Dynamic Characterization and Mechanical Simulation of Cantilevers for Electromechanical Vibration Energy Harvesting

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Abstract

Introduction

Ambient energy harvesting has become an interesting topic for powering small-scale wireless electronic devices, medical devices and sensors. Usually, ambient vibrations are sub-1 kHz. Hence, for efficient energy harvesting, devices must provide a resonant behavior at low frequency due to ambient vibration spectrum. In fact, the power produced at resonance is at least one order of magnitude larger than off frequency power. Moreover, in order to obtain large strain, for efficient electromechanical energy conversion, viscoelastic polymer materials, which are more flexible than silicon ones, have been considered for the vibrating MEMS. In this work, two preliminary resonant microstructures made of viscoelastic polymer microcantilevers have been simulated with COMSOL Multiphysics® to deduce both the resonant frequency and quality factor of the first mode. We have also investigated how the resonant frequency and the axial strain vary with the microcantilever thickness. These microcantilevers have been fabricated and characterized.

Use of COMSOL Multiphysics®

The microcantilevers made of viscoelastic polymer are shown in Figure 2. The harmonic vertical acceleration excitation induces the out-of-plane vibration of the structure. However, for a viscoelastic material, the Young's modulus is in a complex form (E=E'+i*E"). The material parameters of the polymer and the tip-mass are as follows: ρ=1150 kg/m3, ν=0.4, E=4.6 GPa +i*0.1 GPa and ρm=4500 kg/m3, νm=0.4, Em=50 GPa. Included in Figure 1 are the experimental geometries of the polymer cantilevers. Figure 3 shows both the experimental and the simulated deflection spectrum for two structures (A and C). This allows deducing the undamped natural frequency (f0), the resonant frequency (fr) and the quality factor (Q). The variation of axial-strain along the cantilever length is an important factor for energy harvester (i.e. piezoelectric, electrostrictive). Figure 4 shows the effect of the microcantilever thickness on both the axial strain and the resonant frequency.

Results

Figure 3 shows the values of the resonant frequency and the undamped natural frequency for structures without and with a tip-mass (A and C). A good agreement is obtained between both the experimental and the simulated results. Also, it can be observed that the tip-mass presence

decrease the resonant frequency which becomes 1.24 kHz for D. We found the simulated Qsim to be 39.9 which is equal to the experimental value. In fact, these structures are targeted to have a resonant frequency sub-1 kHz. From the plots of Figure 4, it is observed that a variation of the thickness from 30 µm to 15 µm can decrease fr_sim to 450 Hz and increase the maximum axial strain from 1.18 x 10-5 to 4.15 x 10-5 for D.

Conclusion

In this work, we have validated the ability to use COMSOL Multiphysics® in harmonic analysis to simulate structures made of viscoelastic polymers for use as resonators in a sub-1 kHz range. Also, this paper shows how FEM simulations can be used for optimizing the mechanical properties of microcantilevers to obtain low resonant frequency and large strain.

Figures used in the abstract

Structures	L (mm)	b (µm)	e (µm)	$L1$ (mm)	$b1$ (mm)	$e1$ (µm)	$f_{r,exp}$ (kHz)	$f_{r,Sim}$ (kHz)
A	1	200	20				4.47	4.47
B	0.94	600	24	380	0.91	48	1.59	1.62
C	0.94	600	25	380	0.91	48	1.7	1.72
D	0.94	300	30	380	0.91	70	1.28	1.25

Figure 1: Dimensions parameters and resonant frequency for two types of resonant structures. A without tip-mass and B, C and D with tip-mass.

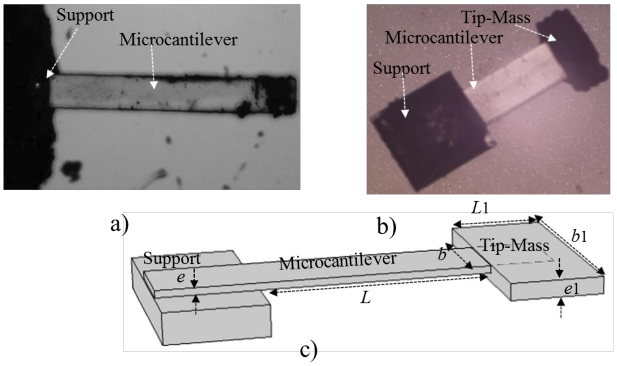

Figure 2: (a) Optical image of resonant structure A. (b) Optical image of resonant structure C. Schematic diagram of viscoelastic polymer microcantilever.

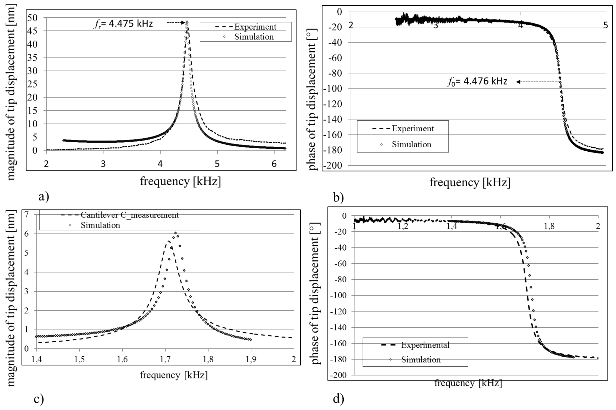

Figure 3: . Experimental and simulated amplitude and phase spectrum of the deflection of viscoelastic polymer cantilever. (a) and (b) for structure A fr,sim= 4.475 kHz, f0,sim= 4.476 kHz and Qsim= 39.9; fr,exp= 4.471 kHz, f0,exp= 4.475 kHz and Qexp= 40. (c) and (d) for structure C fr,sim= 1.725 kHz, and f0,sim= 1.726 kHz ; fr,exp= 1.703 kHz and f0,exp= 1.704 kHz.

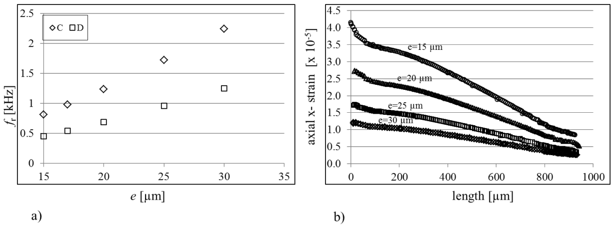

Figure 4: (a) Resonant frequency (kHz) and (b) axial strain variation along the length (L) for D for different cantilever thickness e (µm). The actuation is made by a vertical vibration of the support with a= 1 g*sin(ωt).