Available online at www.sciencedirect.com

SciVerse ScienceDirect

Procedia Engineering 47 (2012) 770 – 773

Procedia Engineering

www.elsevier.com/locate/procedia

Proc. Eurosensors XXVI, September 9-12, 2012, Kraków, Poland

A MEMS energy harvesting device for vibration with low acceleration

Marco Triches[a, b], Fei Wang[a,*], Andrea Crovetto[a, c], Anders Lei[a], Qiong You[d], Xiaoqing Zhang[d], Ole Hansen[a, e]

[a]*DTU Nanotech, Technical University of Denmark, Kgs. Lyngby, Denmark*
[b]*University of Padova, Italy*
[c]*Politecnico di Milano, Italy*
[d]*Shanghai Key Laboratory of Special Artificial Microstructure Materials and Technology & Department of Physics, Tongji University, Shanghai 200092, China*
[e]*CINF, Center for Individual Nanoparticle Functionality, NanoDTU, Denmark*

Abstract

We propose a polymer electret based energy harvesting device in order to extract energy from vibration sources with low acceleration. With MEMS technology, a silicon structure is fabricated which can resonate in 2D directions. Thanks to the excellent mechanical properties of the silicon material, the proof mass could be successfully driven by an external vibrations with acceleration as low as 0.014 g (~0.14 m/s^2). A root mean square (RMS) power output of 1.17 μW under 0.014 g RMS acceleration at 75 Hz is measured when an optimal load of 20.3 MΩ is applied. The frequency response of the device is also studied and a high Q factor of 250 is achieved.

Keywords: MEMS, micro generator, energy harvesting device, wireless sensor networks

1. Introduction

Along with the development of wireless sensor networks, various energy harvesters have been developed aiming to extract power from ambient vibration sources [1-5]. Among them, micro power generators with electrostatic method are of great interest because of its compatibility to the fabrication

* Corresponding author. Tel.: +45 4525 5845; fax: +45 4588 7762.
E-mail address: fei.wang@nanotech.dtu.dk.

doi:10.1016/j.proeng.2012.09.261

process of sensors. Resonant structures with nonlinear parylene beams [4] and circular silicon springs [5] have been fabricated for electret based energy harvesters. In this paper, we demonstrate a prototype energy harvesting device with silicon springs as sketched in Fig. 1. It is composed of two bonded chips with tunable capacitors and a moving part which can be driven by an ambient vibration source. When the polymer electrets on the shuttle vibrate horizontally according to the ambient vibration, induced charges move between the electrodes through an external load and therefore electric current occurs.

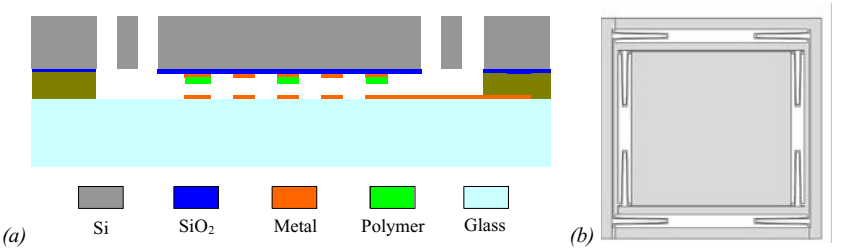

Fig. 1: (a) Schematic view of the prototype energy harvesting device, which consists of a silicon proof mass with charged polymers and a glass wafer with counter electrodes. When the polymer electrets on the shuttle vibrate horizontally due to the ambient vibration, induced charges move between the electrodes through an external load and therefore electric current occurs. (b) Top view of the two dimensional resonant structure with a proof mass and silicon beams.

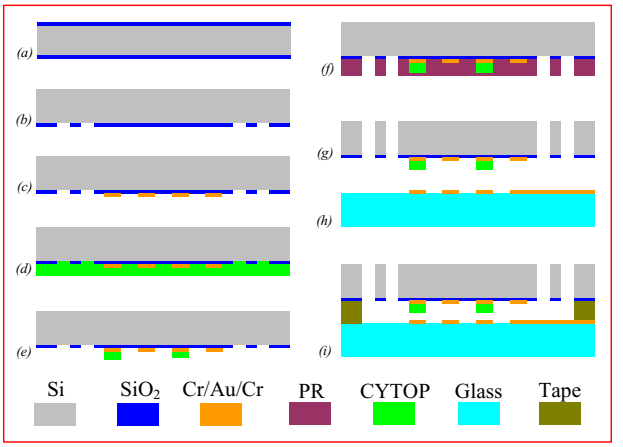

Fig. 2: MEMS fabrication process flow for the device.

2. Fabrication

The fabrication process flow is shown in Fig. 2. We start the fabrication with wafer oxidation. A 2 µm thick layer of SiO_2 is thermally grown. The oxide serves both as the etching mask and the isolation layer for the electrodes. After the SiO_2 layer is patterned using UV lithography and BHF etching, Cr/Au/Cr (10nm/300nm/40nm) metal electrodes are deposited and patterned using lift-off. Then, CYTOP is spin coated for 6 times to reach a thickness of 10 µm. Reactive ion etching (RIE) is applied afterwards to pattern the polymer electrets using a photoresist mask [6]. Another thick layer of photoresist mask is applied afterwards for masking against deep reactive ion etching of silicon. After etching, the photoresist is removed in acetone. Then, the polymer electrets on the silicon chip are charged to -200 V in a corona charging setup. For the glass wafer, metal electrodes are deposited and patterned. Finally, the silicon and the diced glass chips are bonded together with double side adhesive tape, which provides a gap of about

150 µm. For wafer scale fabrication in the future, low temperature wafer bonding with polymer will be a feasible solution [6].

Figure 3 (a) shows the thermal stability of the charges in two polymer materials. The polymers were charged in the corona charging setup and the surface potential measured, then the polymers were heated to either 90 ºC or 120 ºC and the surface potentials re-measured as a function of time at elevated temperature. The results suggest that the charges in CYTOP can survive higher bonding temperature than those in TOPAS. The charges are quite stable in both polymers at temperature lower than 90 ºC. When the temperature increases to 120 ºC, the surface potential of CYTOP drops slightly while most charges in TOPAS are lost. This is simply due to the low glass transition temperature of TOPAS (85 ºC).

In Fig. 3 (b), the polymer pattern and the metal electrodes are clearly seen while the counter electrodes on the glass wafer are shown in Fig. 3 (c). Figure 3 (d) shows the final bonded chip. The overall size of the silicon part is around 1.5 cm×1.5 cm. Figure 3 (e) shows the shaker setup used in the following measurements.

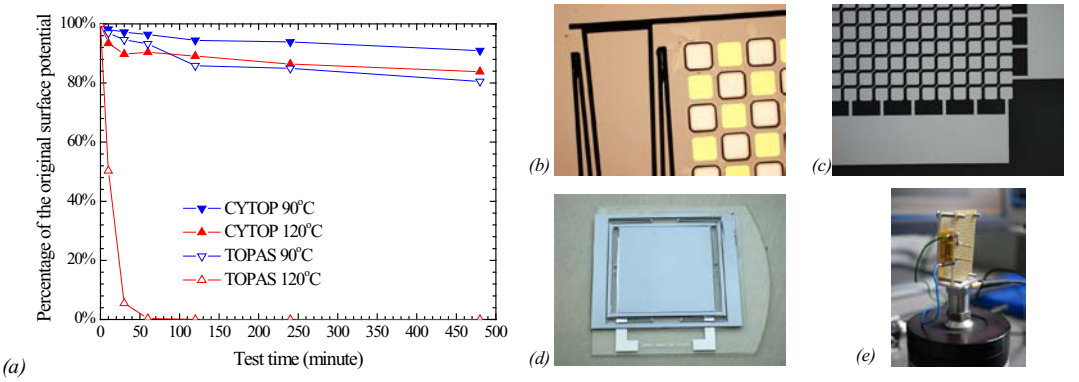

Fig. 3: (a) Thermal stability of the charge stored in the CYTOP and TOPAS polymers; (b) microscope view of the etched silicon wafer; (c) metal electrodes on the glass wafer; (d) the two chips are bonded together; (e) the chip is mounted to a shaker setup for dynamic measurement.

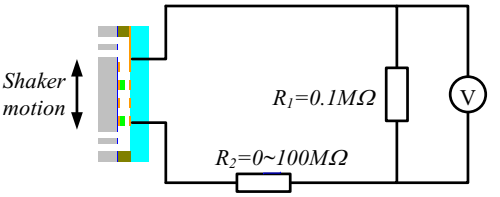

Fig. 4: Measurement setup with an external load.

3. Measurements

Using a shaker setup, the performance of the energy harvester is characterized as sketched in Fig. 4. The shaker (B&K Mini Shaker 4810) is driven by an amplified sinusoidal signal from an Agilent 33220A function generator. The root mean square (RMS) acceleration from the shaker is kept as constant to 0.014g (~0.14 m/s^2) using feed-back control when the frequency is swept from 74 Hz to 76 Hz. The RMS voltage output of energy harvester is measured and the power output is derived. Figure 5(a) plots the output voltage and power at the resonant frequency according to various external loads. The maximum RMS power of 1.17 µW is achieved at an optimal load of 20.3 MΩ. The frequency response of the device is plotted in Fig. 5(b). It is indicated from the plot that the resonant frequency of the structure is around 75

Hz. When the optimal load of 20.3 MΩ is applied, we have achieved a bandwidth of 0.3 Hz which means the Q factor of the full system is 250.

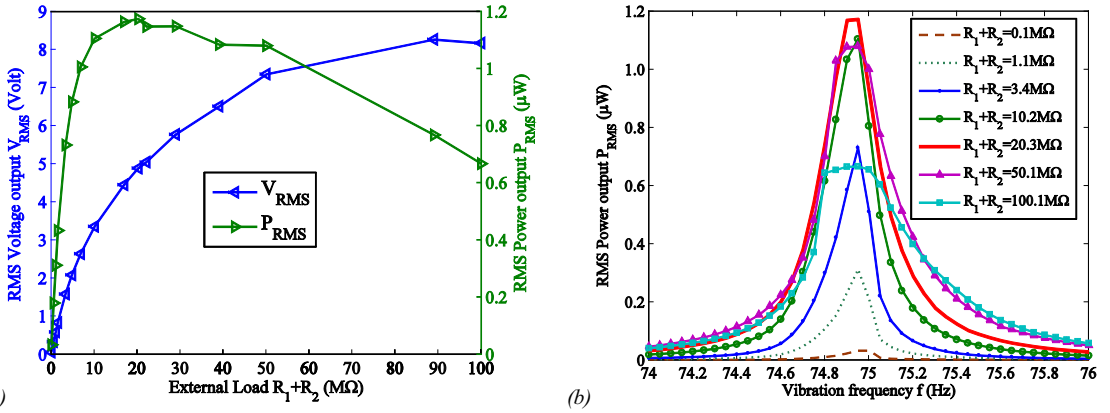

Fig. 5: (a) The voltage and power output of the energy harvester when the external load increases from 0.1 MΩ to 100 MΩ. (b) Frequency response of the energy harvester at various external loads. A bandwidth of ~0.3 Hz is measured when an optimal load of 20.3 MΩ is applied, and therefore the Q factor is estimated to 250.

4. Conclusion

In this paper, we have demonstrated a prototype of polymer electret based energy harvesting device. With a low acceleration of 0.014 g at low vibration frequency of 75 Hz, the prototype device provides a power output of 1.17 μW. With better bonding technique in the near future, this MEMS compatible energy harvester shows promising performance for application to wireless sensor networks.

Acknowledgements

We are grateful for the financial support from the Danish Research Agency (FTP). Center for Individual Nanoparticle Functionality (CINF) is sponsored by the Danish National Research Foundation.

References

[1] Lei A et al., MEMS-based thick film PZT vibrational energy harvester. *IEEE 24th International Conference on MEMS,* 2011, 125-8.

[2] Mitcheson PD, Yeatman EM, Rao GK, Holmes AS, Green TC, Energy Harvesting From Human and Machine Motion for Wireless Electronic Devices. *Proceedings of the IEEE* 2008;**96**, 1457–1486.

[3] Lo H, Tai YC, Parylene-based electret power generators. *Journal of Micromechanics and Microengineering* 2008;**18**, 104006.

[4] Miki D, Honzumi M, Suzuki Y, Kasagi N, Large-amplitude MEMS electret generator with nonlinear spring. *IEEE 23rd International Conference on MEMS*, 2010, pp. 176–9.

[5] Bartsch U, Gaspar J, Paul O, A 2D Electret-Based Resonant Micro Energy Harvester. *IEEE 22th International Conference on MEMS*, 2009, 1043-6.

[6] Wang F, Bertelsen C, Skands G, Pedersen T, Hansen O, Reactive ion etching of polymer materials for energy harvesting devices. *Microelectronics Engineering*. 2012, in press.