A Computational Approach for Simulating P-Type Silicon Piezoresistor Using Four Point Bending Setup

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Abstract

The piezoresistance effect is defined as change in resistance due to applied stress. Silicon has a relatively large piezoresistance effect which has been known since 1954 [1]. A four point bending setup is proposed and designed to analyze the piezoresistance effect in p-type silicon. This setup is used to apply uniform and uniaxial stress along the <110> crystal direction [2]. The main aim of this work is to investigate the piezoresistive characteristic of p-type resistors as a function of doping concentrations using finite element modeling. Simulation results are compared with experimental data. [3]

A four point bending setup is modeled using COMSOL Multiphysics®. The 3D geometry comprises three main components including a top support block, bottom support block and silicon beam (as depicted in Figure 1). The support blocks are both made of plastic (Delrin). A 2 mm square area is allocated at the centre top surface of the silicon beam for placement of the silicon piezoresistors (as demonstrated in Figure 2). To investigate the piezoresistance effect, a two terminal resistor configuration with dimension of 500 × 20 µm is included to determine the resistance change when the silicon beam is subjected to external loading. Four different doping concentration values are used for the piezoresistors namely; 1.0×1019cm-3, 7.6×1019cm-3, 1.2×1020cm-3 and 1.3×1020cm-3. A thin conductive layer with doping concentration of 1.5×1020 cm-3 is defined for the contact regions.

During simulation, a downwards force is applied to the silicon beam; the resultant displacement and stress are recorded. Figure 3 illustrates the principle stresses across the length of silicon bar subjected to 3N downwards force. It can be observed that the centre stress at the surface of silicon beam between two inner supports is uniform and uniaxial (dominated by stress in the x direction). Figure 4 depicts the change in resistance as a function of force up to 3N for the four doping concentration values. The result demonstrates that the resistance change is linearly proportional to applied stress for small force application. Results also show that the piezoresistance effect decreases as doping concentration increases, a trend that is confirmed with experimental measurements.

COMSOL Multiphysics® was employed to investigate piezoresistive effect in p-type silicon for a range of doping concentrations. Simulation results demonstrate a similar trend to experimental results and show that the piezoresistance effect decreases as the doping

concentration increases. The stress and deflection on the silicon beam using a four point bending setup were also simulated.

Reference

1. C.S. Smith, "Piezoresistance effect in germanium and silicon." Physical review 94.1, 42 (1954).
2. R. E. Beaty, R. C. Jaeger, et al., "Evaluation of piezoresistive coefficient variation in silicon stress sensors using a four-point bending test fixture," IEEE Trans. Compon., Hybrids, Manuf. Technol. 15, 904 (1992).
3. T. H. Tan, S.J.N Mitchell et al., "Evaluation of the piezoresistance properties of p-type silicon," 23rd Micromechanics and Microsystems Europe, Ilmenau, Germany, (2012).

Figures used in the abstract

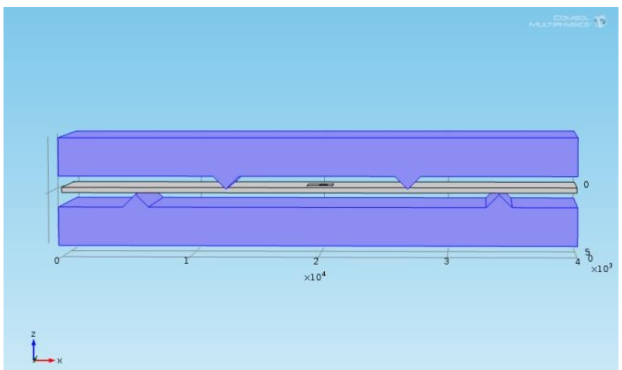

Figure 1: 3D geometry of four point bending setup

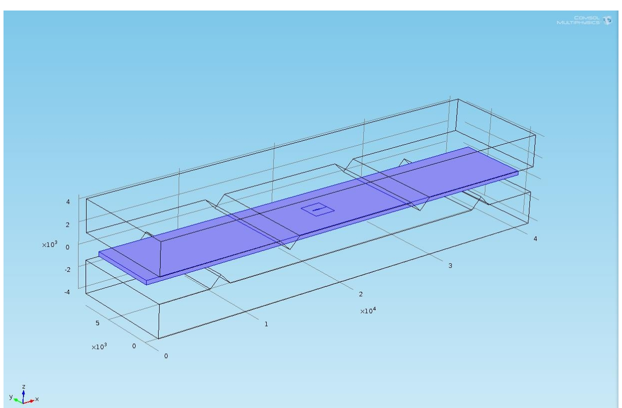

Figure 2: Location of 2 mm square and piezoresistor at the surface of silicon beam

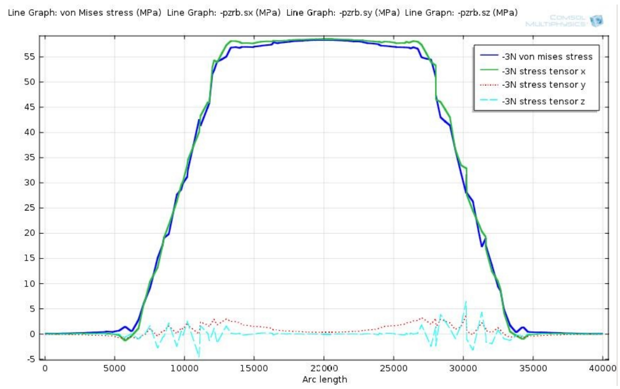

Figure 3: Principal stresses across silicon beam subjected to -3N load

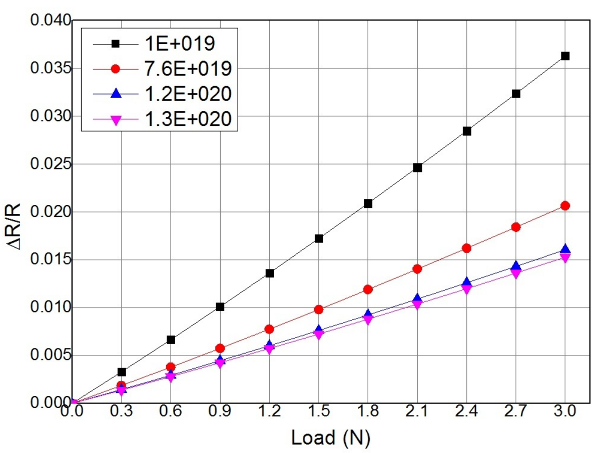

Figure 4: Resistance change vs load applied for a range of doping concentrations