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Design and Simulation of an Energy Scavenger for Microsystem

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Abstract: Energy scavenging is without any doubt a very attractive technique for a wide variety of self-powered Microsystems i.e. wireless sensors, biomedical implants, military monitoring devices and etc. The chip fabrication set up helps us to fabricate and integrate energy scavenger with electronics due to homogeneity. Piezoelectric power generator made by MEMS technology can scavenge power from low-level ambient vibration sources. An attempt has been made to design, optimize the dimensions of cantilever based scavenger and evaluate performance of the system for variety of vibration source and load. The design and simulation of MEMS piezoelectric cantilever beam single, array of cantilever with parallel plate electrode is carried out. The micro-energy harvester is formed using a silicon substrate, lead zirconium titanate (PZT) piezoelectric layer, Pt electrodes and silicon proof mass. The 0.279V output voltage of the piezoelectric energy scavenger is achieved at 2300Hz under 1g (g=9.81) acceleration. The FOM is 1023V/mm3.g and power is 78 µW for load resistance 1000Ω. Finite element simulation was conducted using comsol Multiphysics to obtain the device resonance frequency, deflection of cantilever beam, FOM, Electric potential for optimum dimensions.

Keywords: MEMS, piezoelectric, energy Scavenging.

I. INTRODUCTION

Energy scavenging is the process by which energy is derived from external sources (e.g., solar power, thermal energy, wind energy, salinity gradients, and kinetic energy), captured, and stored for small, wireless autonomous devices, like those used in wearable electronics and wireless sensor networks. Energy Scavenging from ambient vibration offers an attractive means of powering small-scale systems. Not only does it offer a clean, regenerative power source [1, 2], but it also offers a tremendous advantage for systems in which battery replacement is challenging or otherwise undesirable. Replacing or recharging the battery in an MP3 player is merely an inconvenience; replacing the battery in a pace-maker, on the other hand, requires surgery. Energy Scavengers using MEMS technology provide promising alternatives to the battery especially in micro implantable and portable electric system. A great deal of research has been done in recent years on Scavenging energy using piezoelectric [3–5], electrostatic [6], electromagnetic [7, 8], and thermoelectric [9] transduction, or power up sensor nodes [2]. Most of the vibrational harvester operate at frequencies of more than 100 Hz [1–8], making them well suited for Scavenging energy from rotating machinery.

In addition to the high-frequency applications, scavenging energy from the lower frequency, such as human motions, which are typically in the range 1–100 Hz, is quite desirable but comes with greater challenges. One reason is the maximum generated electrical power from a vibrating mass is strongly dependent on ambient vibration frequencies and drops dramatically at low frequencies [10]. This is because the mechanical damping in the air is much larger than the electrical damping and therefore most of the vibrational energy is transferred as mechanical loss instead of to the electrical domains [11, 12]. A second cause of the reduced performance is the fact that, for a given mass, increasingly compliant springs are required to resonate at lower frequencies. This requires additional space to permit large (several millimetre (scale) mechanical displacement, as shown schematically in Fig. 1 therefore results in a low-power density and is hard to be scaled down with MEMS technology. Since the typical resonant frequencies of MEMS piezoelectric energy Scavengers are in the range 100–10 kHz [3,4], to achieve low frequencies (less than 30 Hz), the silicon or silicon dielectric beam needs to be designed as long, thin and narrow as possible, which consume a large chip size and may be easily fractured.

II. CANTILEVER STRUCTURE

Cantilever beam configuration is chosen for its simplicity, compatibility with MEMS manufacturing processes, and its low structural stiffness. The beam configuration is a structure consisting of a silicon base frame, a single piezoelectric element (layer sandwiched between a pair of metal (Pt/Ti) electrodes), and a proof metal mass in free end, as illustrated in Fig. 1. The cantilever device operates as follows. When base frame of the device is vibrated by environmental

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groundwork, simultaneous input force feeds into this second-order mechanical system, then some parts of the cantilever will move relatively to the base frame. That relative displacement causes the piezoelectric material in the system to be tensed or compressed, which in turn induces charge shift and accumulation due to piezoelectric effect. Magnitude of the electric charge voltage is proportional to the stress induced by the relative displacement. It is well known that resonant vibration can amplify the relative displacement remarkably. Thus, the micro generators mechanically resonate at a frequency of the ambient vibration can generate maximum electrical power. Natural frequency of structure is approximately given as

$$\omega = (k / m)^{1/2}$$

by its stiffness (k) and mass (m). This indicates that varying structure dimension of the cantilever can regulate the natural frequency of the power generator.

Table 1. Device Dimensions

	Material	Length	Width	Thickness
Base	Silicon	2500um	500um	20um
PZT Layer1	PZT	2500um	500um	1um
Electrodes	Platinum	2000um	100um	0.5 um
Proof Mass	Silicon	500um	500um	200um

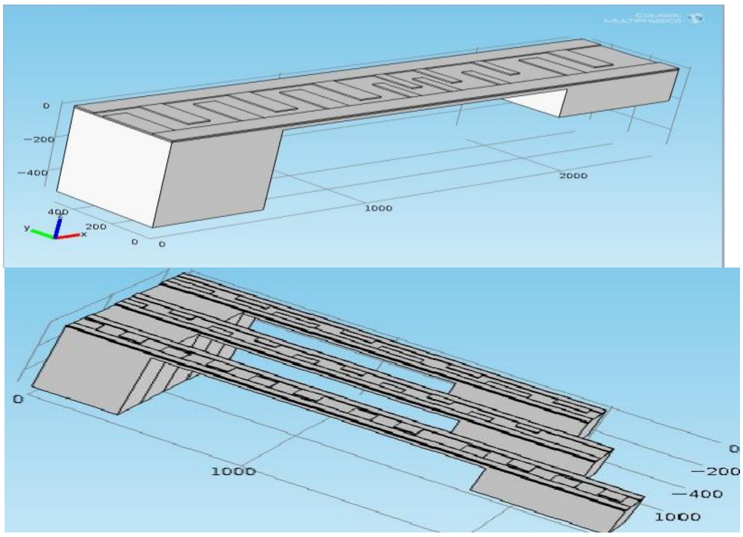

Fig.1 Cantilever beam with proof mass

Figure 1 shows the design of the cantilever beam formed using PZT, Pt interdigitated electrodes and Silicon proof mass. PZT was chosen as the piezoelectric layer due to its low deposition temperature, high piezoelectric coupling coefficient and adhesion qualities to the Si substrate. A proof mass was attached at the end of the beam to obtain maximum power output. The device operates in the longitudinal mode since both the applied stress and the generated voltage are in the z direction. The thin film piezoelectric material was designed and poled alternatively along the +x and –x directions due to the interdigitated electrodes configuration.

MEMS cantilever low frequency energy scavengers typically have thicknesses in µms. Table I shows the device dimensions. It has been reported that the usage of interdigitated electrodes placed on the top of the piezoelectric layer harvests higher output power compared to top and bottom electrodes. This is due to the fact that the separation between the fingers is larger than the film thickness. When the cantilever vibrates, mechanical stress is induced in the piezoelectric layer if enough force is provided by the proof mass. The PZT piezoelectric layer then converts the mechanical strain energy into electrical energy. It generates the charges and extracted through interdigitated electrodes. The output voltage is a function of output charge and capacitance between the interdigitated electrodes. Output power of the system will be optimized if the piezoelectric system is operating at the resonance frequency [18-19].

III. SIMULATION ANALYSIS FOR PIEZOELECTRIC CANTILEVER BEAM

The cantilever structure consists of four layers namely: Si/ PZT/Pt interdigitated electrodes / Silicon proof mass. The chosen piezoelectric layer is lead zirconium titanate (PZT). The interdigitated electrodes are deposited on top of the PZT layer. Finally, to produce higher output, a proof mass was deposited and patterned. The fabrication steps are

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shown in Figure 2. The device was modelled and simulated using a COMSOL Multiphysics which has the capabilities of producing a three-dimensional model based on the layout. The aim of the simulation analysis is to simulate structure for resonance frequency and other relevant parameters. The boundary conditions are applied as discussed .One end of the cantilever beam is fixed and load is applied at the top of the piezoelectric layer. Once the model specifications have been completed, it was meshed using physics controlled mesh, which are preferred for rectangular structures as shown in fig.3

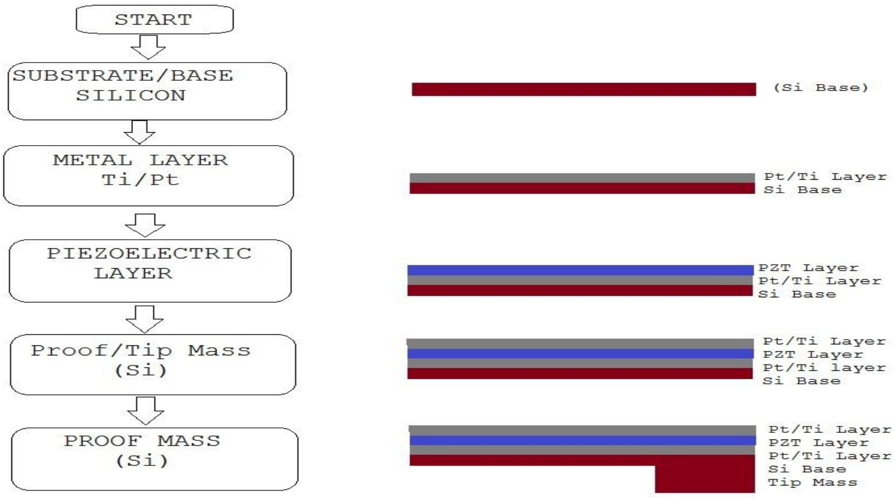

Fig. 2 Fabrication Steps of Piezoelectric Cantilever Beam

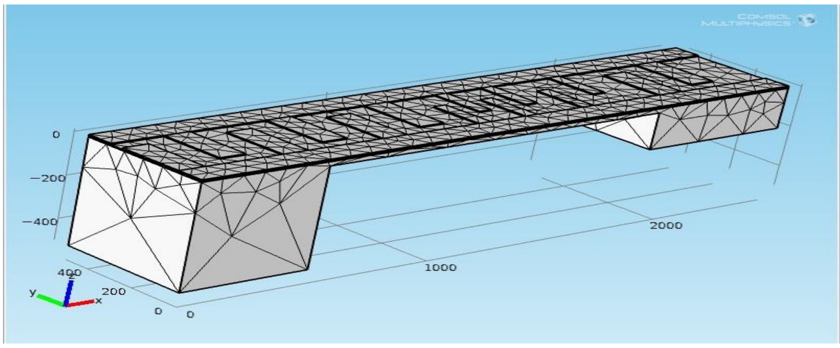

Fig.3 a] Mesh Structure of single cantilever beam

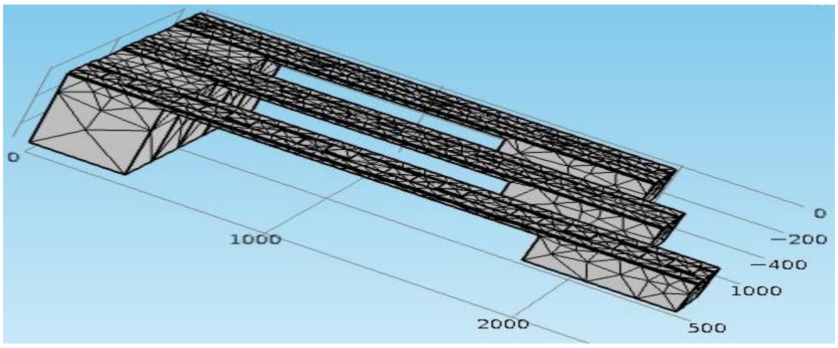

Fig.3 b] Mesh Structure of Design_2

Piezoelectric analysis was done to compute the stress that develops when deformation is prevented or restrained by surrounding materials. A linear coupling relationship between electrical displacement\ electric field strength and the mechanical factors [4] was assumed. To obtain the resonance modes of the structure, modal analysis was performed when a load 1g was applied at one end of the cantilever beam. The results show that the displacement at z direction provides the highest displacement as shown in Figure.4 and Table2 and Table3. Once the mode with highest displacement has been identified, frequency mode analysis was performed to fine-tune the results. Frequency analysis computes a displacement solution based on a user range of input frequencies to find the best resonance frequency which has maximum displacement. The frequency generated was within range of 0 to 4 kHz as shown in Table2. Figure4 shows the graph for displacement versus frequency applied. The graph shows the expected sharp change in displacement as the frequency approaches the Mode 1 value that is 2200 Hz which shows the highest displacement. Calculation of the total charge accumulated can be performed through PZE Charge query that extracts the total charges. The query is performed on the top of piezoelectric layer at different harmonic frequency steps within 0 Hz and 4 kHz as shown in Table 2 and Table 3. It can be seen that the six frequency step shows the total accumulated charge. The charge equation is given by

$$Q = C * V$$

Where

$$C = \varepsilon * A / d$$

Where C is total capacitance, Q is total charge, V is total voltage, ε is permittivity of the piezoelectric material, ε_o is the permittivity of the vacuum is 8.85 x 10-12 C/(Vm), A is Area and d is thickness of the PZT piezoelectric layer.

Table 2 Result for Frequency mode Analysis

	Design_1			**Design_2**			**Design_3**		
Frequency (Hz)	**Displacement (μm)**	**Voltage (V)**	**Charge Density ($\mu C/m^2$)**	**Displacement (μm)**	**Voltage (V)**	**Charge Density ($\mu C/m^2$)**	**Displacement (μm)**	**Voltage (V)**	**Charge Density ($\mu C/m^2$)**
100	0.019	1.573mv	0.724	0.0237	1.446mv	2.31	0.0239	1.509mv	2.373
300	0.0193	1.594mv	0.7348	0.0242	1.463mv	2.355	0.0243	1.526mv	2.399
500	0.0199	1.636mv	0.7566	0.025	1.495mv	2.387	0.0252	1.561mv	2.45
700	0.021	1.70mv	0.7944	0.0265	1.547mv	2.471	0.0267	1.618mv	2.543
1000	0.0236	1.869mv	0.886	0.0301	1.677mv	2.679	0.0304	1.759mv	2.766
1200	0.0264	2.048mv	9.867	0.0342	1.816mv	2.901	0.0345	1.911mv	3.005
1500	0.0337	2.159mv	1.256	0.0452	2.175mv	3.479	0.0459	2.312mv	3.639
1800	0.051	3.622mv	1.912	0.0734	3.023mv	3.848	0.0755	3.3mv	5.204
2000	0.0836	5.706mv	3.512	0.1368	6.018mv	7.273	0.1459	5.522mv	8.73
2200	1.072	0.2709	1.121	1.6027	0.492	7.049	17.82	0.649	8.59
2500	0.0957	0.0288	9.452	0.106	0.0309	3.009	0.0958	8.591mv	2.717
2800	0.0384	8.203mv	3.419	0.0868	6.159mv	6.879	0.0644	5.075mv	5.314
3000	0.0268	5.249mv	2.197	0.4746	0.063mv	7.403	0.7655	0.018mv	6.082

Table 3 Result for Frequency mode Analysis for Different Thickness of PZT Layer

Frequency (Hz)	**Displacement (μm)**	**Voltage (V)**			
		1 μm Thickness	**6 μm Thickness**	**9 μm Thickness**	**12 μm Thickness**
100	0.0237	3.7 mv	1.45mv	1.06mv	0.82mv
300	0.0242	3.8mv	1.46mv	1.07mv	.821mv
500	0.025	3.87mv	1.50mv	1.08mv	0.83mv
700	0.0265	4.00mv	1.55mv	1.10mv	0.85mv
1000	0.0301	4.36mv	1.68mv	1.15mv	0.90mv
1200	0.0342	4.73mv	1.82mv	1.20mv	0.95mv
1500	0.0452	5.64mv	2.17mv	1.30mv	1.11mv
1800	0.0734	7.86mv	3.02mv	1.46mv	1.353mv
2000	0.1368	15.6mv	6.02mv	1.63mv	1.67mv
2200	1.6027	1.28v	0.492v	1.91mv	2.39mv
2500	0.106	0.08v	0.0309v	2.85mv	0.254v
2800	0.0868	16mv	6.20mv	0.0143v	0.157v
3000	0.4746	0.16mv	0.06mv	0.0254v	8.7mv

Figure4a and Fig.4b shows the graph for displacement versus frequency applied for single cantilever beam and design_2. The graph shows the expected sharp change in displacement as the frequency value that is 2.3 KHz which shows the maximum displacement in z direction. Figure5a, Fig.5b and fig.7 shows the graph for voltage versus frequency applied for single cantilever beam and design_2. The graph shows the maximum output voltage at a frequency of 2.3 KHz.

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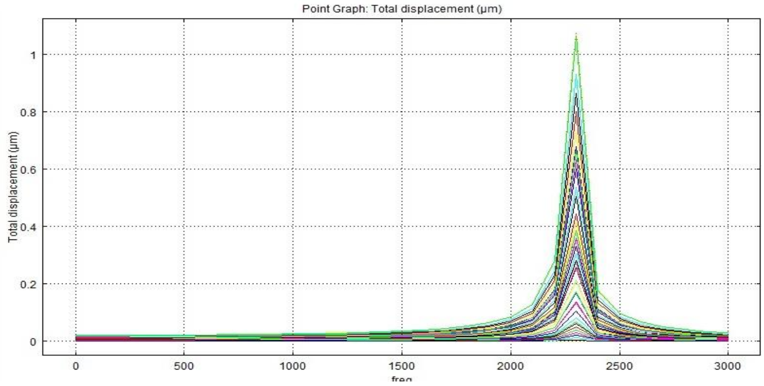

Fig.4 a] Displacement versus Frequency Design1

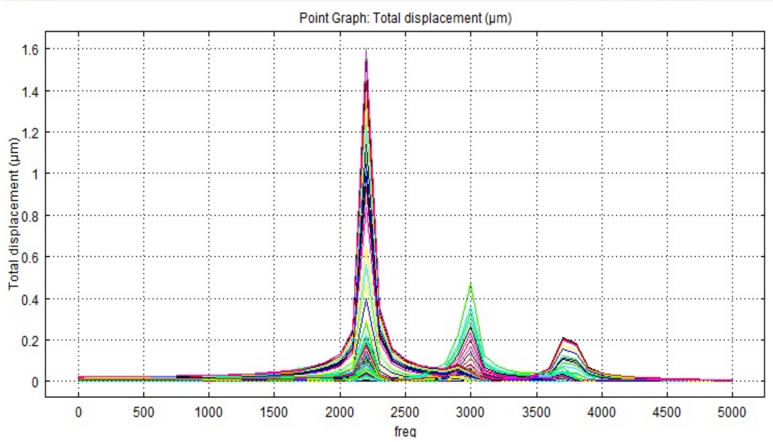

Fig.4 b] Displacement versus Frequency Design2.

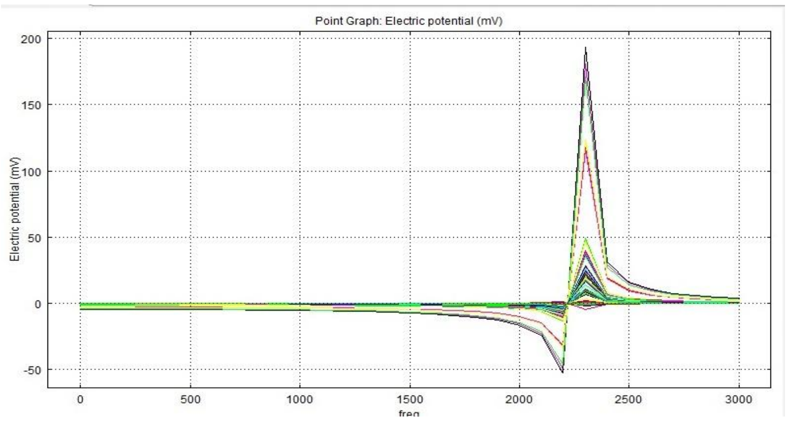

Fig.5a] Voltage versus Frequency Design1

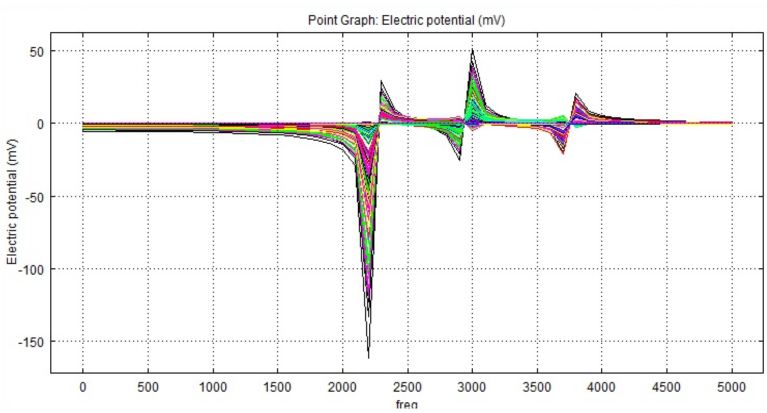

Fig.5b] Voltage versus Frequency Design2

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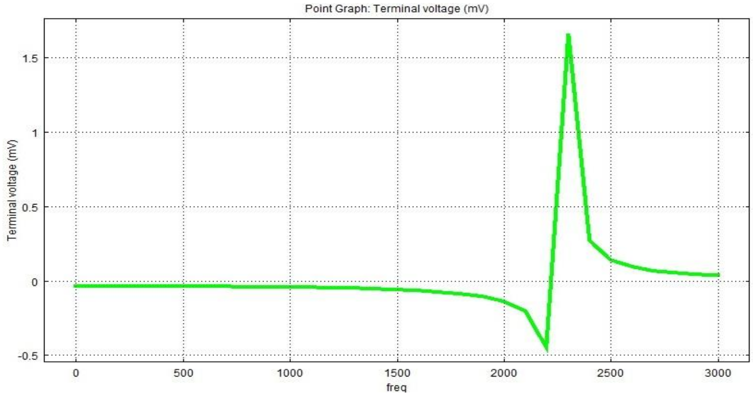

Fig. 6a] Terminal Voltage versus Frequency Design1

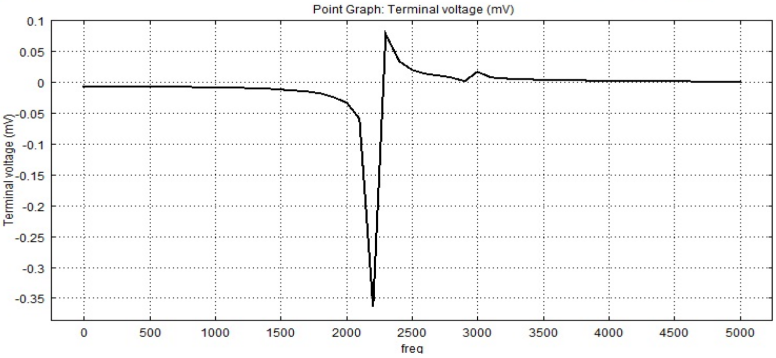

Fig. 6b] Terminal Voltage versus Frequency Design1

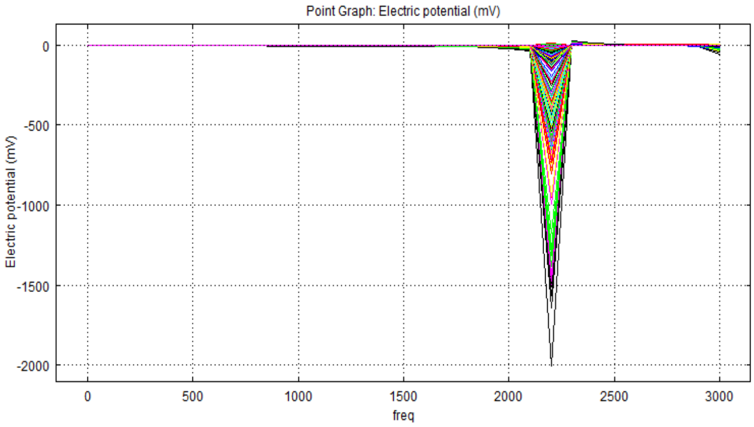

Fig.7 Voltage versus Frequency Design3

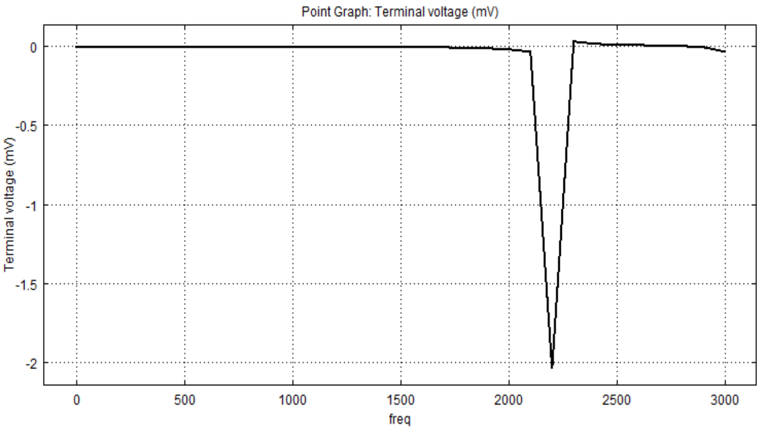

Fig. 6c] Terminal Voltage versus Frequency Design3

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IV. FIGURE OF MERIT (FOM)

A FOM is voltage per unit volume per acceleration is used to compare the performances of different energy Scavengers depicted in Table 3. For the optimized structure proposed in this work a FOM value for single cantilever beam is 561.6 V/mm^3.g and while that of array of cantilever is 1023.36 V/mm3.g for array_1 and 1349.92 V/mm^3.g for array_2.

Table .3 Performance Comparisons with reported MEMS Harvester

Ref	Device	Dimension	Voltage (V)	Frequency (Hz)	FOM (V/mm^3.g)
Our work	**Single beam**	**2500µm*500µm*1µm**	**0.71V**	**2300**	**561.6**
	Array_1	**2500µm*500µm*1µm**	**1.28V**	**2200**	**1023.36**
	Array_2	**2500µm*500µm*1µm**	**1.69V**	**2200**	**1349.92**
[15]	d31 ZnO	27mm *.3mm*0.2mm	4.7 *10^{-9}	10	.9×10-9
[16]	d31 PZT	0.8mm*1mm*10µm	2.2V	528	705
[17]	d31 PZT	2mm*3.2mm*1.39µm	1.6V	60	142.3

V. CONCLUSION

An energy harvester based on piezoelectric energy scavenger has been designed and simulated. The cantilever design and optimization were carried out for both piezoelectric and silicon base dimensions. The thickness, length and width of metal base and PZT were varied in order to get maximum displacement and voltage. A composite cantilever with dimensions 2500µm×500µm×1µm is used to harvest ambient vibration energy. A body load of 1g is applied on top of cantilever. It is found that resonance frequency of 2300 Hz, 1g acceleration and the output voltage of 0.71 V for single cantilever i.e. design1, 1.28V for design2 and 1.69V for design3 which sufficient to drive ultra-low power applications mainly sensor nodes.

REFERENCES

[1] S. Roundy. Energy scavenging for wireless sensor nodes with a focus on vibration to electricity conversion, Ph.D. dissertation, University of California at Berkerley, 2003.
[2] M. Marzencki, Y. Ammar, S. Basrour, Integrated power Scavenging system including a MEMS generator and a power management circuit, Sensors and Actuators A 145–146 (2008) 363–370.
[3] J.-Q. Liu, H.-B. Fang, Z.-Y. Xu, X.-H. Mao, X.-C. Shen, D. Chen, H. Liao, B.-C. Cai, A MEMS-based piezoelectric power generator array for vibration energy Scavenging, Microelectronics Journal 39 (2008) 802–806.
[4] S. Roundy, P.K. Wright, J. Rabaey, A study of low level vibrations as a power source for wireless sensor nodes, Computer Communications 26 (2003) 1131–1144.
[5] Y. Naruse, N. Matsubara, K. Mabuchi, M. Izumi, S. Suzuki, Electrostatic micro power generation from low-frequency vibration such as human motion, Journal of Micromechanics and Microengineering 19 (2009) 1–5.
[6] B. Yang, C. Lee, W. Xiang, J. Xie, J.H. He, R.K. Kotlanka, S.P. Low, H. Feng, Electromagnetic energy Scavenging from vibrations of multiple frequencies, Journal of Micromechanics and Microengineering 19 (2009) 1–8.
[7] R. Amirtharajali, S. Meninger, J. Mur-Miranda, A. Chandrakasan, J. Lang, Self-powered signal processing using vibration-based power generation, IEEE Journal of Solid State Circuits 33 (5) (1998) 687–695.
[8] G.J. Snyder, J.R. Lim, C.-K. Huang, J.-P. Fleurial, Thermoelectric microdevice fabricated by aMEMS-like electrochemical process, Nature materials 2 (2003) 528–531.
[9] H. Kulah, K. Najafi, Energy scavenging from low-frequency vibrations by using frequency up-conversion for wireless sensor applications, IEEE Sensors Journal 8 (2008) 261–268.
[10] Y.C. Shu, I.C. Lien, Efficiency of energy conversion for a piezoelectric power Scavenging system, Journal of Micromechanics and Microengineering 16 (2006) 2429–2438.
[11] V.R. Challa, M.G. Prasad, F. Fisher, A coupled piezoelectric–electromagnetic energy Scavenging technique for achieving increased power output through damping Matching, Smart Materials and Structures 18 (2009) 1–11.
[12] R. Sood, Y.B. Jeon, J.H. Jeong, S.G. Kim, Piezoelectric micro power generator for energy Scavenging, Technical Digest of the 2004 Solid- State Sensor and Actuator Workshop, Hilton Head, South Carolina,2004.
[13] C.B. Williams, R.B. Yates, Analysis of a micro electric generator for microsystems, Sens. Actuators 52 (1996) 8–11.
[14] Hua Bin Fanga, Jing Quan Liua, Zheng Yi Xub, Lu Donga, Li Wangb, Di Chena, Bing- Chu Caia, Yue Liub, "Fabrication and performance of MEMS-based piezoelectric power generator for vibration energy Scavenging," Microelectronics Journal, vol. 37, pp. 1280 – 1284, July 2006.
[15] Wen G. Li, Siyuan He and Shudong Yu, "Improving power density of a cantilever piezoelectric power harvester through a curved L-shaped proof mass," IEEE Transactions On Industrial Electronics, vol. 57, pp. 868 – 876, March 2010.
[16] J.C. Park, D. H. Lee, J. Y. Park, Y. S. Chang and Y. P. Lee, "High performance piezoelectric MEMS energy harvester based on d33 mode of PZT thin film on buffer layer," IEEE Solid- State Sensors, Actuators and Microsystems Conference, pp. 517 – 520,June 2009.
[17] P. Muralta, M. Marzenckib, B. Belgacema, F. Calamea and S. Basrourb, "Vibration energy Scavenging with PZT micro device," Elsevier Proceedings of the Eurosensors XXIII conference, pp. 1194–1196, 2009.
[18] Suresh S. Balpande, Sudhir B.Lande, umesh Akare, Laxman Thakre "Modeling of cantilever based power harvester as an innovative source of power for RFID Tag" in proceedings of 2nd IEEE International conference , GHRCE, Nagpur[Dec16-18, 2009] . http://doi.ieeecomputersociety.org/10.1109/ICETET.2009.152
[19] Suresh S. Balpande, Sudhir B. Lande, " Modeling of PZT Based Power Harvester and Power Aware Control Approach for Pervasive Node BSN " in the proceedings of IEEE International conference on advanced computing , Thapar university, Patiala [6-7/03/09] pp327-332. ISBN: 978-981-08- 2465-5.