Tungsten for CMOS-MEMS Pirani and Ionization Vacuum Gauges

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ABSTRACT

Tungsten has been traditionally used as a plug material to form via pathways between various metal layers and the silicon substrate in CMOS process. However, it is seldom used in MEMS due to its difficulties in fabrication. To some extent, tungsten is consider to be the most suitable material for the CMOS-MEMS vacuum gauges, including Pirani vacuum gauge and ionization vacuum gauge, due to its high temperature coefficient, resistant to the electromigration failure, high melting point, thermionic emission and CMOS compatible. This paper introduces the tungsten application in CMOS-MEMS Pirani and ionization vacuum gauges. For the Pirani gauge, the tungsten microhotplate is employed as the sensory component. For the ionization gauge, the tungsten microhotbridge is adopted as the cathode, grid and anode, respectively.

Keywords: vacuum gauge, pirani gauge, thermal ionization gauge, MEMS, CMOS

1 INTRODUCTION

Due to the rapid advancement in MEMS technology in the past several years, the most common vacuum measuring principles have been successfully applied for the micro vacuum sensors, some of which are implmented in the standard CMOS process. Among them, the Pirani gauge is used to measure the vacuum from 10^5Pa to 10^{-1}Pa and the ionization gauge is applied for the vacuum below 10^{-1}Pa [1,2]. For the Pirani gauge, the most common materials for the heating resistor is among the metals, including platinum, aluminum and tungsten [3-5]. For the ionization gauge, the tungsten is usually adopted as the cathode materials due to its high melting point and thermionic emission. In this paper, the Pirani gauge and the ionization gauge would be implemented on a chip with the standard CMOS process, so the material should be compatible for the Pirani gauge and the ionization gauge both. According to our previous research, the tungsten microhotplate can be adopted as the sensory component in the CMOS-MEMS Pirani gauge [6]. The tungsten microhotbridge can be used as the cathode for the ionization gauge. Thus, the tungsten can be used as the heating resistor for the Pirani gauge and the cathode for the ionization gauge with the CMOS and MEMS manufacture process.

2 THE CMOS-MEMS PIRANI VACUUM GAUGE

The Pirani pressure gauge is a thermal-conductivity-type vacuum sensor. Its operation principle is based on the fact that the heat loss of a hotplate to its ambient through gas conduction is proportional to the molecular density of gas in a vacuum system. The basic structure of Pirani gauge is shown in Figure 1.

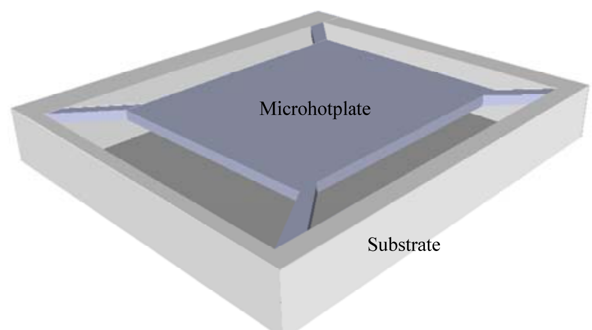

Figure 1: The structure of the Pirani gauge.

2.1 Fabrication of Pirani Gauge

In our design, the tungsten microhotplate is fabricated in 0.5μm CMOS process with two polysilicon layers (Poly1 and Poly2) and three metal layers (Metal1, Metal2 and Metal3). The metal plug between Metal1 and Metal2 is tungsten, and the one between Metal2 and Metal3 is aluminum. For tungsten microhotplate, tungsten is employed as the heater in the form of serpentine resistor instead of via plug in the standard CMOS process [7]. The anchors of the tungsten resistor are connected to Metal2, leaving the Metal1 unconnected. The 0.34μm thick Poly2 is used as a sacrificial layer below the tungsten microhotplate. The etch-windows of the tungsten microhotplate are opened during the bonding pad patterning in a standard CMOS process, as shown in Figure. 2(a).

Figure. 2(b) illustrates that the etch-windows and the bonding pads are etched simultaneously during the bonding pad etching process until the Poly2 is exposed. At last, in Figure .2(c), the Poly2 is removed to suspend the tungsten microhotplate by the improved TMAH etching method which doesn’t etch the exposed aluminum pads. Before starting the process, the new aluminum layer is sputtered at

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the backside of the die to prevent etching from the backside. About 8 hours are required to remove the sacrificial layer in TMAH.

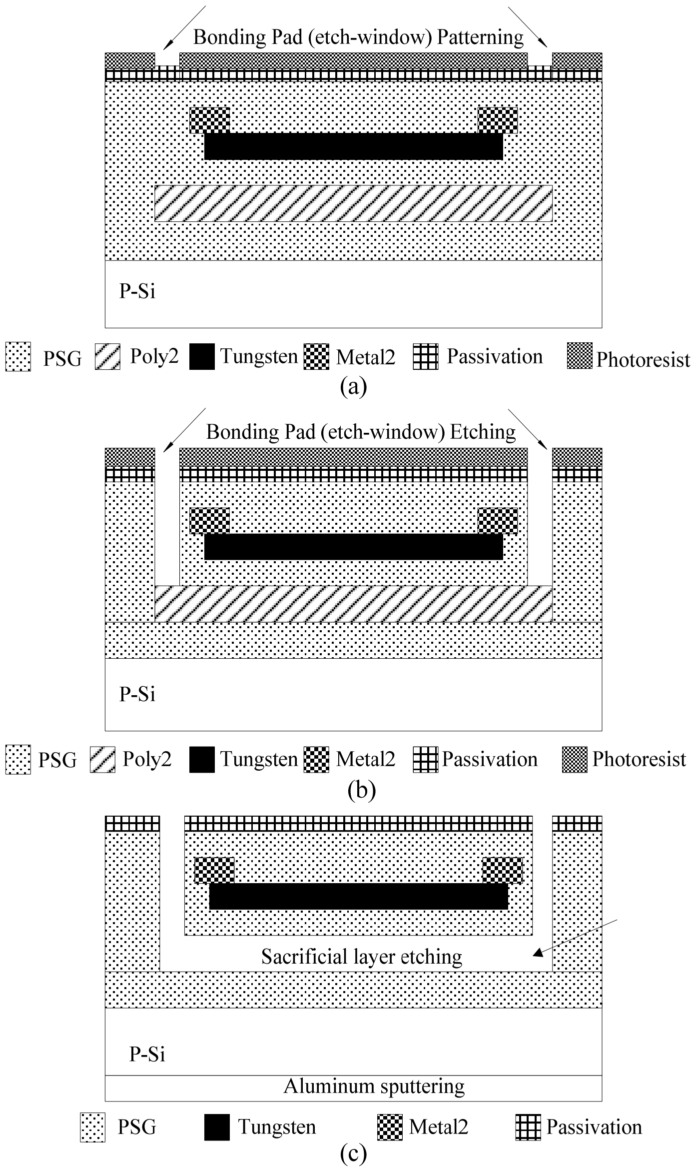


Figure 2: Schematic of cross sections for the tungsten microhotplate fabrication process. (a) the serpentine tungsten resistor implementing and the etch-windows opening. (b) the etch-window etching. (c) the tungsten microhotplate suspending.

Figure 3 shows the optical microscopy picture of the tungsten microhotplate. The tungsten microhotplate with a square area of 60µm × 60µm is suspended by four beams which have a length of 30µm and a width of 15µm. The thickness of the microhotplate is about 4µm. The width of the tungsten resistor is 0.8µm. The suspended gap between the tungsten microhotplate and the substrate is 0.34µm which is the thickness of Poly2.

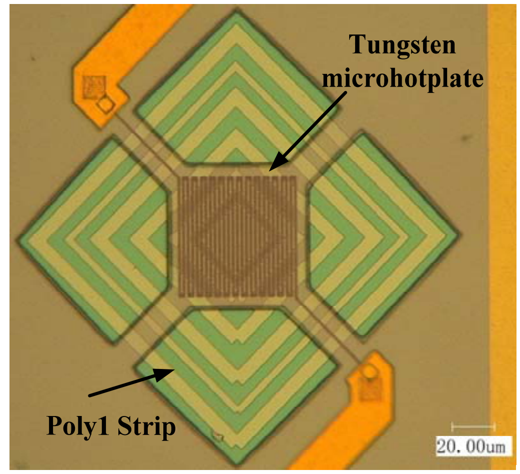


Figure 3: The optical microscopy picture of the Pirani gauge.

2.2 Measurement of Pirani Gauge

The Pirani gauge is fixed in the cylindrical vacuum chamber and the bias current through the microhotplate is 3.85mA. The temperature in the chamber is 30.3℃ measured by the PT100 temperature resistor. The measurement procedure is divided into two steps. First, the gas pressure is decreased from atmosphere to 0.1Pa. Second, when the gas pressure of the vacuum system is below 1Pa, the pump is isolated, then the gas slowly bleeds into the chamber to the desired pressure, and the real-time output voltage of the circuit is recorded with a personal computer using the A/D card.

The measurement results show that the Pirani gauge has a response to the gas pressure ranging from 10^{-1}Pa to 10^{5}Pa, seen in Figure. 4. A good linearity is obtained from 10^{-1}Pa to 100Pa.

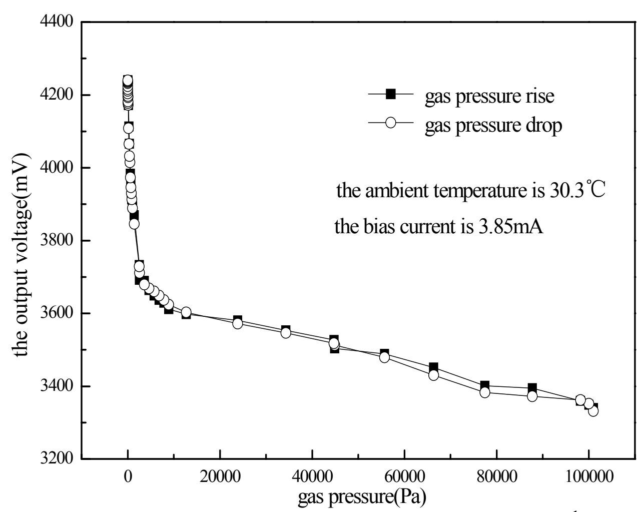
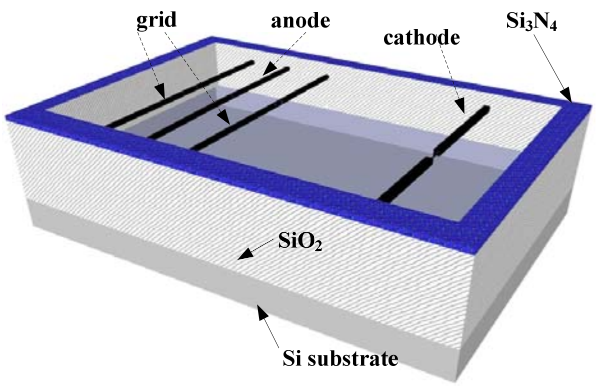


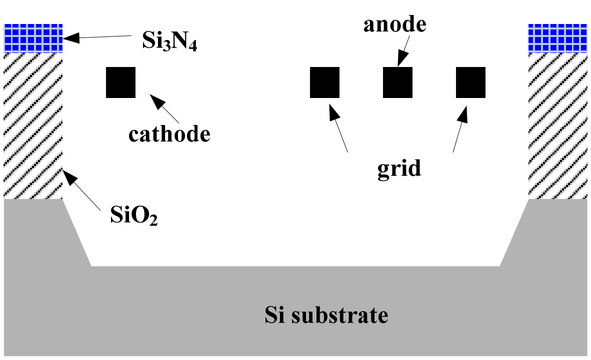
Figure 4: The response of the Pirani gauge from 10^{-1}Pa to 10^{5}Pa.

3 THE CMOS-MEMS IONIZATION GAUGE

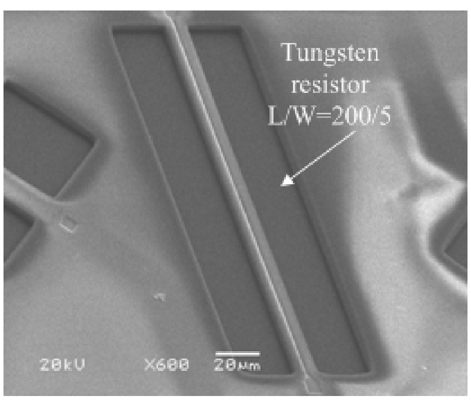
The ionization vacuum gauge is introduced to measure high vacuum, below 10^{-1}Pa. It consists of the cathode, grid and anode. The ion current of anode is proportional to the gas pressure. The cathode materials of the gauge include the tungsten, the nanotube and SiC p-n Junction which all can easily emit electron [8-10]. Among them, the tungsten can be fabricated by the CMOS process. In our design with the CMOS process, the tungsten microbridge is employed as the cathode, grid and anode, respectively, as shown in Figure 5.



(a)



(b)



(c)

Figure 5: The structure of the ionization vacuum gauge.

3.1 Fabrication of Ionization Gauge

With the Post-CMOS etching process to remove the silicon oxide around and the substrate silicon below the microbrige, the tungsten microbridge is exposed to form the cathode, grid and anode, respectively, as shown in Figure 6. The ionization vacuum gauge is designed to response from 1Pa to 10^{-3}Pa.

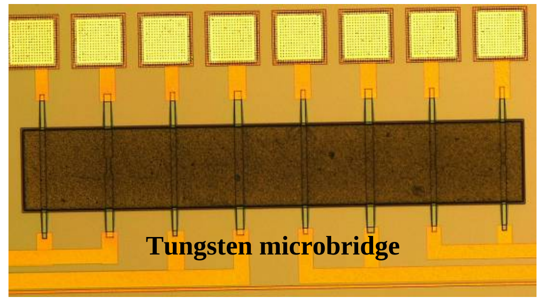


Figure 6: The optical microscopy picture of the ionization vacuum gauge.

4 CONCLUSIONS

Due to the rapid advancement in CMOS-MEMS technology in the past several years, the most common pressure measuring principles have been successfully applied in miniaturized vacuum gauges. The critical materials for the gauge can effect the performance and the manufacturing difficulties.

In this paper, with the adoption of tungsten, it is possible to fabricate the Pirani gauge and the ionization gauge on a chip in the CMOS process. For the Pirani gauge, the tungsten microhotplate is employed as the sensory component. For the ionization gauge, the tungsten microhotbridge is adopted as the cathode, grid and anode, respectively. It will be more convenient for the rough, medium and high vacuum measurement (from 10^5Pa to 10^{-3}Pa) in a chip. What is more, due to the good thermal performance, the tungsten can be applied to other CMOS-MEMS thermal-based sensors to replace the polysilicon or other thermal resistor materials.

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