ABSTRACT
This paper presents a piezoresistive pressure sensor to enhance sensitivity using silicon nanowire. According to published paper, silicon nanowire under width or thickness of 340 nm has good piezoresistive effect. Silicon nanowire of 140 x 200 nm² size has seven times more piezoresistive effect than bulk silicon. This paper proposes the piezoresistive pressure sensor using the high piezoresistive effect of the silicon nanowire. The nanowire is fabricated to be connected like a bridge between the bossed silicon diaphragm and the edge of the silicon substrate. The fabricated piezoresistive pressure sensor has high sensitivity of 337.5 mV/V·MPa and dynamic range of 150 kPa ~ 300 kPa. The pressure sensor size is less than 1 mm² using diaphragm of 200 x 200 μm².

KEYWORDS
Silicon nanowire, Piezoresistive, Pressure sensor

INTRODUCTION
There are many applications for the MEMS pressure sensor in automobile, military, biomedicine, and aerospace areas [1]. The MEMS pressure sensors are categorized into piezoresistive and capacitive type according to measurement way [2]. Piezoresistive type pressure sensors perceive resistance change and capacitive pressure sensors sense capacitance variation under the applied pressure. Especially, piezoresistive pressure sensors have mainly been studied and commercialized because of high yield and wide dynamic range. However, the piezoresistive pressure sensor suffers from the low sensitivity and large size as compare with the capacitive pressure sensor. Many of the piezoresistive pressure sensors studies are trying to improve their low sensitivity using various materials such as high doped silicon and porous silicon [3]. In this paper, the piezoresistive pressure sensor with silicon nanowire is proposed to enhance the sensitivity and decrease the size due to its high piezoresistive effect.

DESIGN
According to the published paper, silicon nanowire under width or thickness of 340 nm has good piezoresistive effect [4]. Particularly, silicon nanowire of 140 x 200 nm² size has seven times more piezoresistive effect than bulk silicon. To enhance the sensitivity and decrease the chip size, the proposed piezoresistive pressure sensor uses the silicon nanowires of high piezoresistive effect.
To get the high sensitivity, nanowires position and size of the proposed pressure sensor should be determined. To decide structure, we used ANSYS simulation. According to simulation result, the silicon nanowires are located to receive the maximum stress when pressure applies on the diaphragm. After arrangement of nanowires, structures of the Fig. 1 are simulated. Fig. 3 shows maximum stress as function of piezoresistive pressure sensor designs such as diaphragm size, membrane thickness and release height.

Figure 3: Ansys simulation results (a) Max. stress vs. membrane size (b) Max. stress vs. membrane thickness (c) Max. stress vs. release height

However, to obtain high maximum stress should take account of a yield issue. So, considering the stress simulation, fabrication safety limit and published piezoresistive effect of nanowire, the proposed piezoresistive pressure sensor was designed to have the nanowire size under 300 x 300 μm², the diaphragm size of 200 x 200 μm², the membrane thickness of 20 μm, and the release height of 12 μm.

FABRICATION

The proposed piezoresistive pressure sensor was fabricated using N-type (100) silicon wafer. Boron ions of 10^{19} Dose/cm³ were implanted on the front of the silicon for the piezoresistance of the silicon nanowire. This is followed by the silicon nitride (SiN) of 200 nm deposition using low pressure chemical vapor deposition (LPCVD). For the silicon wire pattern and electrical isolation, SiN was patterned and the silicon substrate was etched by deep reactive ion etching (DRIE). To fabricate metal pad, after etching the SiN, 1.2 μm thick Aluminum was deposited onto the silicon contact. TEOS (Tetra Ethyl Ortho silicate) of 200 nm deposited on the silicon sidewalls using TEOS deposition and etch method. Silicon wires were released using follow TMAH wet etch after DRIE. Backside of silicon substrate was etched by 363 K TMAH to get diaphragm less than 20 μm thickness. TEOS of front was removed using 49 % HF. Silicon wires were etched by 348 K TMAH to make the silicon nanowires under 300 x 300 nm². Finally, SiN was removed using CF4 gas.

Figure 4: Illustration of the piezoresistive pressure sensor (a) Silicon nitride patterning & Silicon dry etch (b) Al metal deposition and patterning (c) TEOS deposition and etch
(d) Silicon dry etch and wet etch to release silicon wire 
(e) Backside wet etch using TMAH 
(f) Silicon wet etch to get silicon nanowire & Silicon nitride removal

Fig. 5: SEM image (a) piezoresistive pressure sensor using silicon nanowire (b) fabricated silicon nanowire

Fig. 5 (a) shows that fabricated piezoresistive pressure sensor using silicon nanowire and Fig. 5 (b) shows the silicon nanowire of 250 x 250 nm² cross area and 8 μm length.

RESULT

The fabricated piezoresistive pressure sensor was measured using SUSS pressure sensor measurement system. Pressure on the diaphragm was applied by air flow nozzle of the equipment. We measured electrical signal during increasing by 50 kPa. Applied pressure change the resistance of silicon nanowires. And two probes of the measurement equipment are located on separate Al pad. Across the probes, current of 1 μA flow. Depend on the changed resistance and fixed current, we get the voltage change using voltage measurement. Fig. 6 shows the result of the measured piezoresistive pressure sensor using silicon nanowires.

As shown in the Fig. 6, the measured range is from 0 to 300 kPa. But the measurement under 150 kPa has nonlinearity. So the fabricated pressure sensor has dynamic range of 150~300 kPa. And the piezoresistive sensor has high sensitivity of 337.5 mV/V·MPa.

Figure 6: Measured voltage as a function of the pressure

\[ \text{Sensitivity} = \frac{(249 \text{ mV} - 237 \text{ mV})/237 \text{ mV}}{150 \text{ kPa}} = 337.5 \text{ mV/V·kPa} \]

To understand that enhanced sensitivity, we compared the fabricated piezoresistive pressure sensor using silicon nanowire with piezoresistive sensor using structures of silicon bridge and bulk silicon. The measurement results are shown in Fig. 7.

The graph shows that measured result of the three piezoresistive pressure sensors. Pressure sensor of silicon bridge has sensitivity of 38.1 mV/V·MPa and bulk silicon pressure sensor has sensitivity of 8.5 mV/V·MPa.
As a result, sensor of the released silicon bridge structure has 4.5 times more sensitivity than one of the bulk silicon. And pressure sensor using silicon nanowire has 8.8 times more sensitivity than silicon bridge pressure sensor. In other words, fabricated piezoresistive pressure sensor enhances the sensitivity due to released piezoresistors and silicon nanowire of high piezoresistive effect.

**CONCLUSION**

The use of the silicon nanowire enables the fabricated pressure sensor to have the enhanced sensitivity and the reduced sensor size. For the pressure sensor using the silicon nanowire of 250x250nm² cross area, the high sensitivity of 337.5 mV/V·MPa was obtained. Pressure sensor of the silicon bridge has sensitivity of 38.1 mV/V·MPa and the bulk silicon pressure of the conventional flat diaphragm sensor has sensitivity of 8.5 mV/V·MPa.

For further researches, piezoresistive pressure sensor using the nanowire under 50x50 nm² size is under fabricated to be much more sensitivity compare to the conventional silicon piezoresistive pressure sensor despite less size than bulk silicon pressure sensor.

**REFERENCES:**


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