Extended Abstracts of the 2016 International Conference on Solid State Devices and Materials, Tsukuba, 2016, pp677-678

Design and characterization of the disk-shaped piezoresistive pressure sensor

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Abstract

This paper presents a disk-shaped piezoresistive pressure sensor fabricated using a 0.18-µm 1P6M CMOS MEMS process. The pressure sensor was designed with a longitudinal topology for fabrication in polysilicon using a standard CMOS process. Piezoresistive sensitivity was simulated using finite element software. In experiments, a normal force between 100 µN and 10 mN was applied using an Agilent G200 Nanoindenter to enable the detection of changes in resistance. The maximum applied normal force was 20mN, which resulted in a displacement of 8.9 µm. The measured sensitivity for n-type and p-type polysilicon piezoresistors were 468.9 Ω/mN and -492.3 Ω/mN, respectively.

1. Introduction

CMOS-MEMS piezoresistive pressure sensors are used in a wide range of applications, such as tactile sensors [1], accelerometers [2], resonators [3-4], and cantilever beam sensors for the detection of biomolecules [5]. CMOS MEMS technology makes it possible to implement a simple design with straight forward electronic signal processing and ease of integration. Most piezoresistive pressure sensors are fabricated in polysilicon using a CMOS process with a topology based on a cantilever, a bridge, or a square membrane.

The piezoresistive pressure sensors presented in this study employ the similar CMOS MEMS process [3] we reported in previous work, which comprise polysilicon with stacked layers of aluminum and oxides. The type of polysilicon is defined during the implement process in CMOS, whereupon the oxide layers are removed anisotropically using reactive ion etching (RIE) with CF_4, CHF_3, and O_2. Isotopic dry etching with SF_6 and O_2 is then performed for the removal of the silicon substrate beneath the device, as shown in Fig.1. The piezoresistive polysilicon layer is fabricated in a shallow trench in the dioxide layer to avoid backside etching during the release of the silicon.

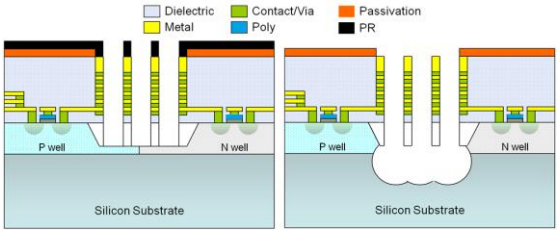


Fig. 1 Anisotropic oxide etching and isotropic silicon etching to the silicon release.

2. Design and Characterization

Finite element analysis software (CoventorWare) was used to simulate the deformation of the pressure sensor and corresponding changes in resistance. The disk-shaped membrane was anchored around the circumference with the center region suspended above the silicon substrate. Normal force was applied in the center of the membrane, and longitudinal piezoresistive sensors were placed as shown in Fig. 2. The simulated longitudinal sensitivity values of n-type and p-type piezoresistors were 187.4 Ω/mN and -205.9 Ω/mN, respectively. When a normal force of 1mN was applied in the center of the sensor, the maximum simulated displacement along the z-axis was 0.717µm with changes in resistance of 187.4 Ω and -205.9 Ω for n-type and p-type piezoresistors, respectively.

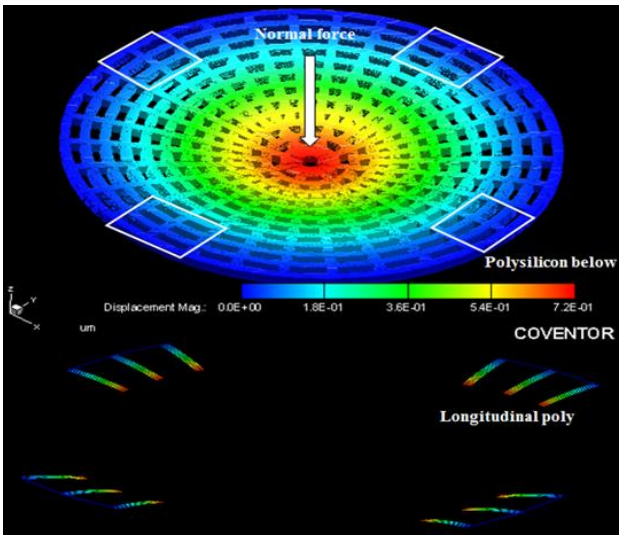


Fig. 2 Structure of disk-shaped membrane rendered using CoventorWare software

Pressure of between 100 µN and 10 mN was applied to the center of the membrane using a nanoindenter, as shown in Fig. 3. When the force is performed on the membrane, the membrane buckles down and elongates the embedding piezoresistive polysilicon layer around the anchor, corresponding to the change in resistance. Fig. 4 presents a scanning electron micrograph (SEM) image of a disk-shaped piezoresistive pressure sensor with a diameter of 500 µm.

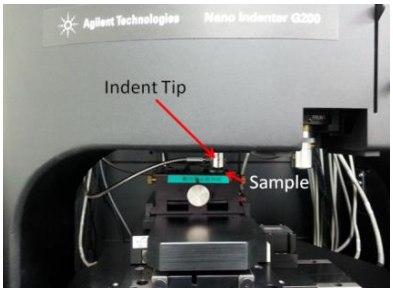


Fig. 3 Agilent Nano Indenter G200 used to apply pressure

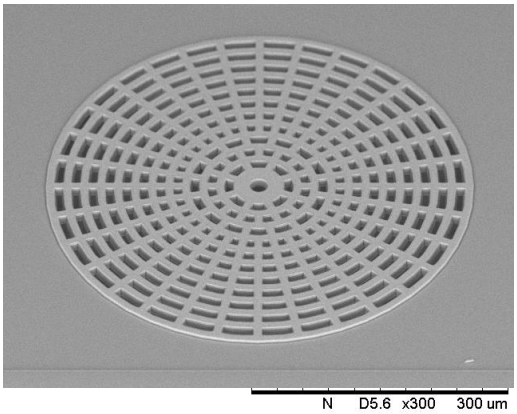


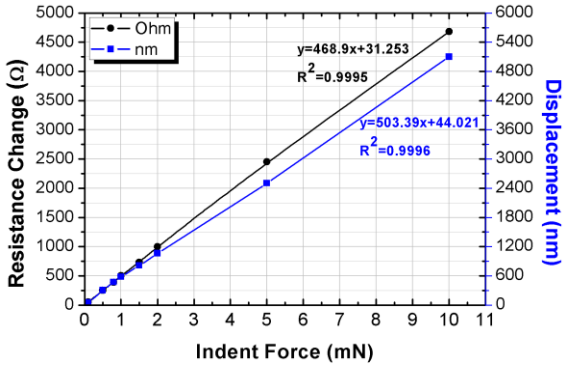
Fig. 4 SEM image of piezoresistive pressure sensor after MEMS post-processing

The initial values of the n-type and p-type polysilicon resistors were 240.94 kΩ and 245.22 kΩ, respectively. The maximum displacement in the center of the membrane was between 54 nm and 5.1μm, corresponding to n-type and p-type piezoresistance of 468.9 Ω/mN and -492.3 Ω/mN, respectively. Figs. 5(a) and 5(b) respectively present changes in resistance and the displacement of the membrane structure in the z-direction relative to indent force.

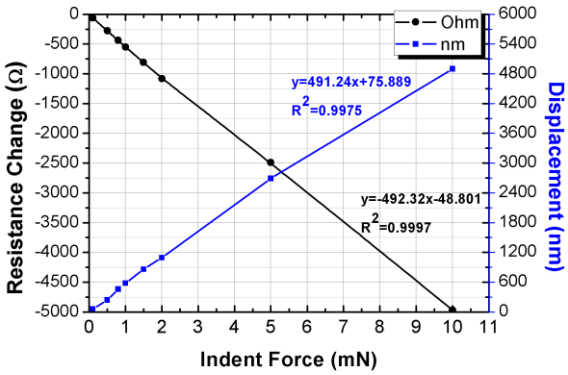
As shown in Fig. 6, when the applied force exceeded 10 mN, the change in sensitivity deviated from its previous linear relationship. This may be due to the force exceeding the elasticity of the device, which resulted in cracking. The maximum displacement in the z-direction in the elastic area was 8.9 μm. Table I compares the simulation results and experiment data obtained from the piezoresistive pressure sensor.

Table I Relationships among indent force, displacement, and changes in resistance: simulation and measurement results

Indent Force	Displacement		Changes in Resistance	
	Simulated	Measured	Simulated	Measured
100μN	72.07nm	57nm	51.396Ω	50Ω
1mN	0.717μm	0.578μm	511.28Ω	500Ω
10mN	6.386μm	5.004μm	4.471kΩ	4.68kΩ



(a)



(b)

Fig. 5 Measured changes in resistance and displacement vs. indent force: (a) n-type polysilicon resistor; (b) p-type polysilicon resistor

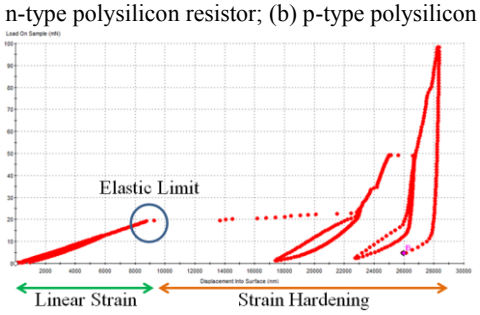


Fig. 6 Measured indent force vs. displacement

3. Conclusions

This paper proposes a piezoresistive pressure sensor using n-type and p-type polysilicon layers fabricated using a CMOS MEMS process. The topology of the membrane used in the piezoresistive sensor could be applied in tactile sensors or pressure sensors.

References

[1] Lomas, T., Tuantranont, A., and Wisitsoraat, A., *Sensors* (2006) 1313.

[2] Haris, Mohd, and Hongwei Qu., *Nano/Micro Engineered and Molecular Systems (NEMS)* (2010) 309.

[3] S.-H. Tseng, M. S.-C. Lu, Y.-J. Huang, Y.-Z. Juang, Eurosensors, Austria, **5** (2010) 1360.

[4] Chiou, J. C., Y. J. Lin, and L. J. Shieh., *Nanotechnology*. **2** (2006) 929.

[5] Chaurasia, Saloni, and B. S., Chaurasia. *Engineering and Systems (SCES),* (2013) 1.