Fabrication of Micromachined Ceramic Thin-Film Pressure Sensors for High Overpressure Tolerance

GWIY-SANG CHUNG

School of Information System Engineering, Dongseo University,
San 69-1, Churye-Dong, Sasang-Ku, Busan 617-16 Korea
phone: +81-51-320-1763, fax: +81-51-328-2526, e-mail: gschung@dongseo.ac.kr

This paper reports on the fabrication process and characteristics of a ceramic thin-film pressure sensor based on Ta-N strain-gauges for harsh environment applications. The Ta-N thin-film strain-gauges are sputter-deposited on a thermally oxidized micromachined Si diaphragms with buried cavities for overpressure tolerance. The proposed device takes advantage of the good mechanical properties of single-crystalline Si as a diaphragm fabricated by SDB and electrochemical etch-stop technology, and in order to extend the temperature range, it has relatively higher resistance, stability and gauge factor of Ta-N thin-films more than other gauges. The fabricated pressure sensor presents a low temperature coefficient of resistance, high-sensitivity, low non-linearity and excellent temperature stability. The sensitivity is 1.21~ 1.097 mV/V·kgf/㎠ in temperature ranges of 25~ 200℃ and a maximum non-linearity is 0.43 %FS.

1. Introduction

Pressure sensors necessarily demand high-performance, resolution, reliability, sensitivity and accuracy. Especially in industries, the sensors are required to be tiny, light, and cheap enough to be able to measure the pressure and the load even under harsh circumstances of high temperature, pressure, humidity, and severe vibration[1]. Conventional pressure and load sensors based on strain gauges are fabricated into a simple structure by a batch process and can be used under harsh circumstances of high temperature and high pressure. However, such devices exhibit low sensitivity, low resolution, and poor reliability and stability due to creep and hysteresis. In addition, it is difficult for miniaturization, integration, multi-function, and mass production with such devices[2].

Recently, the semiconductor pressure sensors have been fabricated by micromachining technology. It is characterized high reliability, small dimensions, and the possibility of mass production, and high sensitivity due to their high resistance and high gauge factor. However, owing to the leaking current in the pn junction, the semiconductor pressure sensors cannot be used in temperature ranges over 120℃ [3]. In order to develop a high temperature semiconductor type pressure sensors based on dielectric isolation method rather than pn junction isolation method, the SOI(Si-on-Insulator) and SOS(Si-on-Sapphire) substrates are currently being used, but they have a high cost and hardness of batch process[4]. To overcome the shortcomings of semiconductor type, pressure sensors for harsh environments require alternative materials such as metallic alloys or ceramics. Pure metals such as Mn, and alloys, Au-Ni, Ni-Cr, Bi-Sb, Cu-Ni and CrN being used as materials of the metal thin-film strain-gauge[5-11], but they have low sensitivity and difficulty of miniaturization because of low gauge factor and it is difficult to form thin-film diaphragms because of inaccurate mechanical grinding of stainless steel. On the other hand, sputter-deposited Ta-N have been known as an attractive class of materials because of their high chemical and mechanical stability and conductivity[12].

The aim of this work is to describe the fabrication process and characteristics of thin-film pressure sensors based on Ta-N strain-gauges for harsh environment applications. The Ta-N thin-film strain gauges are sputter-deposited on a thermally oxidized Si diaphragm with buried cavities for overpressure protectors. It is confirmed that this device has the good mechanical properties of single-crystalline Si as diaphragms fabricated by SDB and electro-chemical etch-stop method, and in order to extend the temperature range, it maintained relatively the high resistance, stability and gauge factor of Ta-N thin-films.

2. Experimental Procedure

Fabrication process consequences of a thin-film pressure sensor are indicated in Fig. 1. A ceramic thin-film type pressure sensor is composed of a Si diaphragm, thin-film strain-gauges and electrode. A Si diaphragm of pressure sensor was fabricated by using SDB(Si-wafer direct bonding) SOI structures with good mechanical properties to accurate membrane thickness control. Also, thinning and accurate membrane thickness control of SOI structures is very important because a SOI active layer is used as a diaphragm of pressure sensors. Electrochemical etch-stop is the most reliable thickness control from among membrane thickness control method. Also it can be controlled some dozens of Å of the final obtained surface roughness and thickness within 0.2 ㎛[13].

In this work, we have fabricated the SDB SOI substrate with buried cavities(850 $㎛^2$ width and 8 ㎛ depth). As well, a 25 ㎛ thickness Si diaphragm is fabricated by using electrochemical etch-stop method at 20 wt.%, 80℃ in TMAH solution. Right after fabricating the SDB SOI structures, 3000Å thickness Ta-N thin-film strain-gauges are realized by R.F. magnetron sputtering on the oxidized micromachined Si diaphragm. The film is patterned in a Wheatstone bridge configuration using lift-off technology. 2000Å thick Al and Au metallization layers are deposited by D.C. magnetron sputtering and patterned covering the interconnections. Finally, the Si substrate with the sensing parts is bonded to the glass substrate by anodic bonding (DC: 1000 V, 450℃) technology and then TO-5 packaged to complete the pressure sensor.

Fig. 2(a) and (b) show a cross-sectional and top views of the micromachined ceramic thin-film pressure sensor. Sensing parts considered shape and position of strain-gauges to obtain high sensitivity and they are designed on the 30×100 $㎛^2$ size, 250 Ω resistance. Also deposition and annealing conditions have been chosen as the optimum condition in order to improve the piezoresistive properties of the sensing parts. Table. 1 shows the deposition and annealing conditions of Ta-N thin-films.

3. Results and Discussion

Electrical and mechanical characteristics such as a TCR, non-linearity, and hysteresis, TCS, sensitivity were analyzed. Fig. 3 shows exemplary plots of the output voltage of the metal thin-film pressure sensor as a function of the applied pressure in temperature ranges of 25℃ to 200℃. The output voltage of the fabricated sensor is nearly constant even at a high temperature up to 200℃. In regard to the temperature characteristic, the Ta-N thin-film strain-gauges on a dielectric-separated sensing parts has a temperature coefficient of resistance (TCR) ranging from -207 ppm/℃ to -222 ppm/℃ at a temperature below 200℃. Therefore, proposed ceramic thin-film type pressure sensor is more excellent temperature characteristics than Si piezoresistive pressure sensors.

Fig. 4 depicts the non-linearity and hysteresis characteristics of the ceramic thin-film pressure sensor as a function of an applied pressure. The non-linearity has a high value of 0.21 %FS. Also, hysteresis has a lower value of 0.43 %FS than load cell using thick-film strain- gauges[14].

Fig. 5 shows the exemplary plots of the sensitivity and the temperature coefficient of sensitivity (TCS) of the ceramic thin-film type pressure sensor as a function of temperature. The sensitivity is 1.21 mV/V·kgf/cm^2 at room temperature and decreases to 1.097 mV/V·kgf/cm^2 against increasing temperature. Nevertheless, the implemented sensor is much more stable in sensitivity than the Si piezoresistive pressure sensors. Also the ceramic thin-film pressure sensor has a TCS of less than 529 ppm/℃ in ranges of temperature up to 200℃ and shows much high-stability to temperature compared with -1300 ppm/℃ of Si piezoresistive pressure sensors[15]. In addition, the long-term stability of the ceramic thin-film pressure sensor at 200℃ is also constant as 43 ppm/hr.

4. Conclusions

This work described the ceramic thin-film pressure sensor, which includes Ta-N thin-film strain-gauges provided on a Si diaphragm as a pressure sensing part, using micromachining and thin-film technologies, and analyzed and evaluated the characteristics of the fabricated sensors. The ceramic thin-film pressure sensor is excellent in both sensitivity and linearity even at high temperature. Also the SDB SOI structure with buried cavities was used as a Si diaphragm for overpressure tolerance to prevent mechanical damage. The ceramic thin-film pressure sensor with SDB SOI structures needed no adhesive materials and it is confirmed having a low creep, high reliability. The output sensitivity amounts to 1.21 to 1.097 mV/V·kgf/cm^2 and the non-linearity is 0.43 %FS in the pressure range of 0 to 2 kgf/cm^2.

Consequently, the ceramic thin-film pressure sensor is expected to be usefully applied for pressure and load sensors that is operable under ultimate conditions, such as high temperature and pressure, and ready for realizing miniaturization, light weight, high performance, low price and integration.

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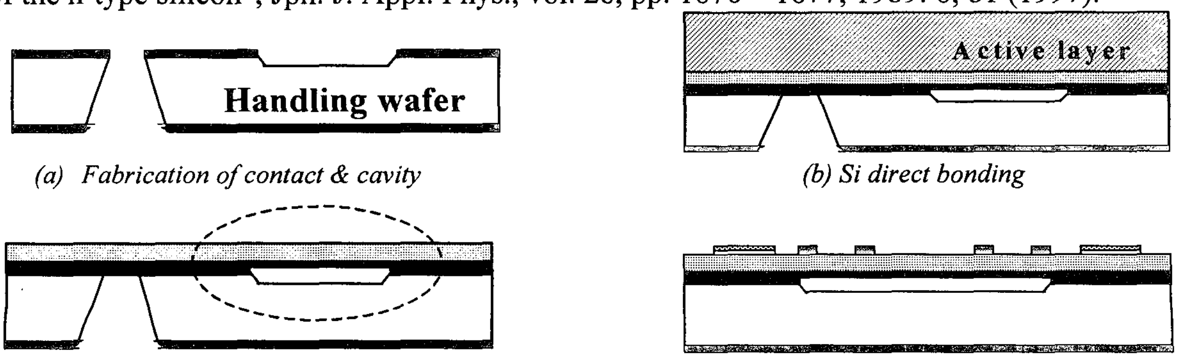
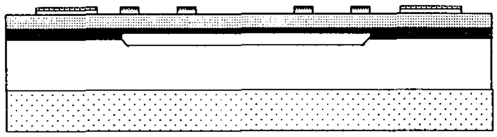


(a) Fabrication of contact & cavity

(b) Si direct bonding

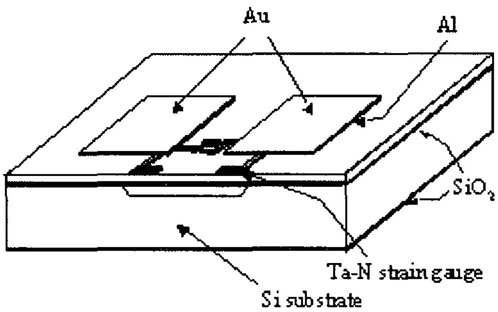
(c) Electrochemical etch-stop(thinning)

(d) Ta-N thin-film formation & metallization

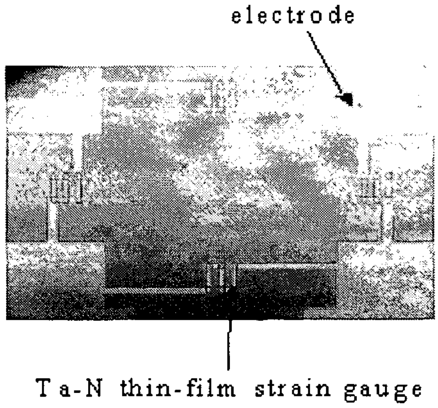


(e) Anodic bonding

Fig. 1. Fabrication process sequences of a micromachined ceramic thin-film pressure sensor for high overpressure



(a)



(b)

Fig. 2. (a) Cross-sectional and (b) top views of fabricated a ceramic thin- film pressure sensor, respectively.

Table 1. *Deposition and annealing conditions of Ta-N thin-films*

Parameter	Deposition conditions
Target	Ta 4" diameter
DC Power	310 V, 100 mA
Substrate	Si
Target-substrate distance	8 cm
Working gas	Ar : 19 sccm N2 : 0.8 ~ 3.6 sccm
N2 gas flow ratio	4, 6, 8, 10, 12, 16 %
Substrate temperature	Room Temp.(27℃)
Working pressure	4.3 mTorr
Annealing conditions	500 ~ 1000℃, 1 hr. 2 × 10-6 Torr

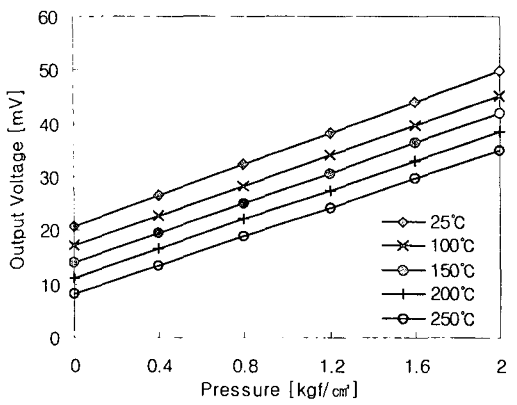


Fig. 3. Temperature characteristics of fabricated the ceramic thin-film pressure sensors as a function of an applied pressure.

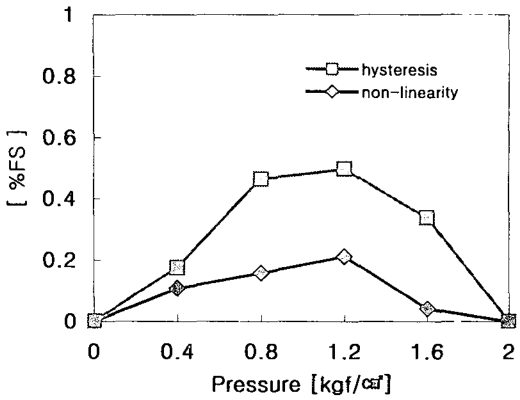


Fig. 4. Non-linearity and hysteresis characteristics of fabricated thin-film pressure sensors

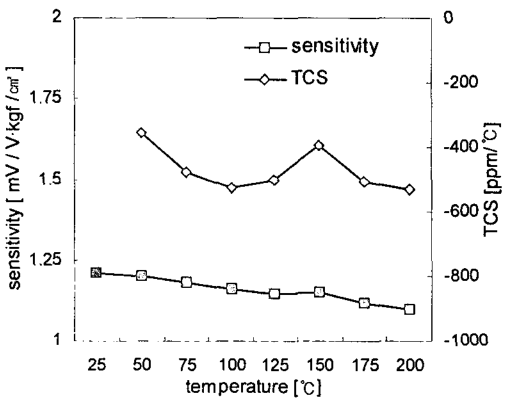


Fig. 5. Sensitivity and TCS characteristics of fabricated the thin-film pressure sensors as a function of a temperature.