Air-spaced PDMS piezo-electret cantilevers for vibration energy harvesting

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Abstract. This paper reports a design of a new prototype of air-spaced cantilevers made from a micro-structured PDMS piezo-electret material for accelerometer and energy harvesting applications. The test performed on these cantilevers in a sensor mode exhibits a stable sensitivity of 385 mV/g for a frequency ranging from 5 Hz to 200 Hz that encompass most macro-scale vibrations. In the energy harvesting mode, the cantilever generates a power of 103 nW with a load resistance of 217 MΩ.

1. Introduction

Piezoelectric materials play an important role in micro-sensors and actuators field. An important progress has been made in the development of piezoelectric materials: the study of aging with respect to external constraints (temperature, mechanical pressure, electric field ...), adjusting proportions in the preparation of conventional piezoelectric materials (ceramics and semiconductors), adjusting of geometrical dimensions of the material to be adapted to the desired applications. However, the malleability constitutes a limit for the integration of these conventional materials in certain applications. During the past fifteen years, high deformable materials (referred as piezo-electrets) were developed and tested to show a significant piezoelectric behavior. These heterogeneous materials consist of a polymer matrix containing micro-cavities. To ensure the piezoelectric behavior, electric charges of opposite signs must be implanted in the inner surfaces of the micro-cavities. The piezoelectric response of this type of material depends on the size, shape and distribution of the micro-cavities introduced into the polymer matrix. These structures are usually used in their thickness mode characterized by a large piezoelectric coefficient d_{33}. In this paper, we propose the development of a micro-structured piezo-electret PDMS material with an enhanced piezoelectric response. This piezo-electret PDMS material is integrated in an air-spaced cantilevers prototype for accelerometer and energy harvesting applications.

2. Sample and prototype preparation

The polydimethylsiloxane (PDMS) used in this work was prepared using the Sylgard 184 silicone Elastomer Kit of Dow Corning. The pre-polymer and the curing agent are mixed at *1:10* proportions. The mixed uncured PDMS was degassed in a vacuum desiccator. The micro-structured PDMS material is obtained by the molding process to be able to control the size and the shape of the introduced micro-cavities. The obtained optimized structures are composed of two micro-structured layers both *40 μm* thick, interposed with three bulk layers each *55 μm* of thickness. The micro-structured layers contain cylindrical micro-cavities of *40 μm* in height and *100 μm* in diameter that are regularly distributed over the structure area with a pitch of *150 μm*. The obtained material has the thickness of *250 μm* and the area of $1\times4\ cm^2$ (Figure 1) [1,2]. To enhance the piezoelectric response, the final structures are poled with a triangular quasi-static voltage with amplitudes between *1 kV* and *8 kV* and at a frequency of *0.5 Hz* for *15* minutes [3]. To demonstrate a possible application, the material was integrated in a mechanical vibration energy harvester. The harvester is composed of two air-spaced cantilevers attached on one side to a fixed base and on the other side to a seismic mass. The top cantilever is made of the PDMS piezo-electret material, the other cantilever, necessary to insure the system stiffness is made of aluminum (Figure 2) [4,5]. Such configuration allows a higher bending of the piezo-electret material than in a case of a simple composed beam. The design has been optimized to obtain the maximum output energy during the mechanical solicitation of the system. The geometric dimensions of the optimized energy harvester are summarized in Table 1.

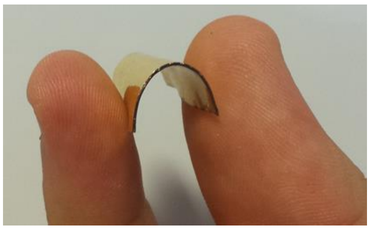


Figure 1. A photo image of the obtained flexible micro-structured PDMS piezo-electret material.

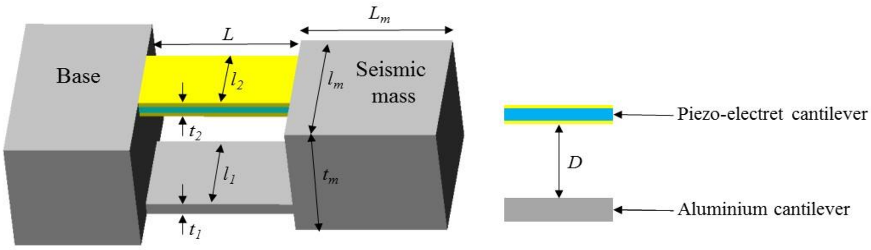


Figure 2. Schematic structures of the air-spaced cantilevers.

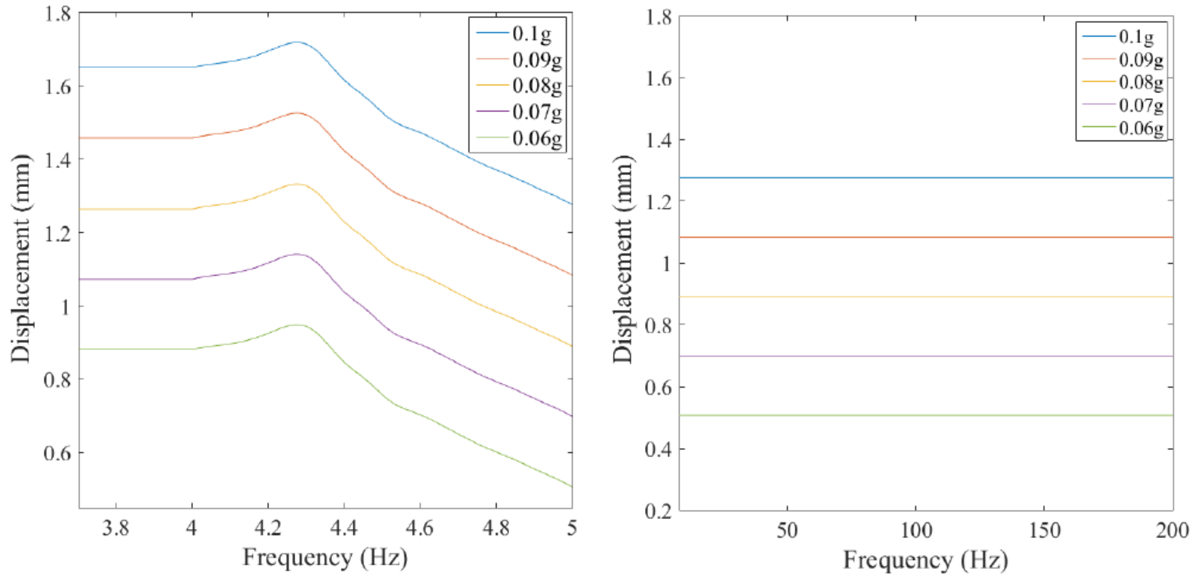
Table 1. Geometric parameters of the air-spaced cantilevers.

L(mm)	l_1(mm)	l_2(mm)	t_1(mm)	t_2(mm)	l_m(mm)	L_m(mm)	t_m(mm)	D(mm)
30.59	20.55	10.34	0.25	0.5	50.59	50.59	2	2

3. Results and discussion

3.1. Resonance frequency and sensitivity of the system

To determine the resonance frequency and the sensitivity, the piezo-electret PDMS material of the prototype is connected to a charge amplifier with a wide bandwidth and large dynamic range [Brüel & Kjær 2634] and placed on an electrodynamic shaker [Data Physics V20]. The shaker acceleration was controlled by an accelerometer [PCB Piezotronics 355B04]. Since we use a very soft material, the acceleration was varied between *0.06 g* to *0.1 g* with steps of *0.01 g* to avoid twisting and buckling phenomena during the system excitation. In addition, the frequency was swept in a range from *3.7 Hz* to *200 Hz,* which is compatible with the frequency range of vibrations that are available in our everyday life. A laser vibrometer [Polytec OFV 3001] is set to the seismic mass to determine the resonance frequency of the system. Figure 3 represents the displacement variations of the system in the frequency range previously specified. In Figure 3, we show separately the displacement in two frequency bands in order to observe the system resonant frequency of *4.3 Hz* for all accelerations (Figure 3a). The displacement is stable over the frequency range from *5 Hz* to *200Hz* (Figure 3b).



(a) (b)

Figure 3. Displacement variations for the frequency ranging from *3.7 Hz* to *200Hz*.

Figure 4 shows the normalized sensitivity of the piezo-electret PDMS material. The system presents a sensitivity of *420 mV/g* at the resonance frequency and a stable sensitivity of *385 mV/g* for the frequency ranging from *5 Hz* to *200 Hz* for various accelerations encompassing most macro-scale vibrations.

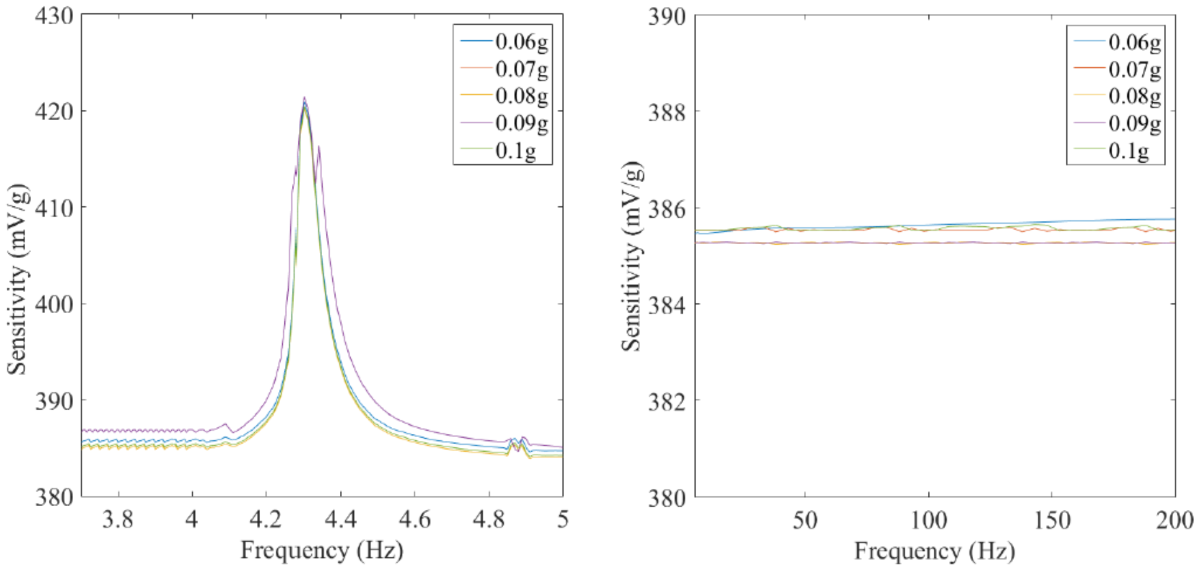


Figure 4. Sensitivity variations for the frequency ranging from *3.7 Hz* to *200Hz*.

3.2. Energy harvesting feasibility study

To study the energy to be harvested from mechanical vibrations applied to the system, the piezo-electret material was connected to variable resistors in parallel with an instrumentation amplifier [INA 116]. The system was excited with an acceleration of *0.1 g* at frequencies ranging from *3.7 Hz* to *200 Hz*. The resistance varied from *130.2 M*Ω to *295.3 M*Ω. The power shows an optimum for a resistance of *217 M*Ω for a capacitance of the material of *171 pF*. The generated power reaches its maximal value of *136 nW* and has a constant value of *103 nW* for frequencies ranging from *5 Hz* to *200 Hz* (Figure 5).

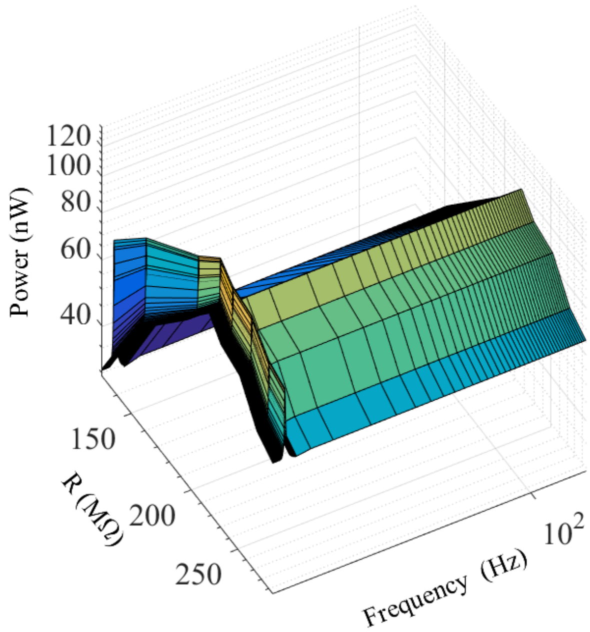


Figure 5. Power generated by the piezo-electret material for the frequency ranging from *3.7 Hz* to *200 Hz*.

4. Conclusion

In this work, a pototype of air-spaced cantilevers made from PDMS piezo-electret material is implemented. In the sensor mode, the system exhibits high stable sentivity of 385 mV/g for frequency ranging from 5 Hz to 200 Hz. In the energy-harvesting mode, the system delivers power of 103 nW to a load resistance of 217 MΩ. This frequency range covers the frequencies of the vibrations existing in our everyday life. Next work will focus design of high-capacitance structure configurations that will better match typical load resistances used in energy harvester systems.

References

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