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Screen printed free-standing resonator with piezoelectric excitation and detection on flexible substrate

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Abstract

This paper reports the design, fabrication and testing of a free-standing encastre beam resonator which is entirely fabricated using screen printing onto a flexible polyimide substrate. The design of the free-standing resonator was achieved using sacrificial techniques. The resonator was designed to be excited at one end of the beam and the vibrations detected on the other end using piezoelectric material. The resonator was 11mm long and 4mm wide with an air gap of 119µm, created by selectively removing the sacrificial layer. The device resonates in air with maximum amplitude of 0.1545 volt at fundamental frequency of 3.834 kHz.

Keywords: Resonator; Screen printing; Sacrificial technology; Piezoelectric

1. Introduction

Electronic textiles (E-textiles) have been a new paradigm in various wearable applications such as military, medicine, communication, entertainment and sports [1]. E-textiles were typically fabricated using woven or knitted techniques, where by the electronic components were attached or soldered onto the textile. Such approaches require specialty yarns and constrain the design pattern to the warp and weft directions. However, these limitations can be solved by printing techniques which provide design freedom and the capability to produce arrays of printed devices simultaneously for mass production. Moreover, by implementing sacrificial technology three dimensional designs

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are also possible. Previous studies have proven the potential of this techniques. For example, cantilever motion sensors [2, 3] and micropump [4] devices have been successfully fabricated using screen printing techniques. This paper further describes the design, fabrication and testing of an encastre beam resonator.

2. Resonator design

Resonant sensors consist of mechanical structure which vibrates at its resonant frequency [5]. The frequency of the resonating structure is affected by the measurand (e.g. strain or mass) and varies as the measurand changes [6]. Micromechanical resonators fabricated using conventional MEMS fabrication techniques have been demonstrated previously for use in a wide range of applications [7].

The resonator presented here is an encastre beam 11mm long and 4mm wide with an 119µm air gap between the beam and the substrate. The air gap is created by the sacrificial layer which allows the free standing resonator to be formed. It was designed to operate in the fundamental mode in which the beam is displaced normal to the flexible substrate.

Piezoelectric (PZT) elements were have been located at each end of the encastre beam for optimal excitation and detection of the resonator's vibrations. The optimum position of the PZT was evaluated using static finite element analysis (FEA) and the maximum stress during deformation was found to be near the clamped area as shown in Fig. 1. By placing the piezoelectric excitation and detection elements in this region, the maximum degree of mechanical coupling between the piezoelectric layer and the resonator structure was obtained. The simulated resonant frequency of mode 1 was X.XX kHz.

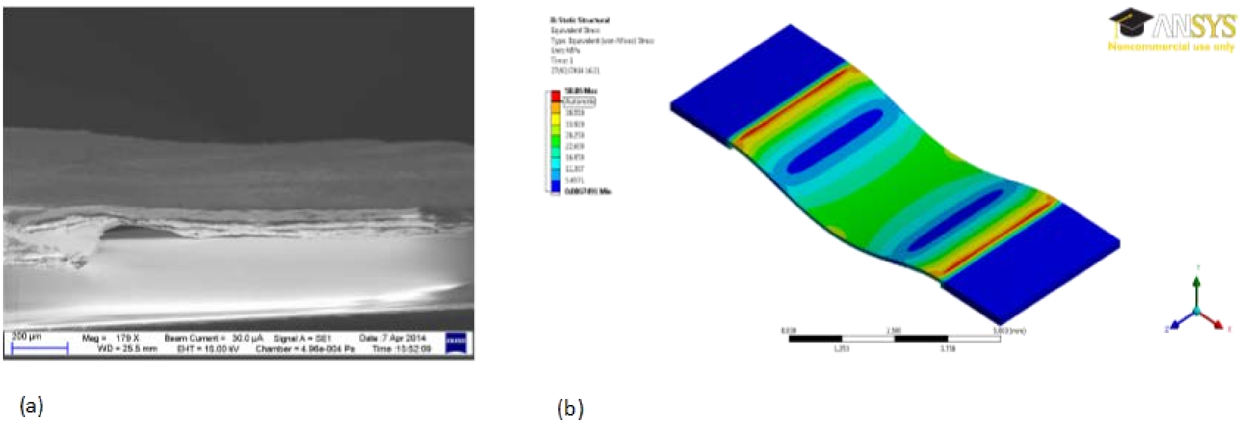


Fig. 1. (a) SEM image of free-standing encastre beam (b) Stress distribution near to clamping area of the encastre beam

3. Fabrication

The screen printing process is essentially a process of depositing a paste onto a substrate through a patterned mesh. A paste is applied to the upper surface of the screen and spread across the screen in a process known as flooding. A squeegee is then traversed across the pattern surface. The patterns on the screen are printed on the substrate as shown in Fig. 2 (a).

In order to fabricate the free standing resonator beam, a water soluble sacrificial paste, Fabink-TC-SF 6002, supplied from Fabinks Ltd was used. This paste was first deposited on the flexible polyimide substrate and cured at 80ºC for 3 minutes. Several layers were printed until the desire thickness was obtained. Then, Minico dielectric was printed at the sides and top structure of the resonator followed by the bottom electrodes. The dielectric and electrodes were cured at 80º for 10 minutes and 130ºC for 5 minutes in the box oven respectively. The piezoelectric layer and the top electrodes of the resonator were also printed. The piezoelectric layer was cured at 110ºC for 10 minutes. Finally the sacrificial layer of the resonator was removed using agitated water at 90ºC. The final resonator and the printing sequence are illustrated in Fig. 2 (b) and (c) respectively.

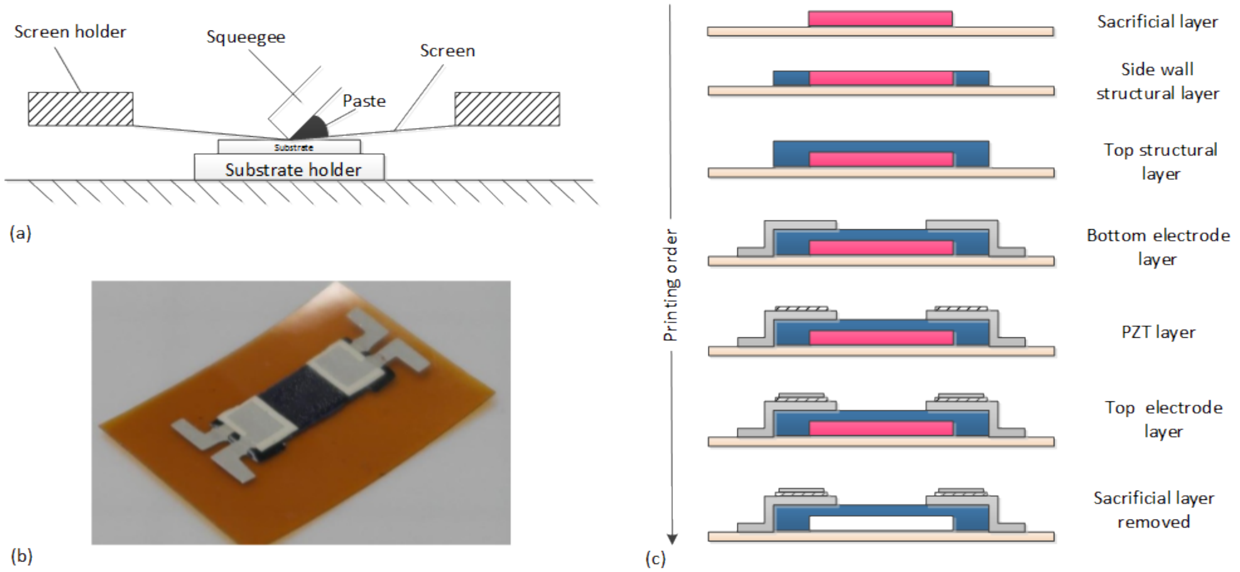


Fig. 2. (a) Screen printing process; (b) Free standing resonator after removal; (c) Printing sequence of resonator

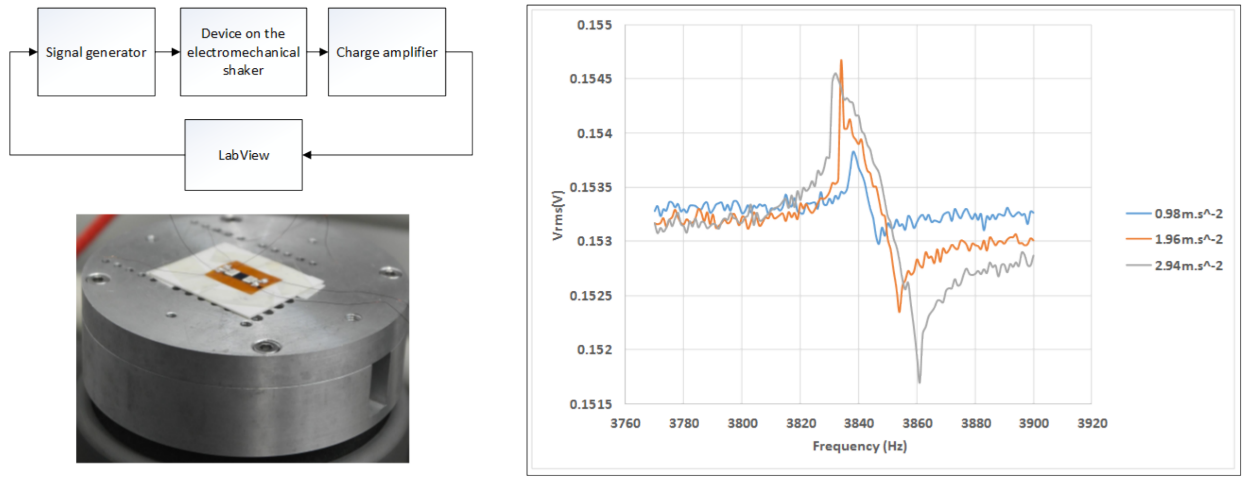
A polling process is essential in order for the piezoelectric material to become active. The piezoelectric elements were connected electrically to a high voltage supply and heated up to 160ºC. After the temperature stabilized, the voltage supply was turned on for the 10 minutes. At the end of the polling process, the device was allow to cool down and the d_{33} value was measured. Table 1 show the d_{33} value measured after the poling process of each end of the resonator.

Table 1. The d_{33} value of resonator A, B and C

Sample	Side A (pC/N)	Side B (pC/N)
Sample A	19	16
Sample B	20	21
Sample C	19	19

4. Resonator testing

Resonator function was tested by placing a sample on a shaker and connecting the piezoelectric detection element to a charge amplifier. This was carried out at atmospheric pressure and the piezoelectric output voltage was measured over a frequency range of 3.7 kHz to 3.9 kHz with increment of 1 Hz at different acceleration level of 0.98 m/s^2, 1.96 m/s^2 and 2.94 m/s^2. The result shows that the average resonant frequency of 3.835 kHz can be obtained by measuring the voltage output of the resonator. The experimental setup and the results are as illustrated in Fig. 3.



(a) (b)

Fig. 3. (a) Experimental setup and the resonator on the shaker (b).Output voltage versus frequency sweep at one end of the encastre beam.

5. Conclusion

This paper has presented the design, fabrication and testing of a free standing encastre beam resonator fabricated solely using screen printing techniques. The piezoelectric element has been tested on the electromechanical shaker and maximum amplitude of 0.1545 volt was obtained at natural frequency of 3.835 kHz. This compares well with the simulated resonant frequency and confirms the fabrication process has successfully realised a free standing resonant structure. Future tests will include exciting the beam on one end and detecting the resonant frequency by measuring the output voltage on the other end.

Acknowledgements

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