Miniaturized ceramic platform for metal oxide gas sensors array

N N Samotaev
National Research Nuclear University MEPhI (Moscow Engineering Physics Institute), Kashirskoe shosse 31, 115409 Moscow, Russian Federation

Corresponding author e-mail address: nnsamotaev@mephi.ru

Abstract. In work is developing an ultra-fast, low cost and technology flexible process for production array of ceramic MEMS microhotplates for using in semiconductor gas sensors orientated to small series applications, where is sufficient to produce 10-100 samples with a different layout of heaters and membrane per day.

1. Introduction
Currently, gas-sensitive metal oxide sensors are most widely used as discrete microelectronics elements, one type containing gas sensitive material and one microhotplate accordingly for one. This is typical for mobile phones [1], wireless network applications [2-4], in tasks of monitoring air quality [5], and other tasks aimed at large-scale production. On the other side encountered multi gases analysis problems associated with needs to have in same time to activate several types of gas-sensitive materials and respectively independent microhotplates for ones [6].

The multi gases analysis tasks can be divided according to metrological principles for the following:
- The using array of sensors for the analysis of several different types of gases [7];
- Using array of sensors as comparative elements to compensate for external factors [8];
- Building systems such as electronic nose based on neural network algorithm [9].

Technical solving principles of such arrays can be divided into three groups:
- Drawing up of discrete elements microhotplates one body [7];
- Formation on the same chip several separate microhotplates [9, 10];
- Creating one microhotplates large temperature gradient to obtain signals with the same gas sensitive layer located simultaneously at various temperatures [11].

There are microhotplates for gas sensors prepared using standard silicon MEMS technology [12], and to a small extent the combination of ceramics and the classic thick-film technology [13]. This is due in turn to the general trend to reduce the energy consumption of sensor systems using autonomous power sources. On another tern technologically when forming an array of sensors, using both silicon and ceramic MEMS technology absent variation flexibility in the topology by long specificity process occupies a duration from several days (manufacturing photo mask, shadow masks for deposition, sintering processes, and etching, etc.). In our work more attention was focused on the creation of technology, where the time between the design of the array of heaters and final production must take place no more than a few hours.
2. Experimental

Laser micromachining using Minimarker installation [14] with wavelength, 1.064 µm was taken as a basic technological tool. The base material for the microhotplate substrate was monolithic ceramics from aluminum oxide containing 96% alumina because of its cheapness (5 times cheaper than 99.9% alumina) and sufficiently robust for sensor fabrication. As metallization base material, we took platinum-containing composite with additives of organic binder components and borosilicate glass microparticles, which are used for the preparation of finely dispersed paste usable in screen printing process. Microhotplate layout was designed using AutoCAD program and then loaded to the computer of laser engraving machine. According to the previously obtained relationship between the number of laser ablation passes, laser power and depth of engraving, the micromachining process was pre-set. The next steps of fabrication process were the thinning of the whole surface by engraving, cutting of the membrane obtained during the thinning process leading to the formation of beam suspended microhotplate, and dicing the substrate into chips. In the final microhotplate manufacturing step, the platinum ink was deposited on its surface, and then its local laser firing was implemented. The residual, unfired, ink was removed by washing to form microhotplate. Or, alternatively, the ink was fired in an oven, and the heater was formed by local laser ablation.

![Figure 1. Phase of microhotplate production: (a) design of the microhotplate layout in AutoCAD software, dimensions given in mm (b) engraving by laser Al₂O₃ substrate – view from the bottom side; (c) engraving by laser Al₂O₃ substrate – view from the top side; (d) deposition and annealing of Pt paste on the top of microhotplate; (e) deposition and soldering platinum wire by Pt paste on the top of chip microhotplate (wire diameter is of 100 µm); (f) microhotplate under power load (glowing starts approximately at 600 °C for platinum based material of heater).](image)

Microhotplate obtained within technology tests was made during several hours (photos of the microhotplate on different technological steps are presented in Fig. 1). Microhotplate was packaged in TO-8 still package and studied for the power consumption and heating characteristic time. The following results were obtained of microhotplate with 1.7×1.7 mm chip size: consumption power 150 mW at 450°C (Fig. 2b) and heating characteristic time less than 1 seconds. Subsequent studies showed that for more precise design, the simulation of microhotplate in the Ansys program, which gives more accurate heat and power parameters of the manufactured chip, should be carried out initially.
Using a combination of cheap monolithic ceramic substrate, thick film Platinum paste, laser engraving and AutoCAD software for sensor layout design, microhotplates with good mechanical properties were fabricated. Production speed (laser engraving) of single MEMS structure was the order of 1 minute and 1 hour for group annealing of Platinum paste in a belt furnace. Our experiments show that describing the technology in experience hands gives fantastic speed the design and manufacturing of ready-to-use microhotplate in the order of 1 hour. The cost of materials (alumina substrate and Platinum paste) for the manufacturing single microhotplate size 6×6 mm is about 0.50 Euro. For future decrease, microhotplate power consumption haves two ways. First using ceramic materials with low termoconductivity (As example ZrO₂ [15] or porous Al₂O₃ [16]) or second is related to the application of pulsing heating mode for gas sensitive sensor’s layer [17-20].

![Figure 2.](a) Photo of Al₂O₃ substrate before separation microhotplates on single crystals with 1,7×1,7 mm chip size. (b) Thermal characteristics of microhotplate with 1,7×1,7 mm chip size.

For the manufacture of array of microhotplates by the developed technology is possible to use two lines of action – first is creation by laser micromachining a combine several microheaters on a single chip as shown in Figure 3, or create an array of a set of individual crystals microheaters, as shown in Figure 2 (a).

![Figure 3.](a) Engraving by laser array of microhotplate on Al₂O₃ substrate – view from the top side; (b) Engraving by laser array of microhotplate on Al₂O₃ substrate – view from the bottom side.

3. Conclusions
During work implementation by laser micromachining of monolithic alumina was made miniature ceramic microheating MEMS platform for an array of metal-oxide gas sensors. MEMS microhotplates is mechanically stable and has lower power consumption in comparison with the classical thick-film technology. The flexible manufacturing process of technology allows integration of gas-sensitive element arrays with different types of sensitive layers and / or operating temperatures on the single ceramic chip.
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