Perspective technology for low-scale production of SMD MOX gas sensors

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Perspective technology for low-scale production of SMD MOX gas sensors

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Abstract. The article discusses technological and economic aspects of small-scale production of gas MOX sensors. The main technical factors affecting the use of sensors in various applications are described. The perspective laser micro-milling technology for ceramic MEMS producing of microhotplate and SMD package for the MOX sensor is discussed.

1. Introduction

The modern MOX sensor is a combination of several factors - a microhotplate (responsible for power consumption and temperature operation mode), MOX gas sensitive layer (responsible for sensitivity to target gases) and a package (responsible for the possible application in which the sensor is used). Last decades MOX gas sensors development there is a concentration of efforts, in the field of technologies allowing obtaining a cheap product for mass applications in the manner of indoor air quality (IAQ)monitoring [3-5]. Similar solutions were found by the leading manufacturers of MOX sensors (Figaro, Sensirion, Bosch, AMS, SGX and etc). Technological solutions that make it possible to obtain a sensor with satisfactory characteristics for such application consist in the use of a combination of silicon MEMS microhotplate and plastic, metal-plastic or metal-ceramic SMD package. But what to do if for scientific groups which, at the moment there is no market or is it too small for the return of investment in silicon MEMS technology and the production of specialized plastic or ceramic SMD package? In that case need technology process close to 3D prototype philosophy –fast, simple and cheap with ratio to a single sample to total costs.

2. Experimental

As a technology for manufacturing ceramic MEMS microhotplate and SMD packages, it is proposed to use laser micro-milling of monolithic Al_2O_3 [1,2] and screen-print, jet (aerosol) printing technologies to form platinum metallization on MEMS and package. The equipment involved in the described technology does not need clean rooms and is widely represented on the market. The software for technology is simple and accessible at the student level. The only specialized product of the proposed technology is the adaptation of machine vision to obtain the minimum possible size of the MEMS structure of the microheater and the deposition of the MOX gas sensitive layer and platinum metallization, as well as the translation program of the 3D models of MEMS microhotplate and 2D topology of metallization to a 4-axis laser micro-milling facilities for automatic production. Technological steps are follows:

- 3D modeling of MEMS microheater (Fig.1), top and bottom part of the package (Fig. 2) in * .stl format (Autodesk Inventor or SolidWorks program) and 2D modeling topology of MEMS metallization in * .dxf format (Autodesk AutoCAD program).
- Simulation of the MEMS microheater parameters in the ANSYS program for prediction approximate representations about the MOX sensor thermal characteristics (if it need)
- Laser micro-milling of monolithic ceramics on a 4-axis laser facility by using 3D model of MEMS microheater (Fig 3), top and bottom part of the package.
- Deposition of platinum metallization (Fig. 6) using 2D model topology and technical annealing of metallization on MEMS according to specification on screen-print, jet or aerosol platinum materials.
- Laser micro-milling of metallization according 2D model (if it need).
- Deposition and annealing of the MOX gas sensitive layer on the MEMS microhotplate.
- Assembling and conglutination by special glass single parts of sensor into a monolith package, like schematically represented for SOT-23 package on Fig. 2.

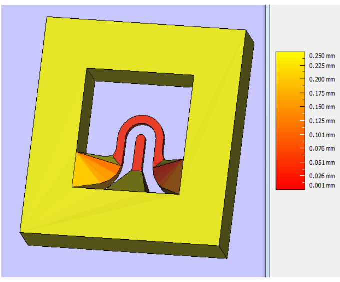

Figure 1. 3D model of microhotplate as a task for laser micro-milling. Right scale is MEMS thickness.

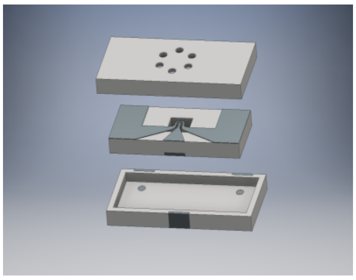

Figure 2. Assembling single parts of sensor into one SOT-23 packages (demension 1,6 x 2,8 x 1,1 mm).

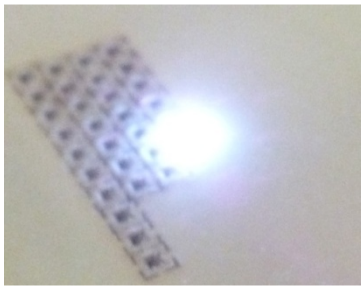

Figure 3. MEMS laser micro-milling on 250 μm thick Al_2O_3substrateby 4-x axis CNC facility.

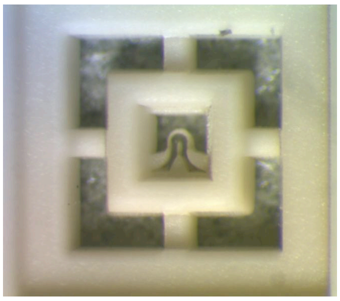

Figure 4. Bottom view of MEMS after laser micro-milling. Chip size 1x1 mm by border of internal frame.

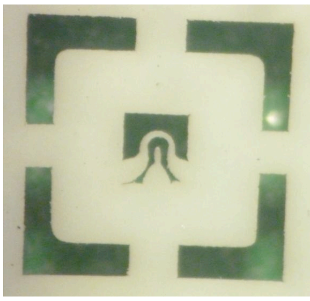

Figure 5. Top view of MEMS. Internal window size 0,3x0,3 mm. Central track width is 30 μm.

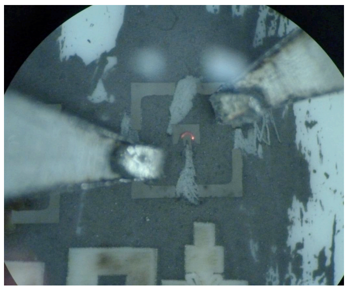

Figure 6. Testing MEMS microhotplate under voltage load (pins). Hot area at ≈ 600°C.

The quality of the final MEMS structure strongly depends on its surface roughness. The minimal roughness will make the MEMS structure more durable, as well as allow for more qualitative metallization deposition processes on the chip surface. To obtain a minimum surface roughness, it is required to use a material whose thickness does not exceed the height of the obtained structure in order to avoid ablation of the volume of the material only in order to reduce its thickness. However, the cost of the final product depends heavily on the cost of the material, in our case, ceramic substrates Al_2O_3. The minimum cost have the workpieces of standard size. The standard sizes of the ceramic substrates being manufactured start at a thickness of 500 μm or higher, which, at a chip height of 250 μm,

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requires excess ablation of the material at a thickness of 250 μm. Operation of laser evaporation of excess material can be justified in the case of a high cost of manufacturing substrates of non-standard thickness and only in the case of a qualitatively selected laser micro-milling mode that does not lead to a strong increase in the surface roughness after removal of excess material thickness.

Laser radiation allows to carry out the process of Al_2O_3 ceramics ablation to a depth of 0.5 to 50 microns in one pass. High radiation power and low speed of the laser beam accelerate the process of micro-milling, but lead to a higher surface roughness, the values of which can be more than 50 μm. Roughness is formed due to the fact that the intensity of laser radiation has a Gaussian distribution, which requires a very accurate selection of the laser beam overlapping region, when the entire material is engraved. On average, the surface roughness is 50 to 300 percent of the ablation depth per one pass of the laser beam. The minimum roughness was obtained by evaporation of the material in one pass at 1 μm and amounted to 2.3 μm (Fig. 7).

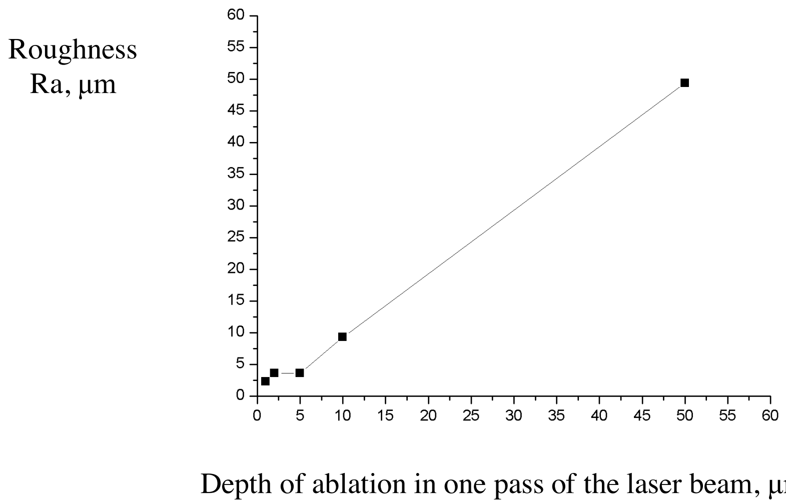

Figure 7. Dependence of the roughness on the depth of ablation in a single pass of the laser beam.

The laser micro-milling process is a complex multifactor physical process, whose behavior, depending on the type of material being processed, has a different character, which requires an empirical selection of the optimal surface treatment regime. Acceleration of the debugging process can be achieved by integrating the measuring equipment, able to produce a visual analysis of the surface obtained. After the ablation of each layer of material, such integration allows to analyze the resulting surface and correct the laser radiation regime by adjusting the radiation parameters or introducing additional cleaning passages aimed only at the surface roughness reducing (Fig. 8). In the process of laser micro-milling, the surface roughness increases with the increase in the number of engraved material layers.

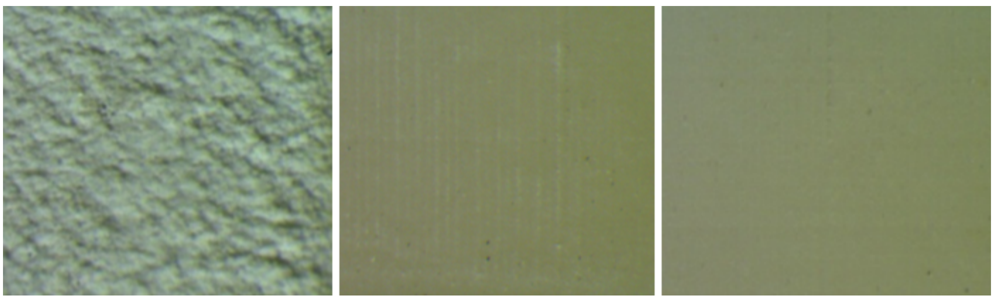

Figure 8. Visual analysis of the processed material surface. The left surface obtained by ablating the material in one pass at 50 μm, the center is at 10 μm, and the right is at 5 μm.

Other than the laser radiation modes, the quality of the final structure depends on the sequence of technological operations performed in one production cycle. Four coordinate laser microprocessing allows to process two sides of the substrate with accuracy of alignment up to 5 μm, which is permissible at the minimum MEMS structure (the central track) size of 30 μm. Two-sided laser microprocessing makes it possible to obtain a more accurate chip geometry, which is close to the 3D model, by reducing the conicity of the side faces of the chips, which is about 9 degrees when microprocessing Al_2O_3 ceramics, or about 80 microns with a substrate thickness of 500 microns.

When working with MEMS structures, one of the problems is the manipulation and moving of chips, the sizes of which do not exceed several millimeters. The application of metallization, a gas sensitive layer, the assembly of small-size chips is a very labor-intensive process, coupled with a large percentage of defects. Two-sided laser processing of the material makes it possible to locate bridges that do not allow the chip to fall out of the substrate after processing, symmetrically relative to the upper and lower planes of the substrate surfaces, which makes possible to fabricate an array of chips that do not require separation during metallization operations, a gas sensitive layer deposition, and gluing of the SOT-23 housing, in other words, until the final assembly (Fig. 9).

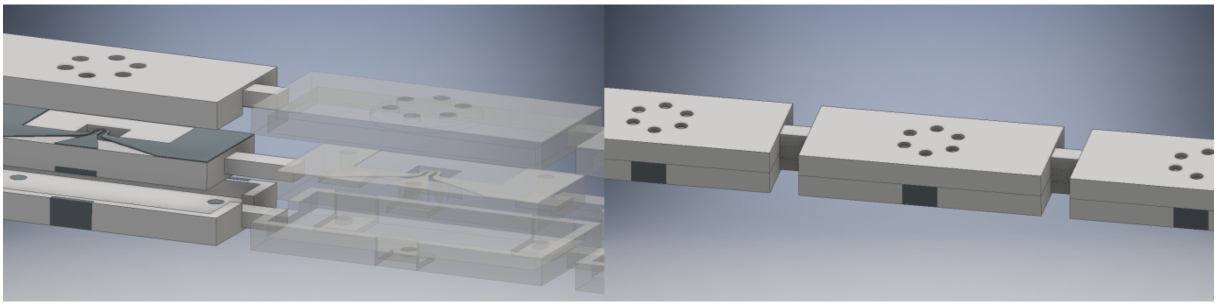

Figure 9. The process of assembling the chip into the SOT-23 housing, without dividing the array to separate chips.

This technology allows the group chips production, which greatly facilitates and speeds up the production process, and most importantly reduces the amount of rejects to a minimum.

Using this approach, experiments were carried out to fabricate a MEMS microhotplate, whose track width was 30 μm and a thickness of 20 μm. The power consumption of MEMS microhotplate at 450°C was approximately 250 mW (350 mW at ≈ 600°C - “burning” platinum temperature, see Fig.6).

3. Conclusion

Current results gives the prospect that manufacture MOX sensor in the SMD SOT-23 package type (max dissipating power by form-factor of package is 350 mW) for surface mounting in a tape is available by using described technology.

Acknowledgements

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