MEMS fabrication at CMP: past and present

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Abstract:

Infrastructures to provide access to custom integrated hardware manufacturing facilities are important because they allow Students and Researchers to access professional facilities at a reasonable cost, and they allow Companies to access small volume production, otherwise difficult to obtain directly from manufacturers. This paper is reviewing the developments at CMP to offer various types of MEMS manufacturing to Students, Researchers and Companies since 1994. CMP has been the first service of its type to introduce MEMS fabrication. Today CMP is offering bulk micromachining on CMOS and GaAs, and various MEMS processes. CAD tools provided by CMP are also reviewed.

I. First MEMS process offered by CMP for prototyping

CMP has been involved for a long time in MEMS (Micro Electro Mechanical Systems) prototype fabrication. CMP started to offer MEMS manufacturing in 1994 with bulk micro machining, which is a volume etching process. This etching is a post process done at die level, based on a wet etching using a TMAH recipe that removes the silicon. This means that all the dielectrics on all areas around the suspended structures need to be removed. This MEMS fabrication was based on a 0.8µm CMOS process from austriamicrosystems foundry, using 2 metal layers and 2 polysilicon layers. An example of structure is shown on the fig. 1. At this moment, the biggest advantage was to merge electronics and mechanics on the same die, in order to have the most powerful sensor or actuator management. All parameters extracted from the MEMS was analysed and treated directly and locally on the integrated circuit. CMP started in the same time to improve packaging methods in order to test these MEMS easily. Lots of projects have been made and structures like matrix micro mirror, oscillators, bridges and membranes have been realised using this process and post process.

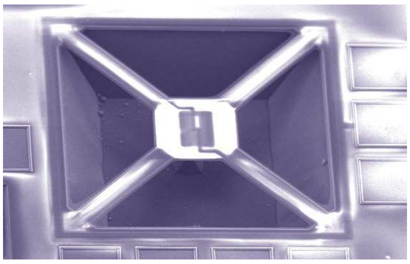

fig *1. 0.8µm CMOS / bulk micromachining*

II. Specific MEMS processes available at CMP

In 1999, CMP introduced in his portfolio all the MUMPs® family (Multi User MEMS Processes) processes, offered by the foundry MEMSCAP. These processes, which are still available at CMP for prototyping, are specific MEMS processes offering the possibility to realise complex, wide and thick structures, on 1 cm^2 dies. They are 3 of them:

- PolyMUMPS process, which is a Polysilicon / Gold surface micromachining, using sacrificial layers to suspend structures for which the fig. 2 shows the process cross section. This process is composed of 7 physical layers, 3 polysilicon layers and 1 metal layer. These polysicon layers are grown during the process and removed at the post process step. Most of the time, processes using sacrificial layers are used to make capacitive devices. Prototypes like microphone, sensors, accelerometers, micro fluidics and display technology devices for example have been also fabricated.

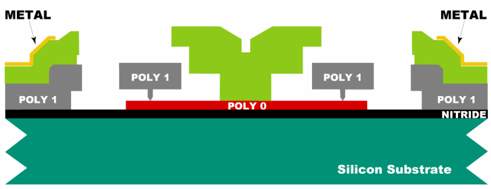

Fig 2. *PolyMUMPS cross section*

- SOIMUMPs process uses the DRIE etching (Deep Reactive Ion Etch) on SOI (Silicon On Insulator). This process enables to etch both front side and also back side of the wafer, to completely suspend the structures. The fig. 3 shows the cross section of this process that enables structures from 10µ to 25µm thick, offering 2 metal layers. Applications are gyros, optical devices and display technology devices.

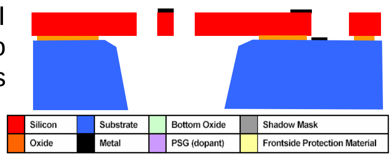

Fig 3. *SOIMUMPS cross section*

- MetalMUMPs process, which uses thick nickel electroplated layer, from 18 to 22µm, as illustrated on the fig. 4. On this process the substrate is etched front side releasing thick structures. Devices in RF (Radio Frequency), micro fluidics have been done, as well as relays and magnetic switches.

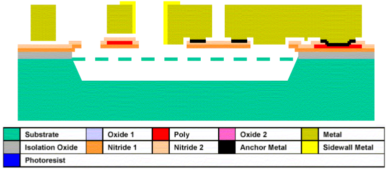

Fig 4. Metal*MUMPS cross section*

III. Low cost bulk micromachining process

In 2006 CMP offered the possibility to fabricate MEMS on a low-cost 0.6µ CMOS process, from the foundry CSMC, which has 2 poly and 2 metal layers. This went in replacement of the 0.8µm process that was available only in mono project wafers and no more on multi project wafers, due to the fab migration to 200 mm wafers. Structures are also released after the circuit fabrication with a wet etching using a TMAH recipe to etch the silicon as well. Systems like comb drives or sensors have been made. The fig. 5 shows test structures giving the minimum and maximum structures width and also a piezoresistive sensors fabricated in 2006. Since this process stopped, this micromachining solution is no more available.

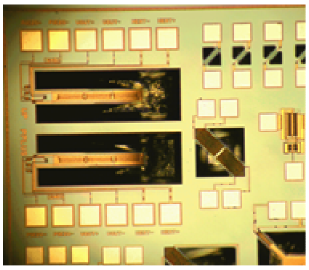
Fig 5. 0.6µm CMOS / bulk micromachining

IV. Bulk micromaching post process on BiCMOS / RF process

In 2006, CMP adds to his portofolio a bulk micromachining possibility, based on the 0.25µm BiCMOS process from STMicroelectronics. This BiCMOS7RF process has 5 metal layers with top thick metal, vertical NPN with Ft = 55 GHz and is convenient for RF designs. It includes MIM capacitors, inductors and bipolar components. The associated post process is called ASIMPS (Application-Specific Integrated MEMS Process Service) and is made at the Carnegie Mellon University (CMU). Mechanical structures are released by RIE (Reactive Ion Etch) and then by DRIE (Deep Reactive Ion Etch as illustrated in fig. 6). Potential devices to be designed and fabricated in the process include accelerometers, gyroscopes, radio frequency (RF) MEMS communication systems (with resonator oscillators, RF filter and High-Q inductors), infrared sensors and imagers, electro thermal converters and force sensors. Some researches are currently made to develop a “bioacoustic membrane” gravimetric biosensor. This is a chip-based biosensor that is aimed at macromolecular targets. The technology enables integration of multiple devices on the same chip. For example, high-Q inductors and micromechanical resonators can be combined for CMOS RF application. In another example, multiple accelerometers are integrated on chip to create a 3-axis inertial measurement system. Furthermore, both the communications and accelerometer systems can be combined to form a wireless micro sensor system. Some application in the biomed have been done, such as a bone implantable stress sensor, with the aim to measure with safe the bone strength. As shown on fig 7, high resolution structures can be realised.

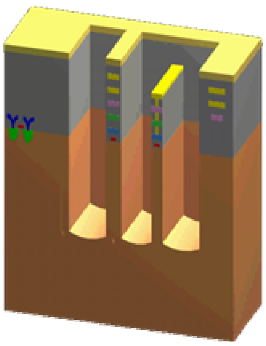
Fig 6. ASIMPS overview

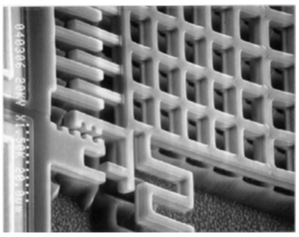
Fig 7. High resolution structure

V. Ultra planar MEMS process

In 2009, CMP introduces the SUMMiT V^{TM} (Sandia Ultra planar Multi level MEMS Technology V) from Sandia. This advanced process uses 5 polysilicon layers, all planarized, as illustrated on the cross section on fig. 8. This process offers flexibility and gives a mechanical robustness in the devices. Systems like comb actuators, meshing gears and transmissions dynamometers, laminated support springs, steam engines, micro engines and micro machines, motors, mirrors and optical encoders, micro sensors, RF MEMS and linear racks can be fabricated. In the BioMed application, some works are focused on a system that may allow large samples to be handled and processed in micro channel devices that are made in sheet and rolled or stacked. Also, a component that separates nucleic acids by size has already been made.

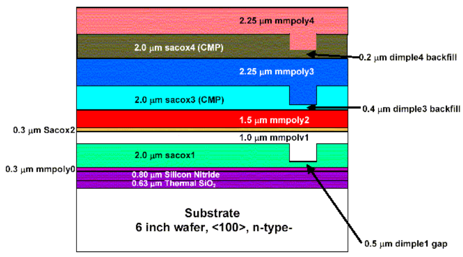

Fig 8. SUMMiT V cross section

VI. Advanced bulk micromachining process

In 2009, CMP developed a combination process / post process to replace the last bulk micromachining no more available. This one is based on the 0.35µm CMOS process from austriamicrosystems. The post process is still a wet etching with a TMAH recipe. This IC process offers 4 metal layers, 2 polysilicon layers, high resistive poly, 3.3V and 5V power supply and opto option. A first validation prototype has been manufactured in Q4 2008. Using these results, a second prototype has been fabricated Q2 2009, using an additional mask to etch stacked oxide butting MEMS structures. Results showed that both oxide and silicon have been fully etched, so the structures are well suspended and movable. This post process is available for all MPW 0.35µm CMOS MPW scheduled by CMP.

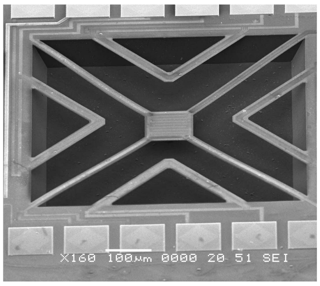

Fig 9. 0.35µm CMOS / bulk micromachining

VII. Conclusion

CMP recognized a long time ago the importance of MEMS. Since the introduction of MEMS manufacturing, many projects have been successfully manufactured for many various applications. The portfolio has been continuously expanding. It is planned to introduce soon NanoMUMPs.