International Journal of Engineering Research
Volume No.3, Issue No.12, pp : 737-741

ISSN:2319-6890)(online),2347-5013(print)
01 Dec. 2014

Power Variation with Electret Surface Potential and Frequency of Vibration in Vertical Vibration based Cantilever-Electret Micro-Power Generation

Akin-Ponnle A.E.[1, 2], Ponnle A.A.[1] , Falaki S.O.[1]
[1] Department of Electrical and Electronics Engineering, Federal University of Technology, Akure, Nigeria.
[2] Research and Development Department, Engineering Materials Development Institute, Akure, Nigeria.
E-mail: nicebikky@yahoo.co.uk, ponnleakinlolu@yahoo.co.uk, swolefalaki@yahoo.com

Abstract*—A cantilever-electret based electrostatic micro-power generator for energy harvesting was set up in which Cyclic Transparent Optical Polymer (CYTOP) was used as the electret, and the upper electrode was made in form of an A-shaped cantilever which was fabricated from materials of copper with embedded glass epoxy. The cantilever was vibrated in the vertical direction in close to contact point mode of operation. Experimental result showed that the average output power increases with increasing electret surface potential, and the minimum distance to contact point decreases with increasing electret surface potential. Also, variation of output power with frequency was investigated by first observing the natural vibration of the cantilever amplitude with frequency. The natural amplitude was found to decrease with increasing frequency, thus making the average output power to decrease with increasing frequency. However, for the fabricated cantilever when operated over a wide frequency range, it was further confirmed by experiments that the output power variation peaks around 40Hz with maximum output power of 2.7nW with 1MΩ externally connected load and then decreases with increasing frequency.

Keywords— **Electret, Cantilever, Micro-Power Generator, Energy Harvesting, Average Output Power, Frequency, Surface Potential.**

I. Introduction

Energy harvesting is a process of capturing small amounts of energy that would have been lost, and this captured energy can be used to power technologies such as wireless sensor networks (WSNs), micro electro-mechanical and nano electro-mechanical system devices, and other handheld devices (Beeby *et al*., 2006; Kibong *et al*., 2012). Micro-power generation is the development of very small electric generators or devices to convert heat or motion to electricity, for use close to the generator. These devices provide power sources for portable and very light weight electronic devices, and have a longer operating time than existing batteries.

In the past, some energy harvesting approaches have been investigated as potential sources of renewable power. One of the most abundant and readily available energy sources is ambient motion (Roundy *et al*., 2003; Tiwari *et al*., 2013). Vibration energy is richly available from mechanical machines, human body, inside a building and the outside environment. Recently, much attention has been drawn towards the devices that can harvest vibration energy from the environment and replace batteries in handheld devices or WSNs (Roundy *et al*., 2003; Lo *et al.*, 2007). According to Galchev *et al*., (2011), “it is in the low frequency portion that available vibration energy from ambient motion can be found in many practical applications such as environmental monitoring, structural monitoring, security and military applications, agricultural automation and medical/body-worn devices”. Mechanical energy in the form of vibrations is commonly available in low frequencies up to 100Hz, and can be converted into electrical forms by means of energy harvesting techniques (Sardini and Serpelloni, 2011). Some researchers have worked on development of micro-power generators for energy harvesting in the low frequencies up to 100Hz (Kulah and Najafi, 2004; Naruse *et al*., 2008; Edamoto *et al*., 2009; Sari *et al*., 2010; Galchev *et al*., 2011).

The choice of a specific transducer mechanism for energy harvesting from vibration is heavily dependent on both the operating conditions, and the available space given by the application environment (Hoffmann *et al*, 2008). There are four major techniques that can be used to generate electricity from mechanical vibrations: electromagnetic, piezoelectric, magnetostrictive and electrostatic methods of generation.

In electrostatic approach, use of an electret is common (Borland *et al*., 2003; Miki *et al*., 2009;Tsutsumino *et al*., 2006; Altena *et al*., 2011; Akin-Ponnle *et al*., 2014). An electret is a stable dielectric material with a quasi-permanently embedded static electric charge; which, due to the high resistance of the material, will not decay for a long period of time. An electret acts as an electrical counterpart of a permanent magnet. Modern electrets are usually made by embedding excess charges into a highly insulating dielectric, e.g. by means of an electron beam, a corona discharge, injection from an electron, electric breakdown across a gap or a dielectric barrier.

The concept of vertical vibration based cantilever-electret micro power generator is illustrated in Figure 1. An electret dielectric with air or other medium is placed between two plate electrodes as shown in the figure. The electret is attached to the lower electrode (base electrode) while the upper electrode (counter electrode) is allowed to vibrate freely in the vertical direction. Free charges are deposited on the electret by external charging and when placed in the arrangement shown, charges are induced to the upper electrode and there is transport of charges if connected to an external load due to changes in the capacitance between the two electrodes.

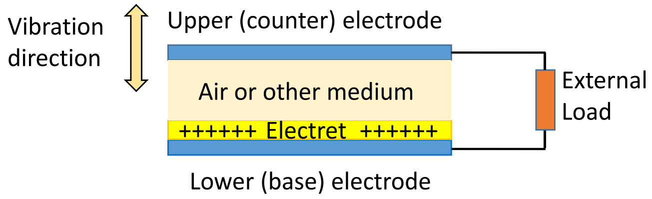


Figure 1: Basic concept of the vertical vibration based cantilever-electret micro power generator.

In vertical vibration based cantilever-electret micro power generator, some of the factors that affect the power output to an external load are overlapping area of the electret and the cantilever plate, mean distance between the cantilever and the electret surface, amplitude of oscillation of cantilever, frequency of vibration of the cantilever, magnitude of the electric charge on the electret surface (surface potential), and parasitic capacitance. Cantilever shapes on average power output to an external load were investigated by Akin-Ponnle *et al*., (2014).

Cyclic Transparent Optical Polymer (CYTOP) has been demonstrated to be a good electret material with high charge density (Tsutsumino *et al.*, 2006; Lo *et al.*, 2007; Nagasawa *et al.*, 2008). CYTOP is a perfluoronated amorphous (non-crystalline) polymer with ultra-high light transparency levels, which was developed by Asahi Glass Company, Japan (Asahi Corporate Brochure). Attractive properties of the polymer include: high thermal stability; low dielectric constant and high dielectric breakdown strength (11kV/0.1mm); low water absorption and high impermeability; low surface tension and excellent chemical resistance to acids, alkaline and organic solvents. Also, since it is thermoplastic, it lends itself well to extrusion coating. It can be dissolved in special fluorinated solvent for thin-film coating, and could be applied using a variety of coating methods. CYTOP is for industrial applications only, and may not be used for medical, food or military applications.

The objective of this work is to set up a cantilever-electret micro power generator with vibration in the vertical plane; and investigate the variation of generated output power with electret's surface potential and frequency of vibration. CYTOP was chosen as the electret material.

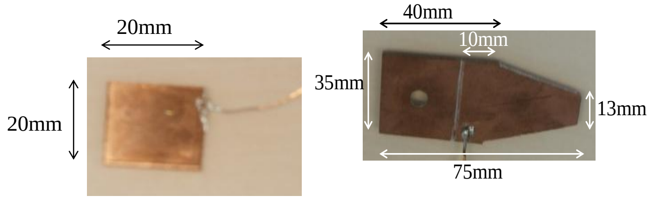
II. Materials and Methods

The micro power electrostatic generator was developed by first fabricating the electret and the cantilever, and then setting up the generator.

A. *Electret Formation and Cantilever Fabrication*

Cyclic Transparent Optical Polymer (CYTOP CTL-809A) from Asahi Glass Company, Japan was employed as the dielectric material. The substrate for the lower electrode was fabricated from a copper plate with a thickness of 1.5 mm. Four samples into sizes of 20 mm by 20 mm were produced. The sample substrates were washed with ethanol and distilled water using a vibrator, after which the samples were dried using Nitrogen gas. Few drops of aminopropyltriethoxysilane were deposited on the copper substrates and spin-coated using a spin coater. Then, CYTOP was applied to the substrates, spin-coated and soft-baked. This process was repeated four times to obtain the required film thickness and then fully cured. Electrical connections were made to the sample substrates to complete them as the lower electrodes, and were then charged using a corona charging set up.

The upper electrode was made in form of an A-shaped cantilever which was fabricated from a material of double-sided copper with embedded glass epoxy. Electrical connection was made to the cantilevers. In addition, a thin film of laser reflector was pasted around the tip of the cantilever to aid sensing of the displacement of the cantilever by a laser projecting device. A completed sample electret with a conductor connected is shown in Figure 2 (a), and the fabricated cantilever with its dimensions is shown in Figure 2 (b).



(a) (b)

Figure 2: (a) A completed sample electret with a conductor connected. (b) The fabricated A-shaped cantilever.

B. *Micro Power Generation Set Up and Experimental Procedure*

The micro-power generator consisted of an upper electrode (as a cantilever) and a lower electrode (with electret film on it) facing each other. The two electrodes were connected, through a coaxial cable, to an external load resistor of 1MΩ across which the output of the generator was obtained. The schematic of the experimental set up is shown in Figure 4. The micro power generator was mounted on a shaker (Vibropet PET-05) and also connected to a precision stage. The shaker is controlled by a laser vibrometer (ONOSOKKI LV-1710) that sets the vibration waveform, amplitude, acceleration and the frequency via a vibration exciter (Asahi APD-200FCG). The precision stage was connected to a stage controller which can be operated manually or by a computer.

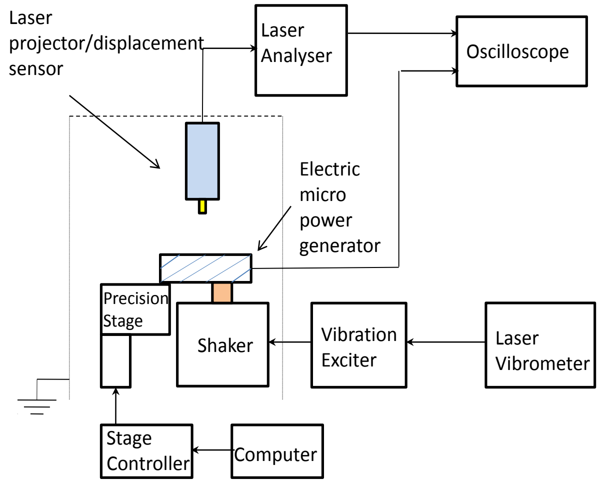


Figure 4: Experimental setup for the micro-power generation.

A laser displacement projector/sensor was mounted close to the top of the generator to sense and measure the amplitude of vibrations of the cantilever. The laser displacement projector/sensor works in conjunction with a Laser Impedance/Gain Phase Analyser (Yokogawa-Hewlett Packard 4194A) from which the vibration waveform was obtained via one of the input channels of a digital oscilloscope (Tektronix TDS2014B). The movement of the cantilever with respect to the lower electrode was observed with a high frame rate digital camera. The electrical output of the micro power generator was connected to another input channel of the digital oscilloscope. The oscilloscope was used for observation and data acquisition.

Experiments were performed on the generator by vibrating the upper electrode in the vertical direction in close to contact point mode using the shaker representing mechanical vibration from the environment. The external vibration waveform was set to be sinusoidal. The set of experiments conducted involved;

i. The variation of the generated output of the A-shaped cantilever generator with four different electret surface voltage at a fixed frequency of vibration of 100Hz, acceleration of 30.2m/s^2 and cantilever vibration amplitude of 0.15mm (pk-pk); and

ii. The variation of the generated output of the A-shaped cantilever generator with varying frequency of external vibration at a fixed electret surface potential of -330V.

In (i), the minimum mean distance to contact point (where there is no distortion of the output waveform) was noted for each electret surface voltage. In (ii), the vibrator amplitude was not compensated and was initially set at 0.15mm (pk-pk) at a frequency of 100Hz. Thereafter, the frequency was reduced in decrements of 10Hz, and waveforms were acquired. Output data was acquired by the digital oscilloscope and were analysed using MATLAB software.

III. Results and Discussion

A. Average Power with Electret Voltage

Figure 5 shows the average power with four different electret's surface potential for the A-shaped cantilever generator. The frequency of vibration is 100Hz, the external load resistance is 1MΩ and amplitude of vibrator is 0.15 mm (pk-pk) at an acceleration of 30.2 m/s^2. The average output powers indicated in the figure are the values at minimum displacement to contact point. The figure shows that higher output power is realized with higher electret surface potential.

Figure 6 shows the minimum mean distance to contact point i.e. minimum distance between the cantilever and the electret for distortion-less output waveforms, for each of the electret's surface potential. Also, the figure shows that the minimum mean distance to contact point is reduced with higher electret's surface potential (reduced to the permissible limit imposed by the peak amplitude of vibration).

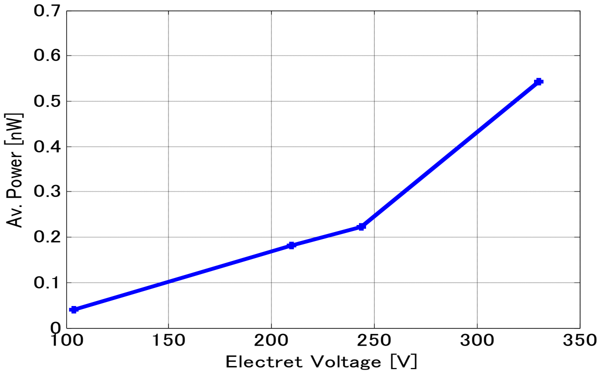


Figure 5: Average generated power with four different electret's surface potential for the A-shaped cantilever generator.

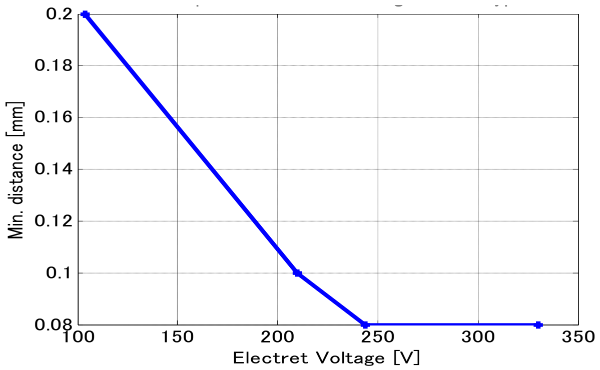


Figure 6: Minimum mean distance to contact point for each of the electret's surface potentials of Figure 5.

B. Average Power with Frequency

Figure 7 shows the natural amplitude of vibration with varying frequency, of the fabricated A-shaped cantilever generator with initial setting of 0.15mm (pk-pk) at 100Hz. The vibrator amplitude was not compensated and was initially set at 0.15mm (pk-pk) at a frequency of 100Hz, and then varied down to 50 Hz in decrements of 10Hz. This was done in order to observe the natural variation of the amplitude of the cantilever to varying frequency which could also affect the output, as the case is likely to be in real environmental conditions.

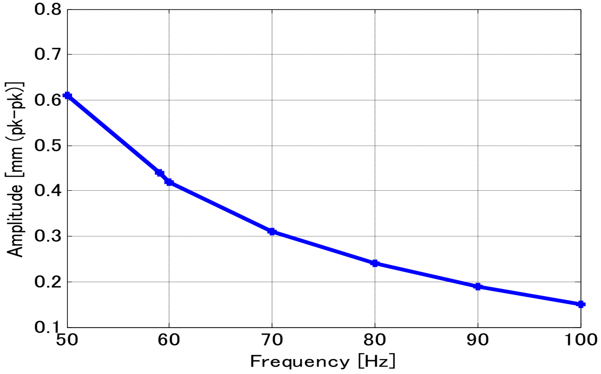


Figure 7: Natural amplitude of vibration with varying frequency, of the fabricated A-shaped cantilever generator with initial setting of 0.15mm (pk-pk) at 100Hz.

Figure 8 shows the plot of the average power with varying frequency of vibration for the A-shaped cantilever generator with same parameters as for other experiments but with electret surface voltage of -330V. The average output power values shown are for those at permissible limit of minimum distance to contact point imposed by the peak amplitude of vibration.

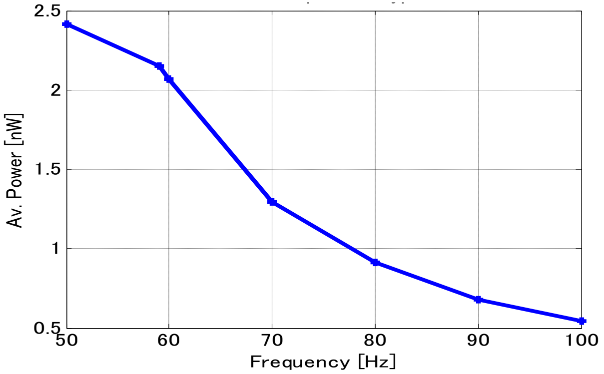


Figure 8: Average generated power against frequency for the A-shaped cantilever generator. The electret has a surface potential of -330V, and the external load resistance is of 1MΩ.

In Figure 8, it can be observed that higher output power is generated with decrease in frequency, though with varying (increasing) vibration amplitude of the cantilever as shown in Figure 7 because the setting of the amplitude of vibration was not compensated in the vibrometer. This result shows that the cantilever has a natural mechanical tendency of greater response to lower frequencies of vibration thereby yielding greater output power.

By further experimenting on the A-shaped cantilever generator down to a frequency of 20Hz under the same conditions as of Figure 8, Figure 9 was obtained which shows the plot of the average power of the A-shaped cantilever generator with varying frequency of vibration down to 20 Hz in decrements of 10Hz.

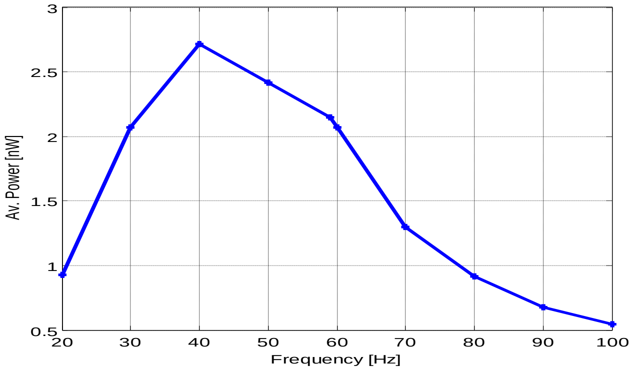


Figure 9: Average generated power of the A-shaped cantilever generator over a frequency range between 20Hz and 100Hz.

Figure 9 experimentally shows that the average output power for the fabricated A-shaped cantilever micro-power generator peaks around 40Hz with maximum output power of 2.7nW and then decreases with increasing frequency. Thus, though the electret-cantilever arrangement does not count on the spring proof-mass design as is the case in electromagnetic counterparts, nevertheless, output power, which is maximum at close to contact point, peaks around a certain low frequency depending on the cantilever that is fabricated.

The rising section of the curve is due to increase in the power as the frequency increases. Though this section is characterized by large amplitudes of vibration, the low value of power obtained initially is due to low frequency of operation. As the frequency increases, the power tends to increase, but there is reduction in amplitude of vibration which tends to reduce the power. So, this acts as a counteracting effect to the increase in power due to increase in frequency. This falling section of the curve is due to the mechanical nature of the cantilever. There is a frequency where the rising section meets the falling section and is the frequency of maximum power.

IV. Conclusion

The fabrication and experimental operations of a macroscopic cantilever-electret micro-power generator set up with vibrations in the vertical plane for energy harvesting have been presented. The work has shown that higher power is generated with increased electret's surface potential and the minimum mean distance to contact point reduces with higher electret's surface potential. Also, there is natural tendency to generate higher power with lower frequencies of vibration. The power peaks around a certain frequency which is cantilever/generator dependent. The electrical characteristic of the generator increases the power with frequency, while the mechanical characteristic decreases the power with increase in frequency.

Acknowledgement

We express profound gratitude to Professor H. Kuwano and Associate Professor M. Hara, of the department of Nano-Mechanics Engineering, Graduate School of Engineering, Tohoku University, Sendai, Japan, in whose laboratory the experimental aspect of this work was carried out.

References

i. Altena G., Hohlfeld D., Elfrink R., Goedbloed M.H., and van Schaijk R. (2011): "Design, Modelling, Fabrication and Characterization of an Electret-based MEMS Electrostatic Energy Harvester". Proceedings Transducers IEEE, Beijing, China, pp. 739-742.

ii. Akin-Ponnle A. E, Ponnle A. A., and Falaki S.O. (2014): "Vertical Vibration based Electret-Cantilever Method of Micro-Power Generation for Energy Harvesting". International Journal of Engineering and Innovative Technology, Vol. 3, Issue 12, pp. 218-223.

iii. Akin-Ponnle A. E, Ponnle A. A., Falaki S.O., Hara M., and Kuwano H. (2014): "Cantilever Shapes on Power Output in Vertical Vibration based Electret Micro-Power Generation". International Journal of Emerging Technology and Advanced Engineering, Vol. 4, Issue 4, pp. 775-780.

iv. Beeby S. P., Tudor M. J., and White N. M. (2006): "Energy Harvesting Vibration Sources for Micro Systems Applications," Meas. Sci. Technol., Vol. 17, pp.175- 195.

v. Borland J.S., Chao Y-H., Suzuki Y., and Tai Y-C. (2003): "Micro Electret Power Generator," Proceedings 16th IEEE International Conference MEMS, Kyoto, Japan, pp. 538-541.

vi. Corporate Brochure Eng 08-2010, Asahi Glass Co., Ltd. Japan, www.agc.co.jp *vii. Edamoto M., Suzuki Y., Kasagi N., Kashiwagi K., Moizawa Y., Yokoyama T., Seki T., and Oba M. (2009): "Low-resonant Frequency Micro Electret Generator for Energy Harvesting Application", Proceedings 22nd IEEE International Conference MEMS, Sorrento, pp. 1059-1062.*

viii. Galchev T., Kim H., and Najafi K. (2011): "Micro Power Generator for Harvesting Low Frequency and Non-Periodic Vibrations",Journal of Microelectromechanical Systems, Vol. 20, No 4, pp. 852-866.

ix. Hoffmann D., Folkmer B., and Manoli Y. (2008): "Fabrication and Characterization of Electrostatic Micro-Generators", Proceedings of PowerMEMS 2008 + MicroEMS 2008, Sendai, Japan, pp 15-18.

x. Kibong Han, Dongchan Shin, and Yongho Choi (2012): "Research of Wideband Vibration System of Energy Harvesting System for Wireless Sensors," International Journal of Emerging Technology and Advanced Engineering, Vol. 2, Issue 12, pp.49 - 53.

xi. Kulah H., and Najafi K. (2004): "An Electromagnetic Micro Power Generator for Low Frequency Environmental Vibrations", 17th IEEE International Conference on Microelectromechanical Systems (MEMs), pp. 237-240.

xii. Lo H-W, Whang R., and Tai Y-C (2007): "A Simple Micro Electret Power Generator" IEEE Technical Digest PowerMEMS 2007, Kobe, Japan, pp. 859-861.

xiii. Miki D., Horizumi M., Suzuki Y., and Kasagi N. (2009): "MEMS Electret Generator with Electrostatic Levitation". PowerMEMS 2009, Washington DC, USA, pp. 169-172.

xiv. Naruse Y., Matsubara N., Mabuchi K., Izumi M., and Honma K. (2008): "Electrostatic Micro Power Generator from Low Frequency Vibration such as Human Motion". Proceedings of PowerMEMS 2008 + microEMS 2008, Sendai, Japan, pp. 19-22.

xv. Roundy S., Wright P. K., and Rabaey J. (2003): "A Study of Low Level Vibrations as a Power Source for Wireless Sensor Nodes", Computer Communications, Vol. 26, No 11, pp. 1131-1144.

xvi. Sardini E., and Serpelloni M. (2011): "An Efficient Electromagnetic Power Harvesting Device for Low-Frequency Applications", Journal of Sensors and Actuators A: Physical, Elsevier, Vol. 172, pp.475 - 482.

xvii. Sari I., Balkan T., and Kulah H. (2010): "An Electromagnetic Micro Power Generator for Low Frequency Environmental Vibrations based on the Frequency Up-conversion Technique", Journal of Microelectromechanical systems, IEEE, Vol. 19, Issue 1, pp. 14-27.

xviii. Tiwari R., Gupta M.,and Tiwari O.P. (2013): "Study of different Energy Scavenging Techniques through Vibration and its Micro Power Applications", International Journal of Computer Applications, Vol. 68– No.19, pp. 17-23.

xix. Tsutsumino T., Suzuki Y., Kasagi N., and Sakane Y. (2006): "Seismic Power Generator using High –Performance Polymer Electrets". Proceedings of 19th IEEE International Conference on MEMS, Istanbul, Turkey, pp. 98-101.

xx. Tsutsumino T., Suzuki Y., Kasagi N., Kashiwagi K., and Morizawa Y. (2006): "Micro Seismic Electret Generator for Energy Harvesting" IEEE Technical Digest PowerMEMS 2006, Berkely, USA, pp. 279-282.