Design of Mems-based Gas Sensor Micro Heat Plate

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Abstract. In this academic paper, a mems-based device: micro gas sensor micro heat plate (MHP) was designed and produced. Unlike the traditional MHP, of which the heating electrode and test electrode is with non-coplanar design, the MHP designed in this paper has coplanar heating electrode and test electrode with higher heating efficiency. Platinum was used as heating electrode material in the design. By taking advantage of platinum's property of relatively stable resistance temperature coefficient, as well as by controlling the heating voltage of MHP, the temperature of the gas sensor was accurately regulated. The design also utilized Comsol, the finite element simulation software, to analyze and optimize the heating performance and heat distribution of MHP.

1. Introduction
Micro-electromechanical Systems (MEMS) developed with the progress of semiconductor integrated circuit micro machining technology and ultraprecise machining technology [1-3]. It can integrate micro sensors, micro actuators, signal processing and control circuits, and even interface, communication and power supply into a whole, characterized by such features as small volume, light weight and practicality of mass production, etc [4-6].

Since 1962, metal oxide semiconductor (MOS) materials have been increasingly applied into gas detection. Nevertheless, since a certain temperature is required for MOS materials to react with gas, the power dissipation of sensor is excessive, consequently restraining its further development. In contrast with traditional gas sensor, MOS gas sensor on MEMS technology is equipped with a host of advantages on such aspects as consistency and microminiaturization, which is easier to achieve integration and low power consumption [7-11]. Meanwhile, MOS gas sensor is compatible with the existing silicon-based processing technology, which is the orientation of development for future gas sensor. Within this type of sensor, the MHPs made via MEMS technology can provide heat for MOS air-sensitive thin-film materials. And its thermal performance can exert influences on the displaying of sensor's overall performance [12-13]. Consequently, it is of great necessity to carry out in-depth analysis and research on MHP so that the structure of the sensor can be optimized [14-16].

Within the traditional MHP gas sensor, the heating electrodes and the test electrodes are not on the same plane. With such traditional design, the manufacturing process is complex, and the heat transfer is not very good, and a parasitic electric field is likely to take form among the heating layer,

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insulating layer and testing layer, exerting certain influences on the signal to be tested. In this new design, the heating electrode and the testing electrode are placed on the same plane [16-21]. Compared with traditional devices, the production process has been streamlined, the heating process and heat transfer is optimized, and the parasitic electric field among the "three-layer" structure is avoided.

Platinum was used for both heating electrode and test electrode in this design. The resistance of platinum is equipped with such merits as large range of measurement, good stability and anti-oxidation property. Within a certain range of temperature, the resistance-temperature characteristic curve is linear, and the temperature of platinum electrode can be effectively calculated based on the resistance value of platinum. By gradually increasing the voltage at both ends of the heating electrode of MHP and by measuring the resistance value of heating electrode during the heating and heat generation process, the relation curve for voltage and resistance of the heating electrode can be achieved. The relation curve for voltage and resistance can be further calculated by referring to the linearity between resistance and temperature of the platinum resistance. Eventually, regulation of working temperature can be realized by changing the working voltage of platinum electrode.

Simulation analysis can be carried out on various structures' temperature distribution in the physical field with Multiphysics module in COMSOL, the finite element simulation software [22-23]. In this academic paper, a new-type MHP with four pins was designed, and by using finite element analysis method, the temperature distribution of the new-type MHP was simulated; meanwhile, the structure of MHP was optimized via simulation.

2. The design and fabrication of MHP

The structure of MHP mainly designed in this academic paper is shown in Figure 1 and the plane dimension of the device is 6mm*6mm. With a thickness of approximately 500 μm, the base of MHP consists of three layers: they are SiO_2, Si and SiO_2 respectively from top to bottom, with the thickness of Si being 500 μm and the thickness of SiO_2 being 2 μm. The upper SiO_2 layer is the electrical insulating layer as well as the thermal insulating layer, and the bottom SiO_2 layer is equipped with the function to prevent heat loss.

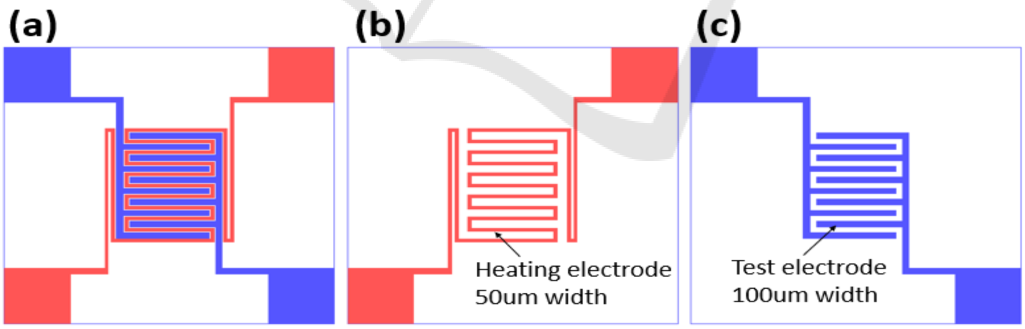


Figure 1. The structure of the electrode on the microplate; (a) overall structure of the electrodes, (b) heating electrode and (c) test electrodes.

The fabrication process of MHP is shown in Figure 2, in which the SiO2 base in the upper layer is processed via spreading photoresist and platinum with a thickness of 200 nm is deposited via electron beam evaporation. The heating electrode and test electrode on the same plane was achieved after getting rid of redundant photoresist and platinum. By proceeding with spreading photoresist, and with plasma sputtering the heating electrode cladded by 200-nm-thick SiO2, the insulating property between heating electrode and air-sensitive material is thus guaranteed.

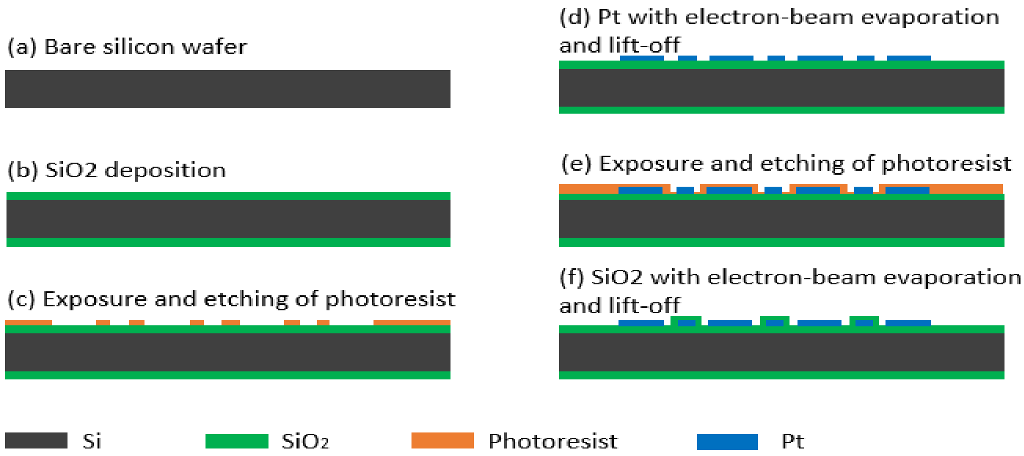


Figure 2. Fabrication process of the MHP for gas sensor based on MEMS.

3. The test of MHP's property

Within a certain range of temperature, the resistance value of platinum metal electrode is linearly correlated with the temperature value. By increasing the temperature after placing MHP into precise temperature-controlled box and by measuring the resistance value of platinum heating electrode during the temperature rise, the relation between the resistance of platinum heating electrode and temperature can be achieved. As illustrated in Figure 3(a), by measuring the resistance value of heating electrode with a width between 40 μm and 50 μm when being heated at 30 ℃-190 ℃, the curve demonstrating how electrode resistance value is varied with the change of temperature can be achieved. Based on Figure 3(a), it is also observed that the resistance value of platinum heating electrode is not linearly correlated with temperature. Furthermore, the experiment also showed that the electrode was lower than its initial value instead of returning to its initial value after being cooled from the heating process.

It is found that the structure of platinum metal film achieved via electron beam evaporation coating is not stable and the resistivity is much higher than normal resistivity. It is necessary to process the platinum metal film with high-temperature annealing so that the compactness of its metal film structure can be restored and its resistivity can be reduced.

In the design, MHP with 50-μm-thick heating electrode was put in tube furnace and heated at 500 ℃ for three hours before it was cooled. After three times of annealing, the resistance value of the heating electrode before and after annealing was measured at 1025Ω, 561Ω, 556Ω and 552Ω respectively. According to the resistance value change of platinum heating electrode, it is known that the change of resistance value was the greatest after first-time annealing, while the change of resistance value after the second-time and third-time annealing was less than 10 Ω, indicating that the resistance value of the heating electrode three hours after the 500 ℃ annealing has already been stabilized.

The annealed MHP was once again put into precise temperature-controlled box so as to measure how the resistance value of platinum heating electrode changed with temperature, and Figure 3 shows how the heater strips with a width of 40 μm and 50 μm change when the temperature varies between 30 ℃ and 200 ℃. By fitting the data from the test in Origin, the linear equation about how the resistance value of MHP with corresponding sizes varies with the changes of temperature can be achieved.

In the test, the annealed MHP was fixed by probe station, the probe was pricked into the pins at both ends of the heating electrode, and stable voltage was applied to both ends of the heating electrode via the probe station to make the platinum electrode generate heat; after the resistance of platinum electrode became stabilized, the resistance value was recorded. The changes of platinum electrode's resistance value when the voltage rose from 0V to 70V was recorded and shown in Figure 3(b). By making use of the measured linear relation between platinum electrode's resistance value and temperature to replace the resistance value on the ordinate in Figure 3. with temperature value, the relation about how platinum electrode's temperature changes with voltage was obtained and was illustrated in Figure 3(c, d).

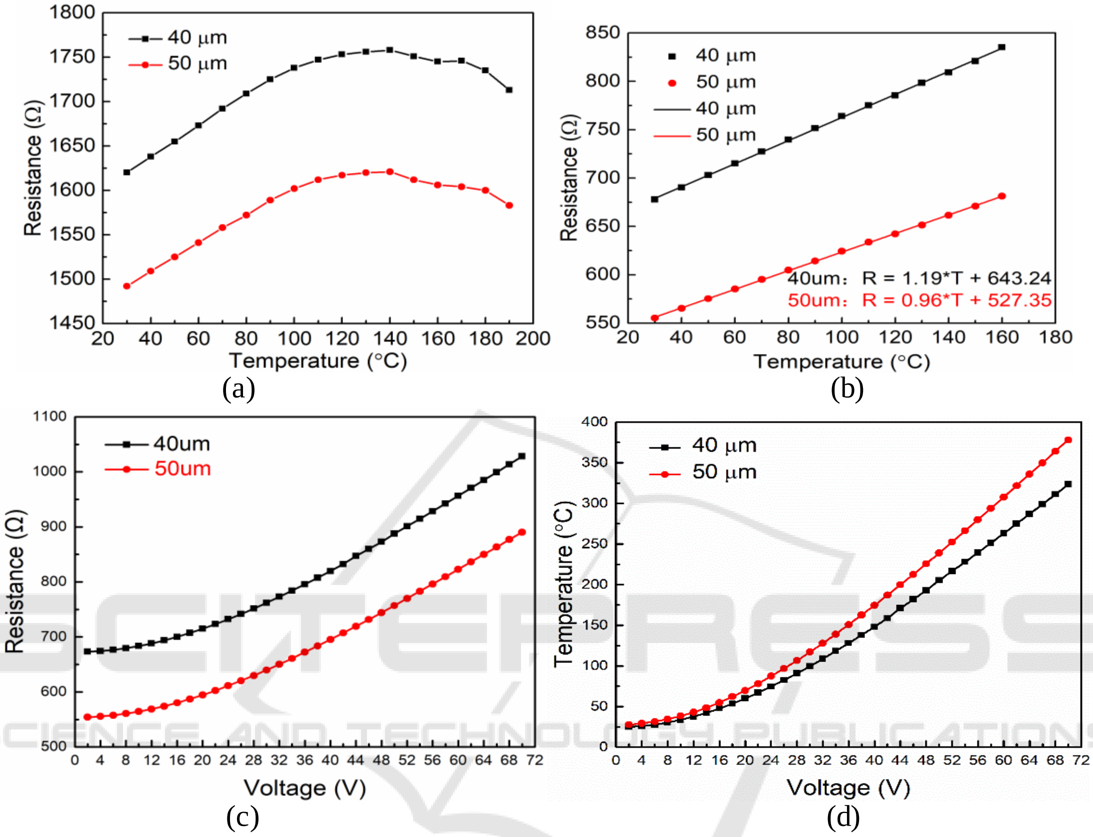


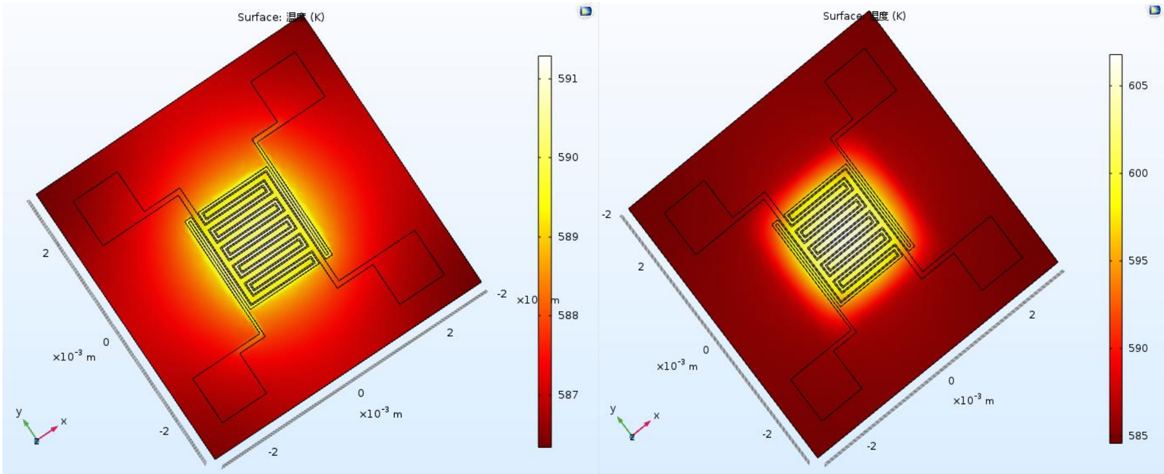
Figure 3. The test of MHP's property.

4. Simulation verification

An analysis was carried out on the heating performance of the designed MHP via the finite element simulation software: COMSOL Multiphysics, and a contrast was made with the test result, so that the optimization of the structure of the initially-designed finished product as well as the improvement of the performance was further achieved.

In the first place, a simulated geometric model was constructed in Comsol. Then, corresponding materials were selected for different sections of the geometric model and the material property was also set up. Afterward, the physical field and condition required by simulation were set up and the whole model was finalized in a gridding state. Finally, the simulation software was operated whereby the heat distribution of the constructed model was obtained.

The module with 50- μm-thick heating electrode was chosen and with the heating voltage of 60V, the thickness of the silicon layer at its base was gradually reduced so at to carry out the simulation. When the constant heating voltage was achieved, the changes of heating temperature in accordance with the change of silica base thickness are shown in Figure 4. It is thereby known that when the heating voltage remains constant, the thinner the silica base is, the higher the value of the MPH at stable heating temperature will be.



(a) Silicon layer thickness of 500um (b) Silicon layer thickness of 5um

Figure 4. Simulation verification.

5. Conclusions

During the preparation process of MHP, the resistance value of metal film electrode obtained by evaporation coating is not stable and highly susceptible to temperature, and thus needs high-temperature annealing. The resistance value of the annealed metal electrode tends to stabilize, and the resistance value before heating and after cooling is no longer changes.

The non-optimized devices in this design have relatively higher heat loss, and this is primarily due to that in the initial design, no consideration is given to the fact that the actual resistance value will increase by a large extent in contrast with the theoretical value after the molding of platinum via evaporation coating. Consequently, it is necessary to carry out a simplified design on the area and length of the platinum electrode, making sure that heating electrode has relatively small resistance and reduces the heating power of the device. Meanwhile, in consideration of conduction dissipation of heat and via simulation, the silicon surrounding the metal electrode is processed by tunneling, so that the heat loss of the device can be effectively improved.

In this design, such procedures as design, production, test and simulation were completed for a new type of MHP for gas sensor. Via the heating and Adding voltage experiment, the relation between the 's working temperature and working voltage was clarified. Thereby, during the actual operation of the, the control over the working temperature of the micro sensor can be realized via changing the heating voltage.

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References

[1] Afridi M Y, Suehle J S, Zaghloul M E, Berning D W, Hefner A R and et al 2002 A monolithic CMOS microhotplate-based gas sensor system *IEEE Sensors Journal* 2 644-55

[2] Belmonte J C, Puigcorbé J, Arbiol J, VilàA, Morante J R and et al 2006 High-temperature low-power performing micromachined suspended micro-hotplate for gas sensing applications *Sensors and Actuators B: Chemical* 114 826-35

[3] Lang W 1996 Silicon microstructuring technology *Materials Science and Engineering: R: Reports* 17 1-55

[4] Payne R S, Sherman S, Lewis S, Howe R T 1995 Solid-State Circuits Conference *Digest of Technical Papers 41st ISSCC IEEE International* 164-65

[5] Zeeshan A and Bushra H 2018 Darboux transformations of supersymmetric heisenberg magnet model *Journal of Physics Communications* 2 035019

[6] Nicolas D and Corinne W 2011 3D Stationary and temporal electro-thermal simulations of metal oxide gas sensor based on a high temperature and low power consumption micro-heater structure using COMSOL *International Comsol Conference 982*

[7] Udrea F, Gardner J W, Setiadi D, Covington J A, Dogaru T and et al 2001 Design and simulations of SOI CMOS micro-hotplate gas sensors *Sensors and Actuators B: Chemical* 78 180-90

[8] Aslam M, Gregory C, Hatfield J V 2004 Polyimide membrane for micro-heated gas sensor array *Sensors and Actuators B: Chemical* 103 153-57

[9] Mo, Okawa Y W, Tajima Y 2001 Micro-machined gas sensor array based on metal film micro-heater," Sens. Actuat, vol.79

[10] Chunmin T, Chenbo Y, Maoxian H, Shandong T 2008 3rd IEEE International Conference on Nano/Micro Engineered and Molecular Systems2008: 284-87

[11] Partridge J G, Field M R, Sadek A Z, Kalantar-zadeh K, Plessis J D and et al 2009 Fabrication, structural characterization and testing of a nanostructured tin oxide gas sensor. IEEE Sensors Journal 9: 563-68

[12] Doyle W 1966 Magnetization reversal in films with biaxial anisotropy *IEEE Transactions on Magnetics* 2: 68-73

[13] Partridge J G, Field M R, Sadek A Z, Kalantar-zadeh K, Plessis J D and et al 2009 Fabrication, structural characterization and testing of a nanostructured tin oxide Gas sensor *IEEE Sensors Journal* 9 563-68

[14] Design study of micro machined thermal emitters for NDIR gas sensing in the 9–12 μm wavelength range

[15] 24th International Spring Seminar on Electronics Technology. Concurrent Engineering in Electronic Packaging. ISSE 2001. Conference Proceedings (Cat. No.01EX492)2001: 0-3

[16] Puigcorbé J, Vogel D, Michel B, Vilà A, Gràcia I and et al 2003 Thermal and mechanical analysis of micromachined gas sensors *Journal of Micromechanics and Microengineering* 13 548

[17] Puigcorbe J, Vogel D, and Miche B 1990 Nonlinear resonant circuit devices (Patent style) *U.S. Patent* 3 624

[18] Chung G S 2004 Fabrication and characterization of micro-heaters with low-power consumption using SOI membrane and trench structures *Sensors and Actuators A: Physical* 112 55-60

[19] Schmida U and Seidel H 2006 Influence of thermal annealing on the resistivity of titanium/platinum thin films *J. Vac. Sci. Technol* vol. 24

[20] Resnik D, Vrtačnik D, Možek M, Pečar B and Amon S 2011 Experimental study of heat-treated thin film Ti/Pt heater and temperature sensor properties on a Si microfluidic platform *Journal of Micromechanics and Microengineering* 21 025025

[21] Kumar H, Singh K K, Sood N, Kumar A and Mittal R K 2014 *IEEE Sensors Applications Symposium (SAS)* 2014 181-84

[22] Velmathi G, Ramshanker N and Mohan S 2010 2D simulations and electro- thermal analysis of micro-heater designs using COMSOL for gas sensor applications *COMSOL Conference I* 2-5

[23] Sujatha L, Selvakumar V S, Aravind S, Padamapriya R and Preethi B 2012 Design and analysis of micro-heaters using COMSOL multiphysics for MEMS based gas sensor *Proceedings COMSOL conference in bangalore*