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Fabrication of Microhater by Selective Laser Sintering of Ruthenium Dioxide Micropowder

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Abstract

During the topology creation by the selective laser sintering method experimental samples of microheater based on ruthenium dioxide micro-powder were made. The resulting structures were used as microheaters to measure changes in the thermal conductivity of gases. A power comparison of standard platinum spiral element widely used in catalytic thermal sensors and microheater produced by the new technology showed the advantage of the latter.

Keywords: laser; MEMS; microhotplate; gas sensor;

1. Introduction

The aim of our work was to create technological process that allowing quickly produce small-scale series of the microheaters for thermal conductivity gas sensors. The similar class of sensing elements are widely used for
measuring high concentrations of flammable gases, usually above LEL or in thermomagnetic oxygen sensors. As a guideline for acceptable results was taken the most similar in thermal and mechanical parameters technology of the platinum microwire winding, e.g. mikroheating pellistor element of thermocatalytic sensors, widely used in Russia and presented in Karpova et al. (2014).

Thermal conductivity sensors typically require for proper operation not high working temperature, sometimes up to 300°C or little more. Mainly next technologies are used for the fabrication of microhotplate platforms possible for use in thermal conductivity measurements in gas sensitive applications:

- silicon technology (CVD which present by Vincenzi et al. (2001), SOI which present by Friedberger et al. (2003), porous silicon which present by Maccagnani et al. (1998));
- ceramic (thin thin alumina films which present in Karpov et al. (2013) and Vasiliev et al. (2008), clip casting under load which present by Vasiliev et al. (2011), LTCC which present by Teterycz et al. (1998) or Rettig and Moos (2004));
- thick film (screen printing which present in Samotaev et al. (2007) or Samotaev et al. (2013));

All of these technologies have really low production cost starting only from large scale (more than ca. 1 million units per year). Moreover, some of these technologies require expensive microelectronics technological equipment and clean rooms for efficient manufacturing; this equipment and tools gives additional non-transparent contribution to the cost of production. Also, some technological processes have technological limitation. For example, it is very hard to create shadow masks with dimension of holes below then 20 μm and use them in sputtering process in ceramic and silicon MEMS technologies. Sometimes, photolithographic process is impossible, because it is very difficult to clean up porous material (typically for ceramic and silicon based materials) after photoresist deposition. Silicon technology and flexible substrates give membranes and platinum heaters characterized by insufficient long-term stability at high temperature. Thick film technology provides too low resolution of microhotplate layout. Therefore, it is possible to mention restrictions for each of these technologies, developed only for mass production of sensing elements. Nevertheless, one restriction is common for all these approaches. All of them require relatively expensive tools for the production (substrate, shadow masks, photomasks etc.), therefore, it is impossible to change anything in technology fast, during several hours or days, what is necessary for the optimization of sensor layout and technology. As a result, the development of new product needs very long period for stabilization of technological process.

In our work, we tried to develop a fast, low cost and technology effective process for the production of microhotplates to be used in gas sensors orientated to the mass application, when where it is sufficient to produce 1-10k samples with different layout and resistance of heater. Of course, this technology can be used as well for middle-scale mass production of gas sensors, up to several thousand units per day. Our main goal in this work was to fabricate low power consuming microhotplate with short thermal response time comparable with the level typical for ceramic MEMS or screen-print technologies. Also additional requirement for material for microhotplate is stability up to 600 °C for using in wireless sensor applications for harsh environmental conditions which describing by Samotaev et al. (2014) or Vasiliev et al. (2014) there are survey present in works Samotaev et al. (2014), Somov et al. (2013), Somov et al. (2011), Somov et al. (2014) show that low power consumption of MEMS platform are critical.

![Fig. 1.](image) (a) The microheater topology (sizes are given in mm). (b) Microheater with homogeneous structure obtained by laser sintering of the ruthenium dioxide powder with the power of 20 W. (c) Microheater with inhomogeneous structure obtained by laser sintering of the ruthenium dioxide powder with the power of 30 W.
2. Experiment

As a material for the microheater a conductive powder consisting of ruthenium dioxide RuO₂ (with particle size of 100 nm) was used. Ruthenium belongs to the platinum group of metals and is not oxidized in air at temperatures up to 930°C, which makes possible its use for high-temperature heating circuits used in gas sensors area as well. Sintering is carried out on the ceramic Al₂O₃ substrate 500 microns thick, onto which a layer of ruthenium dioxide powder of 10 microns is to be deposited. Then, using CO₂ laser (with characteristics shown in Table 1) selective laser sintering was carried out according to the sketch shown on Fig. 1a, developed in the AutoCAD program. Then, using CO₂ laser (with characteristics shown in Table 1) selective laser sintering was carried out according to the sketch shown on Fig. 1a, developed in the AutoCAD program. The difference in the physical structure of the homogeneous and inhomogeneous miroheater could be explained with the help of Fig. 2, which schematically shows the principle of laser irradiation effect on the micropowder. Since the microheater with inhomogeneous structure has the highest ratio "volume / surface area", it was chosen as a further object of research.

![Fig. 2 Gaussian distribution of the laser radiation intensity typical for the production of: I - inhomogeneous and II - homogeneous microheater structure. Literal "S" show the sintering area on the surface of substrate.](image)

![Fig. 3. (a) Group of the laser sintered inhomogeneous ruthenium dioxide microheaters before separation from the alumina substrate; (b) Microhotplate soldered in TO-14 package; (c) The temperature distribution in the three-dimensional model of microheater within the temperature range 80-240 °C obtained in COMSOL program.](image)

| Table 1. Main characteristic of the laser facility. |
|-----------------------------------------------|
| Laser source type | CO₂ tube |
| Wavelength, μm | 10.6 |
| Power (max), W | 80 |
| Focused spot diameter with 80 mm lines, μm | 500 |
| Laser position system - three-axis | Servomotor |
| Maximum speed of the laser beam, mm/s | 300 |
| Software and hardware solution, μm | 2.5 |
3. Result and Discussion

Microheaters obtained during technology testing were easily separated from the ceramic substrate and without any further improvement process were mounted by soldering in the TO-18 package (Fig. 3b). Moreover, during soldering all manipulations with microheater were carried out manually using tweezers, that indicating good mechanical strength of the microheater. Microheater was mounted in the TO-18 package and examined for the power consumption and the heating time constant. We obtained that power consumption compared with classic pellistors using 10 μm glass-insulated platinum microwire consuming (70 mW at 450°C), but heating above 240 °C of microheaters is destroyed one due to local overheating. Workout of modelling in COMSOL program show that temperature distribution in the three-dimensional model of microheater within the temperature range 80-240 °C is not equitable (Fig. 3a). But despite all these shortcomings, the laser sintering technology of microheater is much cheaper technology of platinum microwire.

4. Conclusion

Nowadays, 3-D rapid prototyping technologies become more and more widespread. They are generally characterized by low cost of equipment and materials, the speed of the prototypes design and manufacturing, reduced requirements to the personnel. With the use of simple equipment for selective laser sintering, widely available software like the AutoCAD software and cheap ruthenium dioxide nanopowder the workable microheaters for thermal conductivity sensors were obtained. The power consumption and response time of fabricated microheaters are close to level typical of ceramic MEMS technologies and pelistor type catalytic sensors.

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