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Development of Piezoelectric Micro-Cantilever Gas Sensor

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Summary:

This paper presents the development of on-chip dynamic functionalized PZT based piezoelectric cantilever with self-sensing read-out circuit. The cantilever consists of Pd layer acting as a top electrode and functional layer, with the PZT grown on the bottom Pt/Ti electrode. The cantilever has been fabricated using surface micro-machining and characterized. It demonstrated 0.1 % shift in resonant frequency per 12 MPa stress change in the functional layer and 1.125 μm change in displacement at resonance frequency per 1 MPa stress change in the functional layer.

Keywords: MEMS Cantilever, Hydrogen Sensing, Gas Sensing, Self-Sensing, Piezoelectric

Motivation

As the world transitions to renewable energy, hydrogen is anticipated to play a significant role. However, hydrogen is a colorless odorless and explosive gas, that requires sensitive sensors to detect leaks and ensure safety. In addition to the safety aspect, the environmental monitoring of fugitive hydrogen emissions is of interest to track changes in background hydrogen concentration. Currently there are a range of hydrogen sensors such as semiconductor metal oxides, optical and passive mems cantilevers, these however suffer from either a lack of selectivity, limited operational temperatures or the need for large bulky external equipment. Gurusamy et. al reported a static MEMS based PPB cantilever sensor [1] however, this method used an optical readout which required bulky external equipment. Li et al describes a static cantilever that uses a piezoresistive sensor to detect the changes in Hydrogen concentration [2] while their method is sensitive it requires relatively large millimeter scale cantilevers. Boon-Brett et al discussed the performance of commercially available hydrogen sensors [3]. These sensors operated using a wide range of methods such as catalytic, semiconductor metal oxide and electrochemical sensors. However, these sensors suffered from drawbacks such as low detection limit and high cross sensitivity with carbon monoxide, susceptibility to environmental conditions such as temperature and humidity and variability from sensor to senor. In this work, piezoelectric microcantilever with self-readout circuit that utilizes a highly absorbent functional layer to reduce cross sensitivity and operates in dynamic mode optimized to enhance sensitivity is reported.

Fabrication Process

A surface micro-machined piezoelectric cantilever with a Palladium (Pd) functionalization layer has been fabricated. The fabrication process is illustrated in Figure 1. It starts with an SOI wafer which is oxidized to grow 1 μm thick SiO_2 (Figure 1(a)). The bottom Pt/Ti electrode is then sputtered on the oxidized surface followed by Sol-gel PZT deposition (Figure 1(a)). The SOI/SiO_2/Pt/Ti/PZT (1um) sample is patterned with a Pd thin film acting as both the hydrogen sensing layer and the top electrode (Figure 1(a)). The PZT piezoelectric layer is then etched using photoresist as a mask in an ICP RIE followed by RIE etching of bottom Pt/Ti electrode and silicon oxide layers (Figure 1(a). A SiO_2/Pt/Ti/PZT/Pd cantilever is released by performing SF_6 isotropic silicon etch (Figure 1(a)). The SEM images of the released PZT cantilevers are shown in Figures 1(b) and (c).

Experimental Results

The dynamic behaviors of the released PZT cantilevers have been characterized and presented in Fig. 2. As can be seen from Fig. 2(a), the PZT cantilevers measured 5.85 kHz resonant frequency, quality factor (Q) of 25 dB. The frequency response of the cantilever shifts when the cantilever is biased at different DC voltages. The shift in resonance frequency due to the DC biasing is plotted in Fig. 2(b), showing 5 Hz shift per volt. Translating the biasing DC voltage to stress change in the Pd layer, the shift corresponds to 0.1 % frequency shift per 12 MPa stress change. The tip deflection of the cantilever at the various DC biasing is measured and shown in Fig. 3, exhibiting a sensitivity of 13.5 μm/V or 1.125 μm/MPa. It has been reported that the stress in Pd changes by as much as 200 MPa when in an environment of 5 % hydrogen concentration [5]. This either causes the resonance frequency to shift or tip deflection to change. The shift in resonance frequency and change in tip deflection is captured by a readout circuit which is shown in Fig, 4. The resonance frequency captured by the readout circuit is presented in Fig. 5.

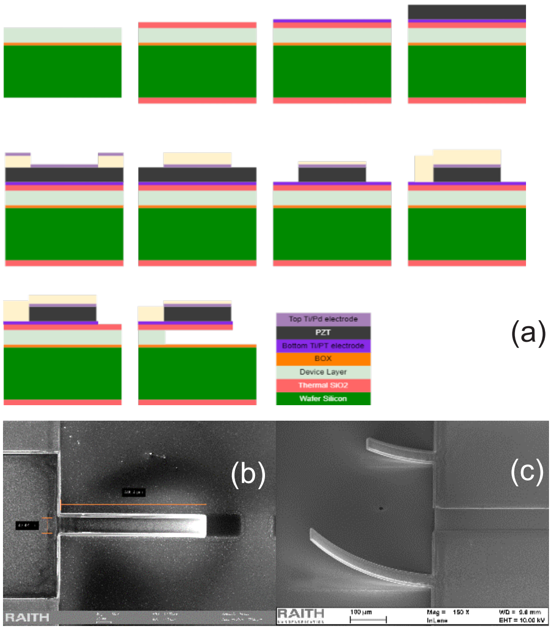

Fig. 1. (a) Fabrication steps for piezoelectric cantilever (b) SEM top view of released cantilever (c) SEM side view of released cantilevers.

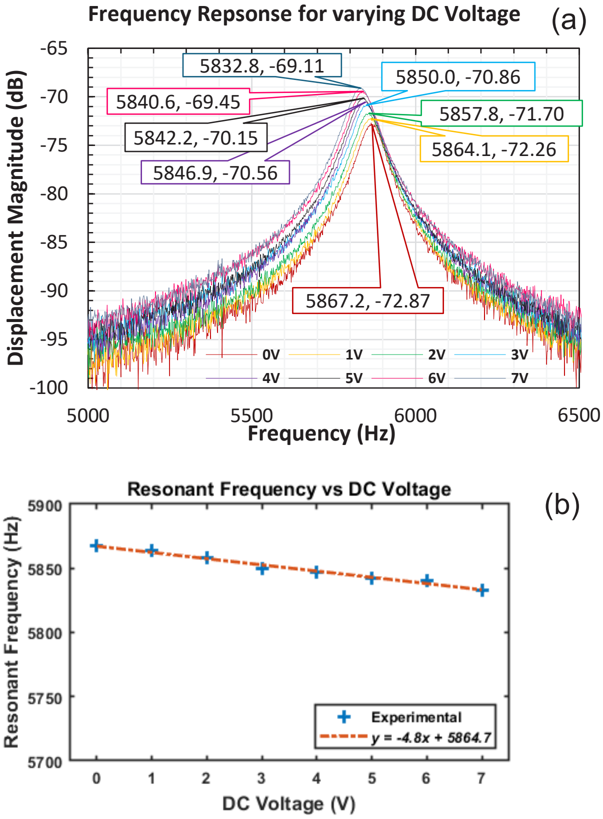

Fig. 2. (a) Frequency response for different stress (applied DC voltage on PZT layer) (b) Shift in resonant frequency due to applied voltage.

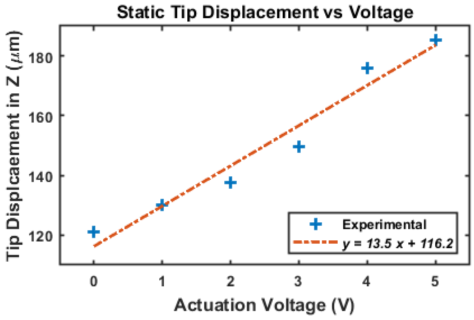

Fig. 3. Tip deflection of cantilever for various DC voltage

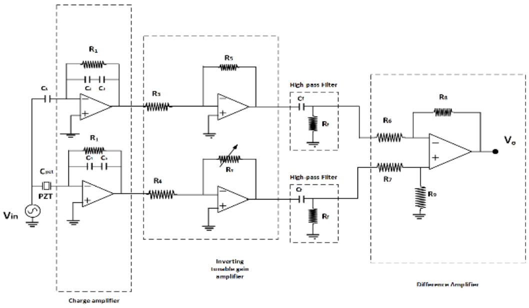

Fig. 4. Self-sensing readout circuit.

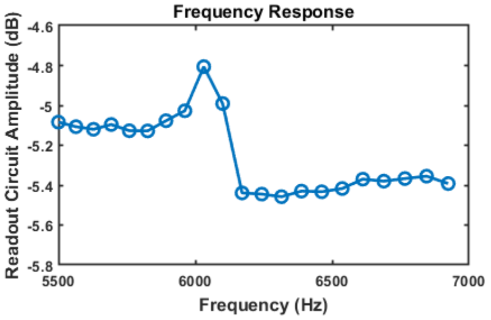

Fig. 5. Measurement of resonant frequency using self-sensing readout circuit.

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