A COMPARITIVE ANALYSIS ON NANOWIRE BASED MEMS PRESSURE SENSOR

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Abstract

This paper compares a MEMS Piezoresistive pressure sensor which utilizes a circular and square shaped polysilicon diaphragm with a nanowire to enhance the sensitivity of the pressure sensor. The nanowires for both the sensors form the bridge between the diaphragm assembly. The high Piezoresistive effect of polysilicon nanowires is used to enhance the sensitivity. The circular and square shaped polysilicon diaphragm with nanowire which are like piezoresistor were fabricated by means of RIE(reactive ion etching). This paper describes the performance analysis, structural design and fabrication of piezoresistive pressure sensor using simulation technique. The polysilicon nanowire has a thickness about 10nm. Finite element method is adopted to optimize the sensor output and to improve the sensitivity of both the circular and square shaped polysilicon diaphragm with nanowire to form Piezoresistive pressure sensor. The best position to place the Polysilicon nanowires to receive maximum stress was also considered during the design process. It was found that the fabricated square polysilicon diaphragm with nanowire has the highest sensitivity of about 156mV/VKPa were as the circular polysilicon pressure sensor gave a sensitivity of about 133 mV/VKPa.

Keywords**:** MEMS; Pressure sensor; nanowire; polysilicon; square diaphragm; circular diaphragm.

1. Introduction

The emerging area of Microelectromechanical systems has originated from IC processing which are small, integrated devices, which combines electronics, electrical as well as mechanical element on a single chip[Zhang *et al.* (2005)]. The combination of microelectronics and mechanical components make MEMS more versatile than the other conventional sensors. The silicon based pressure sensor is one of the major applications of the piezoresistive sensor. Nowadays, silicon piezoresistive pressure sensor is a matured technology in industry and its measurement accuracy is more rigorous in many advanced applications [Zhou *et al.*(2005)]. Silicon based sensors are becoming popular because of the compactness reliability and stability. Silicon is mostly the preferred material for most of the sensors because of its good mechanical and electrical properties. The discovery of piezoresitive effect lead to the wide application of silicon based Piezoresistive pressure sensors. The Piezoresistive pressure sensor uses the deformation of the diaphragm, on which the piezoresitive strain sensors are built as the sensing principle. A giant piezoresistance of 3550e-11Pa-1 has been reported in a self assembled silicon nanowires, by reducing the dimension to about less than 350nm [Jordana and Areny (2006)]. It was found that the silicon nanowire when made to about 340nm has a good piezoresistive effect. It was proposed that silicon nanowires has got seven times the piezoresistive effect than the bulk silicon [Lin *et al.* (1999)].

In this paper, a circular shaped diaphragm with nanowire polysilicon piezoresistive pressure sensor is compared with the square diaphragm with nanowire polysilicon piezoresistive pressure sensor [Maflin and Vimala (2011)]. The finite element analysis demonstrates a promising result for the prediction of sensor performance for both circular and square shaped diaphragm. For the optimum design of sensor sensitivity, the FEA is adopted for the sensor performance design. The design parameters of the pressure sensor includes a nanowire for peizoresistors, nanowire arrangement pattern and nanowire location. The change in resistance, the output voltage and the diaphragm displacement of both circular and square shaped sensors were compared.

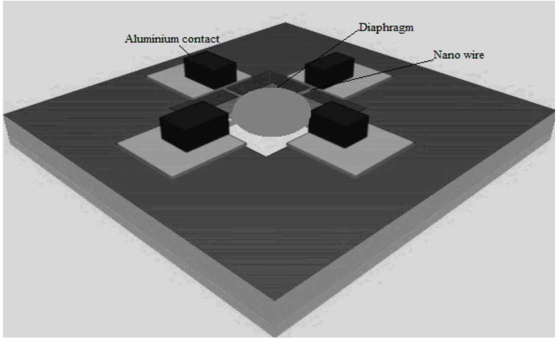

Fig. 1. Piezoresistive pressure sensor using circular polysilicon diaphragm with nanowire

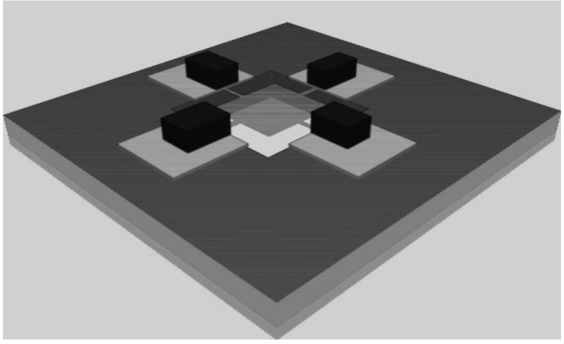

Fig. 2. Piezoresistive pressure sensor using circular polysilicon diaphragm with nanowire

2. Design Consideration and Fabrication

In order to compare the sensitivity of a circular and square shaped diaphragm with a nanowired two piezoresistive pressure sensor was fabricated in the INTELLIFAB module. The wafer substrates was bulk etched using TMAH (tetra methyl ammonium hydroxide). Bulk Silicon Oxide of about 1000nm is deposited. On the layer of SiO2, a thin layer of Poly Silicon is deposited. The film is deposited by a method called Low Pressure Chemical Vapor Deposition (LPCVD).The polysilicon diaphragms were released using reactive ion etching. The proposed pressure sensors had a circular and square diaphragm of approximate area of 1000 nm^2.The thickness of the diaphragm were about 10nm.The polysilicon nanowires were connected across the freely suspended diaphragm and the substrate so as to form a bridge like appearance. Each of the nanowire were 10nm thick, and they were placed in center of the sides of the diaphragm. The nanowires were placed exactly at the center of the sides of the diaphragm because it is reported that maximum stress occurs at the center of the sides of the diaphragm and these are positioned such a way that the nanowires are lying in the high stress area so that maximum Piezoresistive effect can be realized. In order to get high output sensitivity a square and circular shaped polysilicon diaphragm with nanowire piezoresitive pressure sensor is fabricated. Fig 1. shows the schematic of the piezoresistive pressure senor using circular shape diaphragm with polysilicon nanowire and Fig 2. shows the schematic of the piezoresistive pressure senor using square shape polysilicon diaphragm with nanowire. When a pressure was applied on the diaphragms, these silicon nanowires receive maximum stress to change resistance of the silicon nanowire.. Aluminum of 1000nm thickness was deposited to make contact with the nanowires. The metal pads can be used to probe the structure when the fabrication is complete. The metal thickness is chosen to be 2000 A°. After metal deposition, it was patterned using the mask and then the wafers were etched to remove unwanted Aluminum. The aluminum etch is done in a solution composed of: phosphoric acid (80%), nitric acid (5%), $C_2H_4O_2$ (5%) and distilled water. The endpoint for aluminum etches is detected by a rapid change of color on the wafer. The shiny metal look on the wafer is completely taken off. On the aluminium deposited lithographic masking is done, which when exposed UV radiation, helps to etch the aluminium. Lithographic masking is done from the backside of Silicon, and by using RIE process Si substrate along with SiO_2 is etched out. This etching is done to make the diaphragm for the sensor. The diaphragm formed is masked again and the PolySilicon is patterned to make the thin wire like structure that will connect diaphragm with the aluminum metal. After masking, using lithographic process, the polysilicon is etched from outside.

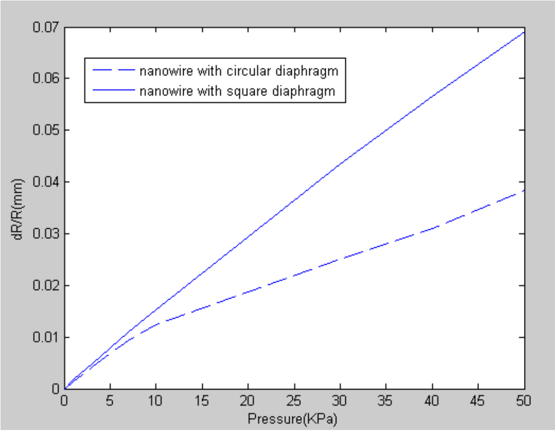

Fig.3. The change in resistance versus pressure of a polysilicon nanowire pressure sensor for circular and square diaphragm

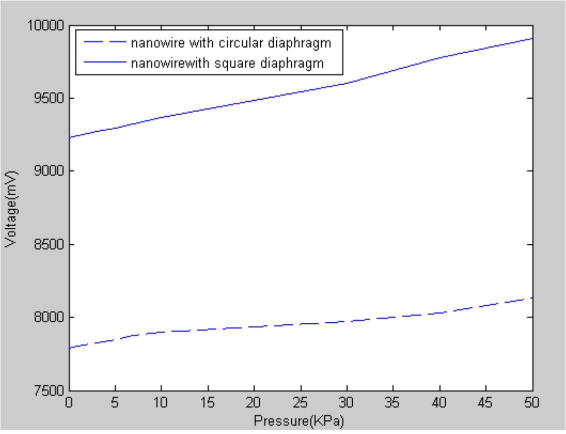

Fig. 4. The output response of a polysilicon nanowire pressure sensor for circular and square diaphragm

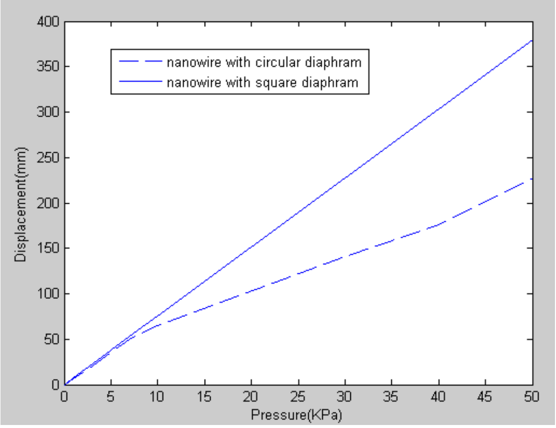

Fig. 5. The displacement versus pressure response of a polysilicon nanowire pressure sensor for circular and square diaphragm

3. Result

The fabricated circular and square shaped polysilicon diaphragm with a nanowire piezoresistive MEMS pressure sensor was tested by applying pressure in the range of 0 to 30 Kilopascal. When a pressure is applied to the diaphragm, the diaphragm of both the circular and square polysilicon diaphragm would deflect. The deflection experienced by the diaphragm assembly causes a change in the resistance of the polysilicon nanowire.The change in resistance causes the wheatstone bridge circuit to experience a imbalance condition as the nanowires are connected as the wheatstone bridge via aluminum contact .Thus the change in resistance of the nanowire assembly constitute a change in output voltage. The sensitivity analyses for a circular and square diaphragm of the polysilicon nanowire pressure sensor were carried out. The bridge is exited by 1V supply voltage. The Fig 3. shows the change in resistance of the bridge with the applied pressure for a circular and square shaped polysilicon diaphragm with polysilicon nanowire.It was seen that the square diaphragm with nanowire assembly have a greater change in resistance than the circular shaped diaphragm. The Fig 4 shows the graph for the sensitivity analysis that is the change in output voltage for an applied pressure for the circular and square shaped diaphragm with nanowire.The output voltage drastically increased for the square diaphragm rather than for circular diaphragm with nanowire. The Fig 5. shows the change in displacement with the applied pressure for the circular and square shaped diaphragm with polysilicon nanowire.The square shaped diaphragm with nanowire showed a greater displacement than a circular diaphragm. Moreover the graphs for circular shaped diaphragm showed nonlinear behavior for higher pressure values.

4. Conclusion

The designing and fabrication of circular and square shaped diaphragm with polysilicon nanowire pressure sensor has enhanced the sensitivity to a great extend. The circular shaped diaphragm with polysilicon pressure sensor of 1000nm diameter and thickness of 10nm has a sensitivity of 133 mV/VKPa were as the square diaphragm of side 100nm and thickness of 10nm has a sensitivity of 156 mV/VKPa.The nanowire assembly replaced the piezoresistor of the conventional pressure sensor. The nanowire itself serve as a piezoresistor giving about seven times the piezoresistive effect more than that of the conventional piezoresistive pressure sensor. It is observed from Fig 3 that the change in resistance of a polysilicon nanowire is greater for square diaphragm rather than the circular diaphragm and it was also observed that the change in resistance is more effective for higher pressure ranges than the lower pressure range for square diaphragm. It is also observed that from Fig 4. the increase in piezoresistive effect was greater for the nanowire polysilicon pressure sensor as the output voltage increases significantly for square diaphragm. It is reported that as the thickness of the diaphragm is reduced there is a increases in sensitivity, but the nonlinearity effect predominates.The circular diaphragm showed nonlinear behavior for higher pressure ranges. As the piezoresistive effect depends on temperature, while we decrease the thickness of the diaphragm the effect of temperature also dominates for both circular and square diaphragm . So it becomes important to design a temperature compensation circuit in the chip. Moreover the piezoresistivity of polysilicon pressure sensor largely depends on the fabrication process. The measurements show that decreasing the thickness of the diaphragm causes a large increase in the sensitivity of the square shaped diaphragm. This enables fabrication of high sensitivity devices where fabrication complies with conventional micro fabrication techniques.

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