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Study of the thermal drifts on the piezoresistivity using mobility model and finite difference method of electric heater

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ABSTRACT

In pressure sensors, four piezoresistors connected in a Wheatstone bridge are often provided with a voltage varying between 5 and 10 V. Unfortunately, this voltage is a source of drifts created by electric heating. This study focuses on the internal heating and piezoresistive effect of piezoresistors represented by the variation of their resistivity. To do this, we use the finite difference method (FDM) to solve the heat transfer equation, taking into account the conduction in Cartesian coordinates for the variable regime. We examine how the temperature affects the piezoresistivity in these sensors when the potential is applied. In this case, the variation of the temperature has been calculated as a function of applied voltage, as well as for the operating time of the sensor. Furthermore, the evolution of resistivity over time was determined for several geometric properties of the membrane using the mobility model. This was established for different doping levels. Additionally, the change in resistivity due to the application of voltage was evaluated. It was observed that resistivity is greatly affected by the temperature rise produced by the applied voltage when the device is actuated for a prolonged time. Consequently, this results in drifting in the output response of the sensor.

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1. INTRODUCTION

Many domains that require the use of piezoresistive sensors with excellent reliability such as industry and biomedical due to their good linearity of output voltage, excellent compatibility with microelectronic systems and some other advantages [1]–[4]. However, they often suffer from the thermal drift. The study of electric heater effect in these sensors types is important to optimize the output characteristics drift [5]–[8]. As a result, several previous research papers have been carried out in this domain in order to lessen this effect, when the bridge is powered by an electric tension. Research by Ansari and Cho [7] was to derives both temperature independent and dependent models for temperature rise created by bias voltage in piezoresistive microcantilevers. Their approach is based on analytical model in steady state for describing the temperature diffusion in microcantilever by self heating [7]. Research by Aryafar *et al.* [9] introduce a novel technique for temperature compensation of piezoresistive pressure sensors. In their technique, additional silicon resistors with negative temperature coefficient of resistivity are used for compensation purpose. More recently, Tian *et al*. [10] have developed an analytical model of temperature characteristics in pressure sensor to investigate the influence factors of temperature zero drift, including temperature dependence of resistivity. In their paper, they have studied the influence of several piezoresistor size combinations on the zero point output of pressure sensors using the finite element method (FEM) technique to effectively compensate for temperature zero drift [10]. To highlight the effect of electrical heating in piezoresistive pressure sensor, Pramanik *et al.* [11] have established an analytical model for self heating in circular-shaped diaphragm sensors. Nevertheless, the sensitivity of the gauge to the constraints of the square form diaphragms sensors is greater than in circular shape when the diaphragm thickness is greater than 2 µm [4], [12], [13]. Similarly, at the same geometric properties of membrane (length or diameter) the circular-shape diaphragms has greater rigidity compared to those of square shape [14]–[16]. As a consequence, square form membranes are more sensitive than circular ones [4]. For this reason and some others uses such as fields that require excellent sensitivity to pressure, the diaphragms of sensors are usually made using square or rectangular shape [16]–[18]. This prompted us to present a numerical model of Joule heating in piezoresistive pressure sensors, with a square shaped membrane [19], [20]. We have analyzed the effect of supply voltage, geometric properties of membrane and the piezoresistor length, this allows us to improve the performance of this sensors. Recently, in the next paper [21] we have studied the impact of thermal drift on sensitivity of pressure sensors. The obtained results allow us to optimize the pressure sensitivity of sensors by optimization the geometric properties. Considering the importance of piezoresistivity effect in the performance of piezoresistive sensor a study was carried out by Ansari and Gangadhara [22]. In their paper, a finite element analysis is used to find the design parameters of the piezoresistor for application in atomic force microscope and some other applications. Accordingly, Kerrour *et al.* [23], have explored the change of resistivity due to temperature for several doping concentrations based on the mobility model of Arora. Their approach, has made it possible to optimize the response of piezoresistive pressure sensors of thermal drifts when used in high temperature areas. So as, to study the reliability of piezoresistive pressure sensors, we have coupled the numerical model of self heating with that of the mobility of Arora to optimize the influence of bias voltage on the piezoresistivity effect, described by the change of the resistivity of the piezoresistor, when applying mechanical stresses. Based on the numerical resolution of 2D heat transfer equation using FDM, we examine the geometrical, electrical and physical parameters influencing the resistivity to optimize the thermal drifts in the response of this sensors. For that, the evolution of temperature due to the self heating was found as a function of operating time of sensor and of applied voltage. Moreover, we have calculated the variation of resistivity in time for several geometric properties of the membrane and for different doping concentrations, as well as, for bias voltage. Afterwards, we embarked on the study of the influence of temperature on sensitivity.

2. THEORY AND GOVERNING EQUATION

Piezoresistive pressure sensor is composed of four gauges placed on the membrane in order to get a high piezoresistivity; thus, to get excellent sensitivity. Thereby, two gauges are placed parallel and the two others perpendicular to the membrane edges as shown in Figure 1. These gauges are connected in a Wheatstone bridge.

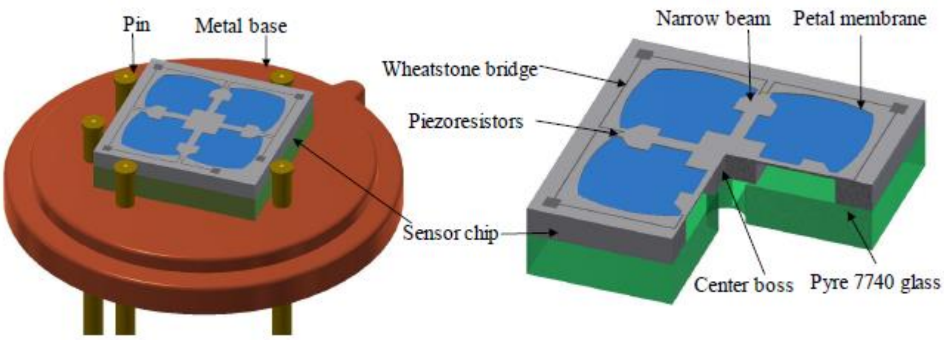

Figure 1. Structure of piezoresistive pressure sensor [14]

The piezoresistivity effect is strongly influenced by the temperature; particularly, that generated by the self-heating, which pushed us to concentrate on this source of heating. This involves the resolution of heat transfer equation in cartesian coordinates for the transient regime. This equation is governed by [7]:

$$-k\nabla^2 T(x,y,t) = -\rho c\frac{\partial T}{\partial t} + Q \quad (1)$$

where k is thermal conductivity, Q is heating flux, ρ is the mass density, t is the time and C is the specific heat. Otherwise, the rate of energy production by electric heater is given in (2) [7]:

$$Q = \frac{A_{pzr}}{L_{pzr}.d.S_m}\frac{V_0^2}{\rho_e} \quad (2)$$

where V_0 is the bias voltage, d is the diaphragm thickness, $S_m = a^2$ is the diaphragm area, $Lpzr$ is the length of the piezoresistance, $Apzr$ the cross-sectional area and ρ_e is the electrical resistivity expressed in (3) [23]:

$$\rho_e = \frac{1}{q\mu_p(T)N_A} \quad (3)$$

where q is the elementary charge, μ_p is the mobility and N_A is the doping concentrations. The starting condition in the whole structure as in (4):

$$T(x,y,t=0) = T_0 \quad (4)$$

The boundary conditions including the adiabatic heat condition and preserve the heat continuity at the bords can be given as in (5):

$$\frac{\partial T}{\partial x} = \frac{\partial T}{\partial y}\bigg|_{x=y=0} = 0 \quad (5)$$

After discretization in two dimensions of the heat transfer equation in transient state using FDM, we find a system of linear equations which is solved by Thomas method using the MATLAB software. Within the framework of study of the reliability of these sensors, we are interested to the thermal behaviour of resistivity during their operation time. So, we use the formula of mobility established by Arora [24], [25]:

$$\mu_p(T) = \mu_{mn}\frac{\mu_{0n}}{1+\left(\frac{N_A}{N_{cn}}\right)^{\theta}} \quad (6)$$

where μ_{mn} is minimal of mobility, μ_{0n} the difference between the maximum and minimum value of mobility, N_{cn} the concentration reference and θ is an exponential factor are given by [25]:

$$\mu_{mn} = 88\left(\frac{T}{300}\right)^{-0.57} \quad (7)$$

$$\mu_{0n} = 1250\left(\frac{T}{300}\right)^{-2.33} \quad (8)$$

$$N_{cn} = 1.26\times 10^{17}\left(\frac{T}{300}\right)^{2.4} \quad (9)$$

$$\theta = 0.88\left(\frac{T}{300}\right)^{-0.146} \quad (10)$$

By substituting the mobility expression (6) in the resistivity (3), we obtain the final formula of the resistivity as a function of temperature and doping level.

$$\rho_e = \frac{1}{q\left(\mu_{mn}\frac{\mu_{0n}}{1+\left(\frac{N_A}{N_{cn}}\right)^{\theta}}\right)N_A} \quad (11)$$

3. RESULTS AND DISCUSSION

As we have noted in the previous section, the thermal drifts induced by electric heater in piezoresistive pressure sensors affect highly the response of such sensors. This work aims to investigate the impact of the thermal drifts in this sensors when, bias voltage between 5 and 10 V is applied. It also, put emphasis in the study of the geometric influence parameters and doping level on the piezoresistivity effect.

3.1. Influence of bias voltage and operating time on temperature rises

In this section, the study of effect of bias voltage and of operating time of sensors has been performed. Firstly, we have represented in the curve Figure 2, the variations of temperature provoked by the bias voltage established by the numerical model at t=100 min and that of the analytics [7]. The comparison analysis shows a good correlation between the analytical and numerical model (FDM) for the low voltage. Indeed, beyond 8 V there are some differences, which may be due to the mesh, whom it is a source of error in the numerical model. From this figure, we have found that, the higher the bias voltage is, the greater the temperature rise will be, which is in accordance with the theory.

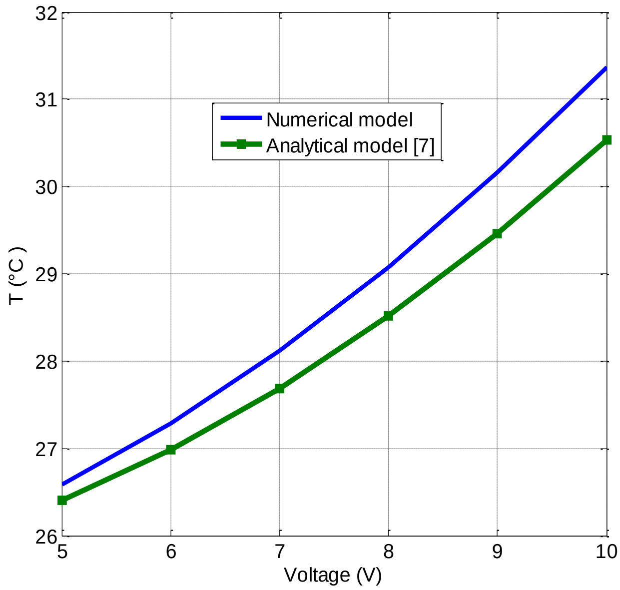

Figure 2. Effect of bias voltage on the rise of temperature

Secondly, as reported in Figure 3, it can be observed that the change in temperature induced by self heating has an exponential form. It is noted that, from t=100 min we are in permanent mode and that the evolution of the temperature stabilizes becoming independent of time. Additionally, the shape of this curve is analogous to the response of a first order circuit. The latter, is characterized by a time constant of the order of 3τ from which the steady state is achieved. It is described as in (12):

$$E(t) = E_m(1 - e^{\frac{-t}{\tau}}) \quad (12)$$

From (12), we can make a correspondence between the temperature *T* and the potential *Ec*. Therefore, we can get a relationship between T and the operating time of the sensor.

$$T(t) = T_m(1 - e^{\frac{-t}{\tau}}) + T_0 \quad (13)$$

where T_m and τ are the constant and the thermal time constant.

Thirdly, the drifts of resistivity when the piezoresistive pressure sensor is in a high temperature environment was investigated by [26], [27]. In our case, we have plotted in Figure 4 the variation of resistivity versus temperature rise created by the electric heater, when the bridge is powered by an electric tension. We can notice a significant increase in resistivity according to the temperature induced by the self-heating. Thereby, drifts in characteristics of the sensor.

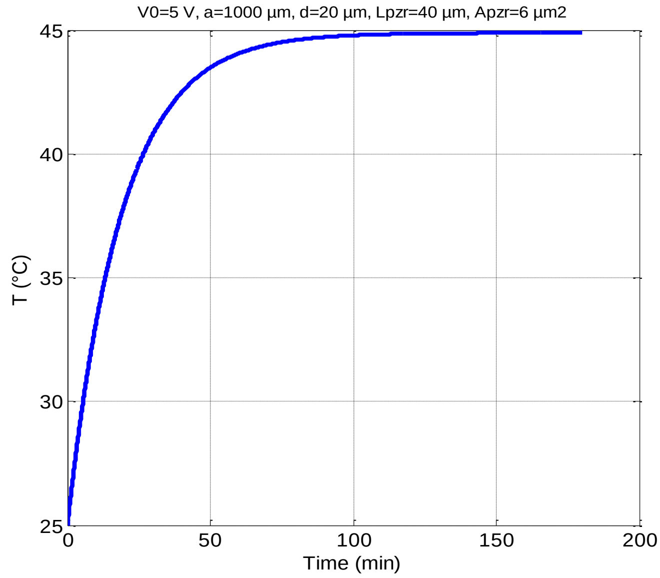

Figure 3. Effect of operating time in the rise of temperature

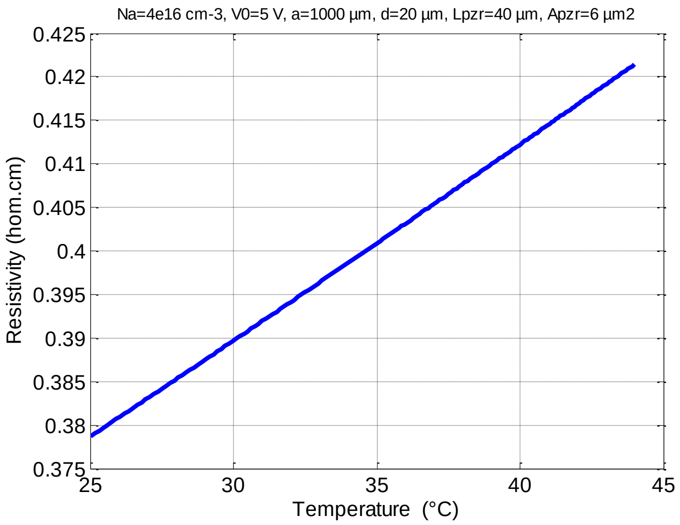

Figure 4. Variation of resistivity versus temperature rise generated by electric heater

3.2. Influence of time and geometrical parameter of membrane on the resistivity ρ_e

The knowledge of resistivity variation when the stress is applied is used to quantify the evolution in the output voltage, produced by these constraints. By coupling the temperature variation in time from the used model in (13) with the Arora mobility (6 and 11), we obtain the change in resistivity ρ_e in operating time of sensors for the p-type silicon (*Na*=4.10^{16} cm-3). The evolution of the resistivity in time and in geometric parameters of membrane are illustrated in Figures 5-7. From the Figure 5, we can observe that the ρ_e is an increasing function with time. This increase is most certainly due to self heating. It is further observed in Figures 6 and 7 that greater the thickness and wide of the membrane are, lesser is the resistivity variation. However, to increase the pressure sensitivity, thickness of the silicon membrane must be reduced.

According to these Figures 6 and 7, the two parameters have an tremendous effect on the resistivity and, hence, on the piezoresistivity. Thus, when these geometric parameters are great, this leads to reduce the self heating. In contrast, it is important to remember that this solution can have consequences on the mechanical and technological behaviour of the sensors, specifically on its pressure sensitivity and reliability on the one hand and on its size on the other hand.

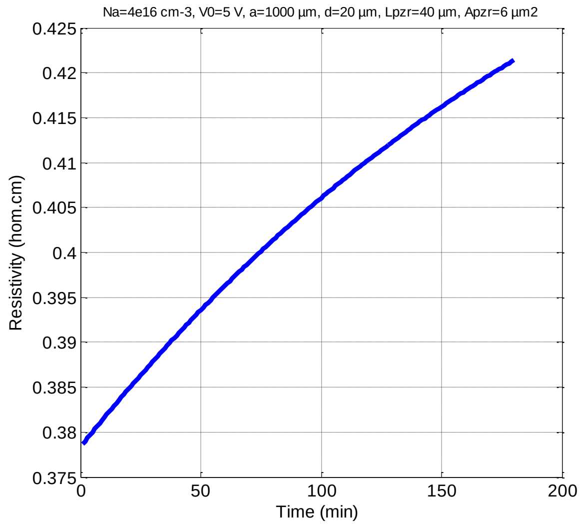

Figure 5. Resistivity variation with operating time

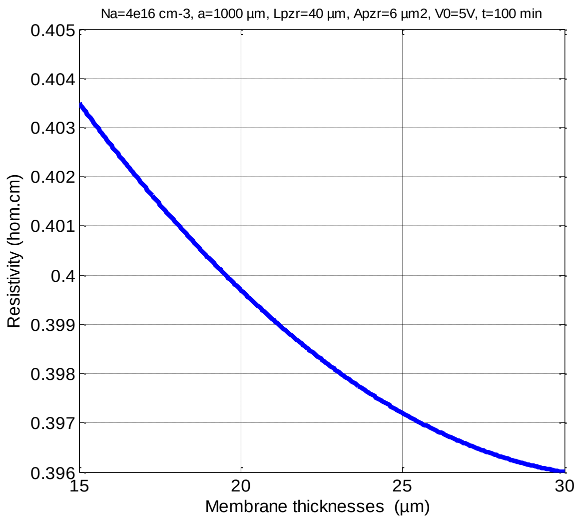

Figure 6. Resistivity variation vs membrane thicknesses

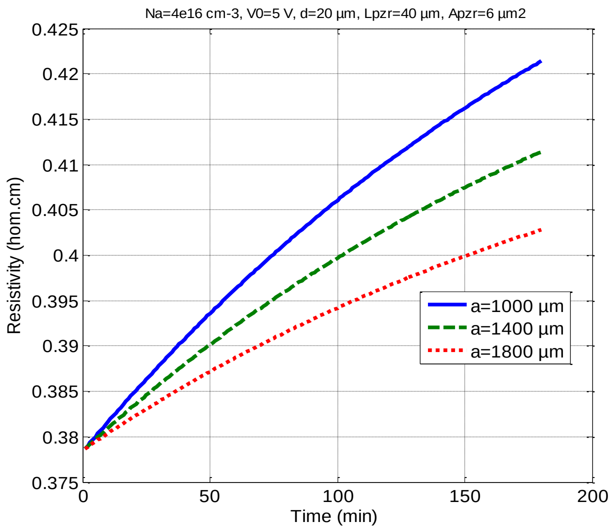

Figure 7. Variation of resistivity in time for different membrane wide *a*

3.3. Influence of time and of doping concentrations on the resistivity

In the same way, we have varied the operating time and doping level with the fixing of the other parameters. We found that the resistivity decreases by increasing the doping level as shown in Figure 8. Afterwards, the ρ_e becomes independent of the operating time for high doping concentrations. So, the change in resistivity can be reduced by increasing the doping concentration.

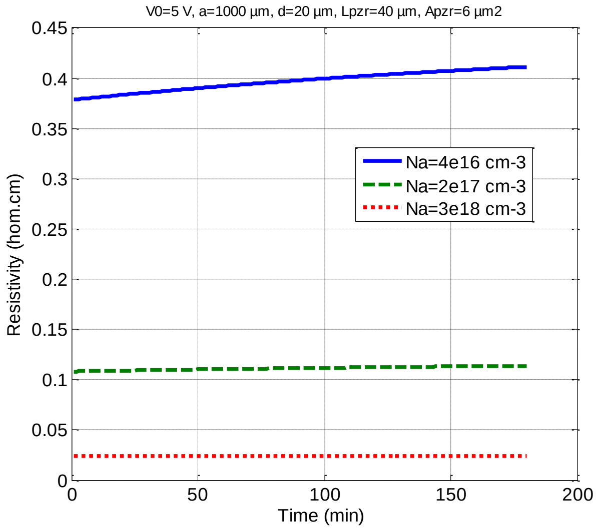

Figure 8. Resistivity variation vs time for different doping concentrations

3.4. Influence of applied voltage on the resistivity

The effect of the bias voltage in the resistivity is plotted in Figure 9. It is noticed that the ρ_e observes an increase when the applied voltage is increased. This is apparently due to the phenomenon of internal heating in the piezoresistor. As we have pointed out earlier, the applied voltage involves a rise in temperature subsequently it leads to an increase in resistivity. To summarize, the increase in resistivity due to the application of a voltage of a bridge appeared low, but it leads to drifts in the sensor response.

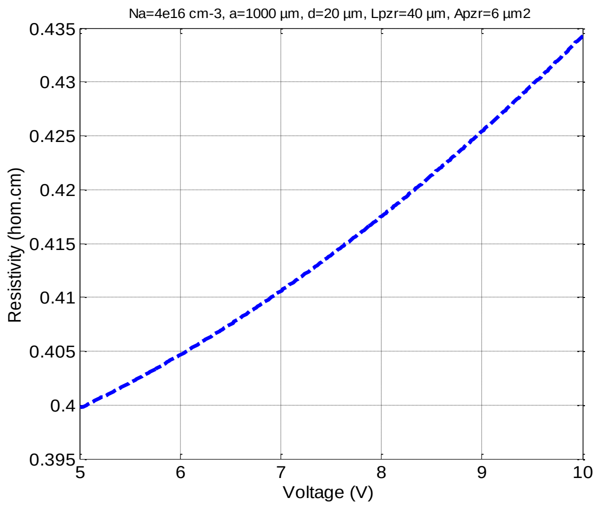

Figure 9. Resistivity variation vs voltage

3.5. Effect of temperature rise generated by electric heater on sensitivity

The output characteristics of the piezoresistive pressure sensors in terms of sensitivity is of great importance. The sensitivity of these sensors is an essential characteristic to optimize their output response. In the center of the square-shaped diaphragm of thickness d and length a, their sensitivity is expressed in (14) [28]:

$$S(T) = 0.1479\left(\frac{a}{d}\right)^2 \pi_{44}(N_0, 300K)P(N,T) \quad (14)$$

where π_{44} is the piezoresistive coefficient established by [29].

As mentioned earlier in Figure 3, for a bias voltage of 5 V and for 100 min of the operating time of the device, the temperature rise caused by electric heater can reach 45 °C. This encouraged us to study the influence of temperature on sensitivity when the temperatures rise from room temperature to 45 °C. Accordingly, it can be established by coupling the change of temperature as a function of time from the used model in (13) with (14). It has also been observed in Figure 10 that the sensitivity decreases almost linearly with temperature. Subseqeuently, it causes a drift in the output characteristics of the sensor upon application of a voltage. So, the results revealed that the self-heating effect on the sensitivity is significantly reduced for a short operating time and for a low applied voltage.

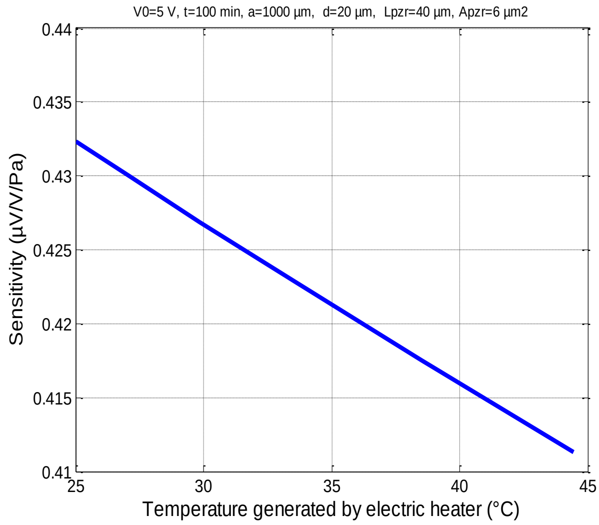

Figure 10. Variation of sensitivity vs temperature rise induced by self-heating

4. CONCLUSION

In summary, this research has confirmed that it is possible to model, accurately the thermal drift provoked by bias voltage in piezoresistive pressure sensors, by coupling the finite difference model for a self heating whit these of the Arora mobility. The model developed gives an opportunity to study the temperature rise created by supply voltage in such sensors. The results proved that low bias voltage should be applied to lessen electric heater on the piezoresistivity effect, which is characterized by change of resistivity. They furthermore show that the evolution of temperature is proportional to the time and takes a steady state value from 100 min. So, the self heating effect is reduced substantially for a short operating time of sensor.

In addition, we have attempted to study the geometric influence parameters on the resistivity to optimize the performance of the device. The results showed that the resistivity decreases as the geometric parameters of the membrane increase. Therefore, self heating can be reduced, when these parameters are great. Nevertheless, these parameters are themselves limited by: the dimensions of the sensor, the pressure sensitivity and reliability. It can be also reduced as a high doping level as possible it is used.

To sum up, this paper allows us to evaluate the furthermore. We have also endeavored to study the influence of the temperature rise induced by the Joule heating on the sensitivity of the sensor. The results confirmed that the sensitivity is a decreasing function of temperature rise. So, to reduce thermal sensitivity, a low supply voltage must be applied. Reliability of the device it equally permits to improve the output characteristics of the sensor according to the application for which it is dedicated.

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REFERENCES

[1] G. Hu, F. Huang, C. Tang, J. Gu, Z. Yu, and Y. Zhao, "High-performance flexible piezoresistive pressure sensor printed with 3D microstructures," *Nanomaterials*, vol. 12, no. 19, pp. 1–16, 2022, doi: 10.3390/nano12193417.

[2] R. Gao *et al.*, "Design, fabrication, and dynamic environmental test of a piezoresistive pressure sensor," *Micromachines*, vol. 13, no. 7, pp. 1–15, 2022, doi: 10.3390/mi13071142.

[3] B. Tian, H. Shang, L. Zhao, D. Wang, Y. Liu, and W. Wang, "Hermeticity analysis on SiC cavity structure for All-SiC piezoresistive pressure sensor," *Sensors*, vol. 21, no. 2, pp. 1–11, 2021, doi: 10.3390/s21020379.

[4] L. Lin, H.-C. Chu, and Y.-W. Lu, "A simulation program for the sensitivity and linearity of piezoresistive pressure sensors," *Journal of Microelectromechanical Systems*, vol. 8, no. 4, pp. 514–522, 1999, doi: 10.1109/84.809067.

[5] Z. Kordrostami, K. Hassanli, and A. Akbarian, "MEMS piezoresistive pressure sensor with patterned thinning of diaphragm," *Microelectronics International*, vol. 37, no. 3, pp. 147–153, 2020, doi: 10.1108/MI-09-2019-0060.

[6] Z. Yao *et al.*, "A high-temperature piezoresistive pressure sensor with an integrated signal-conditioning circuit," *Sensors*, vol. 16, no. 6, pp. 1–12, 2016, doi: 10.3390/s16060913.

[7] M. Z. Ansari and C. Cho, "A conduction-convection model for self-heating in piezoresistive microcantilever biosensors," *Sensors and Actuators A: Physical*, vol. 175, pp. 19–27, 2012, doi: 10.1016/j.sna.2011.12.014.

[8] A. M. L. Lanzolla, F. Attivissimo, G. Percoco, M. A. Ragolia, G. Stano, and A. Di Nisio, "Additive manufacturing for sensors: piezoresistive strain gauge with temperature compensation," *Applied Sciences*, vol. 12, no. 17, pp. 1–14, 2022, doi: 10.3390/app12178607.

[9] M. Aryafar, M. Hamedi, and M. M. Ganjeh, "A novel temperature compensated piezoresistive pressure sensor," *Measurement: Journal of the International Measurement Confederation*, vol. 63, pp. 25–29, 2015, doi: 10.1016/j.measurement.2014.11.032.

[10] B. Tian, H. Shang, and W. Wang, "Research on temperature zero drift of sic piezoresistive pressure sensor based on asymmetric Wheatstone bridge," *Silicon*, vol. 14, no. 10, pp. 5445–5451, 2022, doi: 10.1007/s12633-021-01330-x.

[11] C. Pramanik, S. Banerjee, D. Mukherjee, and H. Saha, "Development of SPICE compatible thermal model of silicon MEMS piezoresistive pressure sensor for CMOS- MEMS integration," in *Proceedings of IEEE Sensors*, 2006, pp. 761–764, doi: 10.1109/ICSENS.2007.355580.

[12] H. Wang, D. Zou, P. Peng, G. Yao, and J. Ren, "A novel high-sensitivity MEMS pressure sensor for rock mass stress sensing," *Sensors*, vol. 22, no. 19, pp. 1–15, 2022, doi: 10.3390/s22197593.

[13] X. Ren, X. Liu, X. Su, and X. Jiang, "Design and optimization of a pressure sensor based on serpentine-shaped graphene piezoresistors for measuring low pressure," *Sensors*, vol. 22, no. 13, pp. 1–19, 2022, doi: 10.3390/s22134937.

[14] Q. Meng, Y. Lu, J. Wang, D. Chen, and J. Chen, "A piezoresistive pressure sensor with optimized positions and thickness of piezoresistors," *Micromachines*, vol. 12, no. 9, pp. 1–13, 2021, doi: 10.3390/mi12091095.

[15] A. V. Tran, X. Zhang, and B. Zhu, "Mechanical structural design of a piezoresistive pressure sensor for low-pressure measurement: a computational analysis by increases in the sensor sensitivity," *Sensors*, vol. 18, no. 7, pp. 1–15, 2018, doi: 10.3390/s18072023.

[16] Y. Duan, S. He, J. Wu, B. Su, and Y. Wang, "Recent progress in flexible pressure sensor arrays," *Nanomaterials*, vol. 12, no. 14, pp. 1–25, 2022, doi: 10.3390/nano12142495.

[17] P. Song *et al.*, "Recent progress of miniature MEMS pressure sensors," *Micromachines*, vol. 11, no. 1, pp. 1–38, 2020, doi: 10.3390/mi11010056.

[18] K. Salah and K. Fouad, "Performance optimization of pressure sensor based on suspended gate MOSFET," *Advanced Engineering Forum*, vol. 30, pp. 43–53, 2018, doi: 10.4028/www.scientific.net/aef.30.43.

[19] A. Beddiaf, F. Kerrour, L. Merouani, and A. Rachid, "Effect of thermal drift in sensitivity of pressure sensor," in *ACM International Conference Proceeding Series*, 2016, pp. 158–161, doi: 10.1145/3029610.3029617.

[20] A. Beddiaf, F. Kerrour, and S. Kemouche, "A numerical model of Joule heating in piezoresistive pressure sensors," *International Journal of Electrical and Computer Engineering (IJECE)*, vol. 6, no. 3, pp. 1223–1232, 2016, doi: 10.11591/ijece.v6i3.pp1223-1232.

[21] A. Beddiaf and F. Kerrour, "Study of the impact of thermal drift on reliability of pressure sensors," *Journal of Engineering Science and Technology*, vol. 12, no. 10, pp. 2677–2690, 2017.

[22] M. Z. Ansari and B. S. Gangadhara, "Piezoresistivity and its application in nanomecanical sensors," *Procedia Materials Science*, vol. 5, pp. 1308–1313, 2014, doi: 10.1016/j.mspro.2014.07.447.

[23] F. Kerrour, A. Boukabache, and P. Pons, "Modelling of thermal behavior N-doped silicon resistor," *Journal of Sensor Technology*, vol. 02, no. 03, pp. 132–137, 2012, doi: 10.4236/jst.2012.23019.

[24] H. Djelti, "Numerical investigation of the performance of AlGaN/GaN/BGaN double-gate double-channel high electron mobility transistor," *International Journal of Electrical and Computer Engineering*, vol. 12, no. 3, pp. 2655–2662, 2022, doi: 10.11591/ijece.v12i3.pp2655-2662.

[25] N. D. Arora, J. R. Hauser, and D. J. Roulston, "Electron and hole mobilities in silicon as a function of concentration and temperature," *IEEE Transactions on Electron Devices*, vol. 29, no. 2, pp. 292–295, 1982, doi: 10.1109/T-ED.1982.20698.

[26] I. Ali *et al.*, "A highly accurate, polynomial-based digital temperature compensation for piezoresistive pressure sensor in 180 NM CMOS technology," *Sensors*, vol. 20, no. 18, pp. 1–19, 2020, doi: 10.3390/s20185256.

[27] M. Jiao *et al.*, "Temperature compensated wide-range micro pressure sensor with polyimide anticorrosive coating for harsh environment applications," *Applied Sciences*, vol. 11, no. 19, pp. 1–13, 2021, doi: 10.3390/app11199012.

[28] A. Boukabache, "Conception, modélisation et réalisation d'un capteur de pression piézoresistif à faible dérive thermique," University of Constantine, 1993.

[29] Y. Kanda, "A graphical representation of the piezoresistance coefficients in silicon," *IEEE Transactions on Electron Devices*, vol. 29, no. 1, pp. 64–70, 1982, doi: 10.1109/T-ED.1982.20659.

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