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Micromachining and Its Application for Pressure Sensors

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Micro-diaphragm pressure sensors with Si_3N_4 diaphragm were fabricated by applying micromachining. The main feature is that it is a planar type sensor formed by single-side processing. The diaphragms and the referencial chambers are formed by undercut-etching of sacrificial layers between the diaphragms and silicon substrates. A micro-diaphragm of 40 μm x 40μm pressure sensor (type-I) was fabricated. However, the pressure sensitivity and the yield for diaphragm forming are still lower. Type-II was fabricated to improve the above problems. The pressure sensitivity is obtained approximately 630 μV/V for a pressure range of 100 kPa, also the yield in diaphragm etching is gained. The advantage is its suitability for development of integrated sensors.

1. INTRODUCTION

Recently, micromachining which utilizes anisotropic etching of single-crystal silicon and forming of thin films are expected to contribute to the development of new functional devices for sensors and actuators[1-3]. This paper reports micro-diaphragm pressure sensors with Si_3N_4 diaphragm less than 100 um, fabricated by applying the micromachining. This conception eliminates cumbersome both-side alignment steps which are necessary to align the resistor patterns with respect to the backsid-etched diaphragm as the conventional silicon pressure sensors. The main feature is that the pressure sensors are planar type sensor with the diaphragm formed by single-side processing solely on the top surface of the silicon wafer. Therefore, compatibility between sensor process and IC process is greatly improved. Also, the silicon pressure sensors have their diaphragms reduced to micron size, lowering the manufacturing cost to a large extent. In this paper, conception and improvement for the micro-diaphragm pressure senor, and the experimental results will be described.

2. CONCEPTION FOR MICRO-DIAPHRAGM

Figure 1 shows conception for the micro-diaphragm processing[4]. The substrate is (100) plane silicon. A diaphragm and a cavity as the reference pressure chamber are formed by undercut-etching of the interface between the diaphragm and the silicon substrate. The sacrificial layer is formed as the etch-channel in the interface between the diaphragm and substrate. Silicon nitride (Si_3N_4) layer is deposited on the sacrificial layer. The undercut is made by anisotropic etching using alkali etchant through the etch -hole opened in the Si_3N_4 layer to remove the sacrificial layer and the silicon substrate. After the entire sacrificial layer is removed, the undercut-etching of the substrate is automatically stopped to give the shape corresponding to the shape of disappeared the sacrificial layer. Therefore, the micro-diaphragm is fomed, with precisely pyramidal shaped cavity, having walls of four (111) planes, and a referential pressure chamber is hollowed out.

Figure 2 shows the undercut-etching characteristics for various sacrificial layers, thermal SiO_2, CVD-SiO_2, PSG and polysilicon. Each sacrificial layer is formed 200 nm thick. When the polysilicon sacrificial layer is utilized, the undercut-etch rate becomes about 100 times as high as in the case of the thermal SiO_2. We have chosen the polysilicon as the sacrificial layer for processing the micro-diaphragm.

3. TYPE-I MICRO-DIAPHRAGM PRESSURE SENSOR

Figure 3 shows a schematic drawing of the type-I micro-diaphragm pressure sensor structure[5]. A square micro-diaphragm of 40 µm x 40 µm is made of Si_3N_4 thin film on the silicon substrate. A pyramidal cavity as the referential vacuum chamber is formed just under the micro-diaphragm by anisotropic etching. The etching is carried out through the etch-holes at the diaphragm corners or edges. The etch-holes are sealed by plasma CVD process after the etching. The polysilicon piezoresistors are formed in the Si_3N_4 micro-diaphragm. Figure 4 shows a photomicrograph of the type-I micro-diaphragm pressure sensor having 40 µm square and 1.4 µm thick Si_3N_4 diaphragm. the 8 µm diameter etch-holes are clearly discernible around the diaphragm. The pressure sensitivity of approximately 200 µV/V is obtained for pressure of 100 kPa. A nonlinearity of less than 1 % of the full scale is obtained.

The micro-diaphragm pressure sensor, like a planar device, can be formed only by single-side processing. Thus the micronization of pressure sensor has been materialized.

However, the pressure sensitivity is still lower than that of the ideal. Also, there are yield losses in diaphragm etching process because of breaking by genaration of bubbles inside the cavity. To improve the above problems, the type-II pressure sensor has been developed in the following.

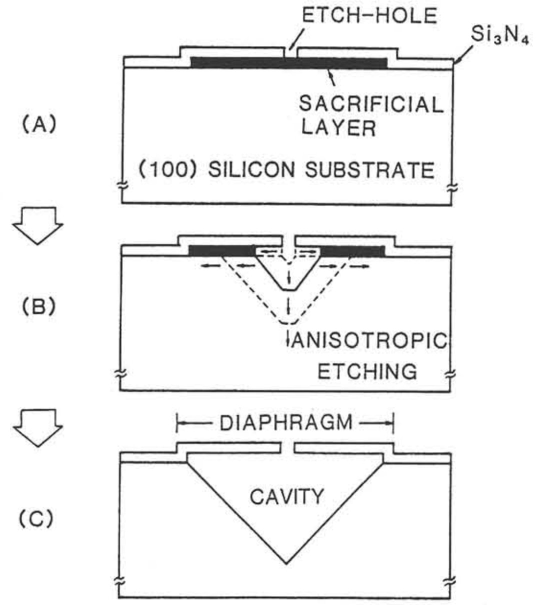

Fig.1 Conception for micro-diaphragm processing.

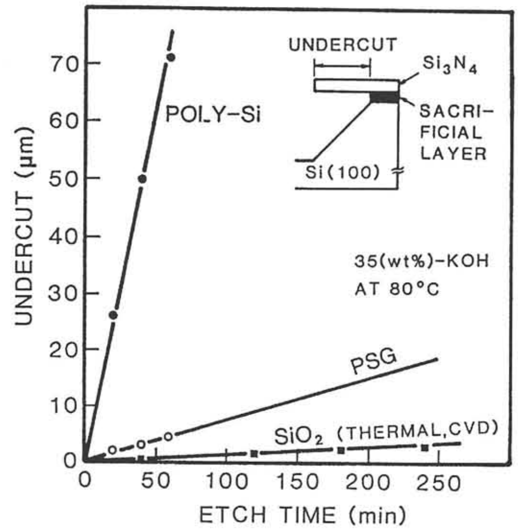

Fig.2 Undercut-etching characteristics for various sacrificial layers.

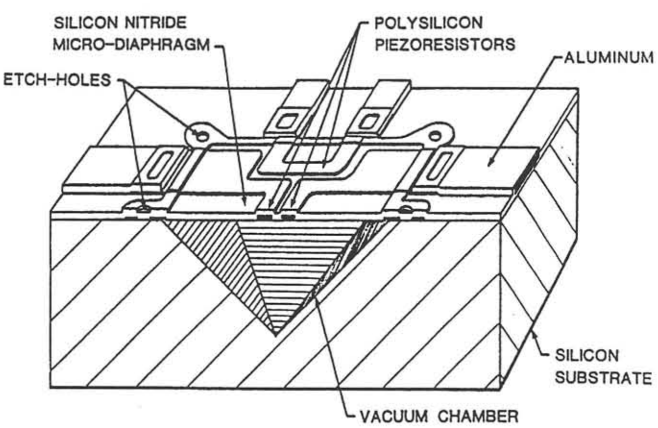

Fig.3 Schematic drawing of the micro-diaphragm pressure sensor structure (type-I).

4. TYPE-II MICRO-DIAPHRAGM PRESSURE SENSOR

Figure 5 shows a cross section of the type-II pressure sensor. The micro-diaphragm pressure sensor is formed by single-side processing. The reference pressure chamber is formed by undercut-etching of the sacrificial layer between the Si_3N_4 diaphragm and the silicon substrate. The center of the diaphragm is supported with a small pillar on the silicon substrate. Figure 6 shows the stress distribution of the x-direction on the micro-diaphragm, simulated with finite element modelling (NASTRAN). Four polysilicon piezoresistors are effectively arranged to gain much resistance change and to form a full bridge on a small area of the diaphragm. Figure 7 shows a photomicrograph of the type-II micro-diaphragm pressure sensor. An 80 μm x 80 μm square-shaped polysilicon sacrificial layer of 200 nm thick is fomed by LPCVD. The polysilicon piezoresistors are implanted boron ion with a dose of 10^{16} cm^{-2} at 30 keV. A 300 nm thick LPCVD-Si_3N_4 is deposited to protect the polysilicon piezoresistors from alkali etchant. The polysilicon sacrificial layer is removed through the etch-holes by using a KOH solution, thereby forming the movebale diaphragm and the cavity as the referential pressure chamber. Finally, on top of these layers, 1 μm thick Si_3N_4 is deposited to seal the etch-holes by plasma CVD. Approximately 1.6 μm of total silicon nitride diaphragm is formed during these process steps.

The pressure sensor is a complete planar type sensor. The yield in diaphragm etching process is gained because of improvement of the sensor structure.

Figure 8 shows the resistance change of the individual piezoresistors of the type-II micro-diaphragm pressure sensor as a function of pressure. As a result the pressure sensitivity is obtaned approximately 630 μV/V with respect to a pressure of 100 kPa. A non-linearity of less than 1 % of the full scale

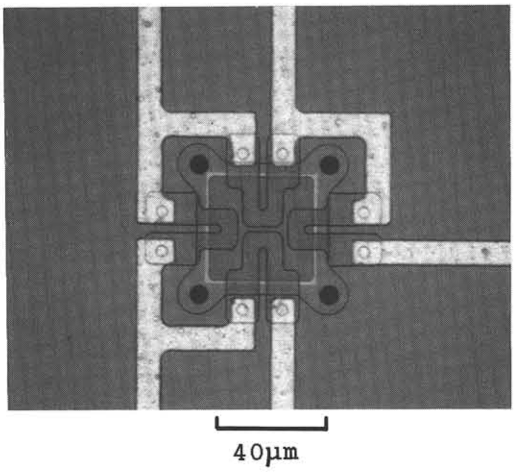

Fig.4 Photomicrograph of the micro-diaphragm pressure sensor (type-I).

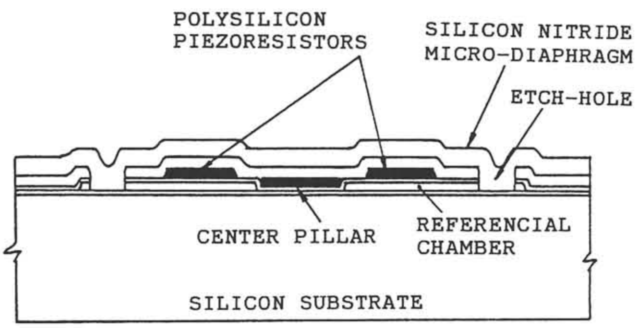

Fig.5 Cross section of the micro-diaphragm pressure sensor (type-II).

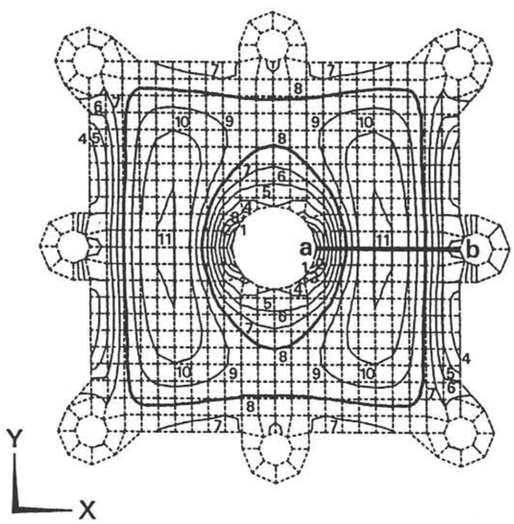

Fig.6 Stress distribution of x-direction on the micro-diaphragm (type-II).

is obtained. Figure 9 shows the temperature characteristics of the pressure sensitivity. The temperature coefficient of the sensitivity is approximately -0.2 %/°C. This is similar to that of general silicon pressure sensor and acceptable value for many applications[6]. The polysilicon piezoresistors are coated with the laminated Si_3N_4. This enables the stable operation of the micro-diaphragm pressure sensor up to a high-temperature range.

5. CONCLUSION

Micro-diaphragm pressure sensors having Si_3N_4 thin diaphragm have been developed. The main feature is that it is a complete planar type pressure sensor formed by single-side processing solely on the top surface of silicon wafer. Compatibility between sensor process and IC process is greatly improved. It is possible the reduction of diaphragm size and lowering of manufacturing cost. Also, it can be widely applied for smart sensors, multiple sensors, sensor arrays and etc..

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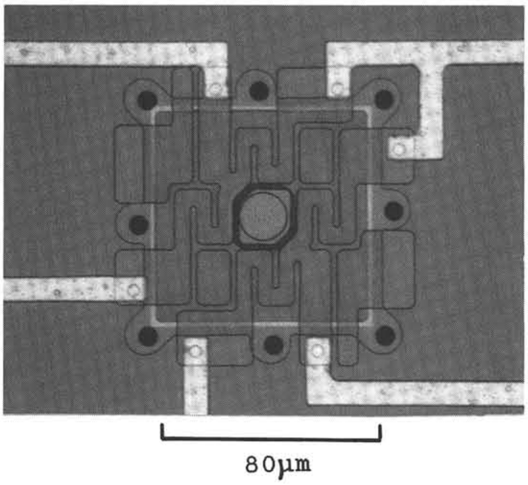

Fig.7 Photomicrograph of the micro-diaphragm pressure sensor (type-II).

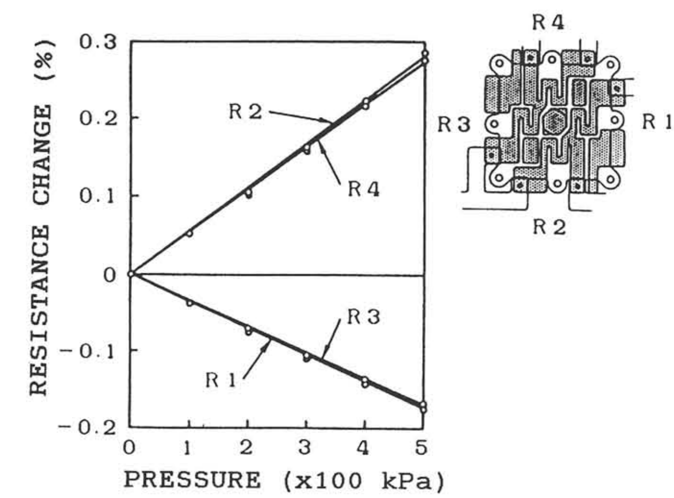

Fig.8 Resistance changes of piezoresistors of the micro-diaphragm pressure sensor (type-II).

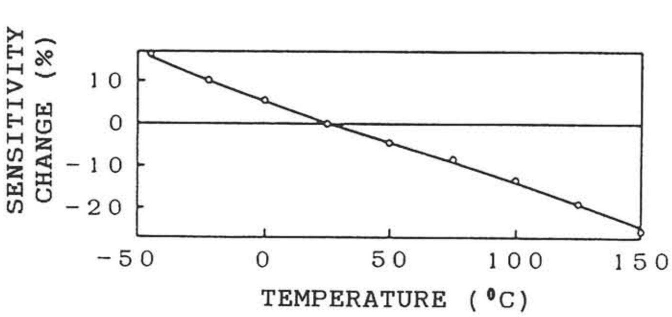

Fig.9 Temperature characteristics of the pressure sensitivity (type-II).