical devices, as well as chemical, biomedical and fluidic applications. The status of MEMS technology is reviewed with particular emphasis on materials issues therein. The materials issues in MEMS are divided into three categories, the MEMS material set, micro fabrication processes, and material characterization and design. Each of these areas is addressed, with particular emphasis on the potential impact of material solutions. A discussion of the future of MEMS and the role of materials in that future is given by consideration with design and fabrication issues.**

Keywords: MEMS, Fabrication Issues, Design Issues, Micro Fabrication

I. INTRODUCTION

THE past decade has seen the rapid growth of micro-electromechanical systems (MEMS) as an important area of technology, whose growth is expected to continue well into the next decade. The basic premise behind the concept of MEMS is that the efficiencies of high volume production and low unit cost achieved by the microelectronics industry over the past 50 years can be translated to devices in which mechanical and electrical components are integrated within a single silicon chip.

The success of MEMS as a key technology in the twenty-first century depends in no small part on the solution of materials issues associated with the design and fabrication of complex MEMS devices. The small scales of MEMS offers the opportunity to exploit materials which would not normally be available for large scale devices as well as taking advantage of scale dependent properties, particularly yield and fracture strength. MEMS also offer the opportunity to materials scientists and engineers to be able to characterize materials in ways that have not hitherto been possible. In this article, current status of MEMS is reviewed with a particular emphasis on the role of materials, as well as some of the opportunities for MEMS to contribute to the wider field of materials science and engineering. Three fabrication routes account for the vast majority of MEMS devices; surface micromachining, bulk micromachining and molding processes. Since the materials used in MEMS are to a great extent defined by these manufacturing processes, it is worth briefly reviewing these processes.

II. FABRICATION ISSUES

Surface Micromachining: Surface micromachining evolved directly from the CMOS (complementary metal-oxide-semiconductor) processes used to fabricate VLSI (very large scale integration) devices. These devices consist of thin deposited layers of conductors, insulators, and semiconductors and passivation layers on doped silicon wafer substrates. In VLSI devices, the layers are deposited, patterned and etched to yield highly integrated electronic devices with very small feature sizes. In surface micro machined MEMS, the layers are patterned and etched to yield electromechanical elements, or are used as sacrificial layers to allow motion of the mechanical layers. A surface micromachining process flow is shown in Figure 1.

The use of CMOS compatible processes and materials permits a high degree of integration of mechanical devices with the electronics required for control, signal processing and power distribution. Commercial examples of highly integrated surface micro machined devices include micro accelerometer chips for controlling automobile air bag deployment and mirror arrays for portable projectors. Micrographs of these devices illustrating the complexity and level of integration that can be achieved are shown in Figures 2(*a*) and (*b*). However, surface micromachining is typically limited to layers of thicknesses less than 5 mm which restricts the ability to create devices which can deliver significant mechanical forces.

Bulk Micromachining: Bulk micromachining involves etching features directly into silicon wafers or other substrates. Typically, if integrated electrical function is required the micro-electronic elements are created using CMOS processes on the top side of the silicon wafer, and then bulk micromachining commences from the other side of the wafer to yield mechanical elements such as thin diaphragms or beams on the top side of the wafer, or passages for fluid flow. This strategy has been used for many years to create small pressure sensors, in which optical, capacitive or piezo-resistive measurements are used to sense the deflection of a thin membrane over a bulk micro machined cavity.

The cavity is subsequently sealed, or evacuated and sealed, to create relative and absolute pressure sensors, respectively. Figures 3 and 4 show a schematic of a bulk micro machined cavity and membrane structure such as might be used for a pressure sensor.

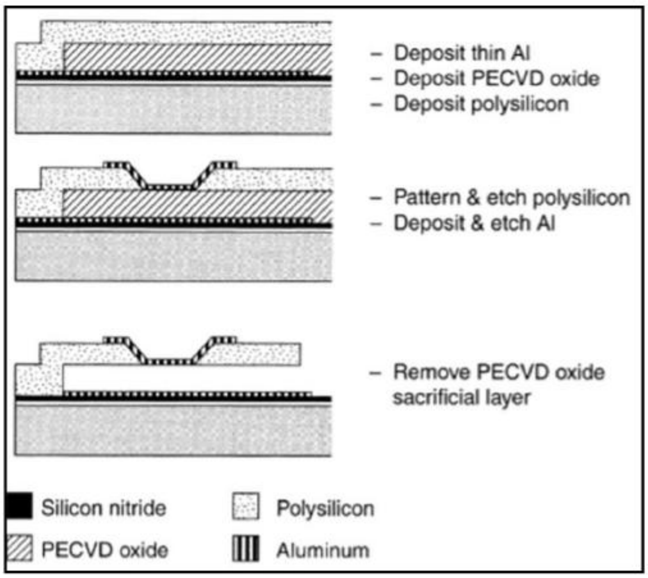


Figure 1. Typical process flow for a surface micro machined device.

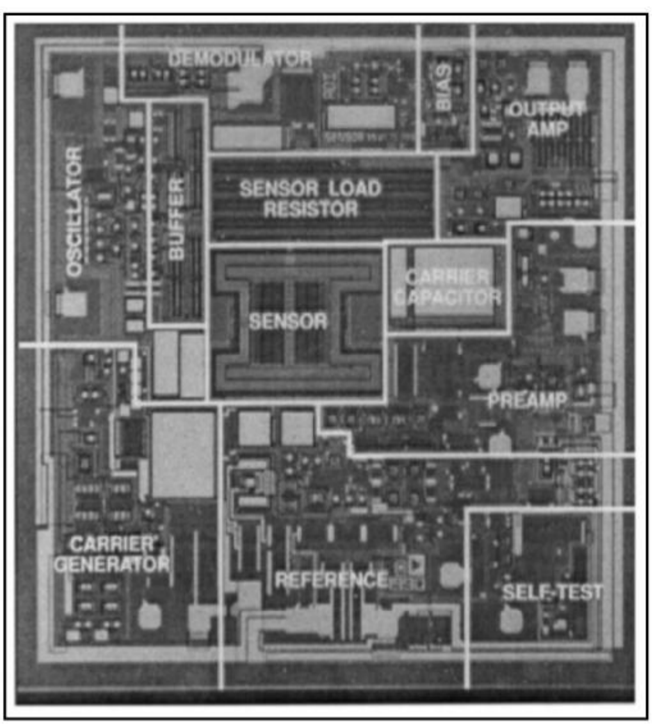


Figure 2 (*a*). Overview of an integrated micro machined accelerometer and signal processing electronics.

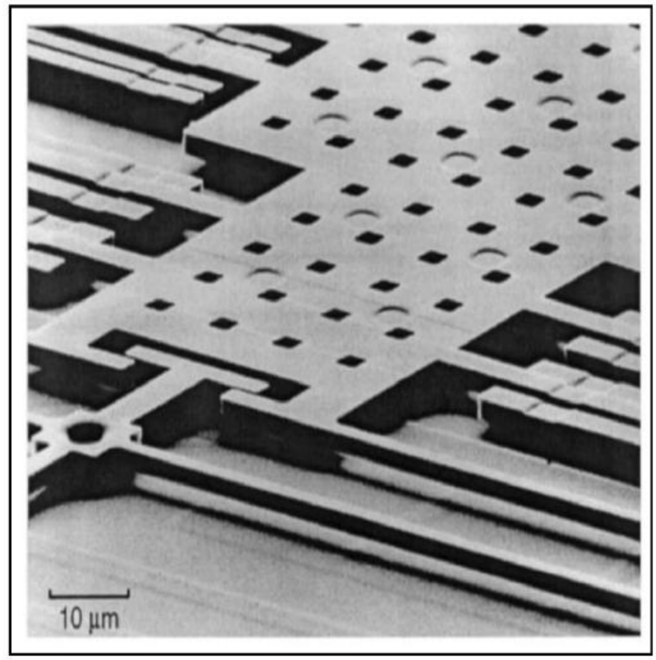


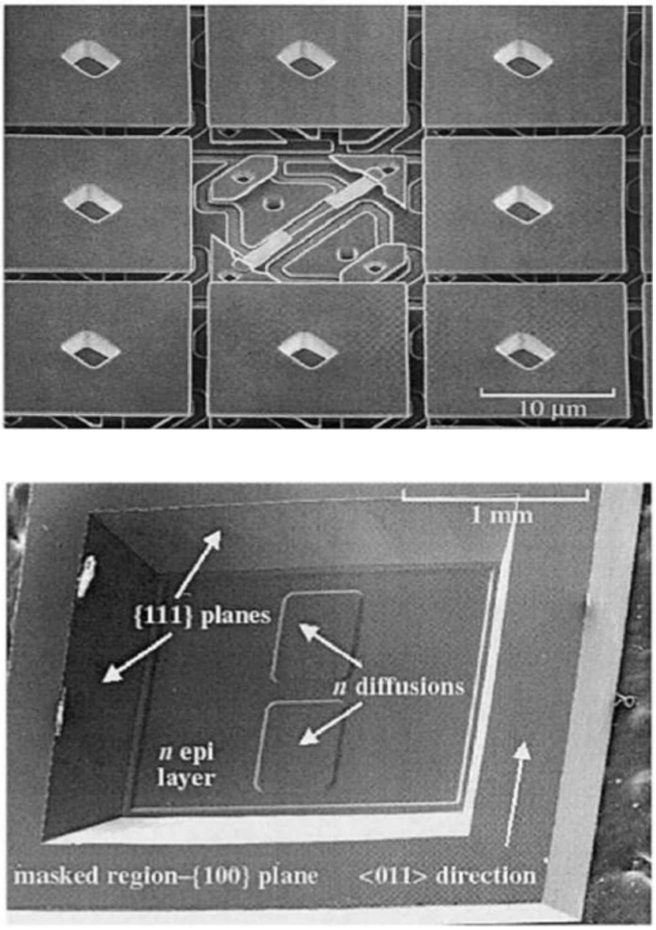
Figure 2 (*b*). Detail of proof micro machined proof-mass and motion sensing capacitance element.

The use of silicon substrate as the basis for mechanical elements of devices permits larger and particularly deeper, features to be used than in surface micromachining. This is an important consideration in MEMS where higher mechanical power or force levels are desired, or in applications involving fluids, such as nozzles for inkjet printers, in which large losses would be associated with flow through the smaller channels that could be realized by surface micromachining.

Molding processes: The third prevalent manufacturing process used for MEMS is the creation of the mechanical elements of the device by deposition of material into a micro fabricated mold. The most widespread such process is ``LIGA'' [the acronym stems from the German expressions for the major process steps: Lithography, Galvanoformung (electroforming) and Abformung (molding)].

The basic process consists of creating a polymer mold by lithography (often X-ray lithography to create high aspect ratio structures) and then electroplating metal into the mold cavities. A typical process flow is shown in Figure 5 which illustrates the small feature sizes and tolerances that can be achieved by this technique.

The idea of using a molding operation is not confined to electro-deposition. Other materials, such as polycrystalline silicon and silicon carbide, can be deposited using chemical vapor deposition and refractory ceramics structures that have been created by slurry processing method.



(*b*)

Figure 3 (*a*) Detail of micro machined mirrors from an array used in a portable digital projector (*b*). A bulk micro machined cavity for a pressure sensor.

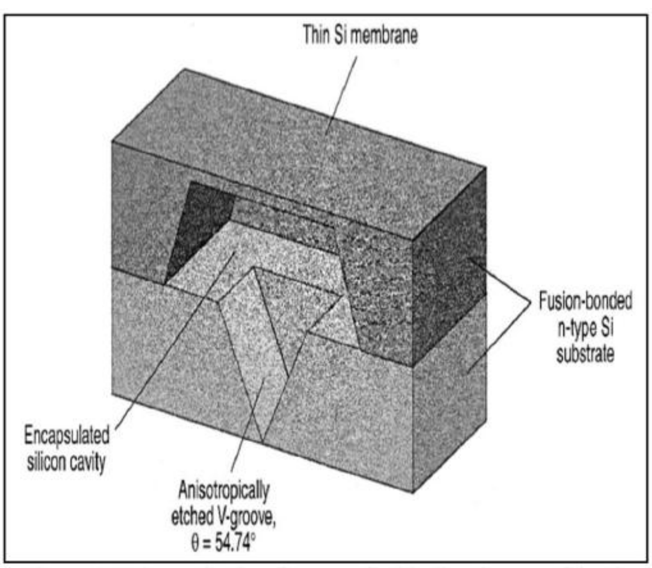


Figure 4. Schematic showing a typical bulk micro machined structure.

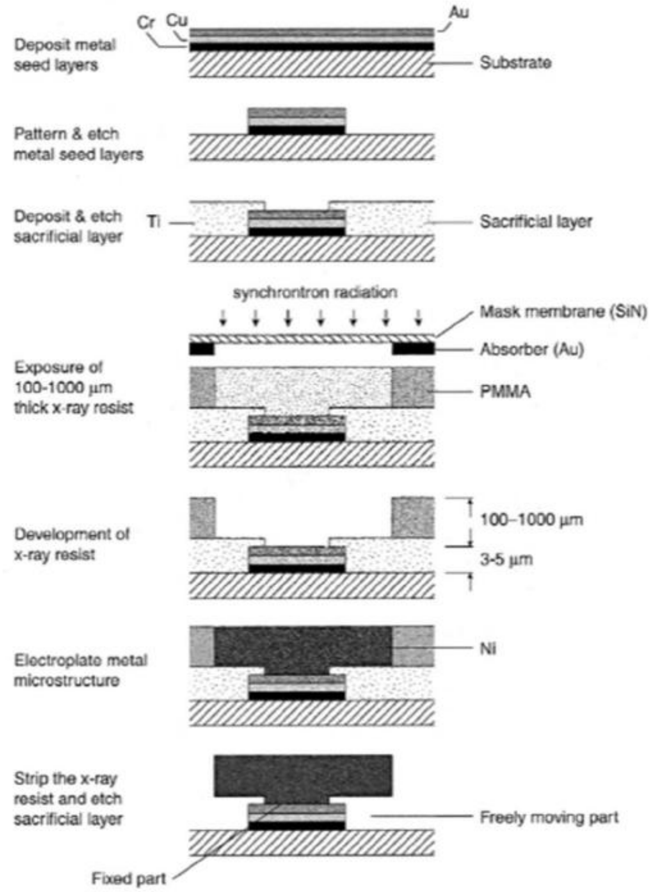


Figure 5. Typical process flow for a LIGA device.

III. DESIGN ISSUES

A key reason for the sustained technical progress and economic growth of the microelectronics industry is the speed and confidence with which complex products can be designed without the need for extensive prototyping. Design in microelectronic devices is largely enabled by the reliability of the simulation tools available and the extremely well characterized electronic properties of the materials being utilized and the processes with which the products are created.

For MEMS to achieve their promise of low unit cost and large volume production, it is important that similar design procedures be developed. Several simulation tools have been developed to address this need and various packages are available commercially and are particularly used in the design of highly integrated MEMS devices.

The development of standardized test methods and material property data bases has lagged behind that of the design and simulation tools, limiting their utility. As early as 1986 the need to develop such a capability was recognized, but it is only recently that wide scale activity has been directed in this area. The issue here is that micro fabricated materials have properties that are highly dependent on the fabrication route used to create them and the scale of the structures that they constitute. The mechanical properties at the micro scale can vary considerably from those measured on bulk samples of material at the macro scale.

Even properties such as density and elastic modulus which are not inherently scale-dependent can be altered from bulk values in deposited layers by the creation of non-equilibrium microstructures, dissolved gases from vapor deposition and the influence of the substrate.

In order to fully realize the potential for accurate and rapid simulation tools for the design of MEMS, models are required which link the material property achieved, to the fabrication route and material used. The first step towards this is to develop standard test methods with which to characterize the mechanical properties of micro fabricated material produced by the same processes and at the same scales as the intended application. This will enable the creation of validated material property and process data bases and correlations between processing route and properties, to permit simulation-based design.

The main design issues considered by various researchers are Elastic properties, Strength characterization, Adhesion and bond strength, residual stresses, Fatigue, surface forces and tribology.

IV. CONCLUSION

Paradoxically the most significant advances in MEMS may occur by developing technologies to produce larger devices with similar unit costs to those for existing microelectronics. These devices would have more useful power and force capabilities than current MEMS and are perhaps more properly termed mesoscale machines.

MEMS also offer considerable opportunities to advance the field of materials science at larger scales. Micro fabricated probe elements enable atomic force microscopes and scanning tunneling microscopes that have revolutionized surface science and tribology. Key areas for materials science to focus on include the extension of the available set of materials that can be micro fabricated, the refinement of the set of processes available to micro fabricate structures, and improvement in the methods used to characterize and select materials for MEMS applications. In addressing these issues, it is important to do so in the context of MEMS as systems, since materials solutions are only viable if they are compatible with the overall fabrication route and the requirements for the application.

V. REFERENCES

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