Oven-controlled pressure sensor and its Mechanical aging

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Abstract. On the purpose of enhancing the performance of piezoresistive pressure sensor and reducing the difficulty of temperature compensation, the oven-controlled technology and mechanical aging method is studied in this paper. To be high efficiency and low consumption of oven-controlled method, the MEMS chip without package is used to reduce the thermal resistance. Furthermore, six-week mechanical aging was applied on the sensor. It is shown the mechanical aging can effectively improve the performance of pressure sensor. When the aged sensor chip was tested at a range of -45℃ to 50℃, the designed sensor can measure the atmospheric pressure as an error less than ±0.2hPa with just consuming 0.8mW power.

1. Introduction

Usually, the high precision pressure sensor is developed with resonant principle, such as silicon resonant pressure sensor [1-5] and quartz resonant pressure sensor [6]. They cannot be widely used in handheld devices due to the high price and big volume. Piezoresistive pressure sensors have been massively used in electronic gadget due to the low price and small volume. However, to obtain high precision, piezoresistive pressure sensors will face the complicated compensation processes.

It is fortune that oven-controlled technology has been widely used to develop high performance oscillator due to the advantages of greatly reducing the difficulty of temperature compensation such as the oven-controlled FABR [7, 8], oven-controlled silicon crystal resonator [9], and oven-controlled quartz crystal oscillator [10]. All of them obtained good performance by full using of merit of oven-controlled technology. In order to take advantage of oven-controlled technology into pressure sensor, Reference [11] had developed an in-chip oven-controlled pressure sensor. However, it is easy affected by the leakage of the vacuum cavity. Reference [12] had also illustrated another oven-controlled pressure sensor. Although it has the characteristics of low error within ±0.5hPa, it is not good enough because the power consumption is relative high about 2.64W. Further work is needed to facilitate the application of the sensor.

For the development of oven-controlled sensor, the stability of sensor is demanded. Among the factors which affect the stability of sensors, mechanical aging will be the most common one. A lot of mechanical aging research focused on the material. In 2000, Michael D. Seale studied the effect of mechanical aging to composite stiffness [13]. And in 2015, Mohammad Hossein Sarfi used aging treatment to prepare experimental material [14]. In 2017, John A. Howarter analyzed the mechanical aging property of Ballistic Fibers [15]. Some mechanical aging research focused on sensor. In 1981, Yasuo Shin applied an USA patent about how to perform the aging treatment for semiconductor gas sensor. All of them illustrated the specifically processes to enhance the performance. When it comes to
the mechanical aging of pressure sensor, there are few specific processes which were depicted. But it doesn’t mean it isn’t important vice versa it is very important so that every company keep it as the key commercial confidential information.

For the purpose of high efficiency and low consumption, the oven-controlled pressure sensor structure was designed and the mechanical aging was studied. The following content would be included in this paper. First of all, the whole sensor will be described. Secondly, the sensor will be simulated with the COMSOL software. Then the performance is tested. Subsequently, the mechanical aging of sensor was studied. The last not least, the sensor is verified by test results.

2. Structure and Simulation

The thermal structure of sensor was designed as that the MEMS chip was directly bonded on the PCB without package which is shown in Fig.1. The platinum resister (Pt 100) is just beneath and sticks closely with the MEMS ship. The heating resistors are located on the center of the print circuit board. Silicon grease filled between platinum resistors and heating resistors. The MEMS Chip was pasted on the PCB. The atmospheric pressure was exerted on the chip through the pipe of metal cap.

![Figure 1. The thermal structure of sensor.](image)

The principle of sensor is shown in Fig.2. The MEMS chip and Heater is electrically connected by microprocessor. By dynamically controlling the heating power the MEMS chip was kept running at the predefined value which was a little higher than the ambient temperature. The dynamically controlling was realized with the PWM module of microprocessor with a PID algorithm.

![Figure 2. Principle of sensor.](image)

The designed structure is simulated in COMSOL and shown in Fig. 3. In the paper, the ambient temperature was -50 °C and the pre-set temperature was 50 °C. The metal cap, part of PCB and surface of silicon gel are set as the interface of heat convection. The parameters of steel, silicon, PCB and silicon gel come from the standard library of COMSOL software.
3. Structure and Simulation
An evaluated sensor is developed as Fig.4.

3.1. Power consumptions
The power consumptions are measured by oscilloscope shown in Fig. 5; and can be calculated by effective voltage and resistance of heater about 5Ω. It is shown in table 1 the maximum power consumption of whole system is about 0.8W. The duty cycle can be got from oscilloscope as well. It is suggested from the experiment data that the system can function well due to the maxim duty cycle just 27.1%; and there are enough driving capability for the circuit to maintain the sensor running in constant temperature 50°C.
Figure 5. Results measured by oscilloscope.

Table 1. The power consumptions experiments data.

| Ambient temperature (℃) | 50 | 40 | 30 | 20 | 10 | 0 | -10 | -20 | -30 | -40 | -50 |
|-------------------------|----|----|----|----|----|---|-----|-----|-----|-----|-----|
| Duty cycle (%)          |    |    |    |    |    |   |     |     |     |     |     |
| Effective voltage (V)   |    |    |    |    |    |   |     |     |     |     |     |
| Power consumption (W)   |    |    |    |    |    |   |     |     |     |     |     |
| 0                       | 0.12 | 0.21 | 0.28 | 0.35 | 0.43 | 0.51 | 0.58 | 0.66 | 0.75 | 0.8 |

3.2. Aging

Six-week mechanical aging experiments are done for enhancing the performance of pressure sensor. During the aging, the pressurization-depressurization cycle was set about 10 minutes. And the sensors were measured once at a 6-day interval. The differences of the original output data between consecutive aging weeks are recorded and shown in Fig. 6. It is illustrated that the difference value of consecutive aging weeks is decreased when the aging time no more than five weeks while increased when the aging time longer than five weeks. It means that the sensor has an optimal aging time. To figure out this time is important for the application of sensor.

Figure 6. Results of Mechanical aging.
3.3. Performance of sensor
The aging sensor was compensated at pre-set temperature and measured when the ambient temperature range from -45°C to 45°C shown in Fig. 7(a) and (b). It is suggested in Fig. 7(b) that the developed sensor has a resolution within ±0.2hPa. Compared the designed sensor with reference [12] in table 2, the present sensor has better performance at resolution and power consumption.

![Graph](attachment:image1.png)  
(a)  
![Graph](attachment:image2.png)  
(b)

Figure 7. Sensor’s behaviour under different temperatures.

| Reference | Full scale | Resolution | Power consumption |
|-----------|------------|------------|-------------------|
| [14]      | 400~1100hPa | ±0.5hPa    | 2.64W             |
| This work | 100~1100hPa | ±0.2hPa    | 0.8W              |

4. Conclusions
In this paper, on the purpose of enhancing the performance of piezoresistive pressure sensor and reducing the difficulty of temperature compensation, the oven-controlled technology and mechanical aging method is studied. It is shown from the aging experiments that the sensor has an optimal aging time. To figure out this time is important for the application for sensor. When the aged sensor chip was controlled at 50°C, it can measure the atmospheric pressure with an error less than ±0.2hPa by just calibrating it at ambient temperature 50°C. Such results manifested that the present sensor has better performance at resolution and power consumption.

5. Acknowledgments
This research was funded by National Natural Science Foundation of China (Grant 61871363) and by Key Project of Beijing Municipal Natural Science Foundation (Grant Z16002).

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