Chips with everything – reloaded

The roadmap for MEMS predicts monolithic MEMS/CMOS integration, opening the door to a new era of 'chips with everything'. By **Tony McKie**.

Micro Electro-Mechanical Systems (MEMS), or microsystems, comprise mechanical structures formed on a silicon substrate by selective etching of layers of different materials deposited on the silicon wafer; a process known as micromachining.

Many types of mechanical structures can be created this way. Some examples in production include a cantilever beam that undergoes a deflection when the component is displaced, allowing orientation or acceleration to be measured (see figure 1). This is the basic component of MEMS accelerometers, motion sensors and gyroscopes which are widely used in car safety systems, gaming and smartphones. Similarly, MEMS microphones can be created by removing a sacrificial sublayer to create a small silicon diaphragm. The MEMS substrate is usually copackaged with electronic circuitry to translate the mechanical response of the MEMS device into a representative signal. The circuitry may present the corresponding analogue value directly at an external pin or may implement a/d conversion.

These widely used MEMS devices are produced using 'surface micromachining'. Bulk micromachining, in contrast, is typically used to perform processes such as boring arrays of apertures at ultra small and tightly controlled diameters to create components for controlling ink deposition in inkjet printers. This long established class of MEMS devices still accounts for the largest proportion of MEMS production today; although applications and production volumes of surface micromachined devices are growing more quickly. Surface micromachining allows systems with movable parts to be built on top of the substrate, allowing designers to implement mechanisms for numerous and diverse functions within unprecedented small dimensions.

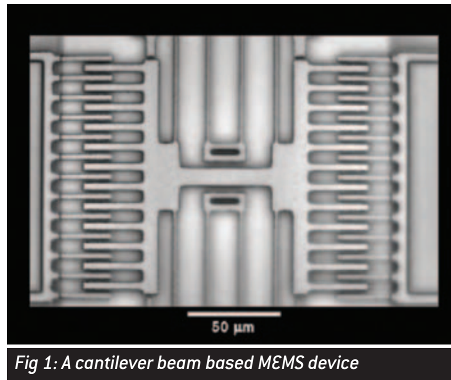

Fig 1: A cantilever beam based MEMS device

McKie: "Moving to vapour phase etch release will enable MEMS structures to be fabricated above cmos circuitry."

MEMS link to cmos

The fundamental processes used to create MEMS devices are broadly similar to those used in cmos fabrication. However, the structures are less complicated and different types of materials are used. For example, the design of a typical MEMS device does not call for multilayer metal deposition. In fact, the use of metals has been generally impossible for MEMS devices produced using wet etching processes, since the wet etching agent – typically liquid hydrofluoric acid (HF) – tends to attack materials such as aluminium.

There are many similarities between cmos and MEMS fabrication and, indeed, many MEMS devices are built on otherwise unused cmos lines. However, whereas cmos design rules are driven by Moore's Law, this does not apply to MEMS technology. While the drive to miniaturise is present, the objective with MEMS is to achieve greater sensitivity, rather than to increase processing speed or device capabilities. Complex MEMS structures, such as those with rotating parts (see figure 2), have their own miniaturisation challenges. Generally, however, miniaturising a structure such as a membrane is relatively straightforward and limited mostly by the mechanical properties of the material. Thanks to the pace of cmos development, the lithographic techniques available for producing MEMS devices are well ahead of the natural limits of the materials in use today.

MEMS design and build

MEMS design is in its infancy relative to CMOS. As the technology matures, the variety of structures and the techniques used to create them, will become more standardised. In this respect at least, MEMS evolution will follow a similar path to cmos.

However, the penetration of MEMS into new markets and applications will not only be defined by the ability to produce standard structures at ever finer geometries.

Device designers will continue to demand the flexibility to create innovative structures and to experiment with new and different materials; for example:

- to optimise the system's behaviour and properties
- to build previously unachievable structures

Manufacturing techniques

The technology and market drivers and the design implications facing the MEMS industry bring several manufacturing challenges. In addition to developing processes that are compatible with the materials device designers wish to use, the trend toward finer geometries, as well as market demands for lower unit costs, are two major factors demanding enhanced control and selectivity. Greater control and selectivity are critical to ensure suitable production yield.

In pursuit of this, the etch release process – the final stage of fabrication for surface micromachined MEMS devices that releases the structure from the surrounding sacrificial material – is evolving from wet chemistry to sacrificial vapour release (SVR) using anhydrous HF or xenon difluoride (XeF_2).

Unlike wet etching, SVR is known to remove sacrificial silicon or oxide completely without damaging the mechanical structure. This delivers the enhanced selectivity necessary to achieve finer structures, while improving repeatability and uniformity to maximise yield. The surface preparation, acid introduction, neutralisation and subsequent drying stages implicit in a wet process are also eliminated.

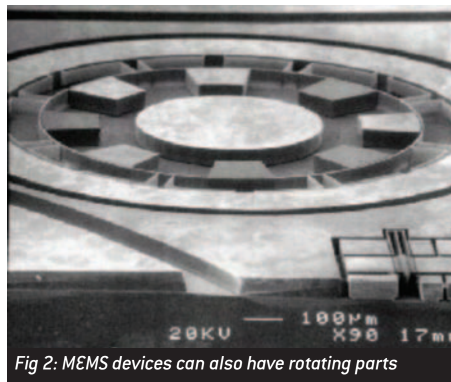

Fig 2: MEMS devices can also have rotating parts

Moving to vapour phase etch release will also enable MEMS structures to be fabricated above cmos circuitry, since it is cmos process compatible. New classes of monolithic MEMS/cmos devices will allow product developers to add extra functionality, increase reliability, reduce dimensions and reduce surface mount assembly costs. Remaining challenges, however, include developing suitable MEMS technologies that will not compromise the integrity of the underlying cmos structure.

Another challenge is to produce MEMS devices in extremely large numbers to meet consumer volume demands and price points. Some in the industry have put forward batch etching as a natural solution to meet growing demand. However, single wafer processing is known to achieve a lower cycle time per wafer as well as superior uniformity and wafer to wafer repeatability. This is expected to remain the preferred approach for MEMS fabrication.

The present and future

Today's high volume applications for MEMS devices include orientation sensing for mobile devices, motion detection for game terminals and various automotive applications. These functions rely on MEMS accelerometers, motion detectors or gyroscopes built using the structures similar to the cantilever beam described earlier. MEMS microphones are also used in products such as mobile phones, enabling reduced size and delivering more rugged performance compared to traditional technologies.

Other types of devices are also emerging. Market analyst Yole Développement has identified complex MEMS mechanisms enabling functions such as micro autofocus and micro zoom for camera phones and digital cameras as major growth drivers for the future.

Devices arriving in the market now include the RF-MEMS variable capacitor, which is produced using SVR with XeF_2 chemistry to etch sacrificial silicon without attacking the device's aluminium support layer. This device will allow a single tuner to be adjusted using the MEMS RF device, replacing multiple tuners in multiband handset designs. Benefits include simpler circuitry and reduced design time, in addition to freeing space inside the handset for yet more functionality.

This typifies the central role of MEMS in electronic product design. While its influence will not be as great or as far reaching as that of the semiconductor revolution, in an age where product differentiation is critical to success in the marketplace, MEMS gives designers important new abilities to deliver increased functionality and thereby maximise brand value.

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