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Design and testing of piezoelectric resonant pressure sensor

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ABSTRACT

A stainless steel resonant pressure sensor with a new design is proposed with piezoelectric excitation and detection. The sensor consists of a sensing diaphragm, inclined trusses, vertical mounts and a resonating beam. The deflection of the diaphragm is transferred to the resonating beam via specially designed inclined trusses and vertical mounts. The analytical model of the sensor is developed using Ritz method and direct stiffness method for the non uniform sensing diaphragm and resonating beam respectively. The relation between strain due to applied pressure and change in the resonance frequency is derived. The sensor is also modelled numerically using MEMS CAD Tool CoventorWare. The sensor is fabricated with three different grades of stainless steel namely SS 304, SS 431, 15-5 PH, using Electrical Discharge Machining (EDM) and wire cut EDM process. The sensors are tested for its characteristics for an input pressure of 0–25 bar. The sensor fabricated using 15-5 PH is found to have good linearity, repeatability, higher sensitivity and low hysteresis compared to the sensors fabricated with SS 304 and SS 431. The sensor design is simple, fabrication involves well known machining process, self packed and hence cost effective.

1. Introduction

Pressure is an important physical parameter to be measured in almost all fields of engineering and industrial applications. Pressure measurements are not only important for monitoring and control, but also for measuring other parameters like flow and level. The development of pressure sensors is one of the well established areas in sensor technology. Pressure sensors which depend on vibrating structures for sensing, work on the principle of resonance frequency shift with applied pressure and are advantageous over other conventional sensing techniques [1–3]. The key advantage is that the frequency output is essentially in digital form and therefore can be easily integrated with digital electronics and instrumentation systems. In addition, the resonant measurement principle is usually based on the mechanical properties of the structure rather than the electrical properties and can be shown to offer stable performance, high resolution, reliability and response time as specified in [4]. Among the excitation and detection methods used in resonant sensors, piezoelectric excitation and detection is gaining importance in recent years as the piezoelectric excitation offers advantages like strong forces, low voltage, high energy efficiency, linear behaviour, high acoustic quality and high speed [5–7].

Pressure sensors with stainless steel as sensing diaphragm are widely used to measure high pressures in corrosive environments. A complete self packaged stainless steel high pressure capacitive pressure sensor was developed and studied for its performance in harsh environments [8,9]. A capacitive pressure sensor was designed and fabricated by Chang and Allen [10] which consists of stainless steel substrate, stainless steel diaphragm and surface micromachined back electrode for low pressure measurement. A piezoresistive pressure sensor using metallic thin film as a strain gauge bonded on to a stainless steel diaphragm was designed and fabricated for rail fuel injection systems [11]. An electro thermally excited silicon nitride resonant pressure sensor with enhanced sensitivity was developed [12] and a complete analytical model of the resonant pressure sensor is presented by Yang and Can [13]. A resonant pressure sensor with a quartz double ended tuning fork as a resonator bonded onto a silicon diaphragm was fabricated and tested [14]. The advantage of using quartz resonators is that they can be easily excited and detected, which makes them simpler as compared to other schemes.

The pressure sensors reported in [12–14] are micro resonant pressure sensors, in all these sensors the applied pressure is transferred to the resonating beam via a silicon island supported on the diaphragm. In the proposed pressure sensor design the stress due

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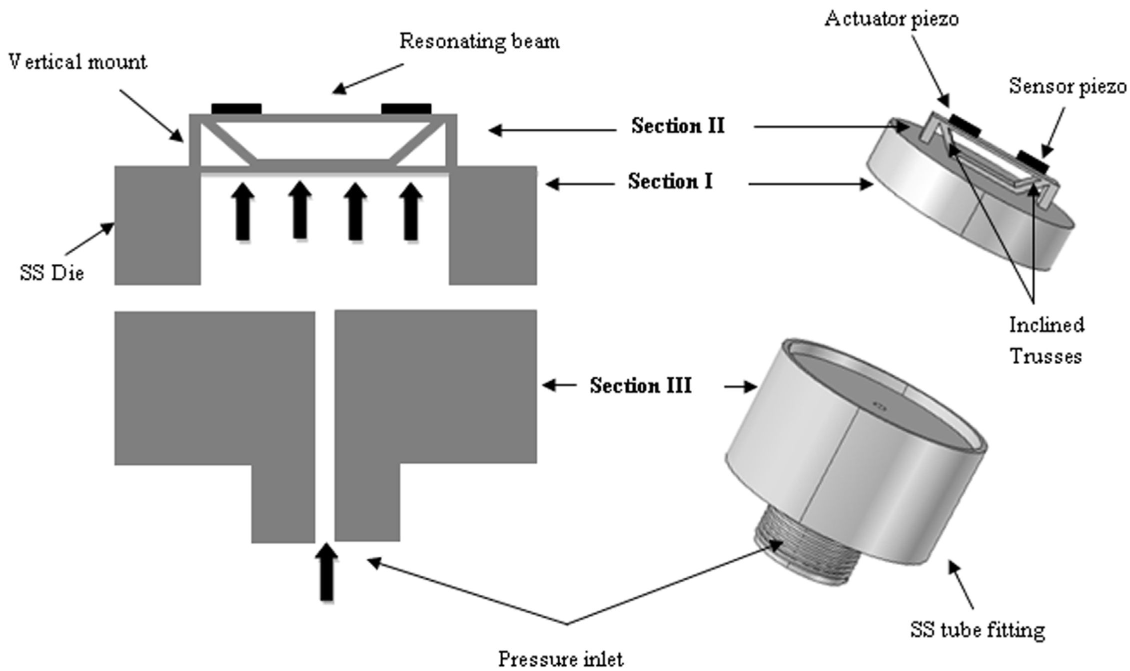

Fig. 1. Cross sectional and 3D view of the resonant pressure sensor.

to the applied pressure on the diaphragm is transferred to the resonating beam by a new mechanism: 'V' shaped stress transmission mechanism comprising of vertical mounts and inclined trusses at an angle of 45° to the horizontal plane with their base resting on the diaphragm (which functions like an island in micro pressure sensor proposed in [12–14]). The type of stress transmission mechanism

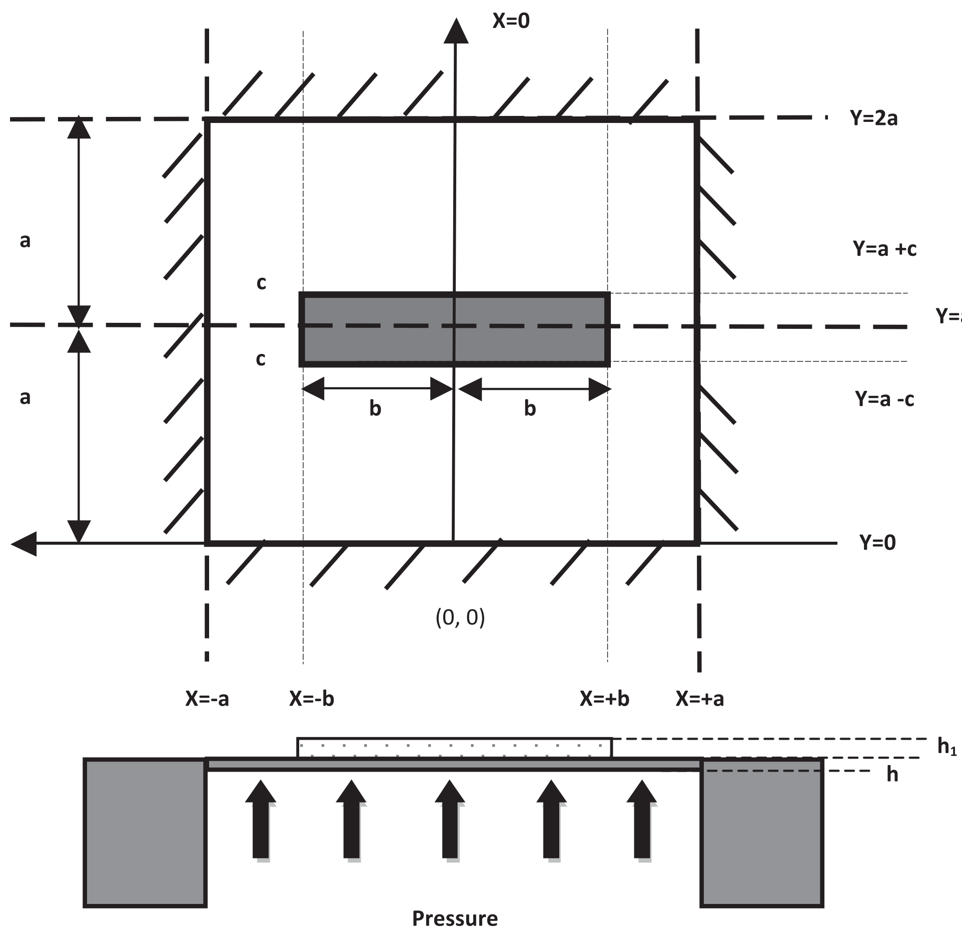

Fig. 2. Top and cross sectional view of the sensor (Section *I*).