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Screen Printed Low Frequency Piezoelectric Micro Energy Harvester with Extended Mass

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***Abstract*—This paper presents a screen printed piezoelectric micro energy harvester with a low resonant frequency. The energy harvester was optimized with an extend mass, which reduces the resonant frequency and tip displacements of the device within a limited space. The fabricated device has dimensions of 10mm×9mm×0.5mm and has a resonant frequency of 262Hz. It produced an average output power of 0.37µW when excited at a sinusoidal vibration with amplitude of 4.9m·s^{-2} (RMS) and its resonant frequency. The design was simulated using ANSYS coupled field analysis and the experimental results match the simulation results with a difference less than 8.4%.**

I. INTRODUCTION

RECENT development in piezoelectric micro energy harvester has seen its resonant frequency being reduced from kHz to a range between 100 and 300Hz [1][2][3]. Vibrations with frequencies within this range are widely available in environment, which makes low frequency micro energy harvesters more useful in practical applications.

Morimoto et al. [1] reported a piezoelectric energy harvester composed of c-axis-oriented (PZT) films transferred onto stainless steel cantilevers. A 2.8µm thick PZT film was epitaxially grown on Pt/MgO substrates using RF-magnetron sputtering and transferred to 50µm thick stainless steel cantilevers. This device had dimensions of 18.5×5mm² and had a resonant frequency of 126Hz. Its output power was 5.3µW under a vibration of 5m·s^{-2}. Stoppel et al. [2] fabricated a piezoelectric energy harvester using MEMS processes. The device had a 2µm thick AlN layer deposited on a 200µm SOI wafer. The total dimensions were 5×7.2mm². It had a resonant frequency of 259.8Hz and an output power of 1.9µW when excited at vibrations of 1.6m·s^{-2}. Lei et al. [3] presented a micro PZT energy harvester that was fabricated using the combination of MEMS and screen printing processes. A 27µm thick PZT film was printed on a pre-processed silicon wafer. The resulting device has an average resonant frequency of 333 Hz and its output power was measured as 39.3µW at 9.8m·s^{-2}. Fabrication in the above research all somehow involved MEMS processes which are more expensive compared to screen printing processes.

This paper presents a piezoelectric micro energy harvester with an extend mass. It has a resonant frequency lower than 300Hz and was fully fabricated using the screen printing processes, including the inertial mass. A coupled field analysis was carried out to model the design and simulation results were used to compare with the experimental results.

II. DESIGN AND FABRICATOIN

A T-shape piezoelectric energy harvester was designed in previous research to condense the proof mass along the direction of the width rather than the span of the cantilever so that the tip displacent can be reduced for low profile applications [4]. To further reduce the resonant frequency without increasing the tip displacement, a structure with extened mass was designed. The mass is extend from the arms of the T-shape strucutre towards the fixed end of the cantilever as shown in Fig. 1.

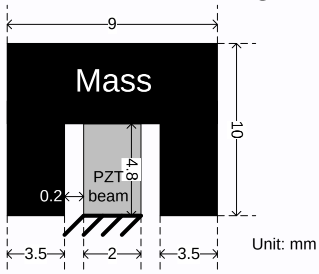

Fig. 1. Piezoelectric energy harvester with extended mass.

The designed piezoelectric energy harvester has a bimorph structure as shown in Fig. 2. Designed thickness of each layer was marked in the figure and such dimensions results in a resonant frequency of 286Hz. The thicknesses in brackets are values measured in the fabricated device that will be discussed later.

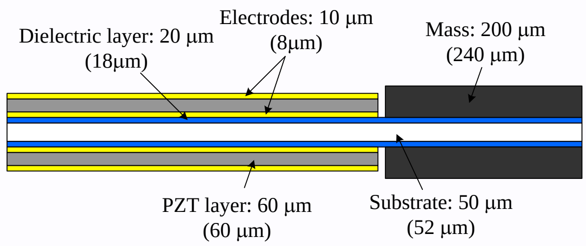

Fig. 2. Cross section through the bimorph piezoelectric energy harvester.

The substrate material is 430S17 stainless steel which was chosen because it is compatible with the firing temperature required by the screen printable pastes. The lead zirconate titanate (PZT) printable paste used in this work was based upon a piezoelectric ink formed by blending PZT-5H powders of different particle size [5]. Other pastes used in the generators were commercially available and supplied by Electro-Science Laboratories Inc. These were an insulating dielectric (ESL4924), a gold conductor for the bottom electrodes (ESL8836) and a silver polymer paste (ESL1901-S) for the top electrode. A bespoke high density tungsten based printable paste was used to form the inertial mass so that the devices are able to be fabricated completely using the screen printing process [6]. The resulting film density is 9550 kg·m^{-3}. The total mass is around 0.3 gram. Fig. 3 shows a batch of screen printed piezoelectric micro energy harvesters with extended masses.

Fig. 3. A batch of screen printed piezoelectric micro energy harvesters.

Polarisation of the PZT layer was achieved by simultaneously heating the devices and applying an electric field across the top and bottom electrodes. An electric field of 6 MV·m^{-1} was applied and the samples were heated to 200 °C. The field was maintained for 50 minutes comprising 30 minutes poling at 200 °C and 20 minutes cooling down. The resulting d_{33} coefficient was around 100 pC/N. Fig. 4 compares the size of the piezoelectric micro energy harvester with a one-penny coin.

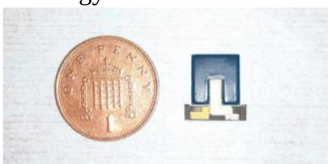

Fig. 4. Size of a screen printed piezoelectric micro energy harvester.

III. EXPERIMENTAL RESULTS

The energy harvester was tested on a shaker (Labworks ET-126) with a programmable resistance box and a PC with LabVIEW software collecting the data. The design was modeled in ANSYS with direct coupled field analysis between the mechanical and piezoelectric domain. Together with coupled physics circuit simulation in ANSYS, the performance of the piezoelectric energy harvester can be fully simulated. Details of this simulation method can be found in [7].

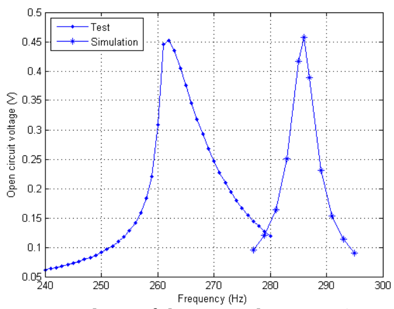

Fig. 5. RMS open circuit voltage of the energy harvester (excited at 4.9m·s^{-2}).

In all tests presented in this paper, the energy harvester was excited at a sinusoidal vibration with amplitude of 4.9m·s^{-2} (RMS). The two PZT layers were connected in parallel. Fig. 5 compares the simulation and test results of the RMS open circuit voltage of the device. It shows that the actual resonant frequency (262Hz) is 8.4% lower than in the simulation (286Hz). This is because the actual thicknesses of the layers are slightly different from the target values as shown in Fig. 2. Fig. 6 shows its output power when the harvester was connected to various resistive loads and Fig. 7 shows the output power at the optimum load resistance. It was found that the measured optimum load resistance (290kΩ) is just 7.4% off the simulated optimum load resistance (270kΩ). Furthermore, the maximum output power in the test (0.378µW) matches the output power in the simulation (0.382µW) with a difference of only 1%.

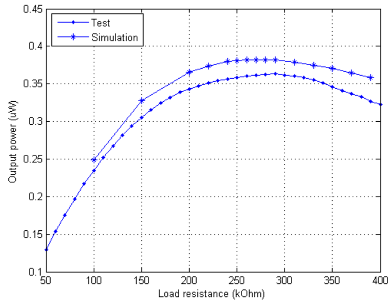

Fig. 5. Average output power of the energy harvester with various resistive loads (excited at 4.9m·s^{-2}).

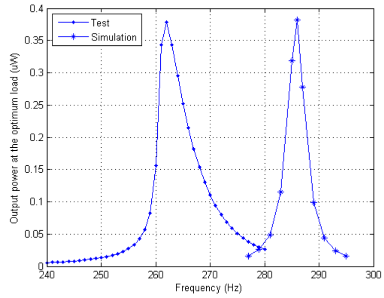

Fig. 6. Average output power of the energy harvester when connected to the optimum resistive load (excited at 4.9m·s^{-2}).

IV. CONCLUSIONS AND FUTURE WORK

A piezoelectric micro energy harvester with dimensions of 10mm×9mm×0.5mm was fabricated using low cost screen printing processes. An extended mass was designed resulting in a resonant frequency of only 262Hz. The experimental results match the ANSYS simulation with reasonable differences. However, the output power of this energy harvester is still low. Future work will include optimizing the design for a higher output power and designing the power conditioning circuit for the improved energy harvester.

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