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Simulation and Analysis of MEMS Energy Harvesting Device and Effect of Substrate Thickness on Power Density

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Abstract: Energy harvesting; that is, harvesting small amounts of energy from environmental sources such as solar, air flow or vibrations using small-scale (≈1cm3) devices, offers the prospect of powering portable electronic devices. Numerous studies have shown that power densities of energy harvesting devices can be hundreds of µW; however, the literature also reveals that power requirements of many electronic devices are in the mW range. In this research paper simulation of MEMS based energy harvesting and effect of piezoelectric thinfilm in carried to evaluate the efficiency and power density of the device.

Keywords: MEMS, piezoelectric, thickness, thinfilm.

I. INTRODUCTION

Sustainable energy is the process of extracting fraction of the energy from the eco system (e.g., wind, water, heat, vibration) to power a small, low-power electronic system directly or to charge an electrical storage reservoir (usually a rechargeable battery or capacitor) that can be used to power a relatively high implementation at a later time. Most of what the we know about energy harvesting has come in the last fifteen years or so, and it's enough to give us hope that several electronic systems will have built-in energy recovery capabilities in the future. Nevertheless, the relatively small amounts of electricity that may be delivered by energy collecting devices is now proving to be a hurdle to adoption. Device optimization is one approach to greatly increase the power density of a harvesting device. Another option to improve the power output is to employ 'harvesting circuitry,' which is circuitry that is normally linked to the harvesting device's output to condition and/or manage the electrical power output. Energy harvesting from the environment is not a new concept. Windmills and water wheels have been around for millennia, and serious study on them has also been going on for that long. Scientists conducted research on waterwheels and discovered that the overshot wheel (driven by water falling on the wheel from above) is two times more efficient than the undershot wheel through experimentation. The direct piezoelectric effect is used in MEMS piezoelectric energy harvesting devices to transform the energy of a vibrating surface into an electrical current. Shaking a cantilevered beam linked to a piezoelectric film accomplishes this. The piezoelectric material gathers electrical charge and transmits it to a circuit as the vibration bends the beam. The mechanical force balance equations, as well as Kirchhoff's rules for the harvesting circuit, are utilised to model this system, and they interact thanks to the piezoelectric coefficients.

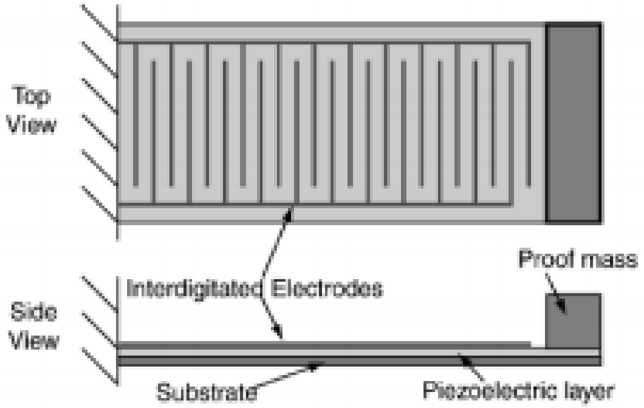

Fig.1 MEMS piezoelectric bimorph.

A basic MEMS piezoelectric unimorph beam is depicted in Figure 1. A piezoelectric film with associated electrodes, a substrate, and a proof mass make up this device. Each of them performs a distinct role. As it bends, the piezoelectric film (often constructed of PZT or AlN) generates electrical charge and delivers it to the interdigitated electrodes. The beam is stiffened by the substrate (typically metallic), and the proof mass aids in increasing inertial forces and lowering the device's resonance frequency. All of these features are built on a millimetre or even tens of micrometre scale, which is fascinating. one of the early investigations on the use of piezoelectric materials for energy capturing A PVDF film was put into the rib cage of a mongrel dog as part of their experiment. This energy harvester was created for medical uses and was expected to generate electricity on the order of 18 milliwatts. However, a mechanical modelling of the dog's ribs yielded only 20 watts, while the actual experiment yielded only 17 watts at an 18-volt peak voltage [7]. The viability of compressing PVDF film to gather energy from a windmill The enormous high-speed rotor utilised in conventional generators is a severe safety concern for everyone in the vicinity. He expected a 100-watt-per-cubic-centimeter output, but the material costs continue to outweigh the apparent benefits, and his proposed device has yet to be built [8]. The concept of extracting energy from a live entity, particularly a human. He did some calculations in theory to see how much power could be generated by harvesting body heat, respiration, or blood pressure. His conclusion was that the most practicable and least intrusive way would be to gather energy from human walking [29]. PVDF and piezoceramics are being used to capture energy within a shoe. The PZT and PVDF were easily fitted into a running sneaker, but the magnetic generator was too heavy and intrusive to be useful. A PVDF device measured around 1 mJ every step, while a PZT unimorph device measured around 2 mJ per step [12].

II. SIMULATION

The first step of the simulation is to design the geometry of the beam. As it can be seen, the harvesting device consists of a cantilevered beam with a mass attached on the end. The harvesting device consists of a cantilevered beam with a mass attached on the end. This tool is currently capable to simulate two kinds of piezoelectric harvesters: Unimorph and Bimorph. The Unimorph beam consists of only one piezoelectric layer and a metallic substrate layer; whereas the Bimorph has two interconnected piezoelectric layers in a sandwich-like arrangement with the metallic substrate. Beams with more substrate or piezoelectric films (i.e. Multimorph). Geometry of the substrate such dimensions as length, thickness, width, etc are to be specified. If no substrate is to be simulated, it is possible to input minimum thickness. The gap between the beam and the floor doesn't play an important role at millimeter-sized devices; however, it could affect greatly the squeeze force for MEMS scale cantilevers. After specifying these dimensions, the materials for the beam and the value of the proof mass can be chosen in the mechanical properties.

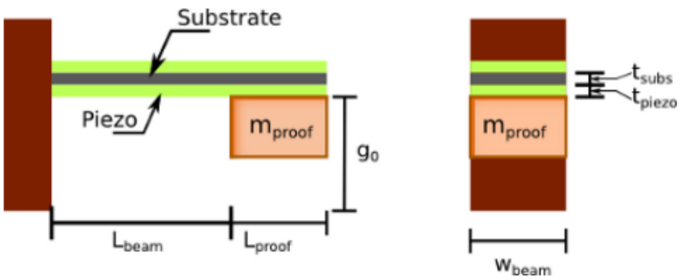

Fig. 2 PZT morph structure.

Fig. 3 Steps of simulations.

The required properties include the modulus of elasticity and density for both materials as well as the transverse piezoelectric coefficient and dielectric constant for the piezoelectric films. The structural damping factor can be known from an experiment, or estimated with a reasonable value such as 0.02 for a 1% damping ratio. the simulation allows testing the device under different excitation conditions. Here an input vibration signal will be generated according to the

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provided options. This tool allows generating sinusoidal, random and impulsive vibrations, and includes some predefined values for measured oscillations from different sources. Also, a recorded file can be uploaded. All of these can be tested at the same time since internally the program will add all the enabled options into a single input signal.

III. Results and Discussion

Solving the differential equations, some statistics and a series of plots are presented. a series of plots can also be analyzed both in the time domain and the frequency domain. Results plots with the values of the output voltage, tip displacement and output power at any instant of the simulation. Also, a plot of the stress in the beam is shown to test both static and dynamic strength limits.

TABLE I Simulation parameters.

Substrate Thickness (µm)	Simulation period (sec)	Sampling frequency (kHz)
100	0.1250	5.1671
150	0.1250	6.6646
200	0.1250	8.1875
250	0.1250	9.7217
300	0.1250	11.262
350	0.1250	12.805
400	0.1250	14.35
450	0.1250	15.897
500	0.1250	17.444

TABLE II Output parameters computed from simulation.

Parameters	Substrate Thickness								
	100	150	200	250	300	350	400	450	500
Natural frequency [Hz]	258.35	333.23	409.38	486.09	563.09	640.25	717.51	794.84	872.21
Open-circuit resonance [Hz]	270.41	349.35	429.21	509.48	589.94	670.5	751.13	831.8	912.5
Average harvested power [uW]	0.00088987	0.002837	0.046472	0.11971	0.14502	9.619	2.6266	1.3049	0.80475
Peak power [uW]	0.01226	0.038341	0.50144	1.0826	1.5796	0.12117	0.019179	0.0077351	0.0042368
Estimated device volume [cm^3]	0.055401	0.072278	0.0941	0.11235	0.12886	0.13526	0.14903	0.1643	0.17982
Power density [mW/cm^3	1.6062e-05	3.925e-05	0.00049386	0.0010655	0.0011254	7.1113e-05	1.7624e-05	7.9427e-06	4.4752e-06
Input RMS acceleration	0.71439	0.72402	0.72965	0.73228	0.73426	0.73537	0.73622	0.73663	0.73718
Power-to-acceleration ratio [Uw/RMS]^2	0.0017436	0.0054118	0.08729	0.22324	0.26899	0.017787	0.0048459	0.0024049	0.0014809

Table I presents the simulations parameters i.e. substrate thickness variation and automated sampling frequency. The substrate thickness is varied from 100 to 500 µm with step size of 50µm. The output parameters are tabulated in Table II. The computed parameters such as natural vibrational frequency, resonance, power harvested, peak power, volume of device, power density, and ratio of power and acceleration. Figure 4 and 5 shows the generated voltage and power with respect the input excitation given for limited interval of time. From the graph it is interpreted that substrate thickness in important parameter in harvesting the power.

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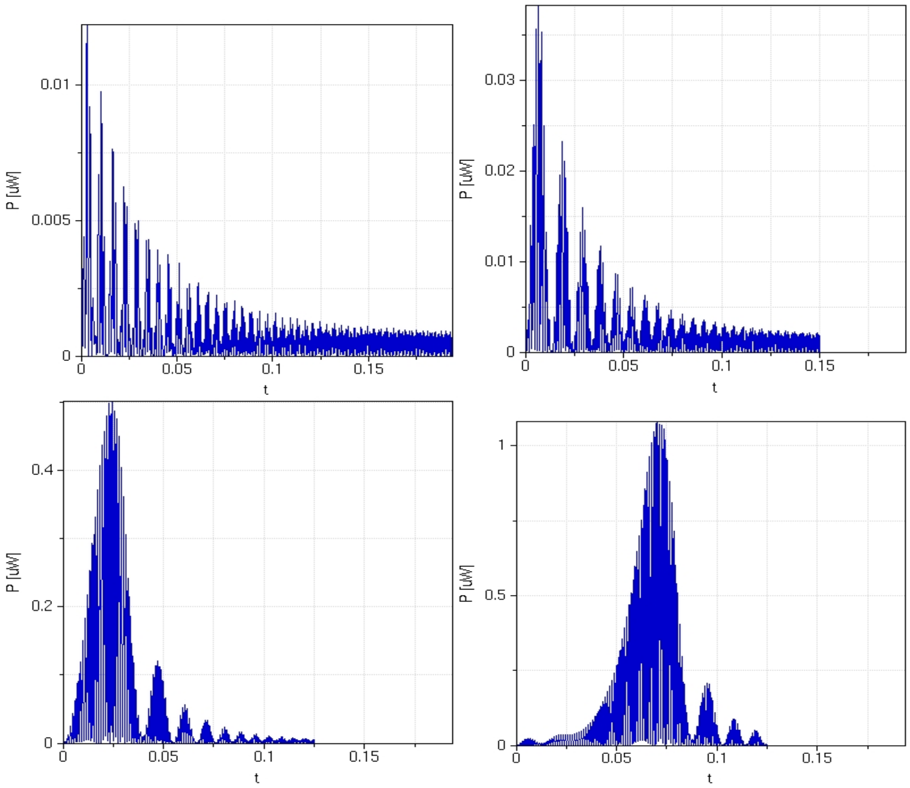

Fig. 4 Harvested power over simulation time period for substrate thickness from 100 to 250 um.

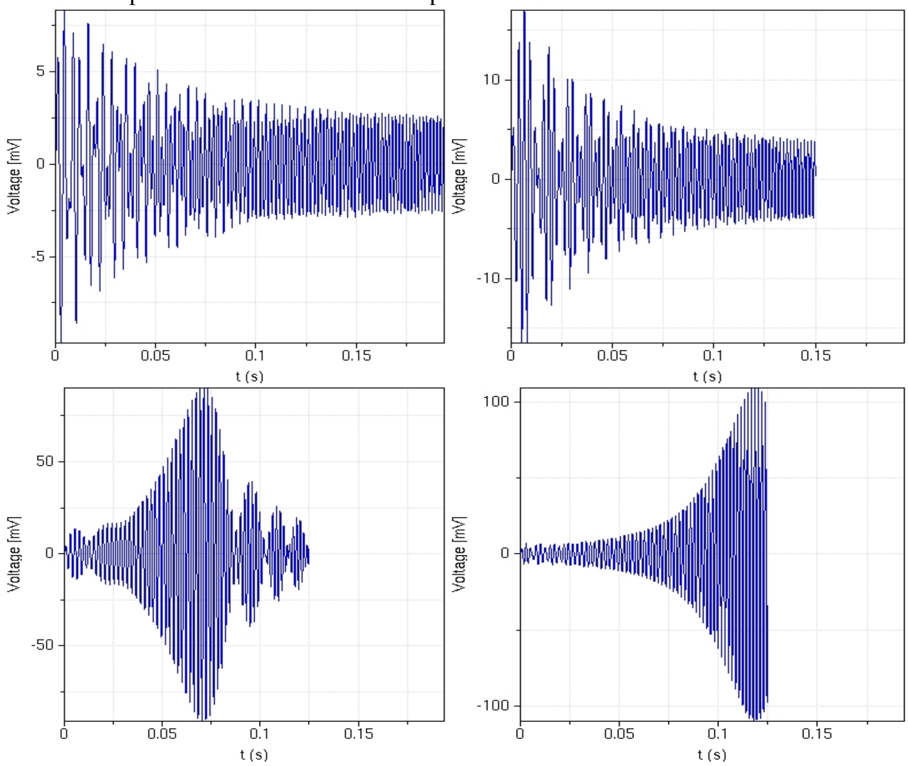

Fig. 5 Voltage response over simulation time period for substrate thickness from 100 to 250 um.

IV. CONCLUSION

The simulation is carried out investigate the effect of piezoelectric material thickness effect on various output parameters of MEMS based energy harvester. Various thickness of thinfilms are considered for the simulations ranging from 100 µm to 500 µm. the maximum peak power value of 1.5796 is obtained for 300 µm thick piezoelectric thinfilm due to the

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natural resonance. Maximum harvested power value is 0.14502 µm. Future prospect of research work is to consider types of external excitations for the simulations.

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