ABSTRACT

The MEMS industry has expanded rapidly in recent years, and more devices are being made utilizing MEMS technology. Therefore, considerable amount of research is directed towards developing efficient MEMS based devices and components. MEMS-based integrated circuit (IC) products created a US$ 5 billion market in year 2005, which is forecasted to grow to over to US$ 12-17 billion by 2015. Among the various sensing mechanisms available for the sensor, piezoresistive type is the most widely used due to a good linear input-output relationship, small size, easy integration with electronics and a well matured fabrication process. The burst pressure approach has been utilized to design a pressure sensing diaphragm by considering the thickness and side length of the diaphragm for better sensitivity and safety factors. However, data regarding burst pressure approach including the maximum deflection of the diaphragm is limited. Compared to the conventional silicon pressure sensors, carbon nanotube based sensors exhibit greater sensitivity and a higher gauge factor. By using the polymer SU-8 as the pressure sensing diaphragm with carbon nanotubes as piezoresistors the sensitivity can be further increased and the pressure sensing ranges can be extended. The objective of the work was to investigate the effect of design parameters like membrane side length, thickness, and geometry and the role played by the material properties of the membrane in determining the performance of the device and to fabricate and characterize a SU-8 based piezoresistive MEMS pressure sensor with integrated multiwalled carbon nanotubes as piezoresistors for low pressure measurements. To fulfill the objective, a detailed finite element analysis was done using ANSYS 12.0 for square and rectangular diaphragms of silicon and SU-8 for varying side lengths and thickness. The stress profiles across various diaphragms were studied to decide the positioning of piezoresistors and to study the effect of piezoresistor dimensions piezoresistive analysis was done using the finite element tool Intellisuite.

During fabrication the silicon substrate was cleaned and a 1 µm thick oxide was grown on the wafer using the tempress furnace. The back side of the oxide grown wafer was patterned using a double sided mask aligner and rectangular diaphragms were released by dry etching of silicon using the SPTS DRIE system. The front side of the wafer was spin coated with SU-8 which was later sputtered with chrome and...
gold films using the Aneleva RF sputtering equipment. The electrodes were patterned on the chrome gold film using a prewritten mask and etching of gold and chrome was done to realize the electrodes. Images of the electrodes were taken using the Leica optical microscope and Scanning Electron Microscope (SEM). Carbon nanotubes were aligned across the electrodes by AC electrophoresis and the current voltage characteristics of the device was studied using the Agilent device analyser. The Young’s modulus of the material was determined using the Hysitron Triboindenter and the Raman spectrum of the aligned carbon nanotubes was obtained the LabRam Raman spectrometer.

Using the burst pressure approach the dimensions of the square and rectangular silicon sensors and that of a SU-8 sensor were optimized. From the study of the stress profile the stress concentration areas were identified, and it was found that the induced stress remains more uniform at the centre of a rectangular diaphragm than a square one thus making the placement of the piezoresistors in that area less error prone during fabrication. The piezoresistors were placed in various patterns in those areas and the sensitivities were determined. The maximum sensitivity was 41.6 mV/V/bar for the square diaphragm and 28.8 mV/V/bar for the rectangular one. Square diaphragms were found to be more sensitive than rectangular ones. The variation in the length of the piezoresistor plays a greater role in determining the sensitivity of the sensor than width and thickness variations. In general, piezoresistors of smaller dimensions were found to be more sensitive. SU-8 based diaphragms exhibited more sensitivity than silicon diaphragms.

In the fabrication process, diaphragms of size 800 µm x 500 µm were realized. Electrodes of three different shapes were patterned on the SU-8 surface. From the optical and SEM images the gap between the electrodes was found to vary from 5 to 15 µm and the CNT network aligned across the electrodes was visible. From the study of the electrical characteristics the CNTs were found to be metallic with resistances varying from 20 kΩ to 1805 kΩ. The resistance of the sensor was found to vary with applied pressure. From the nano indentation studies the Young’s modulus of SU-8 was found to be 7 GPa. The Raman spectrum of the sensor exhibited the two main typical CNT bands a G-band (Graphite band) at 1590 cm⁻¹ and a D- band (Disorder band) at 1350cm⁻¹. The fabricated sensor can be improvised to a biomedical sensor for measuring low pressures.