Study on Silicon Piezoresistive Six-Degree of Freedom Micro Force-Moment Sensors and Application to Fluid Mechanics

DZUNG VIET DAO

The purpose of this thesis is to create a miniaturized silicon piezoresistance 6-DOF micro force-moment sensor. Previous work used many piezoresistors, so it is difficult to miniaturize. In this thesis we found a novel arrangement of piezoresistors and selection of crystallographic orientation. As a result, the total number of piezoresistors is less than half that of previous work.

The thesis consists of 7 Chapters. Chapter 1 gives a thorough review on multi-axis force-moment sensors, summarizes the state of the art and current problems of them, and describes our solutions to these problems. Chapters 2 and 3 review the relevant theory on fundamental and advanced matters on elasticity theory and the piezoresistance effect in silicon, taking into account of cubic anisotropic property, and these are used for designing the 6-DOF sensing chip in Chapter 4. The crossbeam structure has been adopted as the fundamental structure of the sensing chip. Stress analysis was carried out based on elasticity and FEM. Based on the results of stress analysis and the fracture stress of silicon, allowable loads on the sensing chip were determined. Based on the piezoresistance effect, the relation between arrangement of piezoresistor on the crossbeam, crystallographic orientation and the sensitivity was investigated. It was found that by choosing the crystal planes (100) or (111), a suitable arrangement yielded a total number of piezoresistors less that 20. Chapter 5 describes fabrication of piezoresistors by impurity diffusion on device layer in SOI wafer, and fabrication of the crossbeam structure by bulk micro machining of SOI wafer using ICP-RIE. Chapter 6 presents the calibration method and characteristics of the fabricated sensing chip. Small forces and moments were applied to the sensing chip by a nano indenter. The sensitivity, crosstalk, and non-linearity were quantitatively determined. Application of the sensor to measure forces and moments acting on a bed-mounted particle in a turbulent flow of water is described in Chapter 7. The three most important components, i.e. the lift (vertical force Fz), he drag (tangential force Fx) and the roll-up moment have been measured and compared with other experimental data and with simulations. The power-law dependence of force on flow velocity agrees reasonably with available empirical and simulation correlations.