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Improving the Sensitivity of MEMS Piezoresistive Pressure Sensor using Polysilicon Double Nanowire

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ABSTRACT

The paper describes the performance analysis, structural design and fabrication of piezoresistive pressure sensor using simulation technique. A polysilicon double nano-wire piezoresistor was fabricated by means of RIE (reactive ion etching). The polysilicon double nanowire pressure sensor has 100x100nm^2 cross section area and has a thickness about 10nm. Finite element method (FEM) is adopted to optimize the sensor output and to improve the sensitivity of the polysilicon nano wire Piezoresistive pressure sensor The double polysilicon nanowire is fabricated in such a way that it forms a bridge between the polysilicon diaphragm and the substrate. The proposed double nano wire polysilicon pressure sensor is compared with single nano wire polysilicon pressure sensor and bulk silicon pressure sensor. The fabricated polysilicon nanowire has high sensitivity of about 160 mV/V.KPa.

General Terms

MEMS, Piezoresistive pressure sensor.

Keywords

Piezoresistive pressure sensor,Nano wire,substrate.

1. INTRODUCTION

Silicon piezoresistive pressure sensors are used in various engineering applications [1]. They have the advantages of used in most of the commercial application because of its small size, low power, good performance and mass production. Now a day, silicon piezoresistive pressure sensor is a matured technology in industry and its measurement accuracy is more rigorous in many advanced applications [2]. The fundamental concept of piezoresistive effect is the change in receptivity of a material resulting from an applied stress and it is commonly used in pressure sensors[3-4].Silicon is mainly used in semiconductors because it remains as a semiconductor even at a high temperature[5].The crystalline silicon is an ideal micromechanical 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[6].Polysilicon is a very good Piezoresistive material for MEMS sensor because of its higher sensitivity to change in strain than any other metals[7-8].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 [9]. When comparing the piezoresistive pressure sensors with the capacitive sensors, the Piezoresistive pressure sensor have high sensitivity, low yield and high cost due to the complex fabrication process [10]. Capacitive pressure sensors are favoured for low-power ,since they draw no DC power.On the other hand, it is difficult to use post-end circuits to compensate the low linearity of capacitive pressure sensors [11]. In contrast, it can be easier to improve the low sensitivity of piezoresistive pressure sensors by integrating the amplifying circuits [12].It was found that the silicon nanowire when made to about 340nm has a good piezoresistive effect [13]. It was proposed that silicon nanowires has got seven times the piezoresistive effect than the bulk silicon [14].In this paper, a double nano wire polysilicon piezoresistive pressure sensor is proposed to improve the sensitivity [15].The diaphragm size is decrease to get a high piezoresistive effect [16].Its output is been compared with the single wire polysilicon Piezoresistive pressure senor [17] and bulk silicon pressure sensor [18].

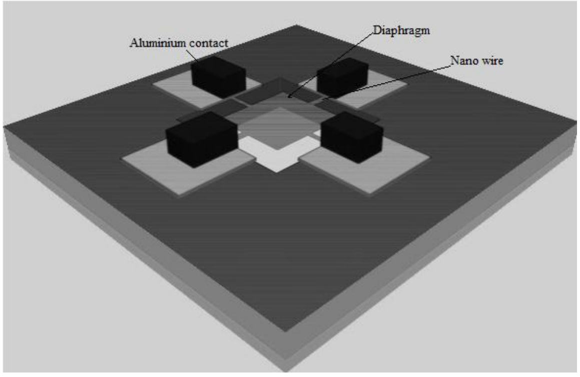


Figure 1: Piezoresistive pressure sensor using single polysilicon nanowire

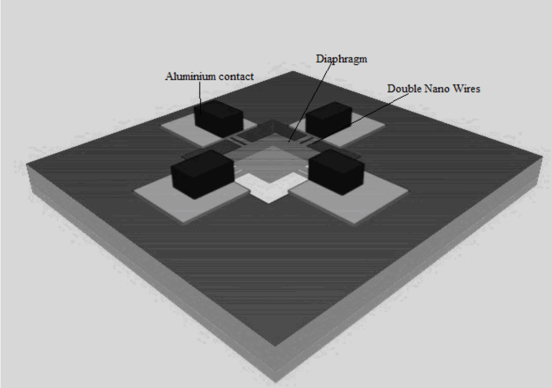
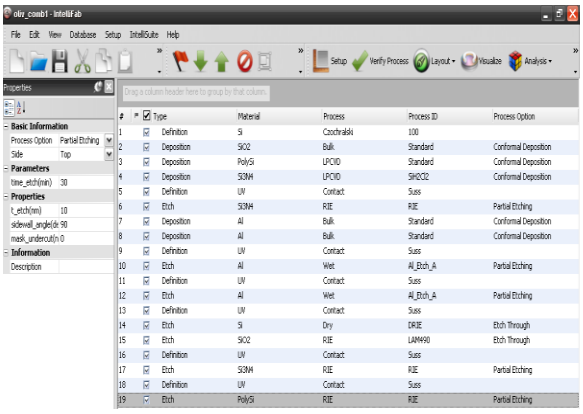


Figure 2: Piezoresistive pressure sensor using double polysilicon nanowire

2. DESIGN CONSIDERATION

In order to improve the sensitivity and to decrease the area of the chip a double nano wired piezoresitive pressure sensor is fabricated. The proposed pressure sensor has a square diaphragm of area 100 x 100 nm^2.The thickness of the diaphragm is 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. In each sides of the diaphragm there were two nano wires each 10nm apart from each other. These nano wires are 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 nano wires are lying in the high stress area so that maximum Piezoresistive effect can be realized. The reason for higher piezoresistance in nanowires is due to enhanced carrier mobility, reduced dimensions and large surface to volume ratio [19-20]. In a paper that was published it was shown that, silicon nanowire which had the width or thickness of 340 nm has good piezoresistive effect [13]. 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 double nano wire polysilicon piezoresitive pressure sensor is fabricated. Figure 1 shows the schematic of the piezoresistive pressure senor using single polysilicon nanowire. Figure 2 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.



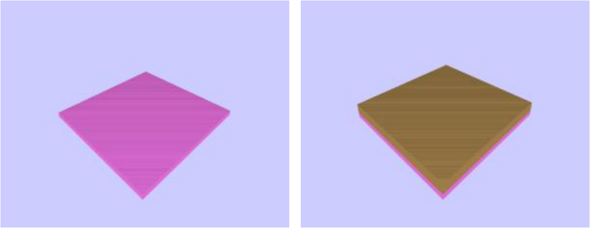
Basic Information
Process Option: Partial Etching
Side: Top
Parameters
time_etch(min): 30
Properties
t_etch(nm): 10
sidewall_angle(de: 90
mask_undercut(n: 0
Information
Description

#		☑ 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

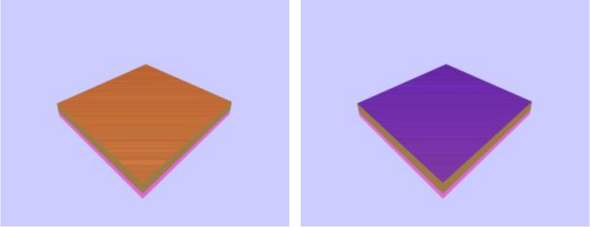
Figure 3.Process for piezoresistive pressure sensor fabrication

3. FABRICATION

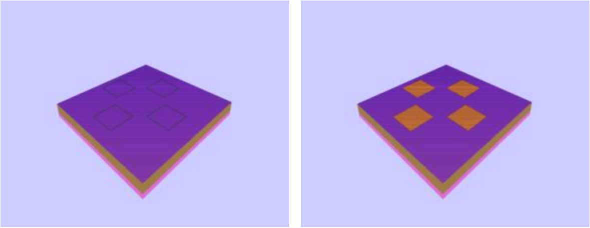
The pressure sensor is fabricated in the INTELLIFAB module. The process table used in INTELLIFAB is shown in figure 3. The wafers substrate, on which the device will be fabricated, will need to be bulk etched. It is etched using TMAH (tetra methyl ammonium hydroxide), which is an anisotropic etchant.TMAH etch silicon much faster in the (100) direction than in the (111) direction. Bulk Silicon Oxide of about 1000nm is deposited over the bare silicon wafer as shown in figure 4(b). This conformal deposition helps to spread the Silicon-di-oxide uniformly on the upper surface of the silicon. On the layer of SiO_2, a thin layer of Poly Silicon is deposited. The thickness should be around 10nm as shown in figure 4(c). Again conformal deposition is used so that Poly Silicon spreads uniformly. 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 layer as shown in figure 4(d). 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 .



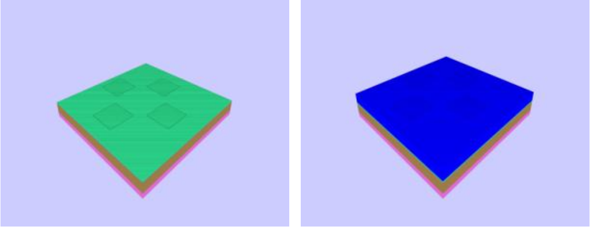
(a)Substrate preparation **(b)Deposition of Silicon**



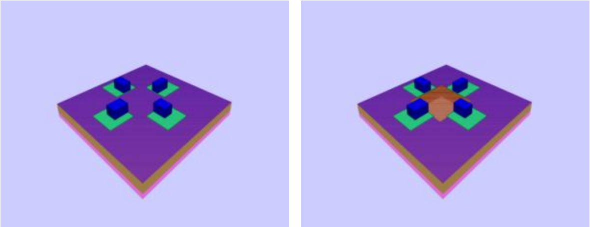
(c) Deposition of polysilicon **(d) Deposition of Si_3N_4**



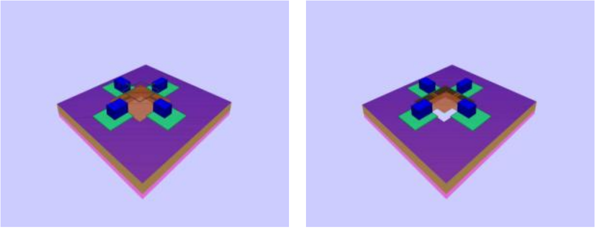
(e) Masking **(f) Etching of Si_3N_4**



(g) Deposition of Aluminum **(h) Masking of Aluminum**



(i)Etching of Aluminum and back side of wafer **(j) Etching of Si_3N_4**



(k) Patterning nanowire **(l) Etching of polysilicon**

Figure 4: Step involved in Fabrication Process

The pressure during the deposition time was 300 mTorr. 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 pattern transfer process is accomplished by using a lithographic exposure tool that emits radiation. Then from the pattern formed, Si_3N_4 is etched from inside. This etching is done using RIE method. Aluminum of 1000nm thickness was deposited as shown in figure 4(g) to make contact with the diffused resistors. The metal pads can be used to probe the structure when the fabrication is complete. After metal deposition, it was patterned using the mask and then the wafers were etched to remove unwanted Aluminum as shown in figure 4(h). The aluminum etch is done in a solution composed of: phosphoric acid (80%), nitric acid (5%), $C_2H_4O_2$ (5%) and distilled water. On the aluminium deposited lithographic masking is done, which when exposed UV radiation, helps to etch the aluminium as shown in figure 4(i). 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 as shown in figure 4(k). the fabrication results in a double nano wired Piezoresistive pressure sensor as shown in figure 4(l).

4. RESULT

The fabricated double polysilicon nanowire pressure sensor was tested by applying pressure in the range of 0 to 50 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. Were the Sensitivity analysis (SA) is the study of change in output voltage with respect to the applied pressure. The nano wire assembly forms the Wheatstone bridge arrangement. The bridge is exited by 1V supply voltage. The figure 5. shows the sensitivity analysis that is change in output voltage for an applied pressure for the double nano wire polysilicon pressure sensor. The figure 6. shows the change in resistance with the applied pressure for a single nanowire polysilicon piezoresistive pressure sensor, double nanowire polysilicon piezoresistive pressure sensor and bulk silicon pressure sensor. It is shown in figure 6. that change in resistance of double polysilicon nanowire was greater compared with single polysilicon nanowire and bulk silicon pressure sensor.

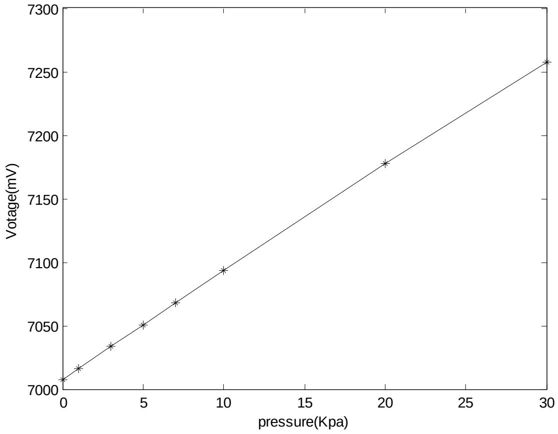


Figure 5: Output Response of double polysilicon nanowire pressure sensor

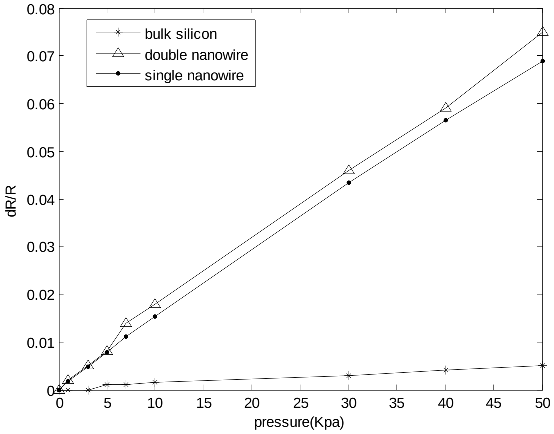


Figure 6: Comparison between bulk silicon, single and double polysilicon nanowire pressure sensor

5. CONCLUSION

The designing and fabrication of double polysilicon nano-wire pressure sensor has improved the sensitivity to a great extend. The double polysilicon pressure sensor of 100x100nm^2 cross section area and thickness of 10nm has a sensitivity of 160 mV/V.KPa. It was shown in the published paper an increase in the piezoresistive effect has been observed in nanowires as large as 480×340 nm^2[13]. It is observed that from figure 6. the increase in piezoresistive effect was greater than 7 times that of the bulk silicon pressure sensor .It is reported that as the thickness of the diaphragm is reduced there is a increases in sensitivity, but the nonlinearity effect predominates. 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 piezoresistve effect due to crystalline silicon is incomparable. Moreover the piezoresitivity 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 [21]. This enables fabrication of high sensitivity devices where fabrication complies with conventional micro fabrication techniques.

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