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Original Article

Study the Effect of Doping Concentration on the Performance of n-Type Poly-Si Cantilever Pressure Sensors

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Abstract *- This study is to evaluate the performance of n-type Polycrystalline Silicon (poly-Si)-based piezoresistive pressure sensors with different doping concentrations. The two primary properties, i.e., mechanical and electrical properties, are the governing factors for the performance of the sensor. The variation in the doping concentrations changed the conductance of the majority charge carrier, which affects the piezoresistivity of the n-type poly-Si. This change in the piezoresistive properties changes the performance of the sensors. The poly-Si is widely used because of its compatibility with micromachining techniques, which make it suitable for Microelectromechanical Systems (MEMS). The investigation focuses on the influence of doping concentration on electron conductivity, which serves as the majority charge transport mechanism in n-type poly-Si and significantly affects the piezoresistivity of the sensor. The analytical model of the sensor is used to find the calculated values for comparative study with the simulated output values. The sensor models were simulated using COMSOL Multiphysics under applied pressures ranging from 0 to 100 kPa for different doping concentrations ranging from 10^{15} cm⁻³ to 10^{20} cm⁻³. The sensitivity and linearity are the two parameters of the sensors that are considered for evaluating the performance of the sensors. Both the conductance and the resistance of the sensors exhibit strong linear relationships with the applied pressure. Conductance increases with higher doping concentration and applied pressure with a positive slope, while resistance decreases under the same conditions. Furthermore, the resistance variation (output span) with pressure decreases as the doping concentration increases. Overall, higher doping concentrations enhance the conductivity but lead to a reduction in sensitivity. The sensor exhibits excellent linearity to input pressure with a negative gradient. The sensitivity of the calculated and simulated output values of the sensor for a doping concentration of 10^{15} cm⁻³ is* 59 mΩ/kPa and 44 mΩ/kPa, *respectively.*

Keywords *- Conductance, Doping Concentration, Linearity, Mobility, Sensitivity.*

1. Introduction

Piezoresistive pressure sensors are the most extensively used MEMS sensors due to their simplicity, high sensitivity, and compatibility with silicon-based microfabrication technology [1, 2]. In particular, silicon-based piezoresistors provide stable, linear, and temperature-robust performance, making them attractive for various applications in the field of automotive, biomedical, aerospace, and industrial process control. Among silicon materials, poly-Si has attracted significant attention for piezoresistive sensor design. Poly-Si offers several advantages, including compatibility with standard micromachining and CMOS processing, relatively lower cost, ease of integration, and favourable mechanical properties [3, 4]. Silicon-based piezoresistive has many advantages, so more study is necessary to find the effect of doping concentration on the material's behavior. This work fills that gap by examining how n-type polycrystalline silicon cantilever piezoresistive pressure sensors perform across a wide range of doping concentrations (10^{17} to 10^{22} cm⁻³). It explores how mechanical stress and strain, together with changes in electrical conductivity, shape the important output parameters such as sensitivity, linearity, conductance, resistance variation, and output span. The COMSOL simulator is employed to simulate the proposed model of the sensor for applied pressures from 0 to 100 kPa. This simulation finds the doping concentration effect on the overall device performance and sensitivity. In addition, an analytical model is also established to find the various parameters that affect the sensitivity and the output span. The simulated results and the analytical results are directly compared to validate the results. This study also aims to identify the effect of doping concentration on sensitivity, linearity, and output span of the piezoresistive pressure sensor. The remaining parts of this study are ordered as follows: Section 2 presents the literature review. Section 3 outlines the sensor structure and the analytical modelling framework, while Section 4 details the simulation setup and modelling parameters. Section 5 presents and discusses the results related to conductance, resistance, sensitivity, and linearity across various doping levels and applied pressures. Section 6 provides a comparative analysis between the analytical and simulated results. Finally, Section 7 concludes the paper with recommendations for doping optimization and suggestions for future work on fabrication and experimental validation.

2. Literature Review

Previous studies have examined the piezoresistive behaviour of silicon layers fabricated using RF magnetron sputtering with Aluminum-Induced Crystallization (AIC). The sensor based on AIC-derived polysilicon is configured in a Wheatstone bridge on an oxidized silicon substrate. These sensors showed effective performance over a pressure range of 10–95 kPa. The device exhibited gauge factors of 5 and 18 for different resistor locations, and a sensitivity of approximately 30 mV MPa^{-1} at a 1 V bridge bias [5].

Poly-Si is widely used in microelectronic and MEMS devices as a sensing layer to sense force, pressure, and accelerometers. The poly-Si has a granular boundary, which increases the resistivity. A poly-Si layer placed on oxidized silicon substrates offers strong mechanical properties along with stable, high-temperature piezoresistive performance. These include analyses of longitudinal and transverse gauge factors and their dependence on crystallographic structure. Research also highlights opportunities for optimizing sensor performance through improvements in mechanical, thermal, and piezoresistive characteristics, supported by examples of commercial poly-Si sensors and emerging fabrication technologies [1, 2, 4].

Previous work has examined the resolution limits of surface-stress-based cantilever biosensors incorporating piezoresistors fabricated through surface micromachining. Sensitivity in such devices depends strongly on the gauge factor, which is influenced by the doping level and grain size. LPCVD polysilicon piezoresistors (300 nm thick) implanted with varying boron concentrations and encapsulated in LPCVD silicon nitride were characterized to assess doping effects. Results showed that the gauge factor decreases by around 40% with increasing boron dose, indicating a trade-off between conductivity and sensitivity [6]. When the doping concentration increases, the thermal noise and stability improve, but it degrades the sensor’s ability to transduce stress into a measurable resistance change [7, 8]. So, there is a need to balance between the doping concentration and the thermal noise for achieving higher performance. Three piezoresistive pressure sensors using diffused, polysilicon, and crystalline silicon resistors were fabricated and tested up to 200 °C and 140 bar. The polysilicon and single-crystal designs showed higher sensitivity in room temperature (0.308 and 0.211 mV/V/bar) than diffused resistors (0.147 mV/V/bar) and remained stable up to 200 °C. Sensitivity decreased with temperature, but oxide-isolated polysilicon exhibited the lowest sensitivity loss and minimal offset and hysteresis, making it the most robust high-temperature option. [9].

This review shows that polysilicon is a strong candidate for piezoresistive sensing due to its mechanical robustness, high-temperature stability, and tunable electrical properties. AIC-derived and LPCVD polysilicon films demonstrate effective piezoresistive behavior, with gauge factor and sensitivity strongly influenced by doping concentration, grain structure, and device configuration. While higher doping improves thermal stability and reduces noise, it significantly lowers the gauge factor, indicating the need for an optimal balance. Comparative studies further show that oxide-isolated polysilicon resistors provide superior performance at elevated temperatures, exhibiting higher sensitivity and lower hysteresis than diffused or single-crystal counterparts. Collectively, the literature emphasizes that doping optimization and material engineering are critical for maximizing the performance of polysilicon-based piezoresistive pressure sensors.

3. Analytical Model

In this analytical model, the analysis is carried out in two main stages. The first stage, Mechanical Analysis, is to calculate the mechanical stress developed on the sensing layer produced by the externally applied pressure. This stress is a very important factor because it causes deformation in the sensor structure, which directly influences the electrical resistance of the n-type poly-Si material.

The second stage, Electrical Analysis, is to calculate the change in resistance due to the induced stress from the applied pressure. In this study, the change in resistance is calculated for the various doping concentrations of the poly-Si.

3.1. Mechanical Analysis

To calculate the mechanical stress, a Three-Dimensional (3D) model of the sensor, as illustrated in Figure 1, is considered. The model represents a cantilever beam structure, which is a common design used in MEMS-based piezoresistive pressure sensors due to its high mechanical flexibility and stress concentration at the fixed end.

The dimensions of the cantilever are Length (l), Width (w), and Thickness (h). The External Pressure (P) is applied on the top of the cantilever; it bends, creating a stress distribution along its length. The stress $T(x)$ produced on the surface of the sensor is given by the following Equation [10-12]:

$$T(x) = -z\frac{6P}{h^3}(l^2 + x^2 - 2xl) \quad (1)$$

Where z is the distance from the neutral plane of the cantilever, the neutral plane refers to a plane in the cantilever structure, where no tensile stress or compressive stress occurs, and x is an arbitrary point on the surface along the length of the cantilever.

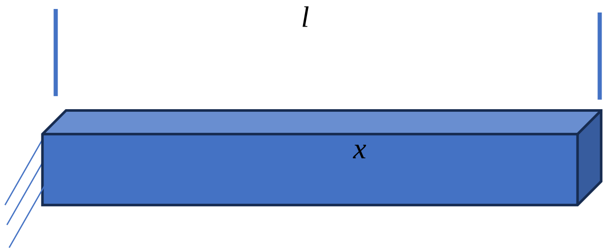

Fig. 1 3D Geometrical structure of the sensor

The maximum stress occurs at the fixed end of the cantilever, where the value of x is zero. The maximum stress of the cantilever on a plane away by z distance is given by the following equation:

$$T(x = 0)\frac{6P^2}{h^3}_{max} \tag{2}$$

The maximum stress depends on the distance from the neutral plane, the Thickness, and the length of the cantilever.

3.2. Electrical Analysis

To calculate the resistance of the sensor due to induced stress for different doping concentrations, the resistance of the poly-Si is calculated with respect to the doping concentration. The resistance of the poly-Si for *n*-doping concentration is given by the following equation:

$$R_0 = \frac{1}{qnu_n}\frac{l_p}{w_p h_p} \tag{3}$$

Where, $q = 1.602 \times 10^{-19}$ C, n = doping concentration, u_n = electron mobility, l_p, w_p, h_p are the length, breadth, and Thickness of the piezoresistive material.

The δR due to deformation on the structure is given by:

$$\delta R = -\pi_l z \frac{6P}{h^3}(l^2 + x^2 - 2xl)\frac{1}{qnu_n}\frac{l_p}{w_p h_p} \tag{4}$$

Where δR is the variation in the resistance, π_l is the piezoresistive coefficient along the length of the piezoresistive materials. The maximum change in resistance of the sensor is given by the following equation:

$$\delta R = -\pi_l z \frac{6Pl^2}{h^3}\frac{1}{qnu_n}\frac{l_p}{w_p h_p} \tag{5}$$

The sensitivity of the sensor is given by the following equation:

$$\delta R = -\pi_l z \frac{6}{h^3}(l^2 + x^2 - 2xl)\frac{1}{qnu_n}\frac{l_p}{w_p h_p} \tag{6}$$

The change in resistance and sensitivity of the sensor for different doping concentrations can be calculated by replacing the value of n and μ_n, as the value of μ_n also varies with varying doping concentration [13].

4. Sensor Model and Physics Setting

In this study, the simulation of the proposed sensor model is performed by using COMSOL Multiphysics software. The Piezoresistivity interface is selected for the simulation, which combines two main modules, Solid Mechanics and Electric Currents. These modules work together to analyse how mechanical stress affects the electrical behaviour of the sensor material.

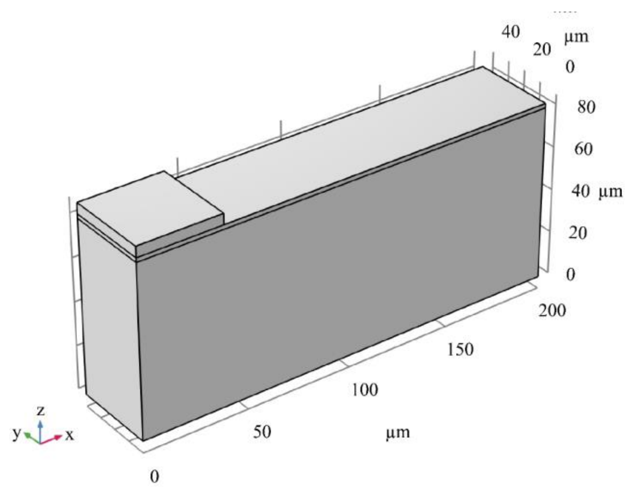

Fig. 2 3D model of the sensor in COMSOL

The geometrical model of the designed sensor is created in COMSOL, as shown in Figure 2. This sensor structure has three layers: silicon as substrate, silicon dioxide as insulating layer, and n-type poly-Si as the piezoresistive sensing layer. Dimensions of each layer used in the simulation are given below.

Table 1. Layer dimension of the sensor

Layers Material	Length (μm)	Width (μm)	Height (μm)
Silicon	200	40	80
Silicondioxide	200	40	2
n-type Polysilicon	40	40	5

After defining the material properties, the necessary physics settings are applied. These include assigning boundary loads to simulate the applied pressure, defining electrical ground and input voltage at the electrodes, and setting the boundary conditions for both mechanical and electrical domains. Once the physics setup is complete, the entire structure is meshed using a fine tetrahedral mesh. This step is a very important part of the finite element method-based simulation.

5. Results and Discussions

The simulations are carried out for the applied pressure range from 0-100 kPa for different doping concentrations at 10^{15} cm^{-3} to 10^{20} cm^{-3} with a step increment of 10-fold.

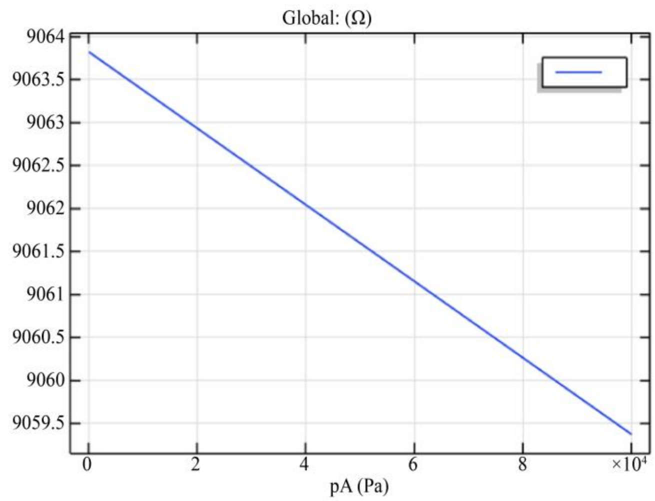

Fig. 3 Resistance vs Pressure of the sensor with doping concentration of 10^{15} cm^{-3}

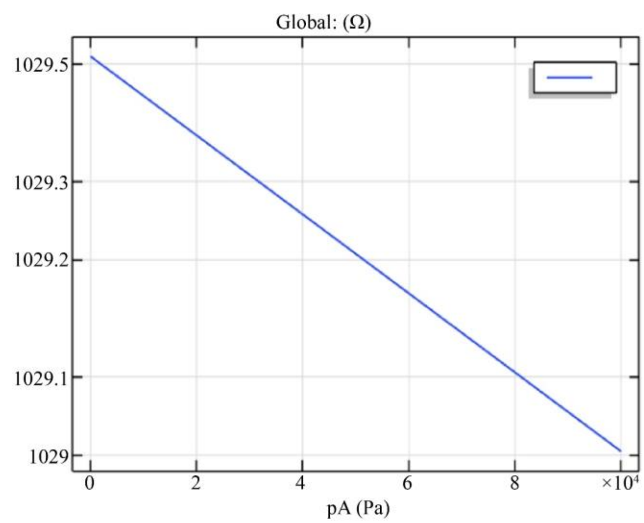

Fig. 4 Resistance vs Pressure of sensor with doping concentration of 10^{16} cm^{-3}

Figure 3 shows the simulated change in resistance with applied pressure for the n-type poly-Si sensor for a doping concentration of 1×10^{15} cm^{-3}. It is observed that 9036.8 Ω of resistance at 0 kPa and 9059.4 Ω of resistance at 100 kPa.

Figure 4 shows the simulated change in resistance with applied pressure for the n-type poly-Si sensor for a doping concentration of 10^{16} cm^{-3}. It is observed that 1029.5 Ω of resistance at 0 kPa and 1029.0 Ω of resistance at 100 kPa.

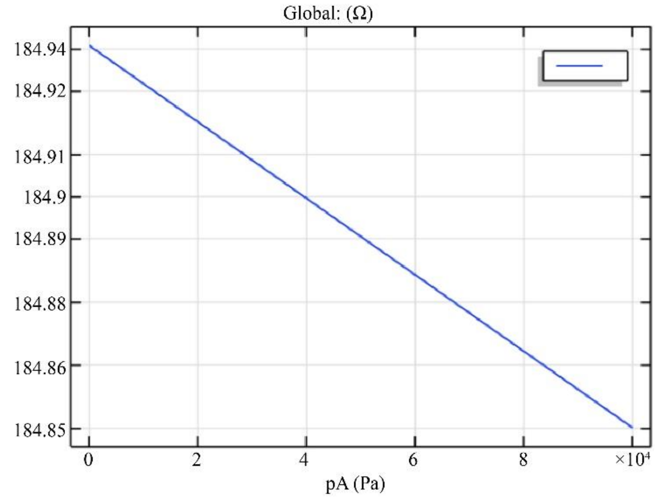

Fig. 5 Resistance vs Pressure of sensor with doping concentration of 10^{17} cm^{-3}

Figure 5 shows the simulated change in resistance with applied pressure for the n-type poly-Si sensor for a doping concentration of 10^{17} cm^{-3}. It is observed that 184.94 Ω of resistance at 0 kPa and 184.85 Ω of resistance at 100 kPa.

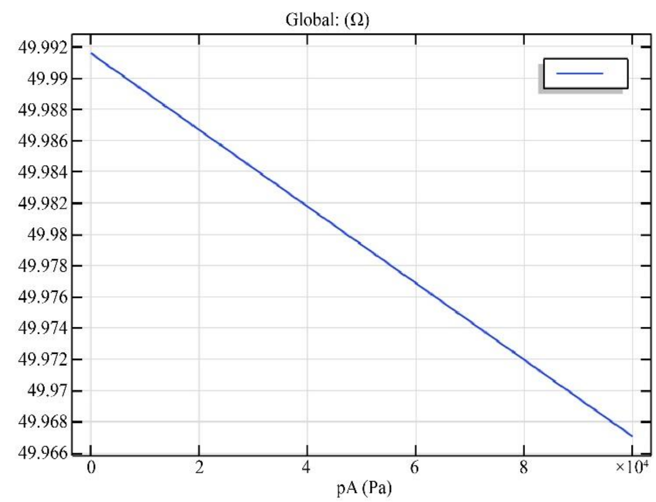

Fig. 6 Resistance vs Pressure of the sensor with a doping concentration of 10^{18} cm^{-3}

Figure 6 shows the simulated change in resistance with applied pressure for the n-type poly-Si sensor for a doping concentration of 10^{18} cm^{-3}. It is observed that 49.992 Ω of resistance at 0 kPa and 49.967 Ω of resistance at 100 kPa.

Figure 7 shows the simulated change in resistance with applied pressure for the n-type poly-Si sensor for a doping concentration of 10^{19} cm^{-3}. It is observed that 11.685 Ω of resistance at 0 kPa and 11.679 Ω of resistance at 100 kPa. Figure 8 shows the simulated change in resistance with applied pressure for the n-type poly-Si sensor for a doping concentration of 10^{20} cm^{-3}. It is observed that 1.5894 Ω of resistance at 0 kPa and 1.5886 Ω of resistance at 100 kPa.

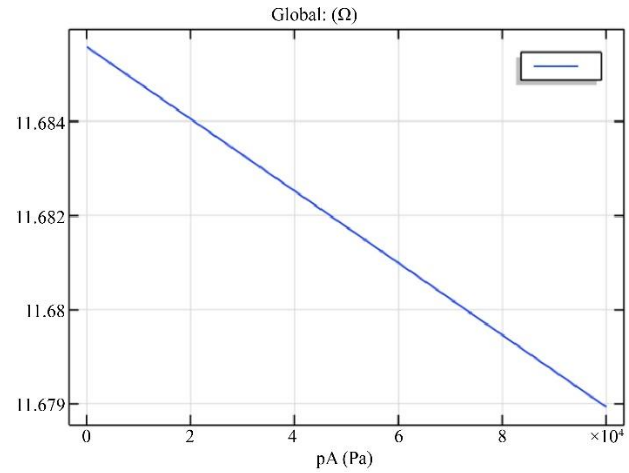

Fig. 7 Resistance vs Pressure of the sensor with doping concentration of 1x10^{19} cm^{-3}

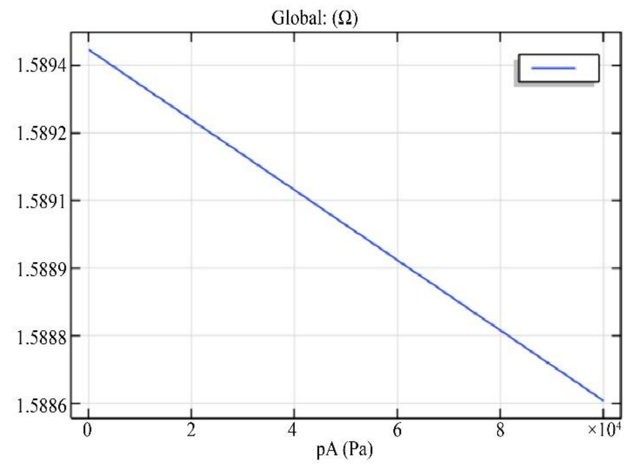

Fig. 8 Resistance vs Pressure of the sensor with a doping concentration of 10^{20} cm^{-3}

The simulation results demonstrate that the resistance of the n-type poly-Si piezoresistive pressure sensor decreases with increasing applied pressure for all doping concentrations ranging from 10^{15} cm^{-3} to 10^{20} cm^{-3}. This inverse relationship (or linearly varying with negative slope) between resistance and pressure confirms the piezoresistive behaviour of the material. The negative slope represents the decrease in resistance. At lower doping concentrations (such as 10^{15} cm^{-3}), the sensor exhibits higher resistance values and a more noticeable change in resistance with pressure, indicating higher sensitivity. However, as the doping concentration increases, the resistances sharply decrease. This is because of the higher charge carrier density, which increases the conductivity. As a result, the resistance change under applied pressure becomes smaller, which reduces the sensitivity.

From Figures 3 to 8, it is observed that the output span also increases when the doping concentration decreases. Further, it is also observed that the outputs are highly linear to the applied pressure, but the polarity of the slope is negative.

Therefore, it can be concluded that the doping concentration plays an important role in determining the sensor's performance. Higher doping levels enhance electrical conductivity but reduce sensitivity, while lower doping levels improve sensitivity but result in higher resistance. For optimal sensor performance, a balanced doping concentration must be selected to achieve a desirable trade-off between sensitivity and conductivity.

6. Comparison between Simulation and Analytical Values

A comparison was made between the simulated output and analytical values to study how the resistance of the n-type poly-Si sensor changes with applied pressure for different doping concentrations. This comparison is made to validate the analytical values with the simulated results. The corresponding values are listed in Table 2.

Table 2. Simulated values and calculated values of the sensor for different doping concentrations

P kPa	Resistance of the Sensor at Different Doping Concentrations											
	10^{15} cm^{-3}		10^{16} cm^{-3}		10^{17} cm^{-3}		10^{18} cm^{-3}		10^{19} cm^{-3}		10^{20} cm^{-3}	
	Cal* (Ω)	Sim* (Ω)	Cal	Sim	Cal	Sim	Cal	Sim	Cal	Sim	Cal	Sim
0	8917.4	9063.8	1040.4	1029.5	189.15	184.94	52.236	49.992	12.610	11.685	1.7339	1.5894
20	8916.2	9062.9	1040.2	1029.4	189.13	184.92	52.229	49.987	12.608	11.684	1.7337	15892
40	8915.1	9062.0	1040.1	1029.3	189.10	184.90	52.222	49.982	12.607	11.682	1.7335	15891
60	8913.9	9061.2	1040.0	1029.2	189.08	184.88	52.215	49.977	12.605	11.681	1.7333	15889
80	8912.7	9060.3	1039.8	1029.1	189.05	184.86	52.208	49.972	12.603	11.680	1.7330	15888
100	8911.5	9059.4	1039.7	1029.0	189.03	184.85	52.201	49.967	12.602	11.679	1.7328	1.5886

P is the Applied Pressure, Cal is the Calculated Values, Sim* is the simulated values*

Table 2 presents a comparison of the calculated (Cal*) and simulated (Sim*) resistance values of a piezoresistive sensor for different doping concentrations under applied pressures from 0 to 100 kPa with a step size of 20 kPa for the doping concentration range from 10^{15} cm⁻³ to 10^{20} cm⁻³. As observed, the resistance of the sensor decreases significantly with increasing doping concentration. At the lowest doping level (10^{15} cm⁻³), the resistance is very high (~8917 Ω), whereas at the highest doping (10^{20} cm⁻³), it drops drastically to around 1.7 Ω. This trend aligns with fundamental semiconductor physics. As doping increases, the carrier concentration rises, which boosts conductivity and correspondingly lowers the material's resistance.

The effect of applied pressure on the sensor's resistance is small but consistent across all doping levels. For example, at a doping concentration of 10^{15} cm⁻³, the calculated resistance decreases slightly from 8917.4 Ω at 0 kPa to 8911.5 Ω at 100 kPa. This shows that the negative longitudinal piezoresistive effect, that is, the resistivity decreases when stress is applied along the direction of current flow. As the doping concentration increases, the resistance becomes even smaller because the baseline resistance is lower. This reduction is the baseline of the resistance that reduces the relative sensitivity of the sensor. For a doping concentration of 10^{15} cm⁻³, the simulated and calculated sensitivities are 44 mΩ/kPa and 59.0 mΩ/kPa, respectively.

Comparison between calculated and simulated values shows excellent agreement with a margin of error less than 2%. This confirmed the validity of the analytical model using simulated values. Overall, these results show that lower doping concentrations provide higher resistance and greater sensitivity to applied pressure. It is also observed that higher doping concentrations result in lower resistance and reduced pressure sensitivity. This highlights the trade-off in designing piezoresistive MEMS sensors: low-doped sensors offer higher sensitivity but may have higher noise, while high-doped sensors provide more stable measurements at the cost of lower sensitivity.

7. Conclusion

This study shows the effect of doping concentration on the electromechanical performance of n-type polycrystalline silicon piezoresistive pressure sensors. The study is performed for the doping concentration ranging from 10^{15} cm⁻³ to 10^{20} cm⁻³ under applied pressures of 0–100 kPa. The calculated and simulated values of resistance are very close, as the deviation or margin of error is less than 2%. This validates the analytical model and confirms the reliability of the simulation approach.

From the simulation and the mathematical results, it is shown that resistance under no applied pressure decreases sharply as the doping concentration increases, from 1.5894 Ω at a doping concentration of 1×10^{20} cm⁻³ to 8917.4 Ω at a doping concentration of 1×10^{15} cm⁻³. The same trend is also followed under the applied pressure, which is that resistance under 100 kPa pressure decreases sharply as the doping concentration increases, from 1.7328 Ω at a doping concentration of 10^{20} cm⁻³ to 8911.5 Ω at a doping concentration of 10^{15} cm⁻³. This is because higher doping introduces more charge carriers and improves conductivity. The output span of the sensor is also decreased from 5.9 Ω at 10^{15} cm⁻³ to 0.0011 Ω at 10^{20} cm⁻³ for the applied pressure 0 to 100 kPa.

These results show the importance of optimizing doping concentration in the design of MEMS piezoresistive sensors, as it affects the sensitivity, linearity, and output span. Overall, this study provides a detailed understanding of the effect of doping concentration on n-type poly-Si cantilever sensors.

References

[1] J. Akhtar et al., "Polysilicon Piezoresistive Pressure Sensors based on MEMS Technology," *IETE Journal of Research*, vol. 49, no. 6, pp. 365-377, 2003. [CrossRef] [Google Scholar] [Publisher Link]

[2] Vincent Mosser et al., "Piezoresistive Pressure Sensors based on Polycrystalline Silicon," *Sensors and Actuators A: Physical*, vol. 28, no. 2, pp. 113-132, 1991. [CrossRef] [Google Scholar] [Publisher Link]

[3] S. Santosh Kumar, and B.D. Pant, "Polysilicon thin Film Piezoresistive Pressure Microsensor: Design, Fabrication and Characterization," *Microsystem Technologies*, vol. 21, no. 9, pp. 1949-1958, 2015. [CrossRef] [Google Scholar] [Publisher Link]

[4] Pilar González Ruiz, Kristin De Meyer, and Ann Witvrouw, *Design of a Poly-SiGe Piezoresistive Pressure Sensor*, Poly-SiGe for MEMS-above-CMOS Sensors, Dordrecht, pp. 51-73, 2014. [CrossRef] [Google Scholar] [Publisher Link]

[5] Ruchi Tiwari, and Sudhir Chandra, "Piezoresistive Pressure Sensor using Low-Temperature Aluminum Induced Crystallization of Sputter-Deposited Amorphous Silicon Film," *Journal of Micromechanics and Microengineering*, vol. 23, no. 9, 2013. [CrossRef] [Google Scholar] [Publisher Link]

[6] Kwang-Ho Na et al., "Piezoresistive Characteristic of Microcantilever-based Biosensor According to Doping Level of Polysilicon Resistor," *Bulletin of the American Physical Society*, 2005. [Google Scholar] [Publisher Link]

[7] Ahmed A.S. Mohammed, Walied A. Moussa, and Edmond Lou, "High-Performance Piezoresistive MEMS Strain Sensor with Low Thermal Sensitivity," *Sensors*, vol. 11, no. 2, pp. 1819-1846, 2011. [CrossRef] [Google Scholar] [Publisher Link]

[8] Jiahong Zhang et al., "Design Optimization and Fabrication of High-Sensitivity SOI Pressure Sensors with High Signal-to-Noise Ratios based on Silicon Nanowire Piezoresistors," *Micromachines*, vol. 7, no. 10, pp. 1-19, 2016. [CrossRef] [Google Scholar] [Publisher Link]

[9] Vinod Belwanshi, Sebin Philip, and Anita Topkar, "Performance Study of MEMS Piezoresistive Pressure Sensors at Elevated Temperatures," *IEEE Sensors Journal*, vol. 22, no. 10, pp. 9313-9320, 2022. [CrossRef] [Google Scholar] [Publisher Link]
[10] James M. Gere, and Stephen P. Timoshenko, *Mechanics of Materials*, 4th ed., Boston, MA: PWS, 1997. [Google Scholar] [Publisher Link]
[11] Stephen D. Senturia, *Microsystem Design*, Boston, MA: Springer US, pp. 29-78, 2001. [CrossRef] [Google Scholar] [Publisher Link]
[12] Minhang Bao, *Analysis and Design Principles of MEMS Devices*, Elsevier Science, 2005. [CrossRef] [Google Scholar] [Publisher Link]
[13] D.M. Caughey, and R.E. Thomas, "Carrier Mobilities in Silicon Empirically Related to Doping and Field," *Proceedings of the IEEE*, vol. 55, no. 12, pp. 2192-2193, 1967. [CrossRef] [Google Scholar] [Publisher Link]