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Modeling and Analysis of pressure sensor with Single Walled Carbon Nanotubes for piezoresistive transduction

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Abstract

The paper deals with modeling of piezoresisitive pressure sensors with Single Walled Carbon Nanotubes (SWCNTs) located on square diaphragm in three different orientations using COMSOL Multiphysics. The sensitivity of the pressure sensors with these configurations are evaluated. The output voltage responses of all three cases are plotted and compared. It is found that the response of the proposed configuration with two SWCNTs diametrically opposite at the edge and other two near the center has a sensitivity of 0.23mV/kPa which is about 43% better in comparison to the other two configurations studied earlier.

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Keywords: COMSOL Multiphysics; Piezoresistance; Pressure sesnor; Square diaphragm; SWCNT.

1. Introduction

Pressure sensors are devices that integrate the mechanical elements with electrical circuitry on a single chip to convert displacement generated by pressure into electrical signals Tai-Ran Hsu (2002). Among the different transduction techniques used for pressure sensing, piezoresistive transduction finds many advantages such as linear output response, high sensitivity, relatively small size and stable output with respect to temperature and age Minhang Bao (2005).

Piezoresistive transducers work on the principle of change in resistance of the sensing element due to the applied pressure or strain acting on it S. Sugiyama et al. (1983). The sensitivity of a piezoresistive pressure sensor depends

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on the amount of change in resistance of the sensing material with respect to pressure applied. Developing a material which possesses higher changes in resistance with respect to a small change in pressure is a challenge and is pursued in many earlier investigations. Some of the piezoresistive materials used there for sensing are metal foils P.F. French and A.G.R. Evans (1989), semiconductors/doped-semiconductors C.S. Smith (1954), composites with semi-conducting Carbon Nanotubes (CNTs) Zhi-Min Dang et al. (2008). Single Walled Carbon Nanotubes (SWCNTs) have been found to possess piezoresistance inherently in them and are widely employed for pressure sensing L. Yang and J. Han (2000), owing to their smaller size S. Iijima (1991).

Mechanical pressure sensors generally consist of a diaphragm as sensing element, square shape being preferred on account of its high strain transition Tai-Ran Hsu (2008). The strain in the diaphragm is converted to change in resistance by piezoresistors placed on the diaphragm. The strain at different points on the diaphragm varies and the positioning of the piezoresistors appropriately determines the sensitivity. The positioning of piezoresistor in particular locations on the diaphragm to harness higher strain transition in order to achieve better sensitivity is attempted in earlier research works Minhang Bao (2005), Tai-Ran Hsu (2008). The study of MEMS mechanical sensors is generally carried through modeling for their performance, using Computer Aided Design tools based on Finite Element Analysis (FEA) such as ANSYS, CoventorWare, COMSOL etc T M Kamel et al. (2010), Giorgio De Pasquale et al (2010). These provide multiphysics modules for analysis of materials like piezoresistors and thus are widely used. A study of diaphragm pressure sensor with CNT piezoresistive units for performance with respect to positioning of CNTs is needed at this point of time. Thus, the following study is an attempt on such modeling of a pressure sensor.

In this paper, a square-diaphragm pressure sensor with three different orientations of SWCNTs is modeled and analyzed using COMSOL Multiphysics. The output responses of piezoresistors are fed to the Wheatstone bridge to yield a voltage output signal as indication of the pressure Karl Hoffmann (1986). Thus, a diaphragm piezoresistive sensor is virtually prototyped to study its output voltage with respect to measurand pressure. The configuration of CNTs proposed with the intention of harnessing the higher strain transition is studied along with other two earlier propositions.

2. Analysis of SWCNT square-diaphragm pressure sensor

A pressure sensor with square diaphragm of silicone dioxide (SiO_2) measuring 200x200nm and thickness 10nm is considered for analysis. Placing of piezoresistive transducer elements on square diaphragm is very crucial to achieve the required sensitivity. Two configurations proposed by earlier authors Minhang Bao [A] and Tai-Ran Hsu [B] are considered along with our own proposition for placing the piezoresistors [C]. In configuration A, all piezoresistors are placed very close to the periphery on the same side of the diaphragm, where two of them are perpendicular and the other two parallel to its edge as suggested by Minhang Bao (2005). In this, all the four piezoresistors are located in the region of maximum compressive strain. In configuration B, the piezoresistors are placed at the mid section of each edge of the diaphragm such that two are parallel and other two are perpendicular to edges Tai-Ran Hsu (2008). In this case also, all the four piezoresistors are placed in the region of maximum compressive strain.

The proposed configuration utilizes positions which can improve sensitivity by virtue of large difference in resistance between piezoresistors experiencing opposite strains, tensile and compressive. As the maximum positive strain is prevailing at the center and maximum negative strain at the edges, K. Yamashita et al. (2007) the configuration C is proposed to take advantage of this high strain transition.

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