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Aerosol Jet Printing of Platinum Microheaters for the Application in Gas Sensors

P V Arsenov[1], I S Vlasov[1], A A Efimov[1*], K N Minkov[2] and V V Ivanov[1]

[1]Department of Physical and Quantum Electronics, Moscow Institute of Physics and Technology, Dolgoprudny 141701, Russia
[2]Moscow Institute of Electronics and Mathematics, National Research University of Higher School of Economics, Moscow 123458, Russia

Abstract. This paper presents the results of characterization of microheaters fabricated on the surface of ceramic substrates by aerosol jet printing with commercially available platinum ink containing colloidal particles with the average size of about 100 nm. The microheater under study represents planar microstructure with variable cross-sectional area comprising narrow segment capable of being heated up to few hundred degrees when current is passed through. The narrow segment is fabricated in the form of single line with the width and height of 50 µm and 6.7 µm, respectively. To remove the organic substance from the deposited material (dry residue of the ink), the printed microheaters were fired at 150°C for 20 min. The dependence of the operating temperature on the power consumed by the microheater was obtained from the measurements of direct current resistance as a function of consumed power with the use of previously determined temperature coefficient of the material ($3.9 \cdot 10^{-3}$ K^{-1}).

1. Introduction

The aerosol jet printing method (AJP) is a universal technology for printing on substrates of various materials using a large selection of functional inks [1]. The use of AJP in the field of printed electronics becomes more and more popular, since the print resolution reaches about 10 microns [2]. This resolution is not possible while using alternative methods, for example, inkjet or screen printing. One of the AJP development areas is a creation of low cost sensors for determination of gas or liquid chemical composition [3]. The basis of this sensors making technology is the application of functional layers of a nanocomposite (gas sensitive material) on a special silicon or ceramics substrates [4]. As a result, the sensor has sufficient selectivity due to the use of nanocomposite material and it has inexpensive mass production capabilities. The main and most difficult task for creating such sensors is the printing of a microheater, which locally heats the gas sensitive layer. Such microheater must accord to a number of geometrical, mechanical, temperature and electrical requirements. For the above reason, in this paper we investigated the printing parameters and characteristics of a microheater for potential gas detectors applications. Also we managed to explore the contactless method of aerosol printing, which allows to form Pt microheaters on thin (<100 µm) ceramic substrates without loss of expensive material. Such aim is an impossible task while using traditional methods of contact manufacturing of microheaters, such as photolithography and screen printing [5].

2. Experiment

The gas sensor microheater was printed using a commercial AJ 15XE aerosol jet printer (Neotech AMT GmbH). The platinum metal nanoparticles ink with the average size of about 100 nm was

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sprayed with a pneumatic atomizer. The flow of aerosol particles in the form of microdroplets contains metallic nanoparticles inside it. In our experiments it was focused on a ceramic substrate based on aluminum oxide (LTCC) with the size of 2.5×0.5×0.1 mm using an argon gas flow. The optimal printing parameters [6], at which the deposited material did not spread on the substrate and was conductive after sintering, were investigated and selected for platinum ink. The aerosol and focusing gas flows were 20 and 5 sccm, respectively. The precipitated ink was dried at 150 °C (20 min) and then sintered at 900 °C (30 min). After that the four-probe method was applied to make electrical measurements. For this purpose, Agilent U1253B multimeter and Keithley 2401 current source and voltage source were used. According to the obtained dependencies of resistance on the applied voltage and formula (1), the temperature of the microheater T was calculated, and the dependence of the temperature on the power consumption P was constructed:

$$T = T_0 + \frac{R - R_0}{\alpha R_0} \quad (1)$$

where T is the temperature of the microheater, T_0 is the room temperature, R is the resistance of the microheater at temperature T, R_0 is the resistance of the microheater at room temperature, α is the temperature coefficient of resistance ($3.9 \cdot 10^{-3}$ K^{-1}) [7]. The formula (1) was taken from [7].

Optical images of the printed structures and their 3D profiles were also obtained using Keyence VHX 1000 microscope and Leica DCM 3D optical profilometer, respectively.

3. Results

Figure 1 shows the microheater images in the form of a curved line on the surface of the LTTC substrate, measured using optical microscope and 3D profilometer.

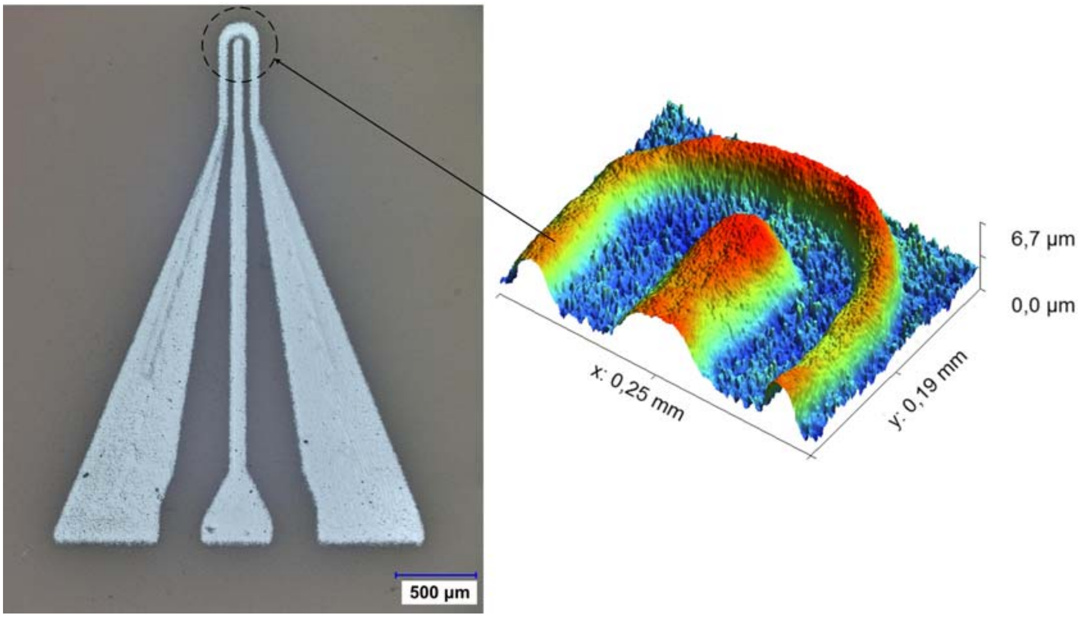

Figure 1. Optical image (left) and 3D profile (right) of a platinum microheater in the shape of a curved line on a LTTC ceramic substrate, measured with optical microscope and 3D profilometer, respectively.

From the image analysis presented in figure 1, information about the width, height, and profile of the deposited microheater structures was obtained, and it was carried out the monitoring of the microheaters for the presence of closures and spreading of the deposited material. Typical widths and heights were 50 and 6.7 µm, respectively.

Figure 2 shows the dependence of the calculated temperature of the microheater, according to formula (1), on the power consumption.

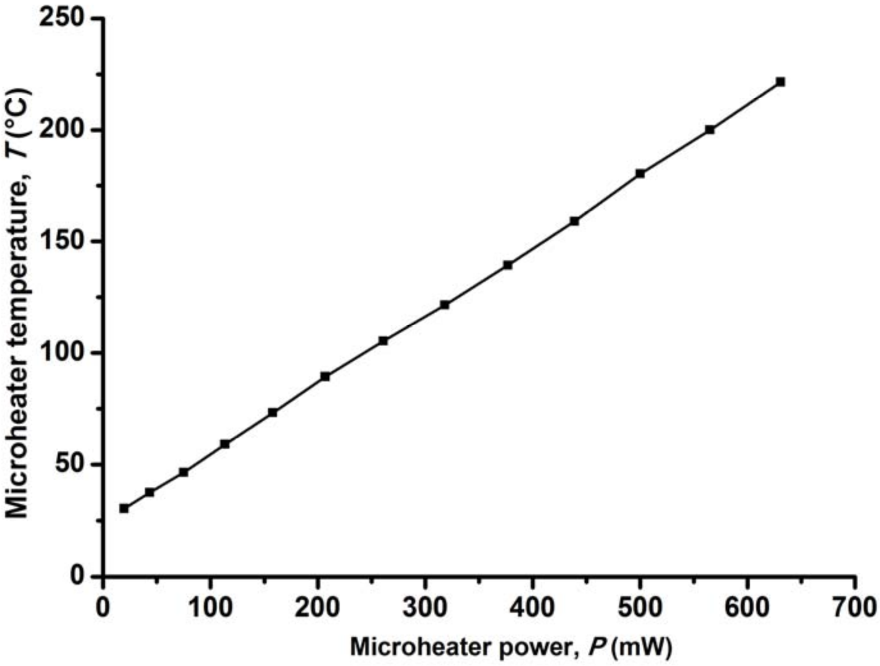

Figure 2. Dependence of the heating temperature on the power consumption of the platinum microheater printed by aerosol jet printing.

From figure 2 it can be seen that the dependence of temperature on power consumption is linear, which is characteristic of this type microheaters. From the analysis of the dependence presented in figure 2, it was established that the recommended power consumption with continuous heating of the microheater to 225 °C should be about 650 mW. In the case of its exceeded, there is an irreversible degradation of the microheater contacts is observed.

4. Conclusions

The paper presents the possibility of aerosol jet printing method usage for the manufacturing of platinum microheaters for potential applications in gas sensors. As a result, printing parameters were selected and microheater templates on ceramic substrates from LTCC were obtained. The dependence of the heating temperature on the power consumption of the microheater was obtained by using the four-probe method. It was established that the recommended power consumption of the microheater is about 650 mW at its heating temperature up to 225 °C, and a further power increase leads to overheating of the microheater.

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