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Enlargement of Frequency Bandwidth of Vibrational MEMS Energy Harvester by High Density Electrets

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Abstract

In this paper, we analytically and experimentally demonstrate the extension of frequency bandwidth of a vibrational MEMS energy harvester by elevating the electret potential. The effective load resistance has been found to have an effect to increase the FWHM (full width at half maximum) bandwidth of the resonant peak when the electret potential is enhanced. At an electret potential of −200 V, the bandwidth has been 2.7-fold extended to 1.89 Hz by changing the load resistance from 0.1 MΩ to 5.0 MΩ.

1. Introduction

Previous study [1] reported an electret-type MEMS energy harvester that is capable of generating 1 mW power or more from the mechanical vibrations of 1 G (9.8 m/s^2) or less. Such an energy harvester is expected to works as a perpetual power source for IoT (Internet-of-Things) sensor nodes but it fails to effectively harvest the power when it misses c the frequency range of the environmental vibrations, owing to the narrow bandwidth of the mechanical resonance behavior [2]. Efforts have been paid in the conventional studies to expand the bandwidth by using, for instance, the bi-stable structures [3] and nonlinear springs [4]. In these methods, however, extra micromechanisms are usually required, resulting in a large footprint. Sometimes such a mechanism does not work well in a small acceleration range.

To overcome this problem, we have newly developed another method to expand the FWHM of vibrational energy harvester by simply tuning the effective load resistance, which was found to work effectively when the electret potential is deliberately set higher than those in the conventional reports.

2. Design and Simulation

Figure 1 illustrates the schematic structures of the vibrational energy harvester based on the symmetrically arranged comb electrodes that virtually cancels the electrostatic constraint force of the electret. Hence, the electret potential can be tuned high without causing the electrostatic pull-in of the electrodes. The load resistance is known to affect the resonant behavior of the harvester as reported elsewhere [5]. In this paper, we focus on the vibration bandwidth.

Figure 2(a) shows the LTspice simulation results of spectra of an energy harvester that is electrically charged at −10 V, −200 V, and −400 V; we change the external load resistance from 1 MΩ to 20 MΩ. None of the resonant frequency or the bandwidth of the harvester is affected by the load resistance when for the electret potential is small (−10 V). When with a large electret potential, on the other hand, the power spectrum has a local minimum at a medium value of the load resistance, where the FWHM (full-width-at-half-maximum) bandwidth becomes large. As shown in Figure 2(b), the FWHM is enhanced from 0.85 Hz to 6.37 Hz for the electret potentials of −10 V and −400 V, respectively.

Figure 3 shows the photograph of the harvester chip and its close-up view on the comb electrodes. The structures are made by the DRIE of the SOI layer, which are then processed to form the electret skins [6].

3. Experimental Result

The power spectra are shown in Figure 4(a) when the developed harvester was excited by 0.1 G acceleration vibrations. The bandwidth was found to become largest when the load resistance was set at 2 MΩ. The FWHM bandwidth is shown in Figure 4(b) as a function of the load resistance between 0.1 MΩ and 70 MΩ. As predicted by the simulation, the bandwidth is found to expand 2.7 times from 0.71 Hz to 1.89 Hz by changing the load resistance from 0.1 MΩ to 5 MΩ. The behavior was also found to agree well with the simulation results.

4. Conclusion

In conclusion, the bandwidth of the electret type energy harvester is found to be electrically tunable by changing the electret potential and the effective load resistance.

Acknowledgements

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References

[1] H. Honma, et al., *in Proc. Transducers 2019 Conference* (2019) 362.
[2] M. S. M. Soliman, et al., J. Micromech. Microeng. **18** (2008) 115021.
[3] F. Cottone, et al., Phys. Rev. Lett. **102** (2009) 080601.
[4] S. D. Nguyen, et al., J. Microelectromech. Syst. **20** (2011) 1225.
[5] H. Honma, et al., *in Proc MEMS 2020 Conferenc*e (2020) S-081.
[6] G. Hashiguchi, et al., AIP Advances **6** (2016) 035004.

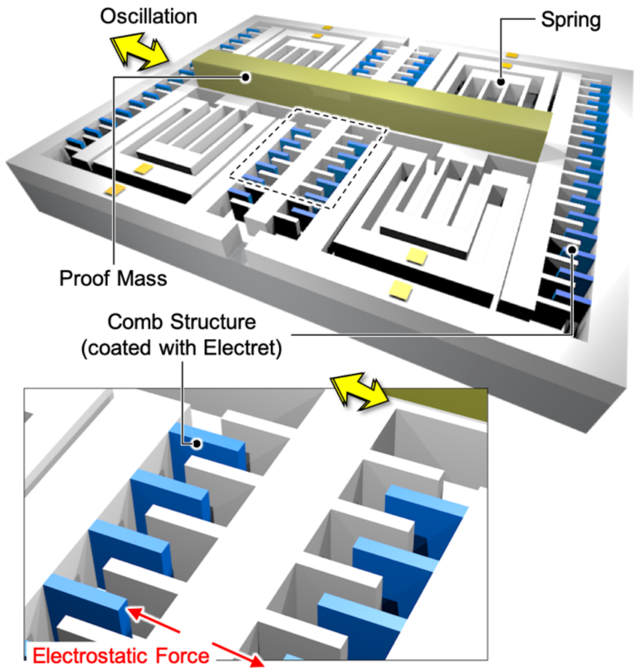


Fig. 1 Schematic structure of the electrostatic energy harvester based on the symmetric comb structures.

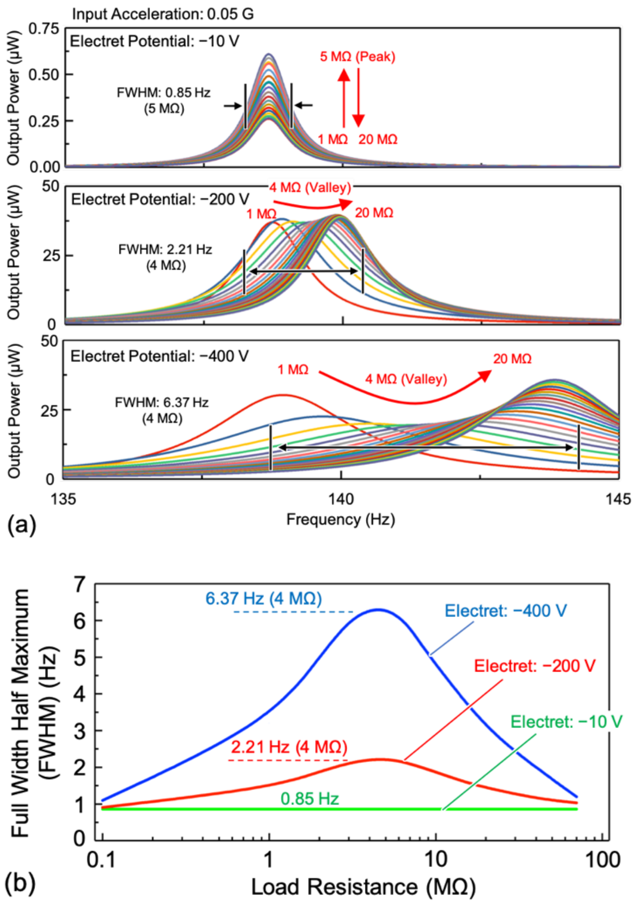
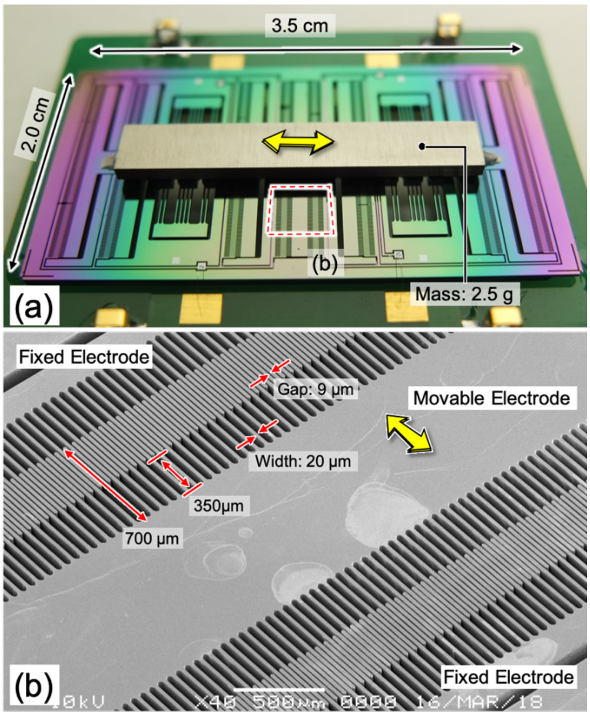


Fig. 2 (a) Simulated output power spectra as a function of load resistance between 1 MΩ and 20 MΩ. (b) FWHM as a function of load resistance. The three models are set on different electret potentials of −10 V, −200 V, and −400 V.



Design Values

- Comb Fingers :900
- Proof Mass : 2.5 g
- Electret Potential : -200 V
- Width of Comb Finger : 20 μm
- Thickness of SOI : 300 μm
- Length of Gap: 9 μm
- BOX : 5 μm
- Maximum Displacement : 350 μm

Fig. 3 Developed energy harvester equipped with symmetric comb structure coated with electret film of −200 V. (a) Device photograph and (b) SEM image of symmetric comb structure.

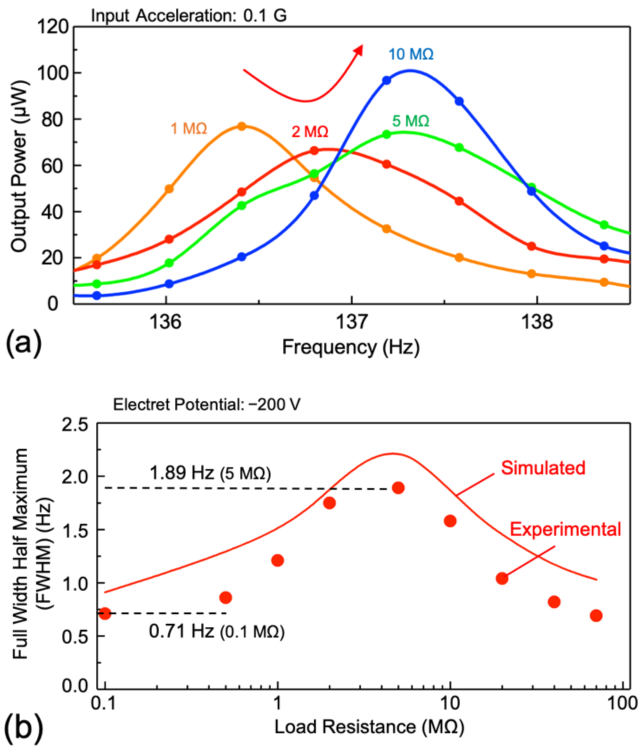


Fig. 4 (a) Experimentally observed output power spectra as a function of load resistance between 1 MΩ and 10 MΩ. (b) Experimental results and numerical analytic result of the FWHM as a function of the load resistance.