Design and optimization of planar structure micro-hotplate

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Abstract

A new planar structure micro-hotplate is fabricated to simplify the manufacturing process of micro gas sensor and shows similar power consumption with the conventional stack one. Two new types of planar structure micro-hotplates are designed to uniform the temperature distribution on the sensitive film deposited on it and decrease the power consumption. As the result of the thermal analysis, the suspended planar structure is the most promising structure because of the homogeneous temperature distribution and the lower power consumption.

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Keywords: Micro-Hotplate; Planar structure; Thermal analysis; Temperature Distribution; Power Consumption

1. Introduction

Lots types of metal oxide semiconductor (MOS) thin film such as SnO₂, ZnO have high response to variety harmful gas. But they should be operated at high temperature up to 500 °C in order to attain sufficient sensitivity. To provide enough heat for the thin film, a device named micro – hotplate (MHP) is usually fabricated in the micro gas sensor. In conventional MHP, the thin diaphragms have been used as a substrate on which a heater, a pair of interdigitated electrode, a gas sensing layer are stacked successive. However such stacked type has many obstacles as follows: First, yield of gas sensor would be reduced due to too tedious fabrication processes, including as many as five to six masks for the lithography

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processes. Second uniform temperature distribution is hard to achieve over the sensing layer. Third, some low-cost processes such as sol-gel are not suitable for this structure.

To solve the above problems, some planar structures MHPs which the heater, the electrode and the temperature sensor were fabricated simultaneously on the same plane of diaphragm were designed by many researchers. W. Y. Chung et al. [1] placed the heater surrounding the electrode, but the sensing characteristics of gas sensor might be limited due to the absence of the interdigitated electrode. This structure is shown in Fig.1. Wang et al. [2] embed the heater in the space between the pair of the interdigitated electrode, but the electrode-spacing was too large to maximize the effectiveness of the interdigitated electrode [3]. This structure is shown in Fig. 2.

Fig. 1 Planar structure designed by W. Y. Chung; Fig. 2 Planar structure designed by Wang

In this paper, we propose a new type of planar structure micro-hotplate with small interdigitated electrode-spacing. We have used ANSYS for the finite element analysis to control power consumption and uniform temperature diffusion over the sensitive film.

2. Fabrication and modeling

2.1. Micro-hotplate fabrication

The micromachined structure was fabricated on a double side polished p-type (100) Si wafer. The thickness of the silicon substrates was 350μm. The basic technological steps for the device fabrication, shown in Fig. 4, can be summarized as follow:

(1) A SiO₂ layer of 500nm of thickness was thermally grown on each side of the silicon substrate. This layer was used as a thermal insulation layer [4] at front side as well as passivation layer during etching at back side. (Fig. 3a)

(2) A Ti adhesion layer (20nm) and a Pt layer (200nm) were deposited successively on the front side of the wafer by r. f. magnetron sputtering. (Fig. 3b)

(3) An etch mask was patterned in the back of the substrate and a window in the SiO₂ layer was defined through wet-etching. (Fig. 3c)

(4) The geometry of the heat, the interdigitated electrode and the temperature gas sensor was defined by the lift-off technique. (Fig. 3d)

(5) Finally, the backside of the wafer was removed by anisotropic KOH etching. (Fig. 3e)
2.2. Micro-hotplate fabrication

The structure of the micro-sensor is shown in Fig. 4. The whole chip size was about 2mm × 2mm × 0.35mm. The heaters were two tapes of Pt 20μm, folded into two double-track structures surrounding the temperature sensor which were located around the central interdigitated electrode. The interdigitated electrode has 10μm finger width and 5μm electrode-spacing. The pattern of the electrode group is shown in Fig. 5.

3. Thermal simulation by finite element method

To obtain a short response time, high sensitivity and good selectivity of the sensor, a uniform temperature profile across the micro hotplate is essential, especially within the sensitive area of the interdigitated electrode [5]. The thermal properties of micro device are most closely associated with the geometry and dimensions of the heater and insulation layer used as well as the materials used for them. Computer simulation will give information on optimal device structure and materials design.

ANSYS is a comprehensive suite of MEMS design tools in the industry. It acts as a seamless integrated design environment that reduces design risk, speeds time-to-market and lowers development costs. The finite element analysis enables detailed 3D multi-physics numerical analysis to support virtually every MEMS application.
In order to compare with the planar structure, a stack structure MHP in which the heater and the interdigitated electrode are on different planes was considered in the present study. In the planar structure, the gas sensitive film on the electrode group was set to 520×520μm in dimension. In the stack structure, both heater and sensing areas were about 300×300μm which was the same dimension with the area of interdigitated electrode in planar structure one.

It was assumed for the simulation that the device be disconnected from any supporting parts, being completely isolated in the ambient air with temperature of 20°C, and that heat be supplied by the heating the heater at a constant rate per unit volume of it. In the stack structure devices, the gas sensitive film is heated by the heater located beneath. In the planar structure, however, the film is heated by the heater surrounding the interdigitated electrode. The representative temperature of each sensing layer is set to be around 400°C. The temperature distribution of the two structures are shown in Fig. 6.

Fig. 6(a) Temperature distribution on the sensitive of stack structure MHP; b) Planar structure MHP

The maximum temperature of the stack structure reached 409°C when the heating power consumption was about 33.84mW. On the other hand, maximum temperature was about 406°C when the power consumption was about 34.2mW. It seems that this planar structure MHP has similar power consumption with the stack structure.

For the stack structure, the temperature varied from 409.43°C to 391.68°C going from the center to the periphery. But for the planar structure, the maximum was seen at the heating resistor, keeping the sensitive film inside at a little lower temperature (about 403°C), and a difference of 14°C between the maximum temperature and minimum temperature was found on the sensitive film. Both of them had a little big temperature variation.

Fig. 7(a) The cross-section of the planar structure type 2; (b) The back view of the planar structure type 3
Two new types (type 2 and type 3, the planar structure mentioned above is type 1) of planar structure MHPs were designed to improve homogeneity of the temperature distribution on the sensitive film. In planar structure type 2, a 10μm thick Si structure named Si Island was added underneath the sensitive area. In planar structure type 3, the front side of the SiO₂ layer was etched to define a suspended structure. The structures of these two new types are shown in Fig. 7, and the temperature distributions on the sensitive film are shown in Fig. 8.

For the planar structure type 2 at the power of 33.84mW, the temperature distribution was much more uniform, the variation being kept less than 4°C as shown in Fig. 8(a). It is because that the thermal conductivity coefficient of Si is much bigger than other materials which are used in the structure. The heater created by the heater could conduct much faster in the Si Island. And the heat in the Si Island could influence the sensitive film conversely. But the maximum temperature was reduced to 399.27°C, means that the Si Island may increase the power consumption of gas sensor.

For the planar structure type 3, the maximum was 404°C when the heating power consumption was about 10.3mW. It indicated that the suspended structure could decrease the power consumption significantly. In the suspended structure, the sensitive area was connected with the Si substrate only through 4 SiO₂ legs with width of 90μm and height of 5μm. Power consumed on the Si structure would be limited both by small thermal conductivity coefficient of the SiO₂ and by low heat transfer area of the legs. More heat would be operated on the sensitive film at the same power consumption. The temperature variation on the film was about 9°C, higher than the planar structure type 2, but lower than the type 1. The temperature distributions over the sensitive area of interdigitated electrode of the three types are shown in Fig. 9.
In the Fig. 9, we can see that the temperature distribution on the sensitive area of planar structure type 3 was more homogeneous than the type 1. These result indicated that, in the case of lower power consumption, uniform temperature distribution could still be appeared on the sensitive area for the suspended structure.

4. Conclusion

A planar structure micro-hotplate could be fabricated far more easily than the conventional stack structure one. The fabrication processes are shown in Fig. 3. The thermal analysis is applied to compare the stack structure with the planar structure type 1. At the same representative temperature, they have similar power consumption. Other two type of the planar structure MHPs are designed to improve the temperature uniformity over the sensitive film and decrease the power consumption. According to the result of the thermal analysis, the planar structure type 3 seems to have uniform temperature distribution and low power consumption.

Acknowledgement

The authors thank the National Natural Science Foundation of China (50875122) for financial support. The authors are grateful to Professor Chunhai Cao at Department of Electronic Science & Engineering of Nanjing University for his support of this project

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