

# FABRICATION OF A THREE-COMPONENT FORCE SENSOR USING MICROFABRICATION TECHNOLOGY AND ITS EVALUATION

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## ABSTRACT

This paper describes the development of a three-component silicon-based force sensor with a square membrane using bulk micromachining process. The designed sensor, with size of 2 mm x 2 mm, has a maximum force range of 5 N in the  $x$ ,  $y$ , and  $z$  direction. Optimal locations of piezoresistors were determined by the strain distribution obtained from finite element analysis and beam theory. Finally three Wheatstone bridge circuits were arranged and verified under  $F_x$ ,  $F_y$ , and  $F_z$  loading conditions. The silicon-based sensor was fabricated using bulk microfabrication technology(MEMS). The piezoresistors for measuring the change of resistance, like strain gage, were embedded in silicon wafer (Si) using ion-implantation diffusion technique. An epoxy mesa(SU-8) is built-up on top of the silicon to convert an applied force to a distributed stress. Finally, the membrane of the sensor was fabricated by using bulk-micromachining process based on the anisotropic etching of the silicon. The ability of the sensor to measure both normal and shear forces is investigated and demonstrated through experimental characterization such as normal and shear sensitivity, repeatability, hysteresis and linearity.

## 1. INTRODUCTION

Generally some force sensors (load cell) based on strain gages have been used to monitor the durability of bridges or buildings from the viewpoint of safety and control material test machines and industry robots, and so on. Especially, in case of robot, the sensor used as wrist of robot hand can control and manipulate the grasping force/torque of some objects. However, it is not available to use the multi-component sensor based on strain gages when robot want to grasp arbitrary objects dexterously like humans. Additionally, its size can also make the dexterous manipulation difficult because it is not possible to handle small objects. Recently as some systems need high sensitivity and accuracy, a new force sensor with small size and high sensitivity, not some conventional load cells, is required to develop. On the other hand, recently micromachining technology (MEMS: micro electro mechanical system), combining integrated circuit fabrication and micromachining fabrication, shows the possibility of development of micro force sensor similar to pressure sensor.

Especially, some researchers have tried to develop a tactile sensor comprised of some small force sensors for tele-operational manipulators, intelligent robots, and haptic interfaces. These tactile sensors can detect normal forces applied on the tactile pixels for gripping force control and generate tactile images for gripping positioning and object recognition. However, in addition to acquiring tactile images and normal forces, knowledge of tangential forces is also critical for force control, and thus, the silicon-based force sensor is required to measure three components. Kane et al.[1] and Mei et al.[2] have fabricated a tactile sensor composed of some three-component force sensors with square membrane type using micromachining technology to show the possibility of realization of tactile sensor. Its fabrication is, however, not easy because of complexity of process and shape of the sensing element. Meanwhile, Wang and Beebe[3] also manufactured a micro shear force sensor with square-membrane type. The fabrication process of sensor is simple, but the sensitivity and temperature compensation of the sensor was not considered. Thus this paper presents a design of three-component force sensor based on the silicon micromachining technique and its evaluation using tester based on three-component load cell.

## 2. DESIGN OF SENSING ELEMENT FOR FORCE SENSOR

Figure 1 shows a square-type sensing element of force sensor which can measure three-component force,  $F_x$ ,  $F_y$  and  $F_z$ . The sensing element consists of membrane, loading block and side block. The total length of membrane is  $2L + d$ , the length and height of loading block being  $d$ ,  $h$  and the thickness of membrane being  $t$ . The three-component force was applied to the upper surface of the loading block as shown in Figure 1. In case of  $F_x$  or  $F_y$  loading, the loading block can improve the sensitivity due to the effect of moment,  $F_x h$  or  $F_y h$  compared with only pure loading  $F_x$ ,  $F_y$ . Meanwhile the loading block and the side block were assumed as a rigid body due to thick thickness compared with thin membrane of sensing element.

**Figure1:** Schematic diagram of a sensing element subjected to  $F_x$ ,  $F_y$  and  $F_z$  loadings.

We designed the silicon-based force sensor as shown in Figure 2, in which the size of the sensor has  $2.404 \text{ mm} \times 2.404 \text{ mm}$ , and its thickness being  $70 \text{ }\mu\text{m}$ . The sensing element of the force sensor was fabricated by  $\{100\}$  silicon wafer which has  $500 \text{ }\mu\text{m}$  thickness. The rated capacity of each loading is  $5 \text{ N}$ , which is within force range necessary to feeling of texture when human touch on surface of object[4]. In case of  $\{100\}$  wafer, the supporting block of sensing element has  $54.74$