Study of piezoelectric cantilever based energy harvester for IOT applications

S.Sunithamani, N. Vidhupriya, K. Sai Srilekha, K. Uday Kumar

Abstract: ***This paper presents the conversion of mechanical vibration into electrical energy using piezoelectric cantilever based energy harvester. By using Comsol Multiphysics 5.2 we constructed various geometries of the cantilever beam in order to compare displacement and voltage and hence calculate the generated power. The effect of these geometries is studied by applying stress or load on the cantilever beam. The H-Shaped cantilever generates a maximum power of 98.37µW at frequency of 65.32Hz, whereas the L-shaped cantilever, rectangular cantilever, rectangular cantilever with a rectangular hole generates less power 55.16µW, 2.85µW and 4.09µW respectively. This piezoelectric energy harvester can be used for powering sensors associated with internet of things (IoT).***

Index Terms:Piezoelectric, Cantilever, IoT, Energy harvester.

I. INTRODUCTION

The continuous improvement in technologies has led to many technological advancements in small electronic devices like portable sensors, transmitters etc. Functionality has been largely broadened and energy efficiency has been greatly enhanced while reducing the size by order of magnitude. Most of these portable devices are powered by conventional battery but the lifespan of the battery is short.In some applications such as, sensors deployed in remote locations or inside the human body however, the replacement of battery at the end of its service life can be challenging or even unpractical. To overcome this battery replacement issue, the solution is the harvesting of energy from pressure changes, vibrations or mechanical impulses. The harvesting of energy is possible by using piezoelectric materials to convert deflections or displacements into electrical energy that can be either used or stored for later use. Piezoelectric as a power generator is mostly used as they have an advantage of producing larger power andease of application.In order to harvest maximum available energy, different geometries namely T, U, V, rectangular are developed and studied in the literature (Agnimitra et al. 2014). Also six different cantilever structures namely RCRC, RCTAC, TACRC, TACTAC, TRCRC, TRCTAC are developed in (Sunithamani, Ebaflora et al. 2017) to produce controlled and regulated output of piezoelectric energy harvester. And twelve different cantilever structures using PZT layer are studied in (Sunithamani, Senbagavalli et al. 2015). PZT length is optimized in (Sunithamani et al. 2014) for a piezoelectric energy harvester with non-traditional cross section. An substrate to piezoelectric thickness ratio is optimized for four different cantilever structures in (Sunithmani et al. 2015).

To maximixe output power a proof mass is placed over energy harvester in (Sunithamani et al. 2017). Various piezoelectric materials are used to coat cantilever beams.P(VDF-TrFE) is used to analyse mechanical and electrical properties of a piezoelectric sensor in (Khoon-Keat Chow et al.2018). Piezoelectric energy harvesters are developed for green energy source (Sunithamani et al. 2015) . In this studyMEMS (Microelectronic Mechanical Systems) based piezoelectric cantilever beams of various shapes (L, H, rectangular) are analysed usingCOMSOL Multiphysics 5.2 to convert mechanical energy into electrical energy. This electrical energy can be used as an alternative power source for portable electronic devices. We compared various geometries of cantilever beams using various piezoelectric materials and the one with well- defined outcomes is chosen as a piezoelectric energy harvester for variousIoT applications.

II. METHODOLOGY

A. DESIGN PROCEDURE

Using COMSOL Multiphysics 5.2 four geometries of cantilever beam are designed. To design a piezoelectric energy harvester the physics of a 3D model of a cantilever is defined as piezoelectric device which includes both solid mechanics and electrostatics. After adding physics the cantilever beam is designed according to the dimensions required. The dimensions of the cantilever beam are length=300mm, width= 19.2mm and thickness=3.23mm. The four geometries of cantilever beam designed are as follows:

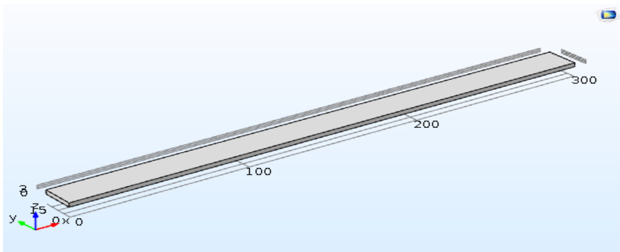

Fig. 1 Geometry of rectangular cantilever

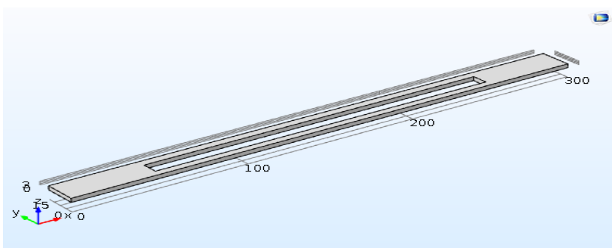

Fig.2 Geometry of rectangular cantilever with a rectangular hole

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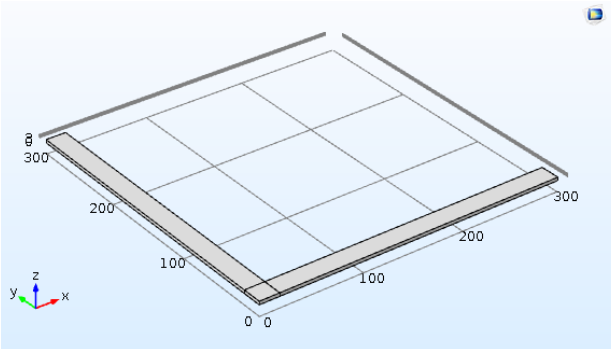

Fig.3 Geometry of L-shaped cantilever

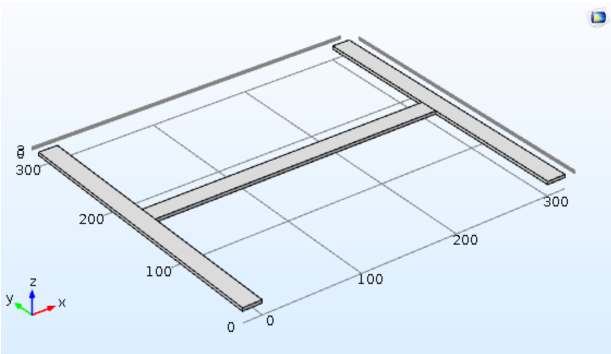

Fig. 4 Geometry of H-shaped cantilever

B. SIMULATION PROCEDURE

After designing the cantilever geometry, one end of the beam is fixed. Then piezoelectric materials such as Lead ZirconateTitanate (PZT-5H), Polyvinylidene fluoride (PVDF), Aluminium Nitride (AlN) and Zinc Oxide (ZnO) are added on to the cantilever beam. We keep the bottom of the cantilever beam as ground and top of the cantilever beam as floating potential. Then a point load of 0.005N is applied at different positions as mentioned in table 2 to 6. Then it is simulated and studied. After analysis of displacement and voltage obtained for various cantilever geometries using different piezoelectric materials the one with best outcome is chosen. The properties of materials used in the design are as follows:

Table I Material Properties

Material Properties	Materials used in the design			
	PZT-5H	PVDF	AlN	ZnO
Young's Modulus (GPa)	63	8.3	344	170
Density (kg/m^3)	7500	1780	3300	5606
Poisson's ratio	0.31	0.18	0.22	0.30

C. POWER CALCULATION

The displacement and voltage values for a particular cantilever geometry are obtained after simulation. Using these values the amount of power generated can be calculated as

$$P = \frac{V^2}{R}$$

Where 'P' is power to be calculated in micro watt(µW), 'V' is voltage obtained in volts(v) and 'R' is resistance in ohms(Ω).

Resistance for a particular cantilever geometry is calculated as

$$R = \rho l/A$$

Where 'R' is resistance in ohms (Ω), 'ρ' is density of the material used in (kg/m^3), 'l' is the length of the cantilever beam in millimetres (mm) and 'A' is area of the respective cantilever beam in mm^2.

III. RESULTS AND DISCUSSION

The figures from 5 to 12 depict the result obtained that relates the displacement and generated piezoelectric voltage for various cantilever geometries. On application of load at various points on the cantilever geometry we obtained various displacement and voltage values. From those we observed that H-shaped cantilever and L-shaped cantilever generates more voltage. But the requirement is to obtain high voltage and power at lower frequencies. This requirement is achieved by H-shaped cantilever. This is obtained on using PVDF as piezoelectric material. It generates 3.01v piezoelectric voltage at 65.32Hz. As per theoretical calculation it produced 98.37µW.

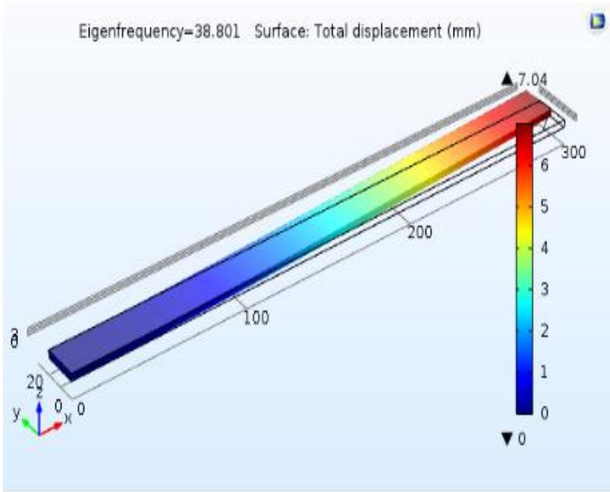

Fig. 5 Displacement of rectangular cantilever

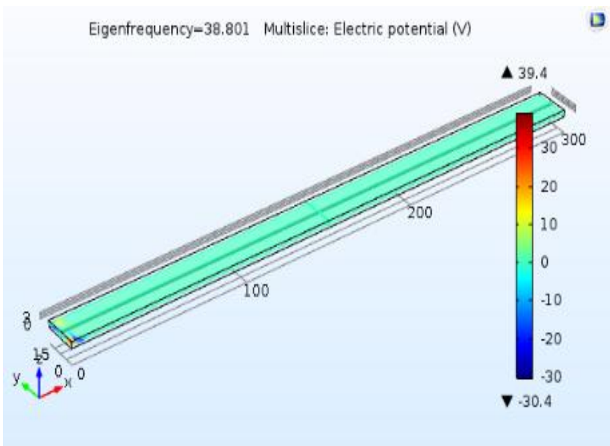

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Fig. 6 Generated piezoelectric voltage in rectangular cantilever

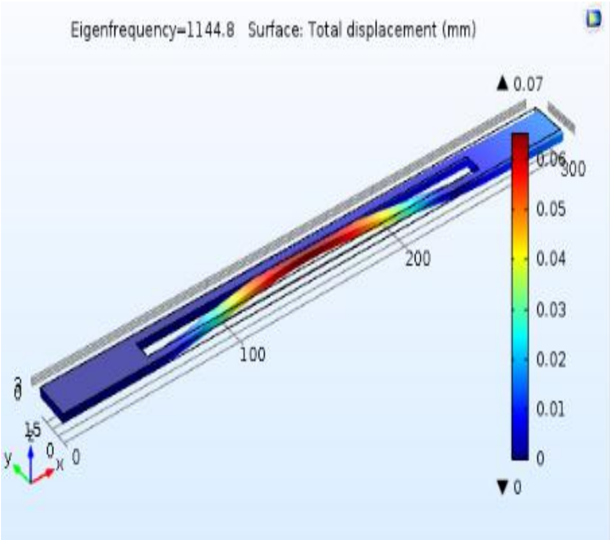

Fig. 7 Displacement of rectangular cantilever with a rectangular hole

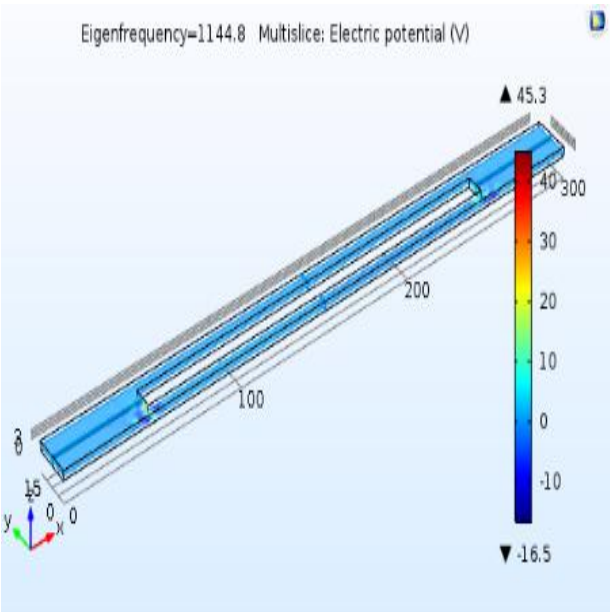

Fig. 8 Generated piezoelectric voltage in rectangular cantilever with a rectangular hole

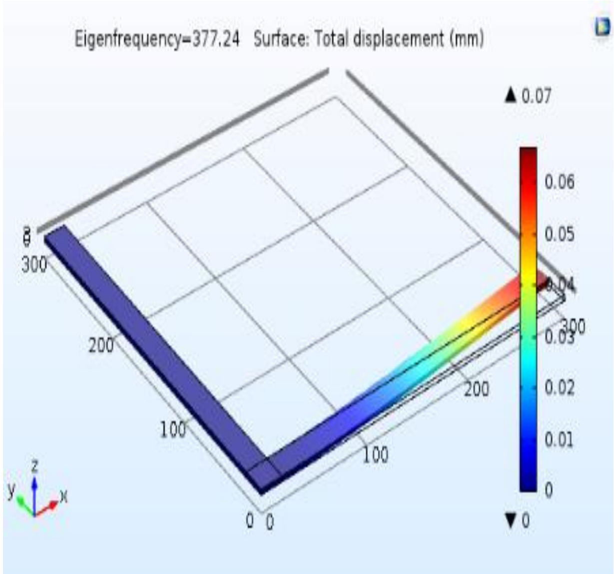

Fig. 9 Displacement of L-shaped cantilever

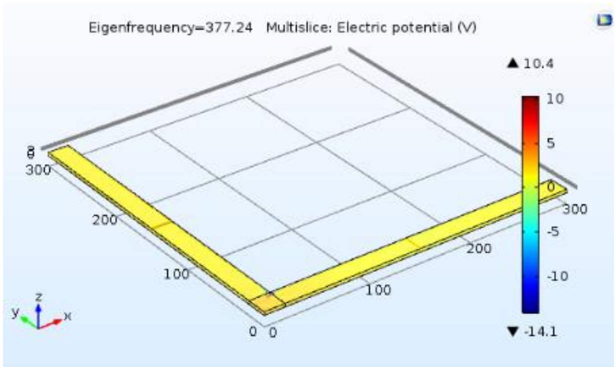

Fig. 10 Generated piezoelectric voltage in L-shaped cantilever

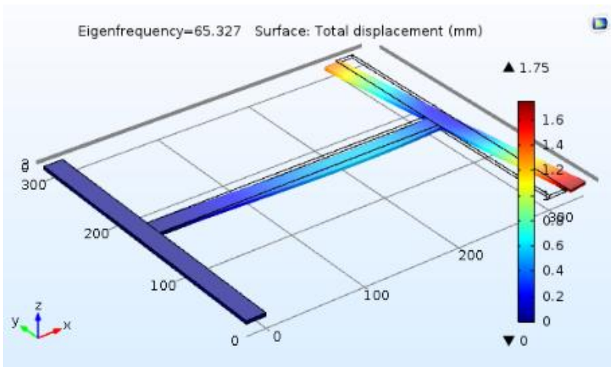

Fig. 11 Displacement of H-shaped cantilever

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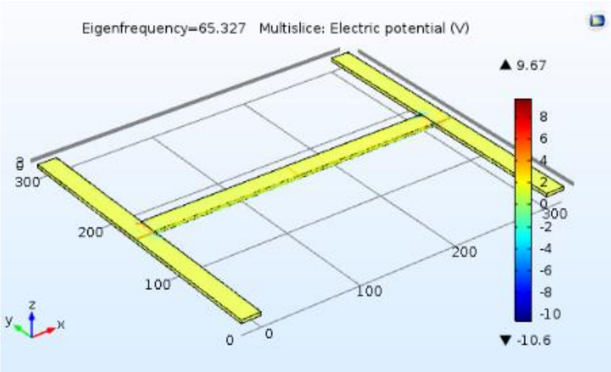

Fig. 12 Generated piezoelectric voltage in H-shaped cantilever

Figures 13 to 16 represent the displacement versus voltage of various geometries coated with various piezoelectric materials. It can be observed that for some geometries displacement is directly proportional to voltage and for others it is vice versa. It depends on the distance at which forceis applied and the material the cantilever is coated.Table 2 to 5 represents values of displacement and piezoelectric voltage obtained by applying point load at distance of few mm from fixed end as mentioned in the tables 2 to 6. It also gives the frequency at which they are obtained. The highlighted text in the tables 2 to 6 represents that it produced maximum voltage.

From table 2 it can be clearly noticed that a rectangular cantilever coated with PVDF generates 0.51v at 38.80Hz with a displacement of 7.04mm and generates 2.85µW power. From table 3 it can be clearly noticed that a rectangular cantilever with a hole coated with AlN generates 1.02v at 1144.80Hz with a displacement of 0.07mm and generates 4.09µW power. From table 4 it can be clearly noticed that L-shaped cantilever coated with AlN generates 3.07v at 377.23Hz with a displacement of 0.07mm and generates 55.16µW power. From table 5 it can be clearly noticed that H-shaped cantilever coated with PVDF generates 3.01v at 65.32Hz with a displacement of 1.75mm and generates 98.37µW power. All this data is combined in the final table 6 gives us comparison of all geometries representing the obtained high voltage and their respective displacement. Power is calculated and then we observed that rectangular shaped cantilevers produce very less power. So they are not much useful. L-shaped cantilever generates high voltage but it is generated at high frequency and H-shaped cantilever produces more power at low frequency. And also PVDF is a flexible piezoelectric material compared to other materials and is of low cost. So itcan be used as a piezoelectric energy harvester to generate power which can be used instead of battery in many portable electronic devices and other IoT applications.

Table 2 Displacement and voltage obtained by rectangular cantilever using various materials

SHAPE OF THE CANTILEVER	MATERIAL USED	POSITION OF POINT LOAD ON THE CANTILEVER			FREQUENCY (Hz)	MAXIMUM DISPLACEMENT (mm)	VOLTAGE (v)
RECTANGULAR CANTILEVER	PZT-5H (Lead ZirconateTitanate)	X (mm)	Y (mm)	Z (mm)			
		300	9.5	3.23	480.19	0.03	0.010157
		250	9.5	3.23	602.90	0.31	0.15063
		200	9.5	3.23	602.90	0.31	0.15110
	PVDF (Poly VinylideneFlouride)	**300**	**9.5**	**3.23**	**38.803**	**6.78**	**0.083703**
		250	**9.5**	**3.23**	**38.801**	**7.02**	**0.51285**
		200	**9.5**	**3.23**	**38.801**	**7.04**	**0.5143**
	AlN (Aluminium Nitride)	300	9.5	3.23	354.06	0.45	0.26036
		250	9.5	3.23	354.06	0.48	0.029386
		200	9.5	3.23	354.06	0.48	0.029476
	ZnO (Zinc Oxide)	300	9.5	3.23	176.74	0.00319	0.0013715
		250	9.5	3.23	163.03	0.31	0.11017
		200	9.5	3.23	163.03	0.31	0.11051

Table 3 Displacement and voltage obtained by rectangular cantilever with a rectangular hole using various materials

SHAPE OF THE CANTILEVER	MATERIAL USED	POSITION OF POINT LOAD ON THE CANTILEVER			FREQUENCY (Hz)	MAXIMUM DISPLACEMENT (mm)	VOLTAGE (v)
	PZT-5H (Lead ZirconateTitanate)	X (mm)	Y (mm)	Z (mm)			
		300	9.5	3.23	317.39	0.82	0.65840

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RECTANGULAR CANTILEVER WITH A HOLE		270	9.5	3.23	317.51	0.89	0.68583
		200	9.5	3.23	51.081	3.2	0.10656
	PVDF (Poly VinylideneFlouride)	300	9.5	3.23	20.396	7.44	0.049676
		270	9.5	3.23	125.27	1.65	0.069492
		200	9.5	3.23	20.418	6.76	0.13193
	AlN (Aluminium Nitride)	**300**	**9.5**	**3.23**	**1144.8**	**0.07**	**1.0272**

Table 4 Displacement and voltage obtained by L-shaped cantilever using various materials

SHAPE OF THE CANTILEVER	MATERIAL USED	POSITION OF POINT LOAD ON THE CANTILEVER			FREQUENCY (Hz)	MAXIMUM DISPLACEMENT (mm)	VOLTAGE (v)
L-SHAPED CANTILEVER	PZT-5H (Lead ZirconateTitanate)	X (mm)	Y (mm)	Z (mm)			
		300	9.5	3.23	104.37	1.16	2.9489
		250	9.5	3.23	104.37	1.18	3.0211
		200	9.5	3.23	104.37	1.18	3.0195
	PVDF (Poly VinylideneFlouride)	300	9.5	3.23	41.158	6.59	1.6378
		250	9.5	3.23	41.159	6.19	1.5862
		200	9.5	3.23	41.159	6.19	1.5852
	AlN (Aluminium Nitride)	**300**	**9.5**	**3.23**	**377.23**	**0.07**	**3.0470**
		250	**9.5**	**3.23**	**377.24**	**0.07**	**3.0793**
		200	**9.5**	**3.23**	**377.24**	**0.07**	**3.0777**
	ZnO (Zinc Oxide)	300	9.5	3.23	173.79	0.1	2.9823
		250	9.5	3.23	173.80	0.1	3.0269
		200	9.5	3.23	173.80	0.1	3.0252

Table 5 Displacement and voltage obtained by H-shaped cantileverusing various materials

SHAPE OF THE CANTILEVER	MATERIAL USED	POSITION OF POINT LOAD ON THE CANTILEVER			FREQUENCY (Hz)	MAXIMUM DISPLACEMENT (mm)	VOLTAGE (v)
H-SHAPED CANTILEVER	PZT-5H (Lead ZirconateTitanate)	X (mm)	Y (mm)	Z (mm)			
		300	160	3.23	167.79	1.27	2.8872
		250	160	3.23	167.85	1.27	2.8935
		200	160	3.23	167.85	1.27	2.8930
	PVDF (Poly VinylideneFlouride)	**300**	**160**	**3.23**	**65.327**	**1.75**	**3.0199**
		250	**160**	**3.23**	**65.348**	**1.75**	**3.0036**
		200	**160**	**3.23**	**65.348**	**1.75**	**3.0031**
	AlN (Aluminium Nitride)	300	160	3.23	602.73	0.11	2.8827
		250	160	3.23	602.92	0.11	2.9056
		200	160	3.23	602.92	0.11	2.9051
	ZnO	300	160	3.23	279.29	0.12	2.8430

	(Zinc Oxide)	250	160	3.23	279.40	0.12	2.8540
		200	160	3.23	279.40	0.12	2.8534

Table 6 Comparison of results obtained and power generated

SHAPE OF THE CANTILEVER	MATERIAL USED	POSITION OF POINT LOAD ON THE CANTILEVER			FREQUENCY (Hz)	MAXIMUM DISPLACEMENT (mm)	VOLTAGE (v)	POWER (μW)
		X (mm)	Y (mm)	Z (mm)				
RECTANGULAR CANTILEVER	PVDF (Poly VinylideneFlouride)	300	9.5	3.23	38.803	6.78	0.083703	0.07
		250	9.5	3.23	38.801	7.02	0.51285	2.837
		200	9.5	3.23	38.801	7.04	0.5143	2.853
RECTANGULAR CANTILEVER WITH A HOLE	AlN (Aluminium Nitride)	300	9.5	3.23	1144.8	0.07	1.0272	4.0926
		270	9.5	3.23	1145.7	0.06	0.91766	3.2663
		200	9.5	3.23	1145.8	0.06	0.94896	3.4929
L-SHAPED CANTILEVER	AlN (Aluminium Nitride)	300	9.5	3.23	377.23	0.07	3.0470	54.01
		250	9.5	3.23	377.24	0.07	3.0793	55.16
		200	9.5	3.23	377.24	0.07	3.0777	55.11
H-SHAPED CANTILEVER	**PVDF (Poly VinylideneFlouride)**	**300**	**160**	**3.23**	**65.327**	**1.75**	**3.0199**	**98.37**
		250	**160**	**3.23**	**65.348**	**1.75**	**3.0036**	**97.31**
		200	**160**	**3.23**	**65.348**	**1.75**	**3.0031**	**97.27**

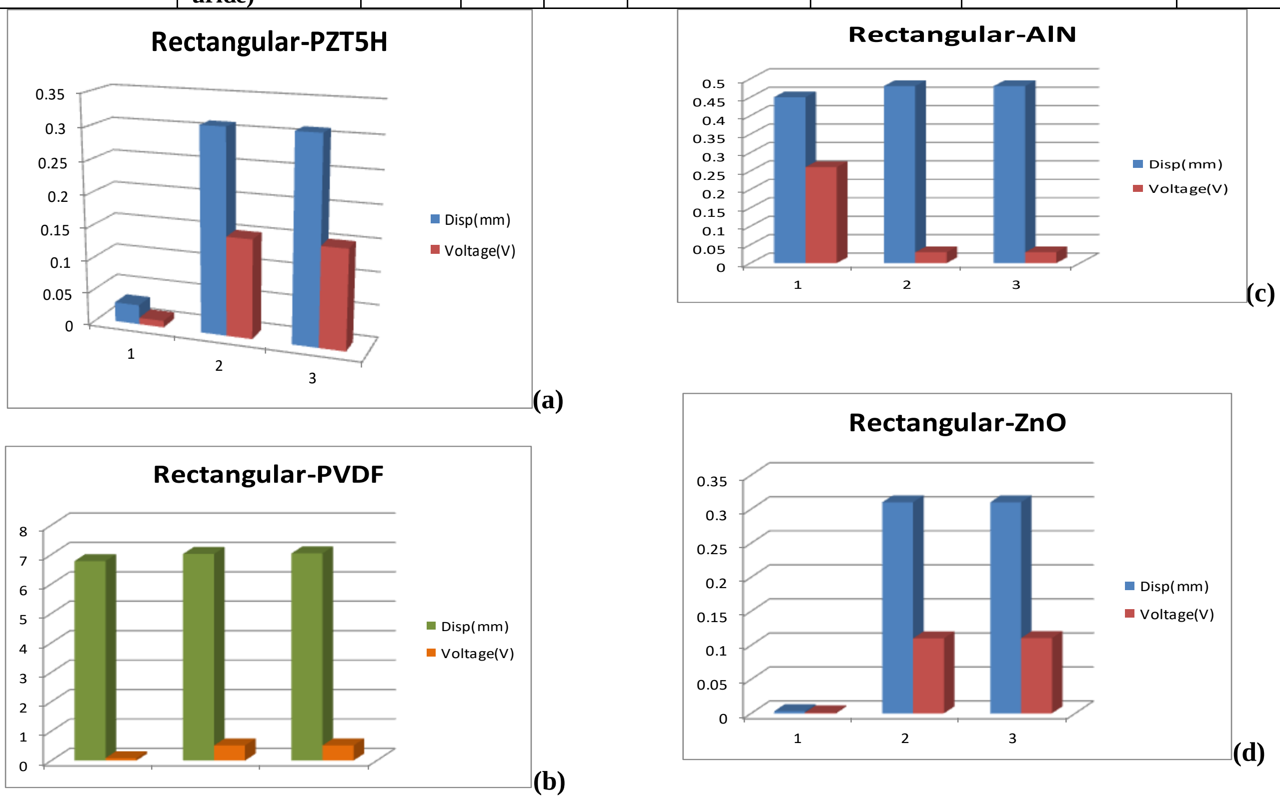

Fig. 13 Displacement Vs Voltage for rectangular cantilever coated with (a)PZT-5H, (b)PVDF, (c)AlN, (d)ZnO

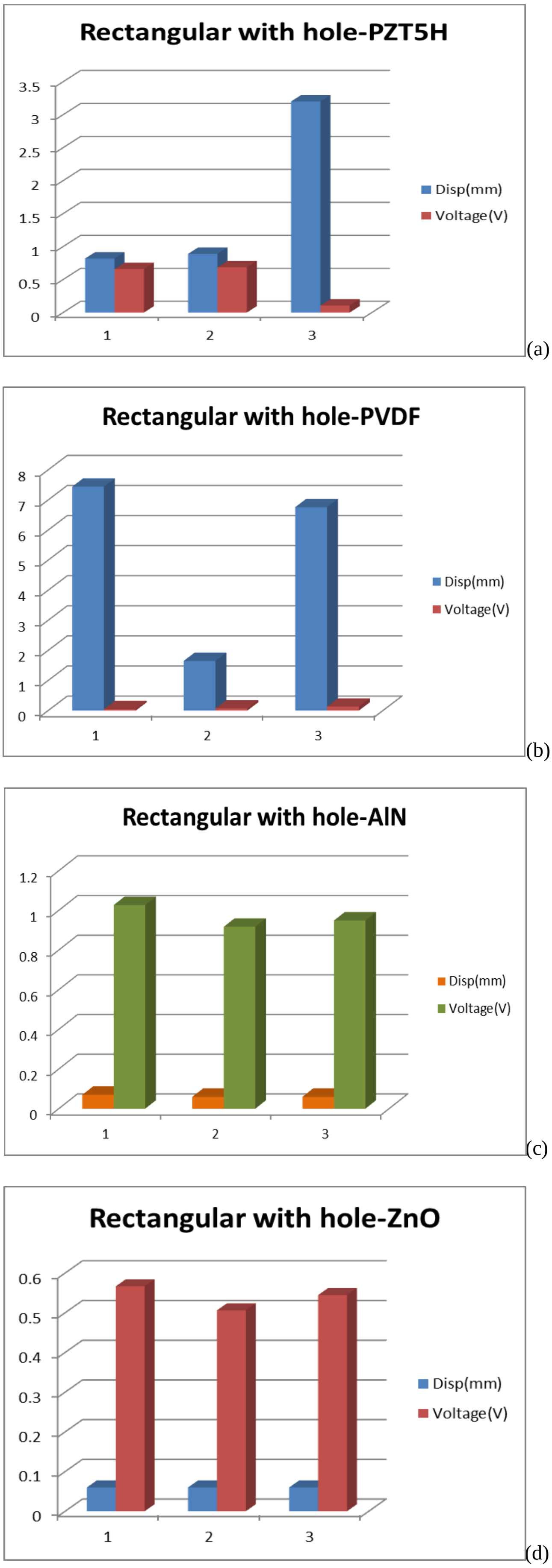

Fig. 14 Displacement Vs Voltage for rectangular cantilever with a rectangular hole coated with (a) PZT-5H, (b) PVDF, (c) AlN, (d) ZnO

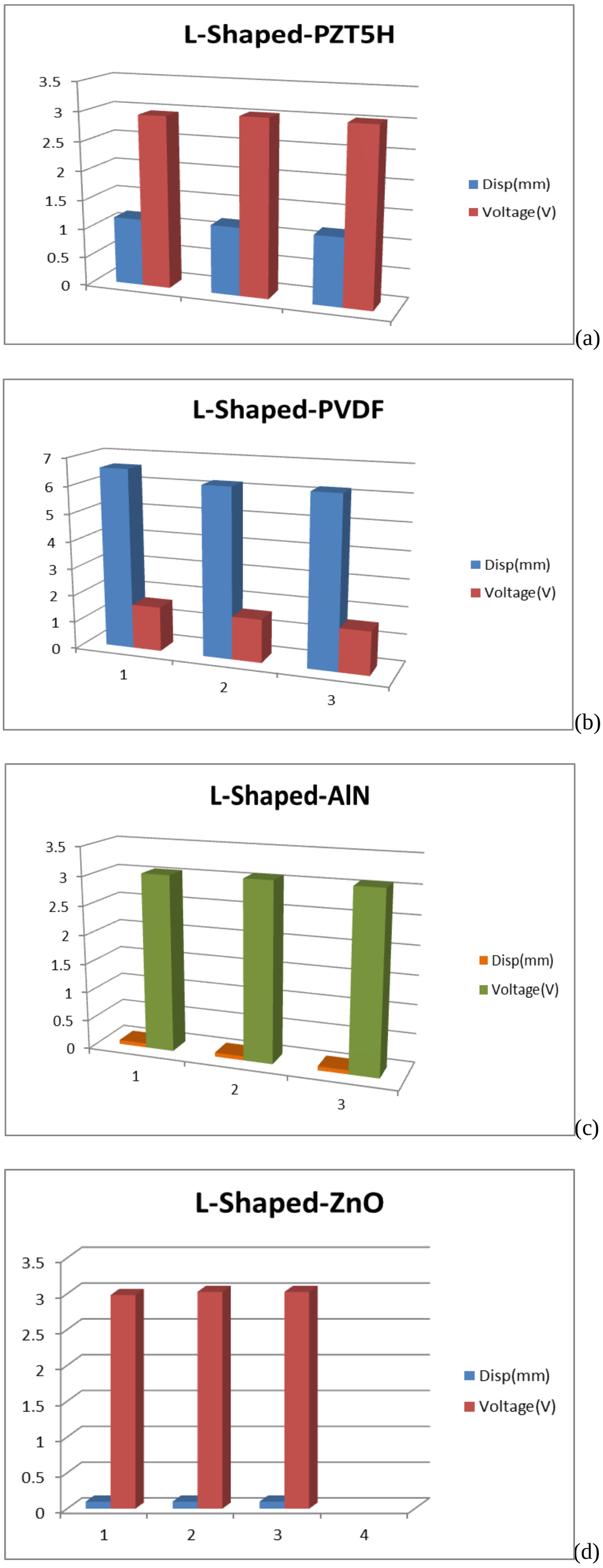

Fig. 15 Displacement Vs Voltage for L-shaped cantilever coated with (a) PZT-5H, (b) PVDF, (c)AlN, (d)ZnO

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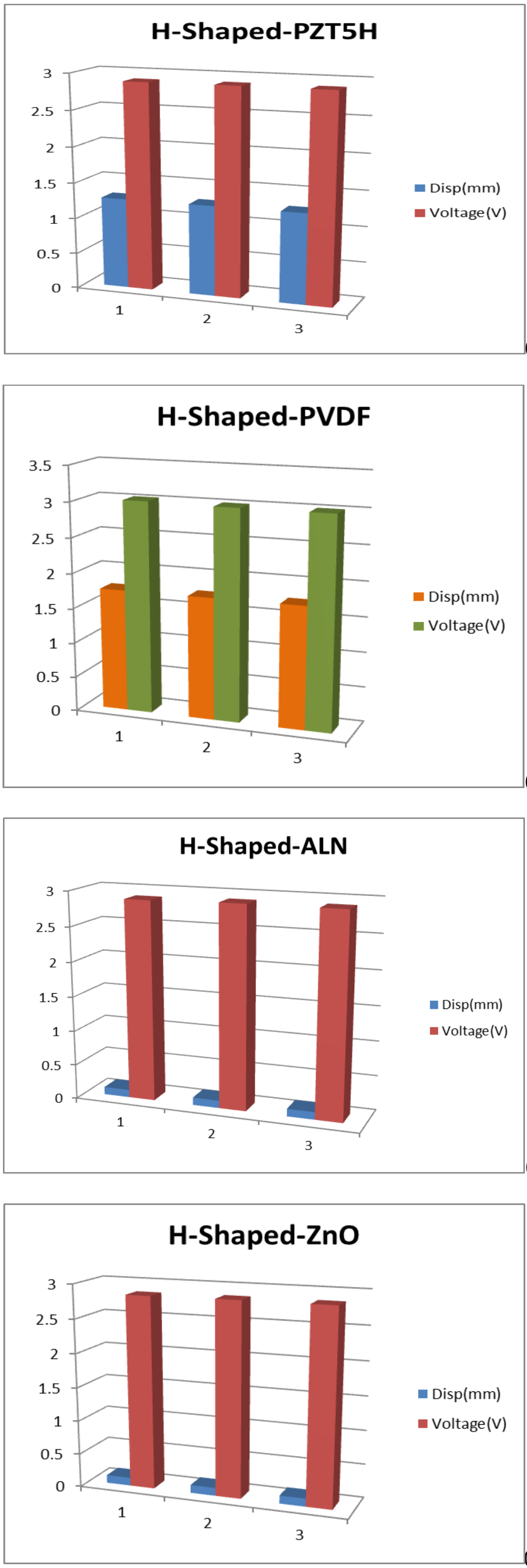

(a)

(b)

(c)

(d)

Fig. 15 Displacement Vs Voltage for H-shaped cantilever coated with (a) PZT-5H, (b) PVDF, (c) AlN, (d)ZnO

IV. CONCLUSION

Cantilever based energy harvester with different geometries with different materials have been studied. Variousanalysis are performed and parameters are compared. It is concluded that cantilever beam withH-shape coated with PVDF material generates maximum power at low frequency than other proposed geometries. So, it can be implemented as energy harvester source for sensors and IoT applications.

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