CMOS Compatible Pressure sensors: a comparison between SiC and SiN

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Abstract – **In this paper we present the fabrication process and comparison between results of SiC and SiN pressure sensor. The pressure sensors were fabricated using surface micromachining technology. The sensors consist of 100 circle membranes with total capacitance of 14pF. For both type of sensors – SiN and SiC, low stress PECVD layers were used. PSG and polyimide sacrificial layers where used for silicon carbide and silicon nitride sensors, respectively. Initial experiments have been performed. Both, SiC and SiN sensors have initial capacitance of about 15pF.**

Keywords – **pressure sensor, surface micromachining, silicon carbide, silicon nitride, polyimide.**

I. INTRODUCTION

Pressure sensors presently constitute the largest segment of mechanical MEMS devices. Often the sensors are fabricated as postprocessing modules and therefore low temperature deposited layers are required. PECVD layers fulfil that requirement and therefore are used by the authors for device fabrication. Post-processing surface micromachining technology is used for fabrication of the sensor. It enables integration of the sensor with electronic read-out circuit on one chip and therefore it has many advantages, including reduction in size (sensor built on the top of existing electronic chip), simplification of packaging and the ability to introduce new functions. However using post-processing techniques means that the mechanical and sacrificial layers must be deposited and patterned at the end of the conventional process and thus only processes using temperatures below 400ºC are allowed.

Silicon carbide was selected as mechanical material due to its good mechanical properties and high chemical resistance [1].

Silicon nitride is commonly used in IC process and therefore it was chosen as one of possible structural material.

As stiction of the structures to the substrate is often observed after the wet etching step employed to release the microstructures [2], an all-dry sacrificial etching step would be preferred.

The sensor fulfilling the above requirements is proposed here. The fabrication process is described and results of fabricated devices are described in this paper.

II. MATERIALS

Silicon nitride is one of common materials in IC technology, and therefore it can be potentially good choice for MEMS application. Silicon carbide appears in many crystallographic forms as well as in amorphous form with wide spectrum of properties. Therefore it finds its place in many fields such as optoelectronics, microelectronics and MEMS. Due to its very good properties such as high mechanical strength, high thermal conductivity, ability to operate at high temperatures, resistance to harsh environment and extreme chemical inertness in a number of liquid electrolytes [2], SiC has great potential in Micro Electro Mechanical Systems (MEMS). The properties of PECVD amorphous SiC can be controlled over a wide range (for example, 1.8eV to 3eV for the optical bandgap and –400MPa to 400MPa for stress) by changing the deposition conditions, especially the ratio of the gases used [3] and also by in-situ doping.

Selection of SiC as structural material is a good choice with a mechanical properties assuring a durable membrane.

As PECVD silicon nitride and silicon carbide are high resistive, an extra material has to be used for electrodes. Aluminium - the most common material was selected.

Since it is standard material in IC-production there is no contamination issue. Moreover, standard CMOS process is ended with aluminium metalisation, which can be used as bottom electrode in the accelerometer.

Two materials for sacrificial layer have been considered: the silicon oxides and polymer. Silicon oxides can be easily deposited, patterned and finally removed. However since the sacrificial layer thickness is only 1 to 2 μm, the capillary forces during wet etching (releasing the structure) causing the stiction of the membrane to the bottom electrode. The solution of that problem could be use of the so-called freeze drying method. As a result the stiction problem is minimized but that process is time consuming.

As the alternative to oxide for sacrificial layer and wet etching, the use of polymer can be considered. The advantage of polyimide is that it is dry etched and therefore no stiction problem occurs. Among the spin-on polyimides available, only those which are IC-process compatible were considered and further those which can withstand further processing at 400°C and that can be dry etched in conventional IC-technology equipment. The PI2610 polyimide (HD Microelectronics) has been selected, since it is a spin on microelectronic material specifically conceived for dry etching, and it has a transition to glass (TG) temperature above the post-processing limit temperature of 400°C.

The final decision of sacrificial layer is determined by the size of the structures. Polyimide is suitable for structures where releasing required underetching of 50 μm. For structures which require bigger underetch in order remove the polyimide the oxides layers should be applied.

III. DESIGN & FABRICATION PROCESS

A. Structure

The pressure sensor was fabricated using surface micromachining technology. It consists of 100 circle membranes with total capacitance of 14pF. Circular shape of membranes was chosen to achieve uniform distribution of stress. FEM simulations showed that in case of square membranes the stress concentration for the same layers configuration could result in breaking of membranes.

The two pressure sensors were fabricated using two sets of materials. First device uses silicon nitride and polyimide as structural and sacrificial material, respectively. Second sensor uses silicon carbide and PSG layers.

B. Processes

The process flowchart is presented below:

1) On the silicon wafer the insulation layers were applied: thermal silicon dioxide followed by LPCVD SiN. Then 1 μm aluminium was sputtered at 350C in Trikon Sigma sputter coater. After lithography the layer was patterned in Trikon Omega 201 plasma etcher, forming the first (bottom) electrode.
2) Next sacrificial layer was processed: (Figure 1a.)

   For SiC sensor:

   - 4% PSG (4% phosphorus in silicate glass) is deposited in PECVD system.
   - After the lithography the sacrificial layer is patterned in Alcatel GIR300 fluorine etcher in $CF_4:SF_6:O_2 = 70:10:10$ sccm gas mixture.

   For SiN sensor:

   - Polyimide layer (preceded by primer) with a thickness of 1 μm was spun on silicon wafers. A 5-6s delay is allowed prior to spinning, to let the polyimide relax and flow on the silicon surface. Spin speed of 5000 rpm are used with a fixed spin time of 30s. A two-step baking, 90°C for 3 min and 180°C for 90s, has been selected in order to get rid of part of the solvent, so to stabilise the film.
   - The curing of polyimide was performed at 400°C in N_2 atmosphere. Although polymerisation starts at about 200°C, higher baking temperatures are preferred as they allow a complete solvent evaporation and yield a higher TG temperature of the cured polymer. (Wafers were loaded at 150°C and stabilised for 1 hour and then the temperature was changed to 400°C). The average shrinkage due to curing is about 20% of the film thickness for the conditions used. Due to poor adhesion of polyimide to Al long curing was performed (12 hours). Alternatively a reduced curing time of 2 hours could be used by applying a thin oxide layer prior to the polyimide.
   - Patterning of polyimide required the use of a hard mask since it is impossible to deposit photoresist directly on polyimide and then selectively etch. First 100nm oxide layer is deposited as a mask for polyimide patterning. Then it is patterned in Alcatel GIR300 fluorine etcher in $CF_4:SF_6:O_2 = 70:10:10$ sccm gas mixture. Next gases were changed to $O_2=50$ sccm to pattern polyimide. Although higher oxygen flow

improves the etch rate, it also drastically decreases anisotropy of etching.

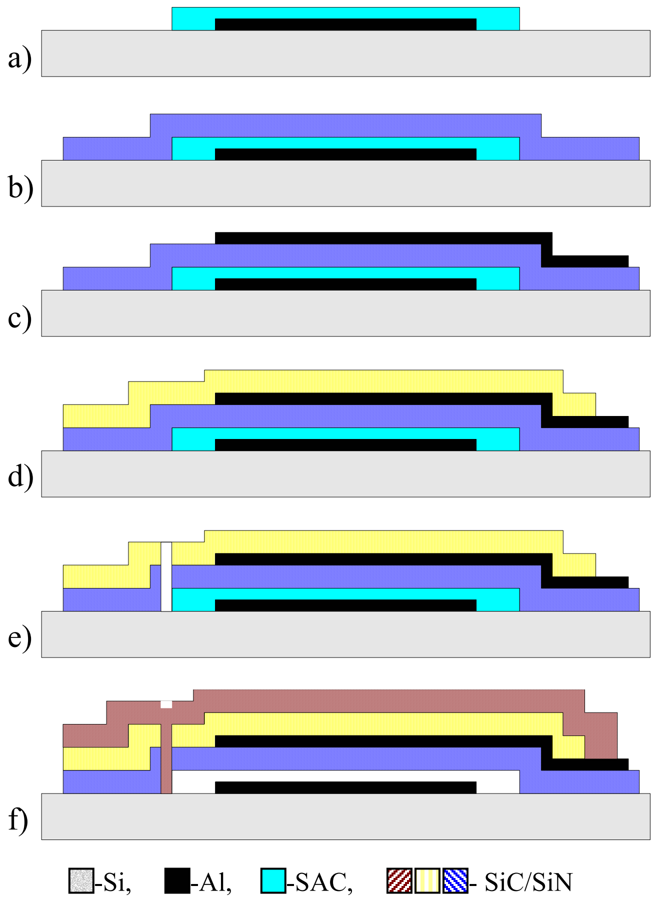

Figure 1. Fabrication steps of pressure sensor.

1 µm of PECVD Low stress SiC/SiN was deposited in Novellus Concept One system, respectively.

SiC was patterned in $CF_4:SF_6:O_2 = 70:10:10$ sccm at 500mbar at power of 60 Watts. The etch rate of SiC was 1100Å/min. 1st (of four) layer of membrane is finished. (Figure 1b)

3) In the next step top electrode was formed. 1.4µm aluminium was sputtered and patterned using the same system as for the first Al layer. (Figure 1c)

4) Second 1 µm PECVD SiC/SiN mechanical layer was deposited and formed. (Figure 1d)

5) At this point the windows to etch polyimide sacrificial layer were opened -etch through both SiC/SiN layers to PSG/polyimide – using $CF_4:SF_6:O_2 = 70:10:10$ sccm plasma at 500mbar at power of 60 Watts (Figure 1e). It is important to keep proper ratio between diameter of membrane and the size of etch windows to be able to fully remove the polyimide.

6) The structure was released by removing polyimide sacrificial layer in rich oxygen plasma in case of SiN sensor. For SiC device the PSG sacrificial layer is removed by wet etching. Micture of 73%HF & IPA was used. The addition of IPA improves the PSG to aluminium etch selectivity[7]. In order to avoid problem of stiction during PSG sacrificial etch, the freeze drying steps were inwolved.

7) As a final step 1.2 µm SiC/SiN sealing layer was applied. The pressure inside the cavity is determined by the working pressure in deposition system. The deposition of SiC is performed at 2 Torr at 400C which corresponds to about 1 Torr at room temperature (Figure 1f)

IV. RESULTS

A charge amplifier, shown in the figure 2, was used for the read-out of the pressure sensors, due to its simplicity and availability. The driving voltage was 1V AC with the frequency of 1MHz.

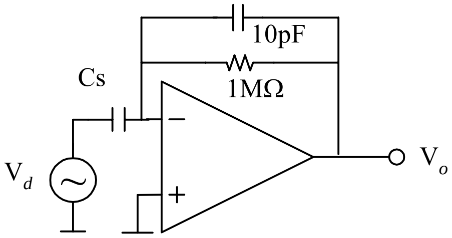

Figure 2. The charge amplifier.

The sensor was placed in pressure chamber and connected to read-out circuit. For the measurements a reference sensor the SX15AD2 SenSym pressure sensor was used. For pressure in range from 1bar up to 5bar measurements the pressure inside chamber was controlled by DPI 520 sensor calibration setup manufactured by ‘Druck’.

The device has been fabricated and the picture of fully released structure is presented on figure 3.

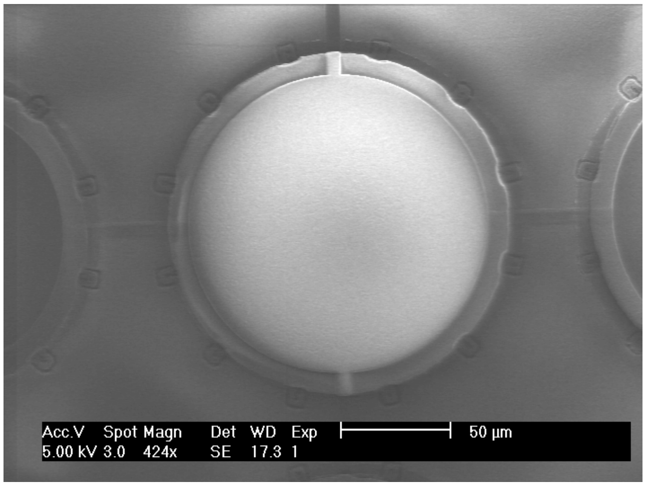

Figure 3. SEM photo of fully released pressure sensor.

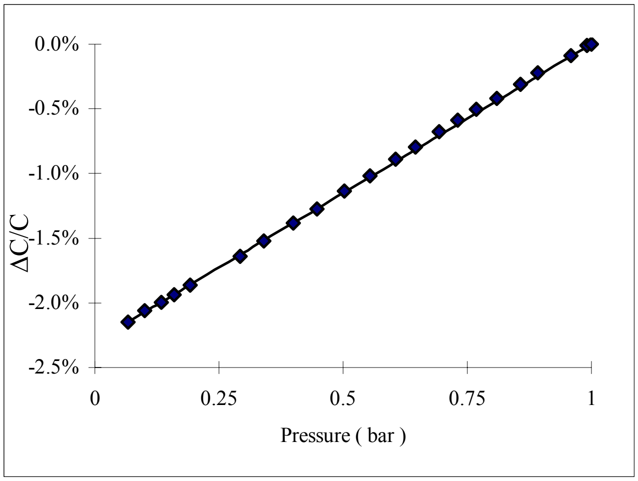

Figure 4. SiC device: Relative change of capacitance vs. applied vacuum

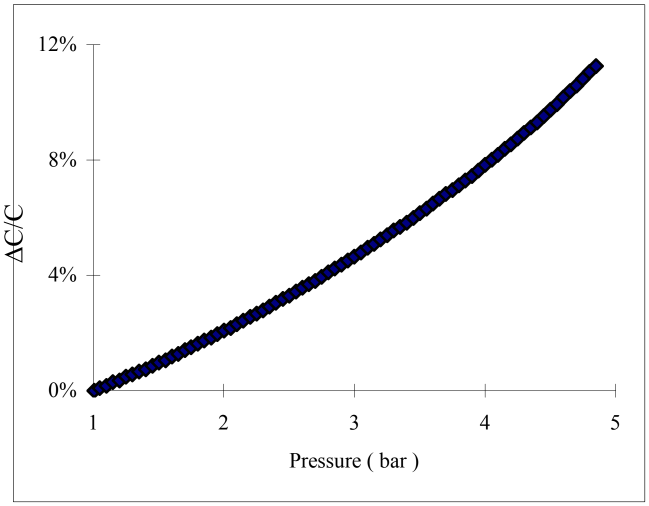

Figure 5. SiC device: Relative change of capacitance vs. applied pressure

For the SiC accelerometer the change of the pressure in range from 10mbar to 1.01bar results in change of capacitance from 14.9pF to 15.3pF. The sensitivity is 0.32pF/bar, compared to the calculated sensitivity of 0.45pF/bar. The non-linearity in the full pressure range (10mbar, 1.01bar) is better than 2%. The change of the pressure in range form 1bar up to 5 bar is 3 pF.

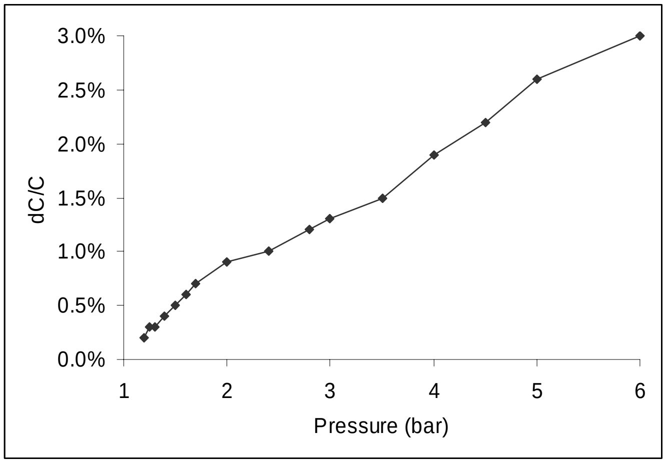

Figure 6. SiN device: Relative change of capacitance vs. applied pressure

The measurements performed on silicon nitride pressure sensor indicate the leaking problem. The reasons are not yet known, but there are two considerable explanations: first - the sealing of the etch windows could be not good, second – the silicon nitride layer could have the pinholes and therefore would not be proper layer for sealing. Based on first points of measurements,where the leakage should have minimal influence, the sensitivity of the device is estimated to be 1%/bar. However that value is below expectance (3%/bar).

V. CONCLUSIONS

An absolute pressure sensor was designed and fabricated using two sets of materials. Surface micromachining was involved in its fabrication. Low stress PECVD silicon carbide and silicon nitride were used for mechanical layer. The SiC sensor was tested under pressure from 1bar down to vacuum resulted in change of capacitance from 15.3pF to 14.9pF. The measurements shows that the SiC is suitable material for pressure sensors. Silicon nitride seems to be to porous to be used for pressure sensors, unless other sealing layer will be used on top of the structure.

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