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# Design, development and reliability testing of a low power bridge-type micromachined hotplate

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ABSTRACT

In this paper, the development and reliability of a platinum-based microheater with low power consumption are demonstrated. The microheater is fabricated on a thin $SiO_2$ bridge-type suspended membrane supported by four arms. The structure consists of a 0.6 μm-thick $SiO_2$ membrane of size 50 μm × 50 μm over which a platinum resistor is laid out. The simulation of the structure was carried out using MEMS-CAD Tool COVENTORWARE. The platinum resistor of 31.0 Ω is fabricated on $SiO_2$ membrane using lift-off technique. The bulk micromachining technique is used to create the suspended $SiO_2$ membrane. The temperature coefficient of resistance (TCR) of platinum used for temperature estimation of the hotplate is measured and found to be $2.2 \times 10^{-3}$/°C. The test results indicate that the microhotplate consumes only 11.8 mW when heated up to 400 °C. For reliability testing, the hotplate is continuously operated at higher temperatures. It was found that at 404 °C, 508 °C and 595 °C, the microhotplate continuously operated up to 16.5 h, 4.3 h and 4 min respectively without degrading its performance. It can sustain at least 53 cycles pulse-mode of operation at 540 °C with ultra-low resistance and temperature drifts. The structure has maximum current capability of 19.06 mA and it can also sustain the ultrasonic vibration at least for 30 min without any damage.



## 1. Introduction

Microhotplates (MHPs) have been widely used for various sensing applications such as gas sensors [1,2]; infrared emitters [3] and flow rate sensors [4,5]. The metal-oxide gas sensors required low power consumption, fast response time and uniform temperature distribution over the sensing materials [6]. These sensors also required the good mechanical stability at high temperatures. The microhotplates are most suitable for gas sensing applications because of its low power consumption. It is generally consists of a resistor (to provide heat) fabricated on a dielectric suspended membrane [1]. Common microelectronic materials that have been used in creating the resistive heater include Al [7], Au/Ti [8], Ni [9], W [10], Ni alloy (DilverP1) [11], Poly-Si [1] and Pt [12] etc. The Al, most widely used as a metallization element in integrated circuit technology, has drawback of low resistivity, oxide formation at even moderate temperature ~400 °C [13]. Similarly, gold has low resistivity and poor adhesion [6]. The heating materials, Ni and W have the oxidation temperature 400–800 °C [14] and 400 °C [15] respectively. An alloy of nickel, chromium, and iron, usually known as nichrome, can be used as a resistance wire. The nichrome oxidizes at high temperature, but the oxidation layer is protective for the residual metal film. The DilverP1 [11], a heating material added the advantages of low coefficient of thermal expansion, corrosion resistant nature, and moderately high resistivity. But more investigation in the fabrication, reliability testing would be needed to optimize the performance. The heating material polysilicon has the advantage of CMOS compatibility but it has less stability of temperature coefficient of resistance (TCR). Also it is attacked by silicon etching solutions such as tetra methyl ammonium hydroxide (TMAH) and KOH during bulk micromachining of silicon. The platinum is an ideal candidate for microhotplate applications because it has high melting point, better reliability, reproducibility, good thermal conductivity, moderate coefficient of thermal expansion and stable TCR. Pt is chemically inert, even at high temperatures. It has a good catalyst for numerous reactions, e.g., for Pt-catalyzed oxidation of hydrogen [16,17]. Also, it can handle large current densities and operate up to 550–600 °C without any structural damage [18].

In general the dielectric membrane is made in two ways, as a micro-bridge-suspended membrane and a closed membrane. The various research groups fabricated the microhotplate by isolating the heater using a dielectric close membrane or a micro-bridge type. The close membranes are fabricated by back-side etching either using DRIE technique or using bulk micromachining

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technique of silicon. However, the micro-bridges are fabricated by front side etching of silicon. These types of membranes provide the better thermal isolation and consume lower power than closed membrane [19]. Many researchers studying to decrease the power consumptions of MHPs by designing the geometry of dielectric membrane [20–23] to decrease the thermal loss through heat conduction, which is the main heat loss mechanism for inducing the power consumption. The characteristics of various platinum-based microheater reported by different researchers are presented in Table 1. Among these works, the microheater is fabricated on a suspended dielectric membrane to reduce the power consumption around 20 mW at 400 °C. But, it is still high in some applications such as portable gas sensor and wireless sensor networks. The power consumption can be reduced by modifying the heated area [32]. Decreasing the power consumption without addressing the reliability cannot allow the commercialization of microhotplate. On the other hand, for more accurate measurements results, the thermal stability of the device is needed. For good stability of the microhotplate, the heat resistance drift should be minimum at high temperatures, typically 400 °C, which is mostly used to activate the gas sensing films. This indicates that the heater material must be stable at high temperature, typically 400 °C. Among most of the above research works, the authors have been used the microbridge type membranes supported by four arms for low power consumption of MHPs. However, the reliability of the structure such as thermal stability, pulse-mode operation, current carrying capability and effects of vibration are not reported, which are essential for commercialization of the device. The main feature of present work is: (i) The hotplate has been fabricated in bridge configuration with low power consumption. (ii) The reliability of microhotplate such as thermal stability over a long time and pulse-mode of operation have been reported. (iii) Maximum current carrying capability of the heater has been determined. (iv) The vibrational testing of the hotplate has also been performed.

The paper is organized as follows. The design and simulation of the device is presented in Section 2. Fabrication and reliability testing of the device are given in Section 3 and Section 4 respectively. Finally, I conclude in Section 5.

## 2. Design and simulation

### 2.1. Structure design of MHP

The total heat flow in a microhotplate can be expressed as:

$$Q_{Total} = Q_{conduction} + Q_{ambient} + Q_{radiation} + \Delta x \quad (1)$$

here, $Q_{conduction}$ is the heat conducted through a closed membrane or a bridge type membrane, $Q_{ambient}$ is the heat conducted through the air, $Q_{radiation}$ is the heat losses due to radiation, and $\Delta x$ is the unknown heat loss including free convection [13]. Decreasing the heated area (active area) can reduce the power consumption of the microhotplate [13]. In the present simulation, a MEMS-CAD Tool COVENTORWARE was used. For simplicity of design analysis, only membrane area with platinum resistor was taken into consideration. Analyzer's MemMech solver of COVENTORWARE was used in the simulation. The MemMech solver includes a range of analysis such as thermomechanical analysis, electrothermal analysis and electrothermomechanical analysis. A single cell microhotplate of dielectric membrane size, 50 μm × 50 μm was designed using COVENTORWARE. The platinum resistor was laid out on the membrane (Fig. 1). The dimensions used in the design are as follows: heater trace width 5 μm, gap between traces 5 μm, hotplate size 50 μm × 50 μm; membrane thickness 0.6 μm and platinum thickness 0.2 μm. The layout of the hotplate consists of three photomasks: MHP-1 for platinum resistor, MHP-2 for cavity etching and MHP-3 for pad opening.

### 2.2. Simulation of MHP

In the simulation of MHP, MemMech solver of COVENTORWARE was used. In the analysis, Si substrate temperature, outside the active area was taken as 300 K during simulation. The materials property used in simulation work was imported from COVENTORWARE library (Table 2). The typical COVENTORWARE plots of temperature distribution, maximum displacement (in

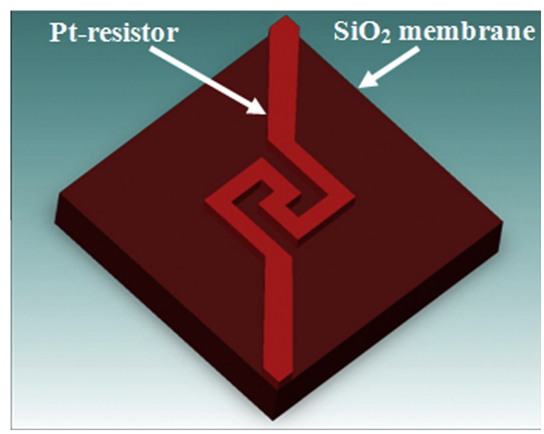


**Fig. 1.** MHP structure designed using COVENTORWARE.

**Table 2**
Properties of materials used in simulation.

| Property | $SiO_2$ | Pt |
|---|---|---|
| Density (kg/μm$^3$) | $2.15 \times 10^{-15}$ | $2.01 \times 10^{-13}$ |
| TCE integral form (1/K) | $5.0 \times 10^{-7}$ | $8.9 \times 10^{-6}$ |
| Thermal conductivity (pW/μm K) | $1.4226 \times 10^{6}$ | $7.016 \times 10^{8}$ |
| Specific heat (pJ/kg K) | $1.0 \times 10^{15}$ | $1.33 \times 10^{14}$ |
| Electrical conductivity (pS/μm) | $1.0 \times 10^{-4}$ | $9.009 \times 10^{12}$ |
| Dielectric constant | 3.9 | 0 |

**Table 1**
Characteristics of various microheaters.

| Heater geometry | Membrane edge length (μm) | Max. temp. (°C) | Thermal time constant (ms) | Power consumption (mW) | Reliability testing | Ref. |
|---|---|---|---|---|---|---|
| Meander | – | 500 | – | 250 | No | [24] |
| U-shaped | – | 170 | 65 | 75 | No | [25] |
| Meander | 85 | 350 | – | 60 | No | [26] |
| N.S. | – | 300 | 25 | 75 | – | [27] |
| Meander | 100 | 600 | – | 33 | No | [28] |
| Irregular | 500 | 870 | 5.2 | 300 | No | [29] |
| Meander with rounded corner | 1500 | 400 | – | 500 | – | [30] |
| 3D Meander | – | 400 | 5 | 20 | No | [31] |