Technological Design of the MEMS-Accelerometer Sensor Element for Ultra-Large Acceleration Ranges

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***Abstract*—The development of new MEMS design technologies makes it possible to develop special accelerometer sensors. It allows to expand the range and methods of MEMS application or apply where it was previously impossible. Special manufacturing technology and breakthrough design of the sensor element allow measure accelerations up to 20000 g.**

Keywords—MEMS; sensor; sensor element; accelerometer; 20000 g

I. Introduction

Within the framework, based on CAD ANSYS simulation [1] of MEMS-accelerometer sensitive element design, a technological manufacturing route was developed. In the developing technological processes, the following standards were established: minimum gaps - 3 microns, open fields(«windows») in the inertial mass for etching the sacrificial layer - 20x20 microns.

II. Results and Discussions

The MEMS-accelerometer sensor element (SE) of the comb type is developed, which operates according to the following principle - the displacement of the inertial mass is recorded via change in the capacitance of two "parallel plates" of the electrodes [2].

The comb crystal is manufactured in a group way using typical microelectronics processes.

At the first stage of manufacturing sensor elements, oxidation of the plate is performed on both sides (operation 1).

Second operation is a photolithography No. 1. Process is performed on the surface of front plate side where topological pattern of the sensor element is formed in a photoresist layer. Oxide etching (operation 3) is carried out in a buffer etchant.

Fig. 1 shows the technological route of the crystal combs manufacturing.

After photoresist removal, ICP etching of silicon is performed via mask layer from the oxide (operation 4) to a depth of 30 microns.

Next, stage is photolithography No. 2 (operation 5). Process is carried out on the backside surface of the plate. Photoresisting layer is produced with a topological pattern of the thinned part of the sensor element. After, the oxide is etched (operation 6) is carried out in a buffer etchant.

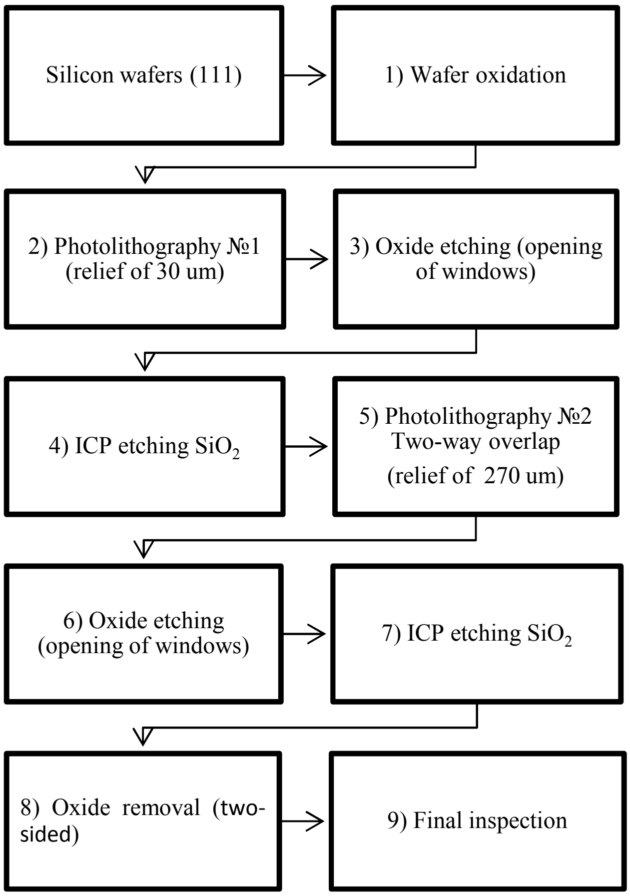

Fig. 1. Technological route of MEMS sensor element manufacturing.

After photoresist is removed through the mask from the oxide, an ICP of silicon etching is performed (operation 7) until vias are produced.

Manufacturing process is completed by removal of oxide residues (operation 8) on both sides of the plate.

Manufacturing process of the sensor element crystal ends with a final control of the produced etching figures quality and size (operation 9).

Next stage in the technological design is the sensor element assembly.

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At the first stage, anode splicing of crystals and bottom side in the composition of the plates is performed. To produce contact pads, aluminum is deposited with 0.5 μm layer thickness via mask layer. After dividing the plate into crystals, a package operation is performed.

To produce the sensor element of MEMS accelerometer (another name of the operation is named as “hanging” (“releasing”)) the inertial mass, a route has been developed and represents the main technological operations, Fig. 2.1 and Fig. 2.2.

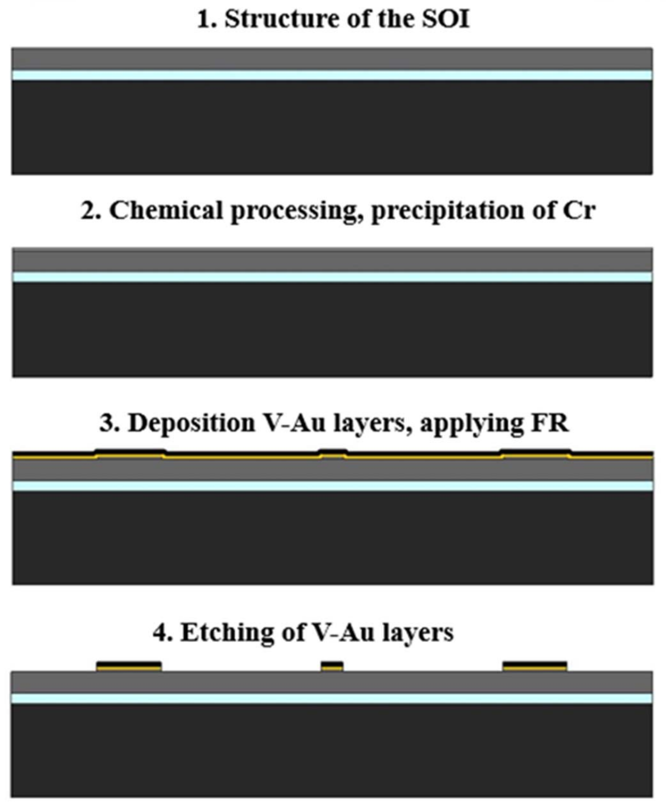

Fig. 2.1. Main technological operations of MEMS accelerometer sensor element manufacturing.

The MEMS sensor element is manufactured by a silicon on insulator (SOI) technology. It has the following structure: working layer - 30 μm, insulator (glass) - 7 μm, bottom side (substrate) - 440 μm.

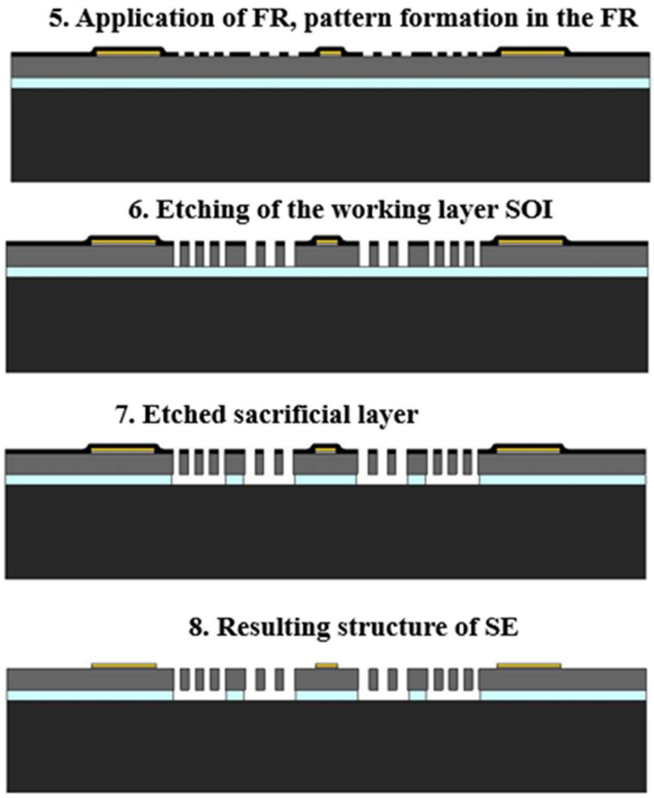

Fig. 2.2. Main technological operations of MEMS accelerometer sensor element manufacturing.

The fourth step is the deposition of V-Au layer with a thickness of 0.7 μm for the producing of contact pads (CP). It is need to carry out photolithography processes and produce a topological figure by etching the V-Au layers with liquid chemical etching (LCE) in a solution of nitric HNO3 (65%) and hydrochloric HCl (35%) acids taken in a 1:3 ratio, (solution named as “Aqua-regia”). The fifth step is to remove the photoresist in a solution of dimethyl and carry out annealing in vacuum for 1 hour at a temperature of 3000 °C. The sixth step is to produce photolithography processes for the ICP process of etching the working layer with a thickness of 30 μm. The final step is to release the inertial mass, i.e. etching in the LCE of the sacrificial layer (glass) and then the photoresist mask residues in the PCE. After all the above operations, the structure of the sensor element with a “hanging” (“releasing”) inertial mass is obtained.

The result of a technological route – is the manufactured sensor element of MEMS accelerometer (shown in Fig. 3).

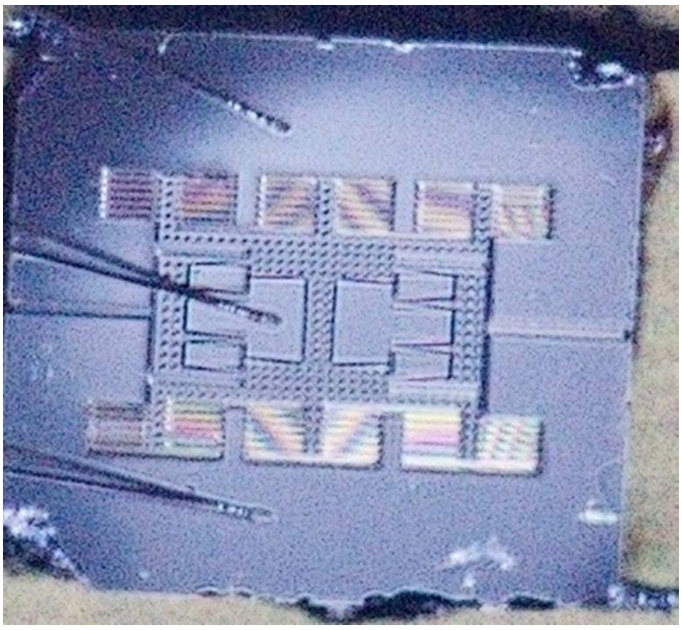

Fig. 3. MEMS-accelerometer sensor element.

The ceramic-metal package 5119.16-A with metallized pads located evenly on 4 sides of package was chosen. All exposed base side of metallized surfaces and metal parts of the package have an anti-corrosion gold coating. The size of the mounting pad is 3.91 x 3.91 mm, which allows to mount a crystal of the sensor. The package was chosen based on the following parameters: resistance to vibration, impact resistance up to 30000g, temperature range (-60 ÷ +250) °C. Also, it allows sealing the internal cavity, which can further contribute to the vacuum for increasing of the MEMS-accelerometer sensor element operating frequency.

The crystal of sensor element is bonding with package by VK-9 glue, (two-component cold cured epoxy composition). It consist on epoxy and polyamide resins modified with organosilicon compounds and mineral fillers (asbestos, boron nitride, titanium dioxide). VK-9 glue provides a strong bonding seam, which ensures the durability of adhesive layer to vibrations, shocks up to 30000g, temperature effects in the range (-60 ÷ +250) °C for a long time, up to 2000 °C - 500 hours, up to 2500 °C - 5 hours.

In case of an overload acting to the SE, the inertial mass lays on the "stoppers", which prevents the destruction of the structure and short circuits between the movable and fixed combs. Also, the design of inertial mass limiters prevents not only short circuits of the combs, but also their direct physical (mechanical) contact with each other, what protects them (combs) from destruction.

The glued-in sensitive element of the MEMS accelerometer into the body is shown in Fig. 4.

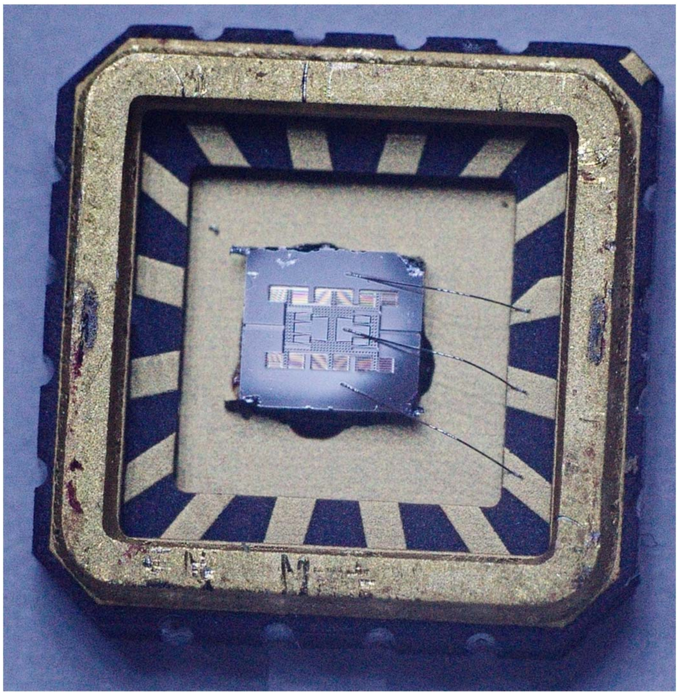

Fig. 4. MEMS sensor element in a package.

The SE is designed to operate in harsh conditions, therefore protection elements – "stops" ("stoppers") were introduced into design. The element consist on the attachment point of the inertial mass and the gap, Fig. 5.

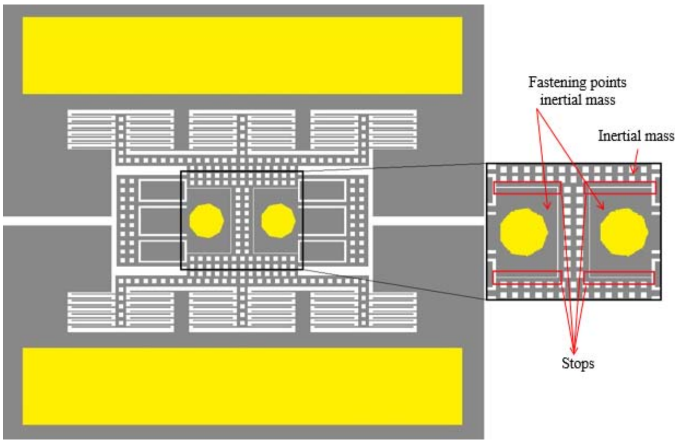

Fig. 5. The design of the MEMS-accelerometer "stoppers" elements.

The principle "stoppers" - the inertial mass under the influence of accelerations, shocks, vibrations, in excess of the measuring range of the SE, lies on the "stoppers", which are the attachment points of the inertial mass. As a result, the SE destruction does not occurred.

The advantage of the "stoppers" design is their direct manufacture in one technological cycle with the producing of the inertial mass itself. Another important side is the process of design, which does not require additional structural elements. It significantly increases the reliability of the SE and reduces labor costs at the design stage.

III. CONCLUSIONS

As a result of the work, a technological route was developed for the manufacture of sensitive elements of MEMS accelerometers with the following parameters:

1) Acceleration of ± 20,000 g;

2) Resistance to blows of 30,000 g;

3) The scale factor of 22 μV/g;

4) Temperature range (-60 ÷ +250) °C;

5) Non-linearity < 1.5 %;

6) Dimensions (7.62x7.62x2.124) mm.

The specialty of sensor elements made along this route is the ability to measure accelerations up to 20000 g.

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