OPTIMIZING THE SENSITIVITY OF MEMS PIEZORESISTIVE PRESSURE SENSOR USING POLYSILICON NANOWIRE

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Abstract

The paper describes the fabrication, designing and the performance analysis of a Piezoresistive MEMS pressure sensor. This pressure sensor uses double polysilicon nanowires to increase the sensitivity of the pressure sensor.The pressure sensor uses circular diaphragm which was fabricated using Reactive Ion Etching method. The pressure sensor has a radius of about 500 nm and thickness of about 10 nm. The polysilicon nanowires form a bridge like appearance between the diaphragm and the substrate. Intellisuite software is extensively used to carry out the finite element analysis. Finite element method (FEM) is adopted to optimize the sensor output and to improve the sensitivity of the circular shaped diaphragm polysilicon nano wire Piezoresistive pressure sensor. The optimum position is also analyzed to place the nanowire to get maximum output. The proposed double polysicon nanowire pressure sensor gave a sensitivity of about 440 mV/VK Pa.

Key words: MEMS, Piezoresistive pressure sensor, Nanowire, Circular Polysilicon diaphragm, piezoresistor.

I. INTRODUCTION

The piezoresistive silicon pressure sensor was one of the first micromachined products manufactured. Silicon is the preferred material for making pressure sensors, because it has the well-established electronic properties with added mechanical properties. Other advantages of silicon include drastically reduced dimensions of the product and mass, batch fabrication and easy interfacing. Silicon pressure sensors can be fabricated either using bulk micromachining or surface micromachining. In bulk micromachining, many methods have been developed to fabricate silicon diaphragms. The MEMS technology is been introduced in to the biomedical applications. In biomedical application it offers the potential to realize small and compact devices with sophisticated functionality. Biomedical application areas include diagnostic tools, surgical Instrumentation, artificial organs and drug delivery devices (1). Silicon piezoresistive pressure sensors are also used in various applications, such as automotive aerospace and biomedical engineering. They have the advantages of small size, low power, good performance and mass production for the micro machined process. Design of micro piezoresistive pressure sensor extensively adopts finite element method (FEM) to realize stress distribution prediction, sensitivity enhancement and nonlinear reduction. In recent years substantial research has been carried out on micro machined, diaphragm-type pressure sensors (2)–(6). These sensors are fabricated by means of new manufacturing technologies such as bulk-micromachining (7), (8) or surface-micromachining (9), (10). Many of them use silicon and its piezoresistivity as the detection mechanism. The fundamental concept of piezoresistive effect is the change in receptivity of a material resulting from an applied stress. Silicon is mainly used in semiconductors because it remains as a semiconductor even at a high temperature. The crystalline silicon is an ideal microme chanical material, with young's modulus and hardness compared to those of stainless steel and its density only one third and yield strength three times greater than that of stainless steel. Polysilicon is a very good Piezoresistive material for MEMS sensor because of its higher sensitivity to change in strain than any other metals. But the main disadvantage of the polysilicon is it is highly dependent on temperature variation. Piezoresistive type pressure sensors uses resistance change and capacitive pressure sensors sense capacitance variation under the applied pressure. The Piezoresistive pressure sensor functions when the resistivity of the sensing resistor changes as the diaphragm defects due to applied pressure. In order to increase the sensitivity, the diaphragm thickness should be thin to maximize the load defection responses. On the other hand, thin diaphragm under high pressure may result in large deflection and nonlinear effects that are not desirable. It is therefore important to characterize the relationship between diaphragm thickness, deflection, and linearity, both analytically and experimentally in order to establish the design guidelines for MEMS pressure sensors.

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(11).In this paper, a circular shaped diaphragm with nanowire polysilicon piezoresistive pressure sensor is proposed to enhance the sensitivity

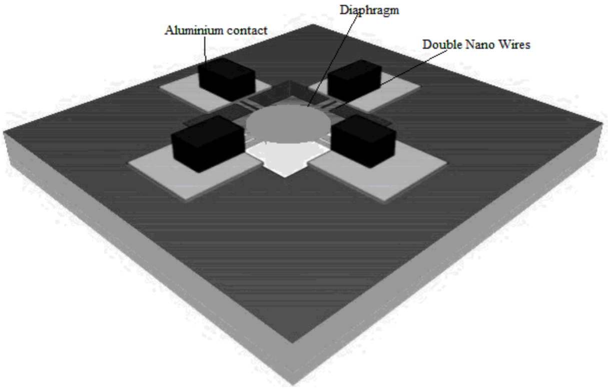


Fig. 1.The Piezoresistive pressure sensor with double nanowire

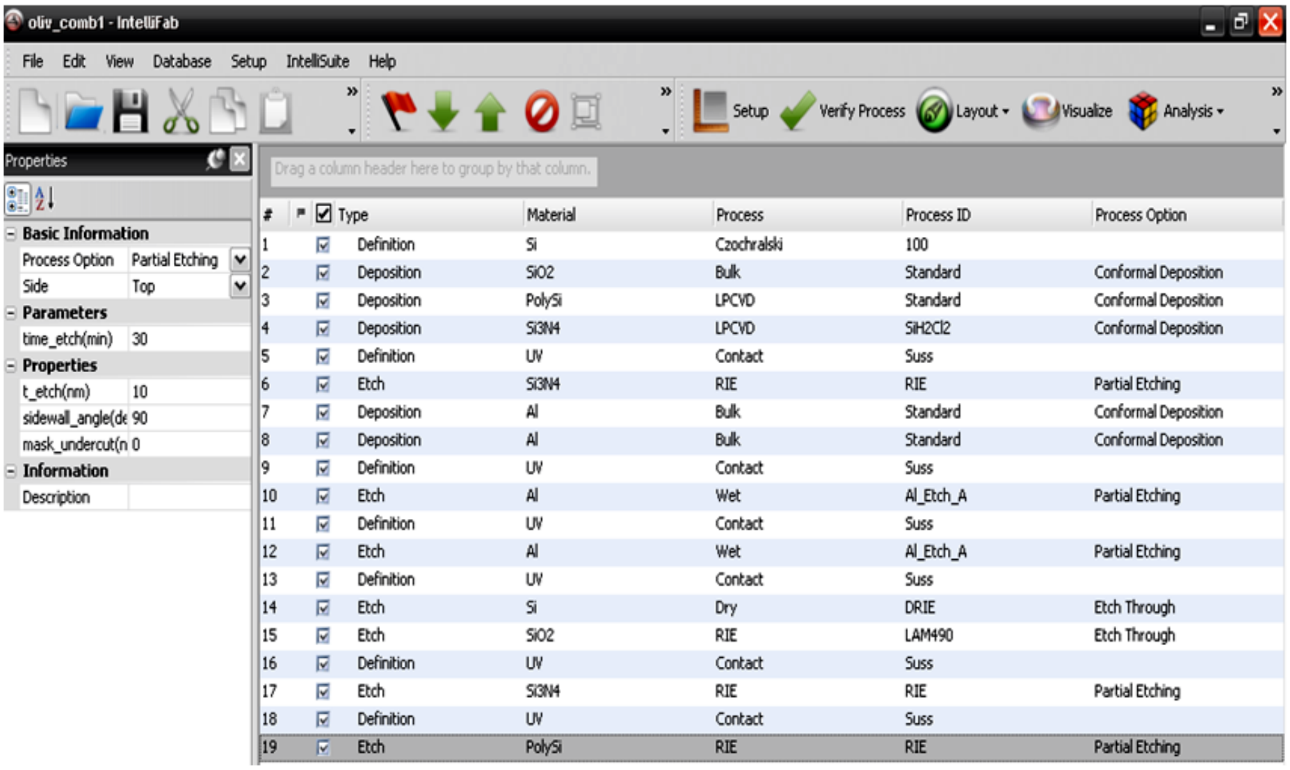
II. DESIGN CONSIDERATION

The pressure sensor was fabricated using reactive iron etching. The designed pressure sensor has a radius of 500nm. The thickness of the diaphragm is about 10nm.the polysilicon nanowires of a pressure sensor is connected as a bridge between the diaphragm and substrate.The fabricated nanowire has a thickness of about 10nm.Each of the nano wires are separated by 10nm spacing between them.These nanowires are placed exactly at the center of the sides of the diaphragm. These nanowires are placed exactly at the center of the sides of the diaphragm because it was found 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. The piezoresistors were replaced by the double nano wire assembly. In a paper that was published it was shown that, silicon nanowire which had the width or thickness of 340nm has good piezoresistive effect (11). Particularly the silicon nanowire of 140 x 200 nm^2 size has reported to have seven times more Piezoresistive effect than bulk silicon. In order to get high output sensitivity a circular shaped diaphragm with double nano wire polysilicon piezoresitive pressure sensor is fabricated. Figure 1 shows the schematic of the piezoresistive pressure senor using double polysilicon nanowire. The silicon nanowires of high piezoresistive effect which are exactly placed at the center of the sides of the diaphragm are respectively connected like a bridge between the silicon diaphragm and the edge of the silicon substrate. When a pressure is applied on the diaphragm, these silicon nanowires receive maximum stress to change resistance of the silicon nanowire.

III. FABRICATION

The pressure sensor is fabricated in the INTELLIFAB module. The wafers substrate, on which the device has to be fabricated, need to be bulk etched using TMAH (tetra methyl ammonium hydroxide). Bulk Silicon Oxide of about 1000nm is deposited over the bare silicon wafer.

On the layer of SiO_2, a thin layer of Polysilicon is deposited. The thickness of the polysilicon is about 10nm.The film is deposited by a method called Low Pressure Chemical Vapor Deposition (LPCVD). A nitride film of 200nm is deposited on the silicon wafers to act as an insulating. Silicon nitride is highly suitable for this purpose because it behaves as a nearly impervious barrier to diffusion. The film is deposited by a method called Low Pressure Chemical Vapor Deposition (LPCVD).Because a nitride film has been deposited on the wafers and the fact that oxide can be grown thermally only at the silicon oxide interface, it is difficult to thermally grow oxide on these wafers. Hence nitride deposited should be etched. Before etching the whole substrate has to undergo a process called “lithographic process”. Lithography is a process of imprinting a geometric pattern from a mask onto a thin layer of material called resist, which is a radiation sensitive material. The mask layout is shown in the figure 3. Then from the pattern formed, Si_3N_4 is etched from inside. This etching is done using RIE method. Aluminum of 1000 nm thickness was deposited to make contact with the diffused resistors. 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:



Basic Information

Process Option	Partial Etching
Side	Top

Parameters

time_etch(min)	30

Properties

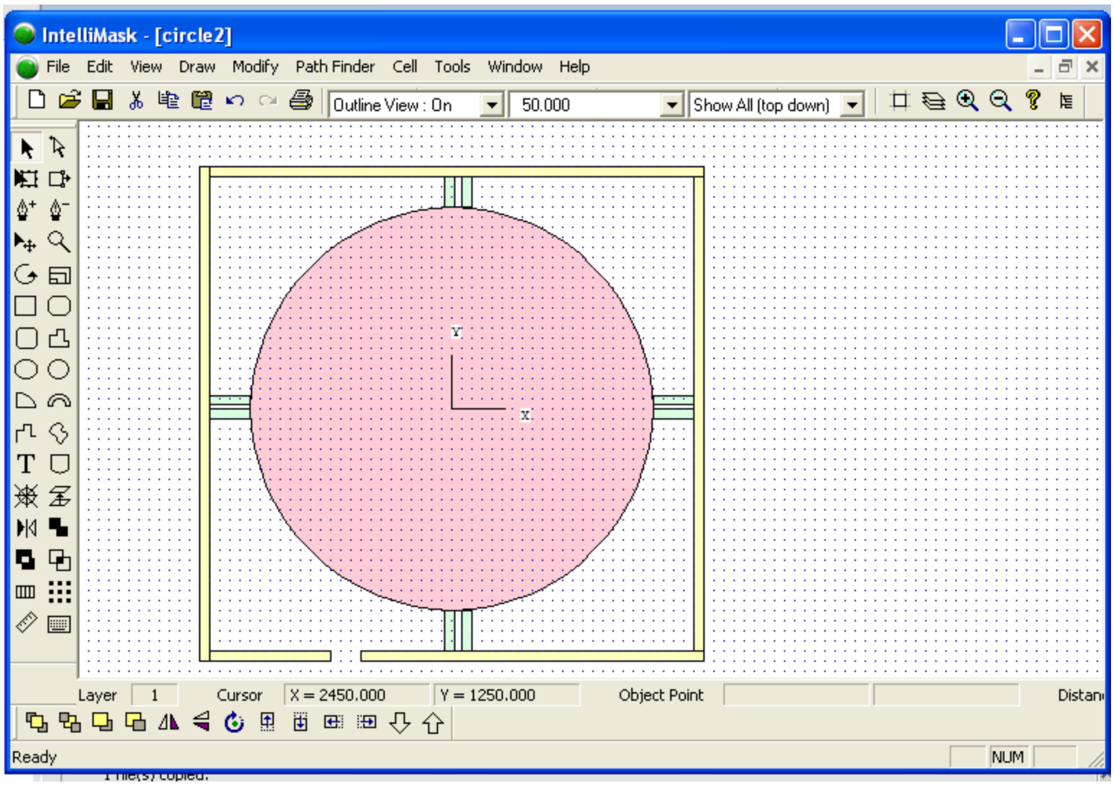
t_etch(nm)	10
sidewall_angle(de	90
mask_undercut(n	0

Information

Description	

#	☑ Type	Material	Process	Process ID	Process Option
1	☑ Definition	Si	Czochralski	100	
2	☑ Deposition	SiO2	Bulk	Standard	Conformal Deposition
3	☑ Deposition	PolySi	LPCVD	Standard	Conformal Deposition
4	☑ Deposition	Si3N4	LPCVD	SiH2Cl2	Conformal Deposition
5	☑ Definition	UV	Contact	Suss	
6	☑ Etch	Si3N4	RIE	RIE	Partial Etching
7	☑ Deposition	Al	Bulk	Standard	Conformal Deposition
8	☑ Deposition	Al	Bulk	Standard	Conformal Deposition
9	☑ Definition	UV	Contact	Suss	
10	☑ Etch	Al	Wet	Al_Etch_A	Partial Etching
11	☑ Definition	UV	Contact	Suss	
12	☑ Etch	Al	Wet	Al_Etch_A	Partial Etching
13	☑ Definition	UV	Contact	Suss	
14	☑ Etch	Si	Dry	DRIE	Etch Through
15	☑ Etch	SiO2	RIE	LAM490	Etch Through
16	☑ Definition	UV	Contact	Suss	
17	☑ Etch	Si3N4	RIE	RIE	Partial Etching
18	☑ Definition	UV	Contact	Suss	
19	☑ Etch	PolySi	RIE	RIE	Partial Etching

Fig. 2. The process table for fabrication of the pressure sensor



Outline View : On

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Layer 1

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Ready

Fig. 3. The mask layout in intellisuite

phosphoric acid (80%), nitric acid (5%), $C_2H_4O_2$ (5%) and distilled water. On the aluminum deposited lithographic masking is done, which when exposed UV radiation, helps to etch the aluminum. 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. The fabrication results in a double nanowire Piezoresistive pressure sensor as shown in figure 1.

IV. RESULT

The fabricated circular shaped diaphragm with a double polysilicon nanowire pressure sensor was tested by applying pressure in the range of 0 to 30 Kilopascal. When a pressure is applied to the diaphragm, the resistance of the polysilicon nanowire changes .The change in resistance causes a change in output voltage. The sensitivity analysis of the double polysilicon nanowire pressure sensor was carried out. The bridge is exited by 1V supply voltage. The figure 4. shows the change in resistance of the bridge with the applied pressure for a circular shaped diaphragm double nanowire polysilicon pressure sensor. The figure 5 shows the graph for the sensitivity analysis that is the change in output voltage for an applied pressure for the circular shaped diaphragm with double nanowire. The figure 6. shows the change in displacement with the applied pressure for the circular shaped diaphragm with double nanowire .

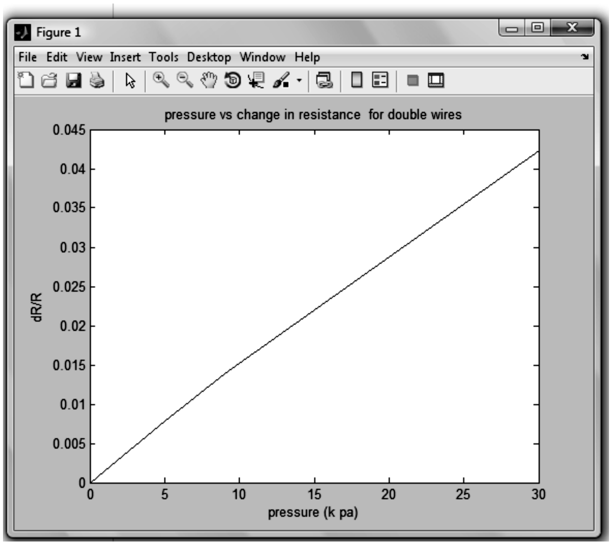

Fig. 4. The change resistance versus pressure of a polysilicon nanowire pressure sensor

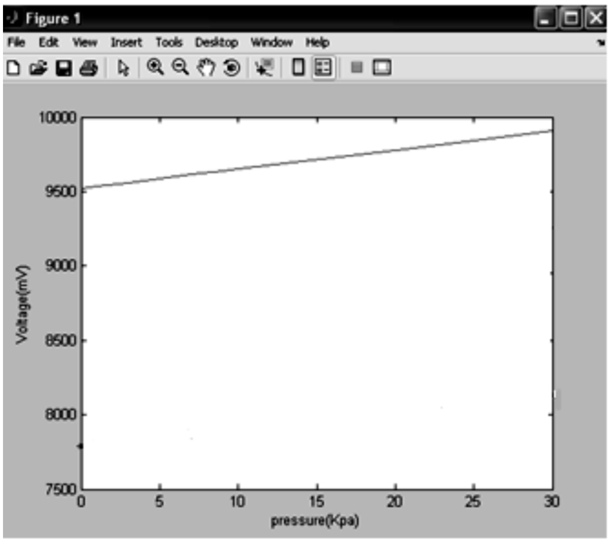

Fig. 5. The output response of a polysilicon nanowire pressure sensor

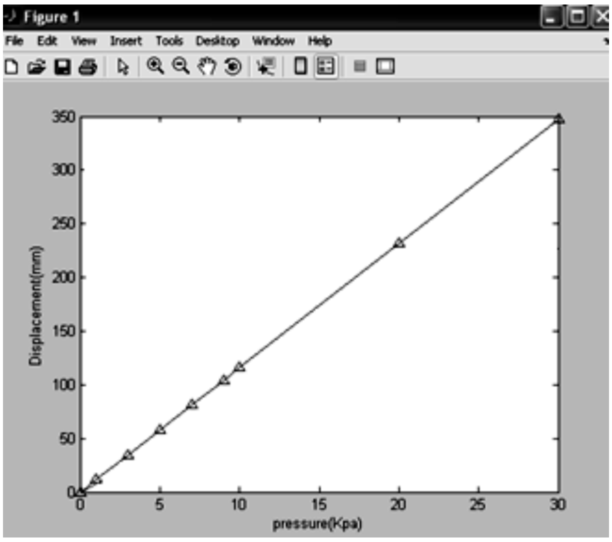

Fig. 6. The displacement versus pressure response of a polysilicon nanowire pressure sensor

V. CONCLUSION

The fabricated circular shaped diaphragm with double polysilicon pressure sensor of 1000nm diameter and thickness of 10nm has enhanced the sensitivity to

440 mV/V.KPa. It was shown in the published paper an increase in the piezoresistive effect has been observed in nanowires as large as $480 \times 340\ nm^2$ (11). It is observed from figure 4 that the change in resistance is more effective for higher pressure ranges than the lower pressure range. It is observed that from figure 5. the increase in piezoresistive effect was observed for the double nanowire polysilicon pressure sensor as the output voltage increases significantly. It is reported that as the thickness of the diaphragm is reduced there is a increases in sensitivity, but the nonlinearity effect predominates.So in order for a proper design of a pressure sensor, consideration has to be made on the diaphragm thickness. As the piezoresistive effect depends on temperature, while we decrease the thickness of the diaphragm the effect of temperature also dominates. So it becomes important to design a temperature compensation circuit in the chip. Even though there is an increase in piezoresistive effect brought about by polysilicon, the piezoresistive effect due to crystalline silicon is incomparable. Moreover the piezoresistivity of polysilicon pressure sensor largely depends on the fabrication process. The measurements show that decreasing the thickness of causes the diaphragm causes a large increase in the sensitivity of piezoresistors. This enables fabrication of high sensitivity devices where fabrication complies with conventional micro fabrication techniques.

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