Abstract

MEMS micro-accelerometers have a wide range of applications, particularly in aerospace and automobile fields, for inertial parameter measurements and vibration monitoring. These are also used in robotics and modern medical diagnostic systems for monitoring and controlling motion of moving objects. Very recently, MEMS accelerometers have been proposed for use in automobile pollution control. Amongst various sensing mechanisms, piezoresistive sensing is popular and widely used due to the simplicity of fabrication and packaging methods. Although continuous improvement in terms of input range, sensitivity and frequency response has been achieved in piezoresistive accelerometers, cross-axis sensitivity and nonlinearity of these devices are still a critical issue in design and development. The present doctoral research work deals with the detailed experimental investigations on MEMS piezoresistive accelerometers that include both design and fabrication, with modified device structures and innovative process techniques to improve the device performance for air craft motion sensing. Various mechanical configurations of cantilever and fixed-fixed beam-mass structures were simulated to determine the induced stress due to in-plane and out-of-plane accelerations. Amongst various designs, the quad fixed-fixed beam structure was found to be the most suitable for the intended application in the present study. The proposed structure consists of a heavy suspended proof mass anchored to a rigid frame via four thin flexures oriented along one axis of the proof mass. Boron diffused piezoresistors located near the fixed ends of the flexures are used for sensing the induced stress and hence acceleration. A detailed simulation has been carried out on the quad beam accelerometer to optimize the structural dimensions of parts like flexures, proof mass, piezoresistors, and the boron doping concentration of the piezoresistors, using a commercially available finite element method based software called CoventorWare™, for achieving the target specifications for maximum prime-axis sensitivity and minimum cross-axis sensitivity and non-linearity and other important parameters. The basic accelerometer structure was fabricated by the bulk micromachining process using a 5% tetra methyl ammonium hydroxide (TMAH) etchant doped with silicic acid and ammonium peroxodisulfate. Test results showed an average sensitivity of 0.111 mV/Vg along the direction perpendicular to the proof mass plane (prime axis) and a maximum sensitivity for in-plane acceleration, which is 1.68% of prime-axis sensitivity. Subsequently, the mechanical design was modified to align the flexures in line with the proof mass edges for the reduction of cross-axis sensitivity. Test results of the modified structure show a 63% reduction of sensitivity along the direction of the flexure width as compared to the previous design. Performance of the sensor was further improved by incorporating a gold layer on the proof mass surface. A major hurdle to incorporate patterned gold layer by lithographic process is the galvanic corrosion of aluminum interconnection lines present in the device by different etchants. Thus, an innovative process step involving silicon shadow mask technique was used to deposit a Cr/Au seed layer on selected region of the proof mass followed by electroplating process to achieve ~20 µm thick gold layer. For electroplated gold dimensions of 2500 µm x 2500 µm x 20 µm, the prime-axis sensitivity is increased by 21.8% with maximum cross-axis sensitivity reduction of 7.6% as compared to the device without electroplated gold. In order to improve the performance further, the thickness of the electroplated proof mass was reduced by selective anisotropic etching from the bottom. It raises the centre of mass of the proof mass that leads to a further reduction of the cross axis sensitivity. The prime-axis and cross-axis sensitivity thus obtained for a typical structure are 85.8 µV/Vg and 0.324 µV/Vg respectively. The calculated performance factor of 586.5 kHz is better than other reported results.

Keywords: MEMS, Piezoresistive accelerometer, Prime-axis sensitivity, Cross-axis sensitivity, Electroplating, Shadow mask, Bulk micromachining, TMAH etchant, Galvanic corrosion, Damping analysis, Temperature sensitivity