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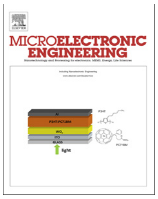

Development and application of planar piezoresistive vibration sensor

Lan Zhang, Jian Lu *, Yuichi Kurashima, Hideki Takagi, Ryutaro Maeda

Research Center for Ubiquitous MEMS and Micro Engineering (UMEMSME), National Institute of Advanced Industrial Science and Technology (AIST), Tsukuba, Ibaraki 305-8564, Japan

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ABSTRACT

By using the surface piezoresistor diffusion method and front-side-releasing micromachining technique, we successfully developed a planar piezoresistive vibration sensor with less process cost, simple structure and less package difficulties. The functional features of the fabricated planar vibration sensors, including the amplitude–frequency response and random vibration response, have been evaluated comprehensively. As the results shown, the vibration sensor has reasonably good sensitivity performance (Min. detectable acceleration: 0.01 g at the Min. responsible frequency of 4 Hz; stable output at the measured signal with frequency >6 Hz and amplitude >0.05 g) for many applications: e.g. as the motion sensor for checking the health condition of human beings, or as the monitor sensor for monitoring the safety and security of infrastructure.

1. Introduction

Recently, with the development of microelectromechanical systems (MEMS) technique, MEMS-based sensors has found many applications in many areas, including pressure measuring [1,2], temperature and humidity sensing [3,4], angular accelerometer, moving track testing [5], and so on. On the other hand, online real-time monitoring of the health condition of civil structures, e.g. historical buildings, aged bridges, is indispensable to reduce the risk of accidents, which can be reinforced by advances of MEMS devices. For the target application, MEMS sensors should have stable performances in-sensitive to environments, low power consumption, easy signal processing, and less integration difficulties.

State-of-the-art microfabricated accelerometers have undergone a number of advances. The capacitive and piezoelectric (PE) sensors are increasingly used in applications for sensing various physical phenomena [6–8]. Both the capacitive- and PE-based vibration sensors are employing the high sensitivity for vibration action measuring. However, for capacitive gauge accelerometers, to avoid environmental effects to device performance of MEMS devices, the high quality vacuum or inert sealing is usually requested, which induces additional high cost for packaging. For PE-based gauge accelerometer, the difficulties of PE-material preparation in the fabrication processes and shortcoming of PE-material property in integrating procedure are restricting its development and application.

Piezoresistance is an alternative effect that operates on the principle that the electrical resistance changes with deformation and is a widely used effect for semiconductor-based sensing. Piezoresistive gauges are insensitive to environmental degradation and have a straightforward approach for signal detection. Packaging is generally low cost, and devices are easy to miniaturize. Depending on the particular semiconducting material properties, piezoresistive effects allow direct and convenient signal transduction methods for electrical and mechanical properties.

Thus, in this work, aiming at the practical request of monitoring sensor that in-sensitive to environments, low power consumption, easy signal processing, and less integration difficulties, we developed a planar mode sensitive piezoresistive vibration sensor with a less expensive process and fewer packaging difficulties. In order to simplify the fabrication processes and decrease device dimension, the planar sensor is fabricated by dry and front-side-only processes using silicon on insulator (SOI) wafer. The functional features of the fabricated planar sensor, including the amplitude–frequency response and random vibration response, have been evaluated comprehensively.

2. Planar vibration sensor structure

We are developing a new type of piezoresistive planar accelerometer, which can be used to be a vibration sensor. The vibration sensor is measuring the external vibration or inertia acceleration in a direction parallel with the plane of the sensor structure. The vibration sensor has a large proof mass and a narrow flexure, the

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* Corresponding author. Tel.: +81 29 849 1180; fax: +81 29 861 7225.
E-mail address: jian-lu@aist.go.jp (J. Lu).

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flexure attached to the proof mass, and a strain-isolation pedestal attached to the flexure.

Fig. 1(a) shows the schematic image of our proposed planar vibration sensor with front-side micromachined piezoresistive gauge. The sensor has a fan-shaped proof mass, and the flexure in this device is much narrower than the pedestal and proof mass, i.e. when the sensor moved by vibration or acceleration, only the flexure has a bending. A Wheatstone bridge piezoresistive gauge was designed on surface of the flexure to detect vibration-induced strain at fix-end of the proof mass. The planar structure enables high device sensitivity with favorable response to low frequency vibration, while not increase the device size. Fig. 1(b) shows the schematic image of the released gap between the proof mass and Si substrate. The FEM (software ANSYS) was used to validate the structure segment of the planar-mode piezoresistive vibration sensor through. The results reveal that 2-μm-thick SiO_2 box layer underneath the proof mass adequately avoids stiction [9]. As shown in Fig. 1(c), the piezoresistor is located in the preferable region of sensor flexure having the single beam. The piezoresistor is located in the preferred region for sensor flexure with a single beam. The sensor has a piezoresistor with a large proof mass and three reference piezoresistors with no proof mass structure. The four piezoresistors are connected in a Wheatstone bridge circuit. The Wheatstone bridge circuit unit can be used to precisely measure and characterize acceleration due to vibration.

With the unique design of above mentioned, in term of fabrication process of vibration sensor, the front-side-micromachining method can reduce integration difficulties and avoid device release from backside of the wafer by expensive and time-consuming deep reactive-ion etching (DRIE). In term of working function, the planar piezoresistor sensor enables easy signal processing capability, high device sensitivity with favorable response to low frequency, while not increase the device size.

3. Fabrication of front-side-micromachined vibration sensor

The process started from SOI wafer has a 2-μm-thick SiO_2 box layer under a 50-μm-thick n-type active Si (100) layer with a resistivity of 0.01–0.02 Ω·cm. The device fabrication was done by front-side-only process using 5 photo-masks as shown in Fig. 2 and described as follows:

(1) The piezoresistors with resistance of 100 Ω/□ on average are defined by boron diffusion (see Fig. 2(a)).
(2) A 100 nm thermal-oxide-passivation layer is generated on the top surface of the active Si layer and patterned. Electrodes are fabricated by sputtering an AlSi metal layer and ion milling, followed by annealing at 430 °C for 20 min for ohmic contacts (see Fig. 2(b)).
(3) A 3.55 μm amorphous fluoropolymer (CYTOP™, Asahi Glass Co., Ltd.) layer is coated onto the target wafer surface and patterned to protect surface components (passivation layer and metal electrode) during the following structure release by DRIE and vapor-phase hydrofluoric acid (vapor HF) dry process (see Fig. 2(c)).
(4) The sensor device is released by vapor HF dry process. Finally, O_2 plasma was used to remove amorphous fluoropolymer material and other residuals (see Fig. 2(d)).

A rapid thermal processing system of Annealsys RTA (AS-ONE, KH Unicon Co., Ltd.) is used in annealing process to make the sputtered AlSi metal layer and piezoresistor have an ohmic contact; A scanning electron microscope (SEM) (S-3000H, Hitachi Co., Ltd.) is used to observe the fabricated vibration sensor; A semiconductor device parameter analyzer (4155C, Agilent Co., Ltd.) is used to measure the current–voltage (I–V) curve of fabricated piezoresistor.

Fig. 3(a) show the SEM image of typical planar vibration sensor structure. As the figure shown, the planar vibration sensor was fabricated with the front-side release process, and the sector-shaped proof mass was supported by one beam flexure with high aspect ratio. The proof mass of vibration sensor structure is caged by the surrounding silicon substrate. Fig. 3(b) shows the magnification SEM image of piezoresistor gauge unit. The typical vibration sensor structure has a supporting single flexure beam with length of 20 μm and width of 8 μm. The effective weight of proof mass and the calculated resonance frequency of a vibration sensor (1-mm-radius, 50-μm-height proof mass) are 50×10^{-3} mg and 3.9 kHz, respectively. The AlSi electrical circuit path is located on the passivation along the top surface of flexure and has an ohmic contact with piezoresistor. As the Fig. 3(b) shown, after the sensor structure is released by vapor HF, the passivation oxide (silicon dioxide) layer and AlSi electrical circuit path are protected well by amorphous fluoropolymer layer. Fig. 3(c) shows the cross-section SEM image of released sensor mass proof and Si substrate. The silicon dioxide sacrifice layer was etched by vapor HF technique, and the proof mass is keeping the hanging gap with the Si substrate. To confirm the whole sensor structure was released well, an infrared microscope was used to observe the sensor chip.

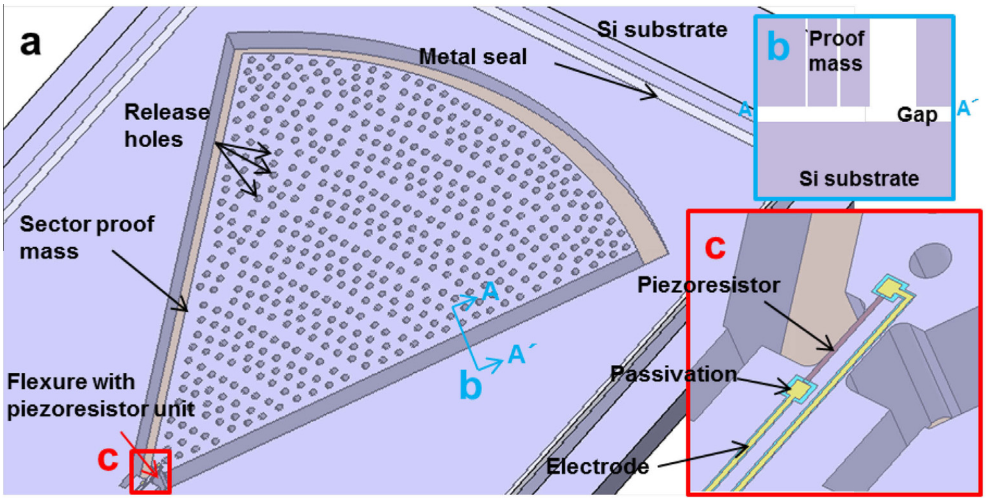

Fig. 1. Schematic view of proposed planar vibration sensor.