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High Accuracy MEMS Pressure Sensor Based on Quartz Crystal Resonator †

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Abstract: This paper reports a high accuracy oil-filled MEMS absolute pressure sensor based on quartz crystal double-ended tuning fork (DETF) resonator, which is suitable for application in ocean, petroleum, meteorological, aerospace and spacecraft field, etc. The pressure sensing unit is mainly composed of DETF resonator, diaphragm and back cavity structure. These pieces are all fabricated by quartz crystal using MEMS process, and are bonded together as 'sandwich' structure to form the absolute pressure sensing unit using glass frit under low temperature and vacuum condition. This process could effectively eliminate the thermal stress effect and form the reference vacuum cavity. The isolated packaged pressure sensor is composed of corrugated stainless steel diaphragm, silicone oil, pressure sensing unit and ceramic base package. The experimental results show that the accuracy is up to ±0.033% FS in the pressure range 0~300 kPa over the temperature range −20 °C~+45 °C.

Keywords: MEMS pressure sensor; high accuracy; quartz crystal resonator

1. Introduction

Resonant pressure sensors are more attractive than common piezoresistive or capacitive pressure sensors for its higher accuracy, higher stability, lower power consumption and inherently digital-type output. High accuracy resonant pressure sensors usually employ resonators such as resonant beams or tuning forks as resonant strain gauges to sense pressure-induced stresses in a diaphragm [1,2]. R.J. Cheng et al. has reported a resonant pressure sensor by combination of DETF quartz resonator and silicon diaphragm [3]. However, the mismatch between quartz crystal and silicon could affect the accuracy and stability of the pressure sensor. In this paper, we report an oil-filled MEMS absolute pressure sensor based on quartz crystal DETF resonator, quartz crystal diaphragm and quartz crystal back cavity structure. The pressure sensor which we report here is believed to be higher accuracy and stability than that using quartz resonator and silicon diaphragm, because the three main parts are all fabricated by quartz crystal with same orientation through MEMS process. And the isolated packaging technology is used to protect the pressure sensing unit and improve the media compatibility of the sensor.

2. Device Design

The MEMS pressure sensing unit is composed of quartz crystal DETF resonator, quartz crystal diaphragm and quartz crystal back cavity structure, as schematically shown in Figure 1. The diaphragm includes a thin portion which deforms in response to applied pressure and a pair of bosses for fixing the quartz crystal DEFT resonator. The bosses are designed to enlarge the strain of resonator, and avoid interference between resonator and diaphragm. The back cavity structure includes a trench which could avoid the contact between the quartz resonator and the structure. The three parts of pressure sensing element are bonded together using glass frit under low temperature and vacuum condition forming a vacuum cavity [4]. The glass frit bonding between bosses and DEFT resonator could obtain lower hysteresis error and higher stability compared with epoxy resin adhesive. And a thick back cavity structure is used to attenuate the effect of mounting stress on DETF resonator.

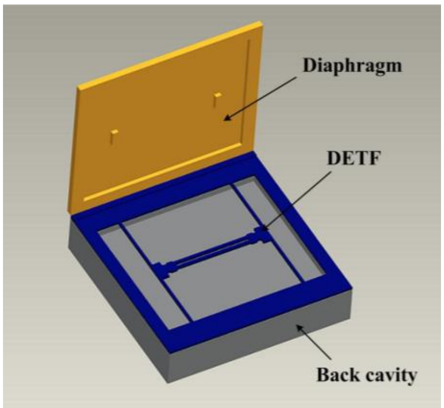

Figure 1. Schematic image of the 'sandwich' pressure sensing unit.

Figure 2 shows the schematic drawing of the quartz crystal DETF resonator with vibration attenuation structure and the electrode distribution on the DETF resonator [5]. The DETF length and width are in the *y* and *x* direction of the Z-cut quartz crystal wafer, respectively. Electrodes are arranged as shown in Figure 2c, so that the electric field is mainly from the field in the *x* direction to obtain the maximum electrical mechanical coupling, according to the finite element analysis. The vibration attenuation structure and stress equilibration joint reduce the transference of vibration energy from the DETF to the diaphragm, and guarantee high *Q* value of the DETF.

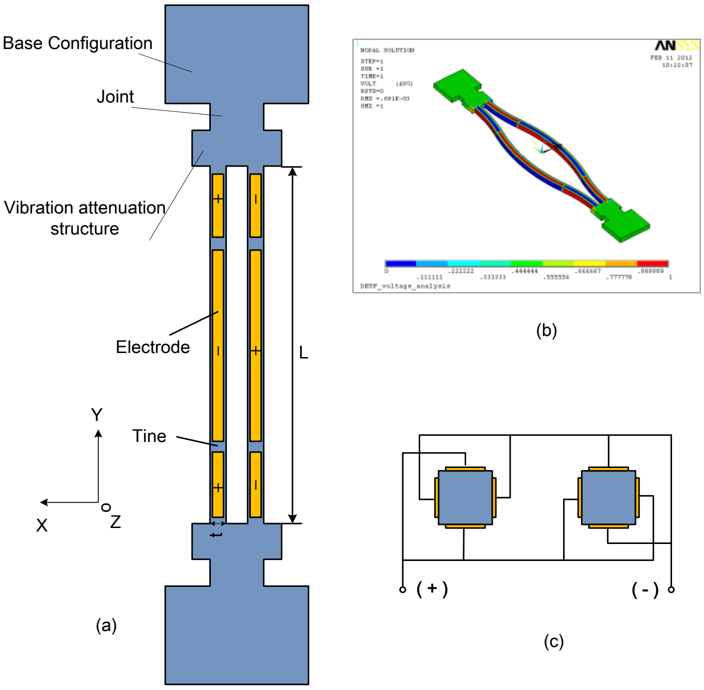

Figure 2. Schematic drawing of (**a**) the quartz crystal DETF resonator with vibration attenuation; (**b**) finite element analysis of the DETF resonator; (**c**) electrodes placed on the DETF resonator.

3. Fabrication

Figure 3 shows the fabrication process of the DETF resonator using quartz crystal anisotropic chemical etching micromachining and three dimensions electrodes deposition technology based on shadow mask process. The thickness of the Z-cut quartz crystal wafer is 200 μm. Cr/Au film was deposited at the both sides of the wafer by heat evaporation, and patterned with typical photolithography process as the mask for quartz crystal anisotropic wet etching. Then the electrode pattern was transferred to the photoresist layer by standard photolithography process and electrodes shapes were formed by wet etching. At last, the side electrodes were deposited based on the shadow mask process. The main process flow of the diaphragm and back cavity structure is similar to the DETF resonator.

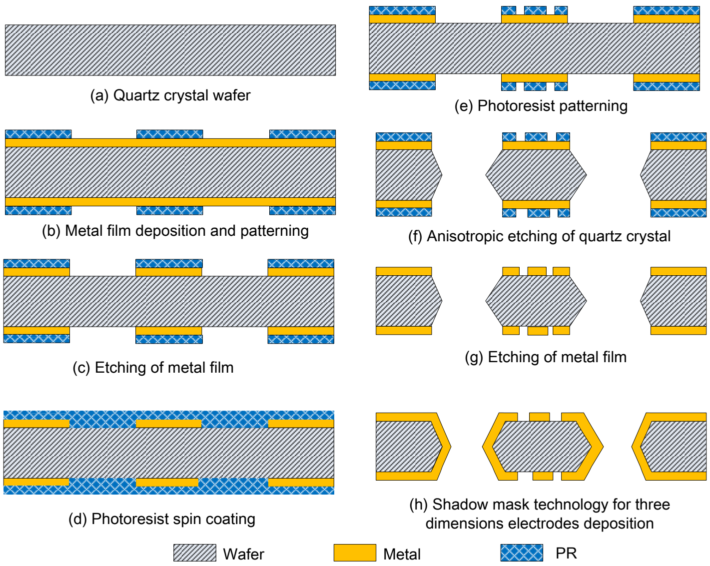

Figure 3. Schematic fabrication process of the DETF resonator.

The three parts are bonded together as 'sandwich' structure to form the absolute pressure sensing unit using glass frit under low temperature and vacuum condition. In view of the special structure, The DETF is bonded to the diaphragm in the first step and to back cavity structure forming vacuum-cavity in the second step. Figure 4 illustrates the image of the pressure sensing unit. The packaged pressure sensor is shown in Figure 5. The pressure sensing unit was fixed in the ceramic package base and corrugated stainless steel diaphragm was welded with the ceramic package base. At last, silicone oil was filled in the packaged cavity for pressure transmission. The isolated packaging with corrugated stainless steel diaphragm and silicone oil is chosen as the packaging strategy for increasing sensor reliability and the measurement of harsh media such as electrolysis, polarization, particulate contamination and corrosion [6].

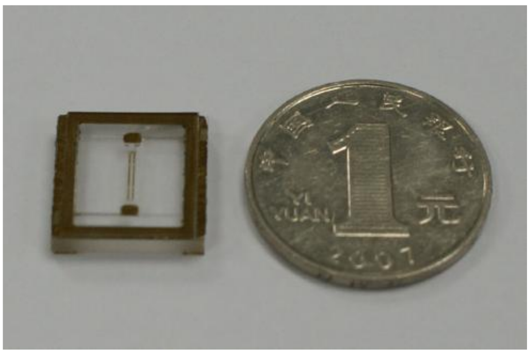

Figure 4. Image of the fabricated all-quartz pressure sensing unit.

Figure 5. The packaged pressure sensor.

4. Results and Discussion

Pierce oscillator circuit was used to excite the DETF resonator and output the steady square signal. Output of the pressure sensor versus applied pressure at different temperature with RS-485 interface is shown in Figure 6.The experimental results show that the accuracy is up to ±0.033% FS in the pressure range 0~300 kPa over the temperature range −20 °C~+45 °C.

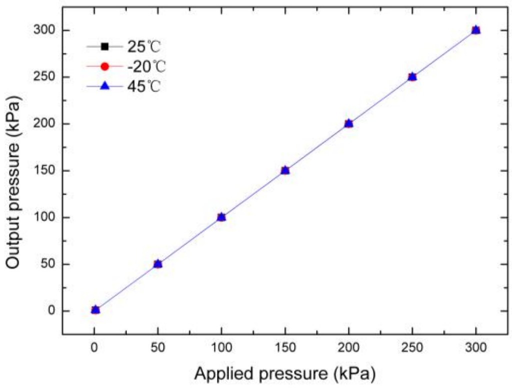

Figure 6. Output of the pressure sensor versus applied pressure at different temperature with RS-485 interface.

5. Conclusions

A novel high accuracy MEMS absolute pressure sensor based on quartz crystal DETF resonator has been designed and fabricated by the standard MEMS process. The isolated packaging with corrugated stainless steel diaphragm and silicone oil is chosen as the packaging strategy. The experimental results show that the accuracy of the sensor is up to ±0.033% FS in the pressure range 0~300 kPa over the temperature range −20 °C~+45 °C.

Conflicts of Interest: The authors declare no conflict of interest.

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