Design, fabrication and characterization of piezoelectric power harvesters realized with silicon micromachining and screen-printing technologies

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Abstract

Energy harvesting from the environment is an attractive possibility in order to realize self-powered wireless sensor systems. In this context the presented work focuses on the mechano-electric conversion of environmental vibrations, by means of piezoelectric effect. Piezoelectric MEMS power harvesters have been designed and fabricated with silicon microtechnology processes combined with screen-printing techniques. Different shapes and designs have been considered and fabricated, comparing the performances obtained during the characterization.

Introduction

In the last few years a lot of attention has been focused on the possibility of harvesting free energy from the environment and convert it into electrical energy to power wireless sensors [1-2]. This allows the avoidance of batteries, realizing an autonomous system that can theoretically operate indefinitely without requiring maintenance and costs for batteries replacement. Among the different low grade power sources freely available in the environment, sunlight, mechanical vibrations and thermal gradients are considered the most promising [3]. The presented work focuses on mechanical vibrations due to their widespread distribution (industrial machines, buildings, infrastructures, aircraft, automotive and human movement). Mechano-electric energy conversion can be performed utilizing different principles (electromagnetic, electrostatic and piezoelectric). The piezoelectric effect is the most promising for the high power density, wide availability of fabrication technologies, miniaturization capability and silicon technology compatibility, allowing the realization of small power sources [4].

In this work piezoelectric MEMS (MicroElectroMechanical Systems) devices have been designed, fabricated and characterized, as vibration power harvesters. These devices have been realized using silicon microtechnology processes, in combination with PZT thick films deposited by screen-printing technique.

Power harvesters fabrication

The designed harvesters consist of silicon cantilevers fixed at one end having a silicon proof mass at the opposite end (Fig. 1). The devices have a total planar dimension of 10 mm x10 mm, while the beam-mass together measures 6.5 mm x 5.5 mm with a mass-beam length ratio (MBR) ranging from 30% to 80% (Fig. 2). The bottom electrode, also working as a diffusion barrier, has been sputtered, on top of which a PZT thick film and the top electrode have been screen-printed.

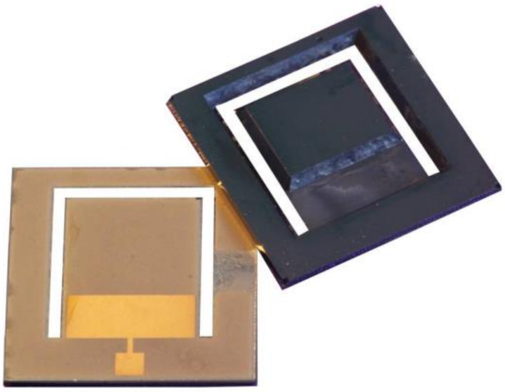

Figure 1: Realized power harvester device seen from two sides. Each device is 1 cm^2.

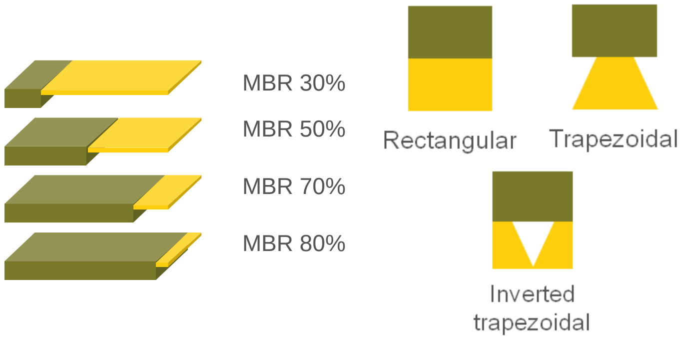

Figure 2: Mass-beam length ratios and shapes used for the harvesters.

Rectangular, trapezoidal and inverted trapezoidal cantilever shapes have been designed and their power conversion performances have been evaluated (Fig. 2).

Experimental results

The devices were glued to PCB fixtures and then mounted on a shaker, imposing a sinusoidal vertical acceleration at the base of the cantilever. A reference accelerometer was fixed to the shaker in order to measure the vertical acceleration. All the measurements were performed with the amplitude of the acceleration set at 0.5 *g* with the device working at the resonance frequency.
Typical values for the measured capacitance of the devices vary from 1.0 nF to 5.8 nF, resulting in equivalent internal impedances from 110 kΩ to 2200 kΩ. The generated charge was measured obtaining charge sensitivities up to 37 nC/*g*. The open-circuit output voltage was also measured by means of a high-input buffer obtaining amplitude values up to 3 V. Measured maximum output power is in the range from 12 µW to 16 µW, while resonance frequency varies from 75 Hz to 250 Hz.
The best performances have been obtained from devices with the rectangular cantilever shape having a MBR of 50% and 70%. The devices with MBR of 50% generate a higher output charge (Fig. 3) while those with MBR of 70% have a higher output voltage (Fig. 4). The lowest resonance frequency is given by the trapezoidal and inverse trapezoidal shapes while considering the rectangular devices it is obtained with a mass-beam length ratio of 50%.

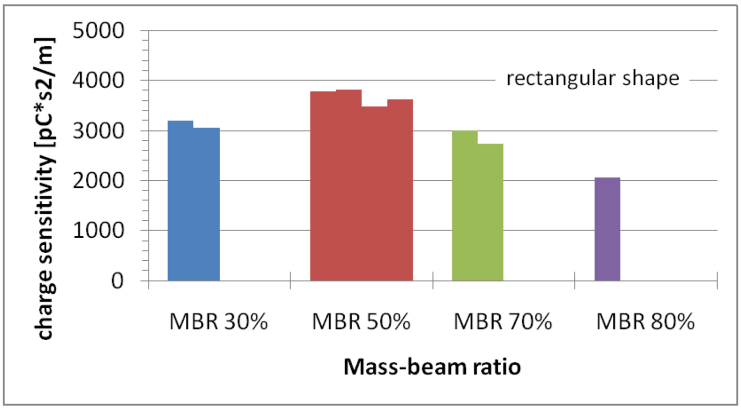

Figure 3: Measured charge sensitivity for rectangular shape harvesters versus mass-beam length ratio, at resonance.

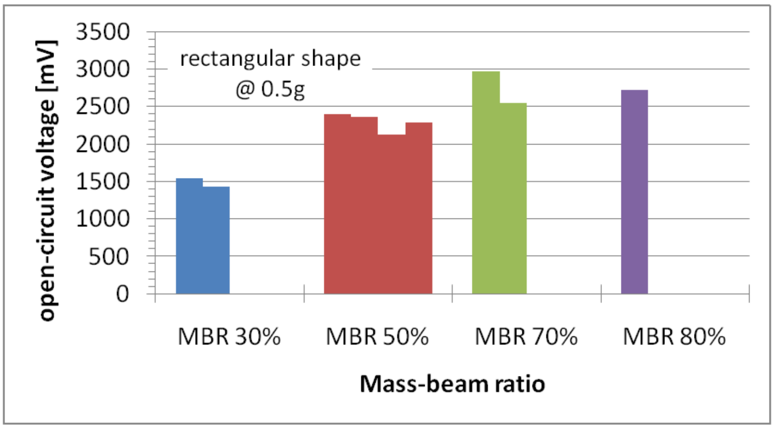

Figure 4: Measured open-circuit output voltage for rectangular shape harvesters versus mass-beam length ratio, at resonance.

Summary and conclusions

PZT thick film based power harvesters were designed, fabricated and tested as vibration power harvesters. Fabrication was done by means of silicon microtechnology processes and screen-printing technique.

Rectangular shaped harvesters with mass-beam length ratio of 50% and 70% gave the best performances in terms of output power.

Open-circuit output voltages and output powers up to 3 V and 16 μW respectively were obtained, exciting the harvesters at resonance with an acceleration amplitude of 0.5 *g*.

References

1. R. J. M. Vullers, R. Van Schaijk, I. doms, C. Van Hoof, R. Mertens, Micropower energy harvesting, Solid-State Electronics, 53, 684-693, 2009.

2. C. O. Matuna, T. O'Donnell, R. V. Martinez-Catala, J. Rohan, B. O'Flynn, Energy scavening for long-term deployable wireless sensor network, Talanta, 75, 613-623, 2008.

3. S. P. Beeby, M. J. Tudor, N. M. White, Energy harvesting vibration sources for microsystems applications, Measurement Science and Technology, 17, R175-R195, 2006.

4. K. A. Cook-Chennault, N. Thambi, A. M. Sastry, Powering MEMS portable devices - a review of non-regenerative and regenerative power supply systems with special emphasis on piezoelectric energy harvesting systems, Smart Materials and Structures, 17, 1-33, 2008.

Acknowledgements

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