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Ferroelectret materials in energy harvesting for human body application

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Introduction

Kinetic energy harvesting systems that is implemented by using piezoelectric material to convert ambient mechanical energy to usable electrical energy represent a promising emerging technology to achieve autonomous, self-renewable and maintenance free operation of implantable or wearable devices. There are two common industrial piezoelectric materials in the market: lead zirconate titanate (PZT) and polyvinylidene fluoride (PVDF). Both of them are unsuitable for human body energy harvesting application due to the high hardness and fragility of PZT and the low piezoelectric coefficients of PVDF, respectively [1]. Therefore, in order to achieve high effective energy generated from human body, it should develop a more flexible, much lighter and highly piezoelectric material.

Ferroelectrets are thin polymer foams or micro-engineered polymer materials which store electric charges in its internal voids, presenting strong piezoelectric-like properties after electric poling. Comparing with these traditional piezoelectric materials, the ferroelectret materials have the lowest elastic modulus, density (Figure 1) and outstanding piezoelectric coefficients which would make them very desirable for human body energy harvesting applications [2]. The piezoelectricity of ferroelectrets originates from the combination of the internally stored charges and the cellular structures. However, the resulting piezoelectric properties of commercial ferroelectrets are limited by the random individual void geometry and irregular overall cellular structure (Figure 2) due to its fabrication processes.

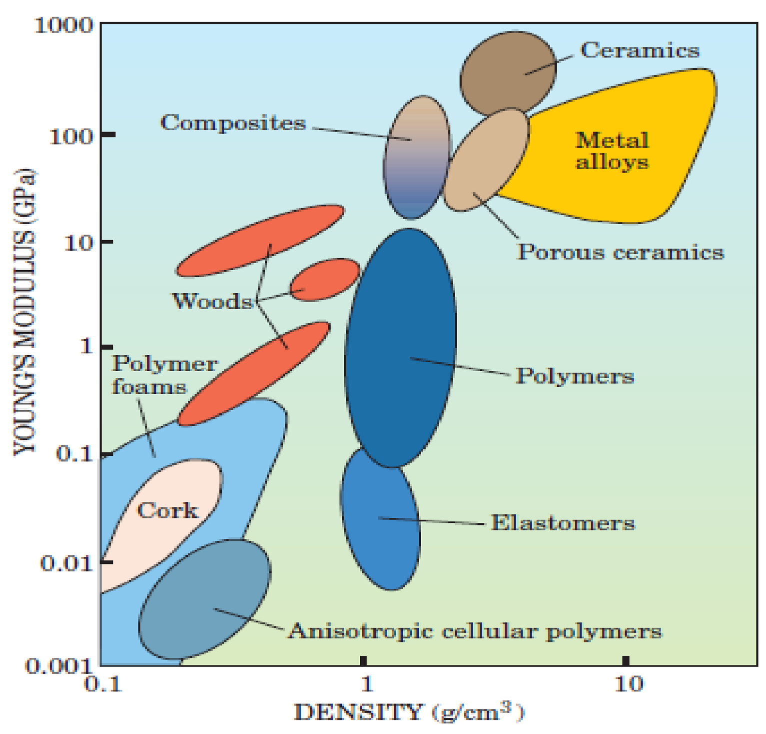


Figure 1: Ashby material property chart [1]

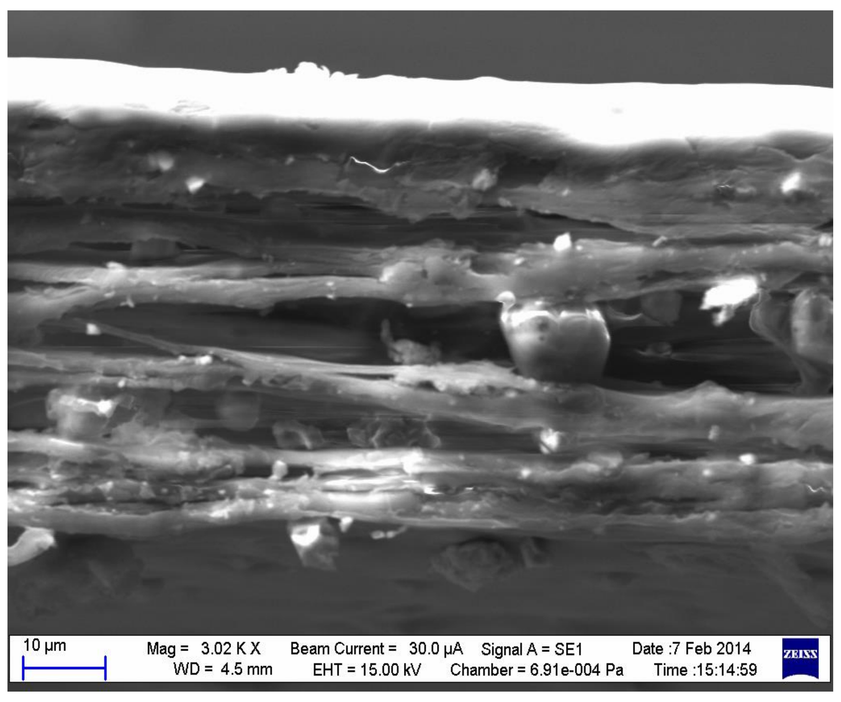


Figure 2: SEM photographs of cross sectional view of commercial ferroelectrets

Aims

- Optimized the piezoelectric properties of ferroelectrets which are associated with the geometry of void and voids distribution
- Develop a fabrication processes to fabricated the optimized ferroelectrets
- Evaluate the energy harvesting performance of the fabricated ferroelectrets

Methodology

A analytical model is established to reveal the relationship between the piezoelectric properties of ferroelectrets and the geometry of the internal void. Base on the analytical model, the designed structure was simulated in ANSYS Finite Element Analysis (FEA) software to predict its piezoelectricity.

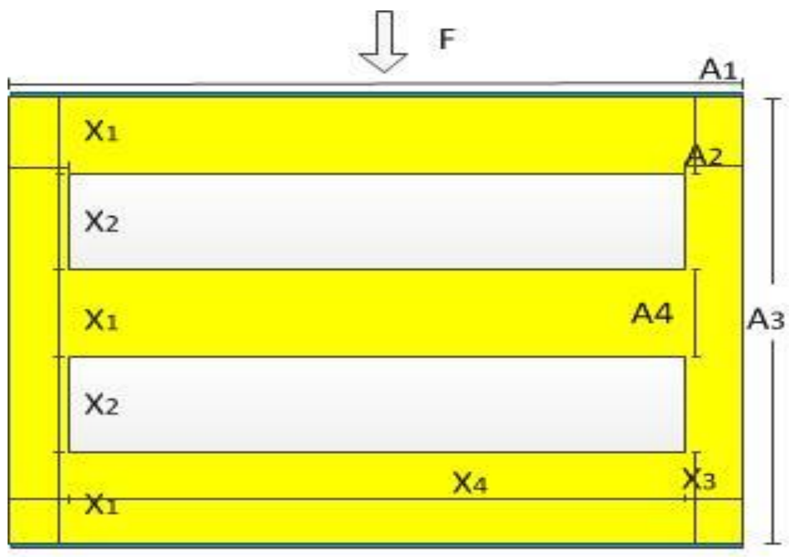


Figure 3: A simplified model for the piezoelectricity of a charge-implanted cellular structure

$$d_{33} = \frac{n(n+1)\varepsilon_1 \sigma tr_1(1-sr_1)^2}{sr_1[(n+1)+n\varepsilon_1 tr_1]^2 c_{33}}$$

$$d_{31} = \frac{n(n+1)\varepsilon_1 \sigma tr_1(1-sr_1)(sr_2-1)\gamma}{[(n+1)+n\varepsilon_1 tr_1]^2 c_{33}}$$

Where sr_1 is the effective area ratio of A_2 to A_1, tr_1 is the thickness ratio of x_2 to x_1, σ is the charge density on void surface, n is the number of void layer, ε_1 is the dielectric constant of polymer, γ is the Poisson's ratio, c_{33} is the elastic modulus of polymer

To investigate the piezoelectricity of the designed structure, The ferroelectrets are fabricated from PDMS using silicon moulds which contain several structures with different geometry of void (Table 1).

Table 1: A summary of designed structure parameter for silicon moulds

Void shape	tr_1	sr_1	Void Thickness	Void width	Void gap	Predicted d_{33}
Rectangular	0.4-0.8	0.25/0.16/0.0625	30/40/50 um	50/75/150 um	50 um	160 pC/N
Parallelogram	0.4-0.8	0.25/0.16/0.0625	30/40/50 um	46.3/71.3/146.3 um	53.7 um	260 pC/N

The fabrication process include:

- Silicon mould was exposed to silane vapour for 1 hour
- PDMS and curing agent were mixed at a 10:1 weight ratio then degassed
- Spin coating the degassed PDMS mixture on the silicon moulds (1)
- Baked the mould at 80ºC for 20 minutes then peel off the cured PDMS from the silicon mould(2)
- Plasma treatment to bound two parts of PDMS together (3)
- PDMS ferroelectret was polarized with corona discharge

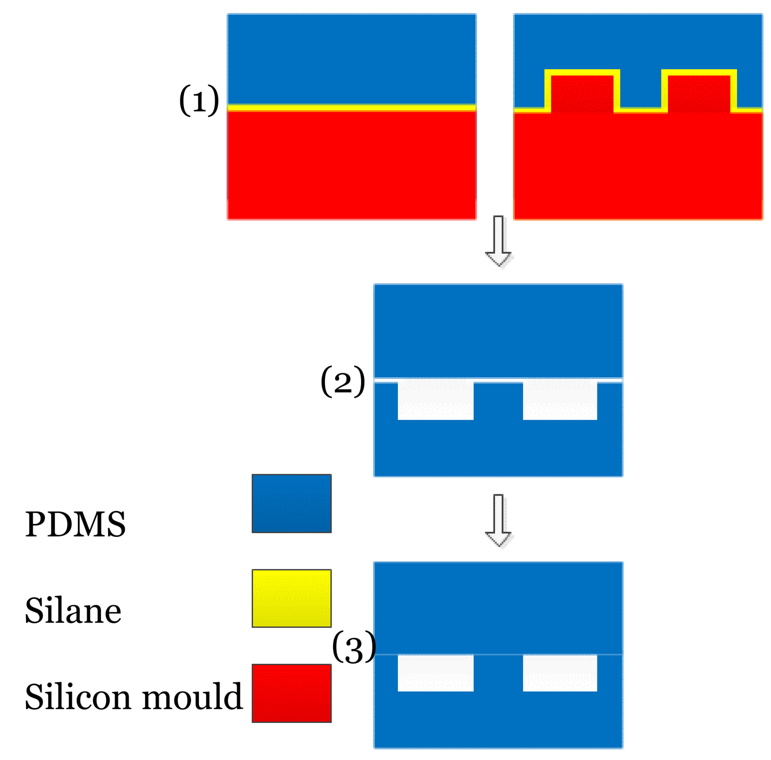


Figure 4: Schematic of fabrication processes

Results

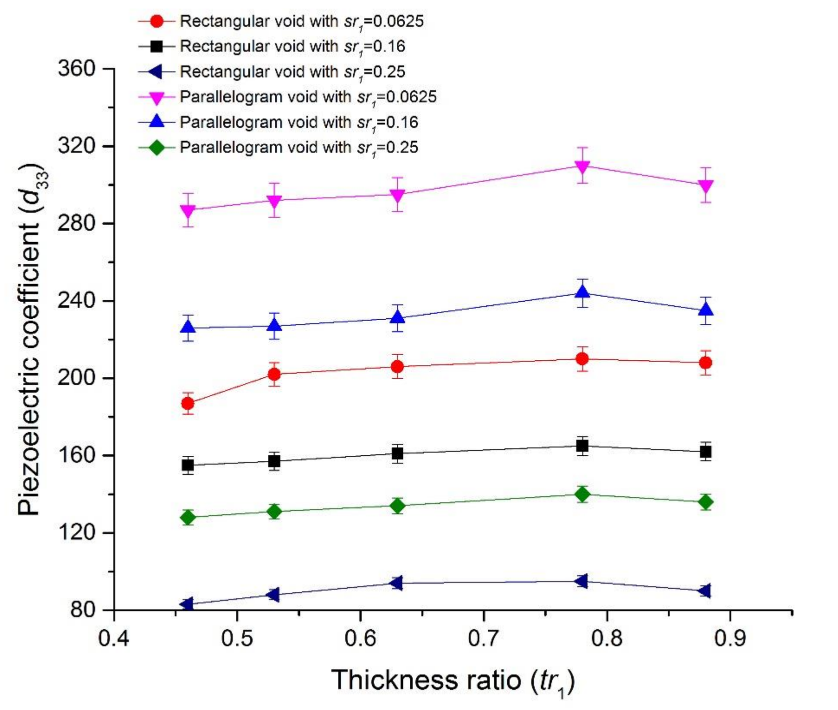


Figure 5: The measured piezoelectric coefficient varying with the thickness ratio for one void layer PDMS ferroelectret

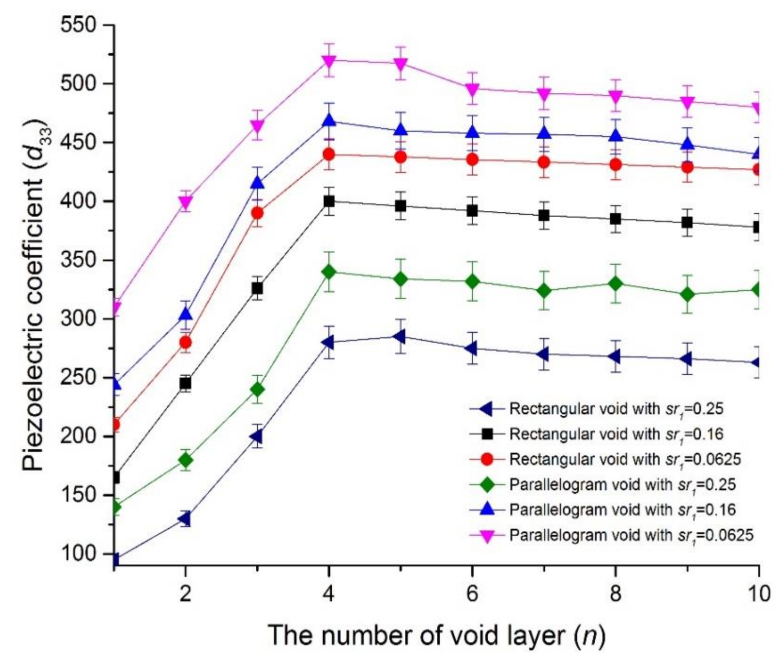


Figure 6: The measured piezoelectric coefficient varying with the number of void layers

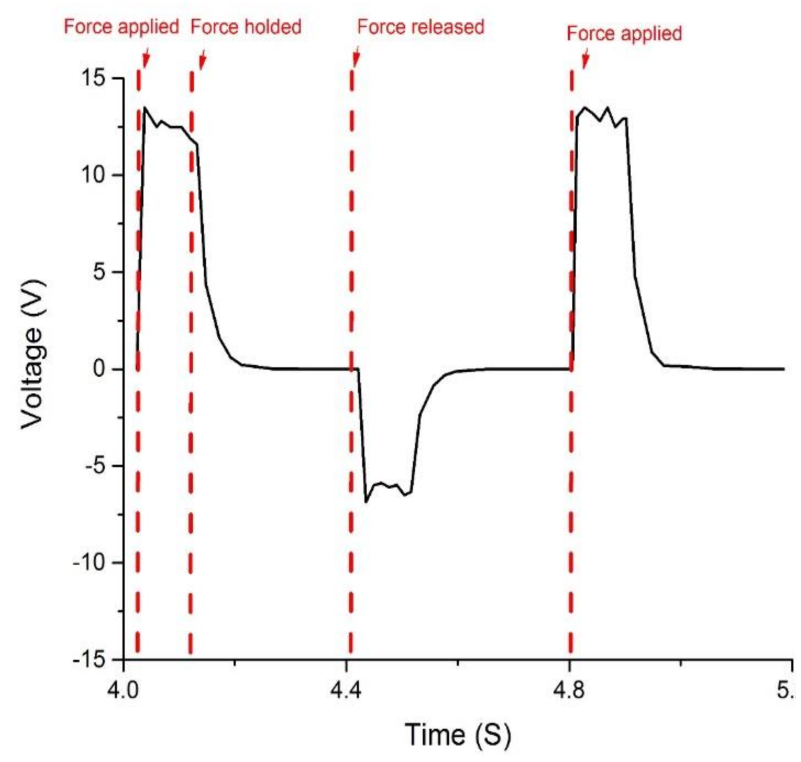


Figure 7: Energy output pulse of PDMS ferroelectret at the optimal resistance of 65 MΩ under 800N slow walking model

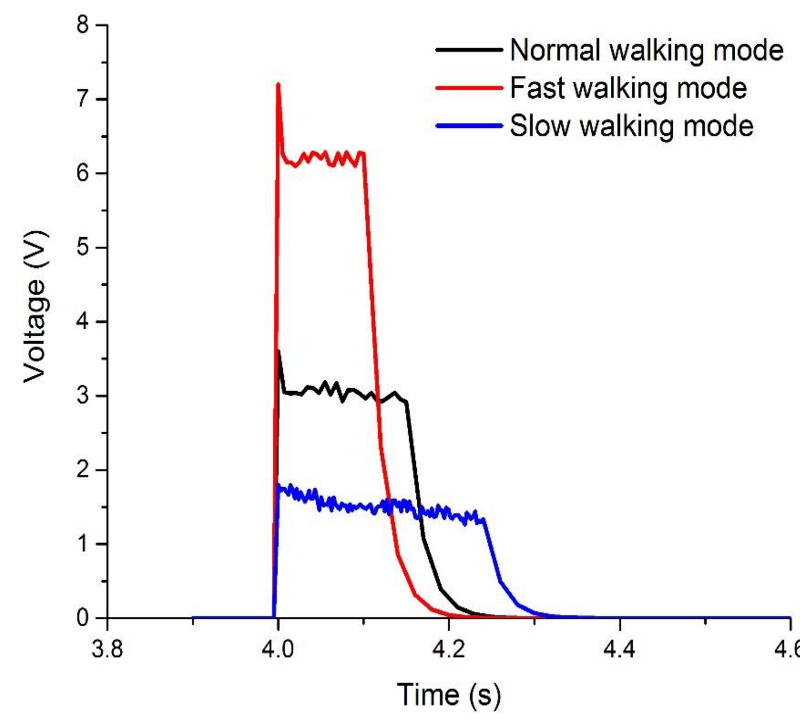
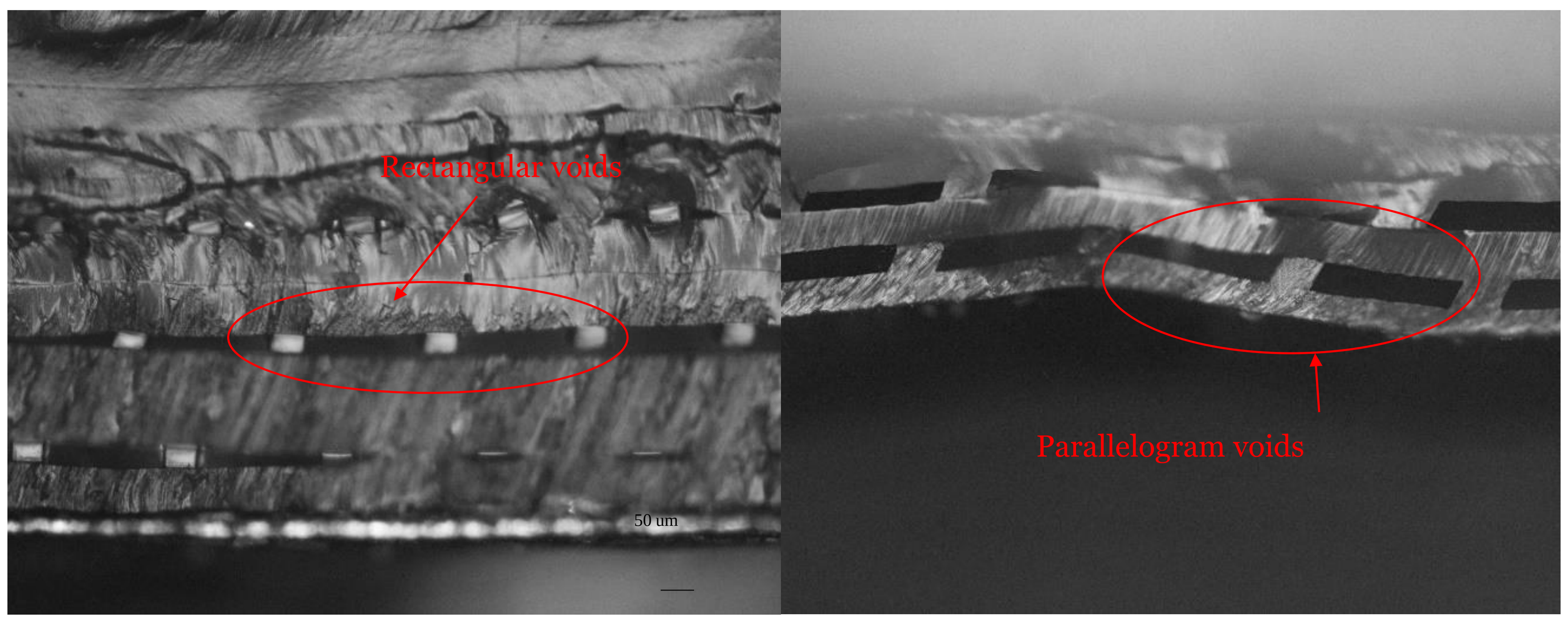


Figure 8: Output voltage pulse for three different walking mode at the resistance of 10 MΩ under a constant force of 800 N



(a) (b)

Figure 9: The image of the cross section image for multilayer PDMS ferroelectret (a) rectangular PDMS ferroelectret (b) parallelogram void PDMS ferroelectret

Conclusion

- The PDMS ferroelectret with lower effective area ratio sr_1 can generate higher piezoelectric coefficients d_{33}; The thickness ratio also can affect the piezoelectric coefficient d_{33}. For one void layer, the optimized thickness ratio is achieved at around 0.8.
- The parallelogram void PDMS ferroelectret can achieve higher piezoelectric coefficients d_{33} and the piezoelectricity of PDMS ferroelectret can be improved by increase the number of void layer in the range of 1 to 4
- The peak and duration of output voltage can be affect by the frequency of footstep
- The parallelogram void PDMS ferroelectret with the maximum piezoelectric coefficients 520 pC/N and size of 2 cm×2 cm generates 0.7 µJ of energy for per footstep.

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Reference

[1] IEEE Micro Electro Mechanical Systems Workshop, January-February 1991, Nara, Japan, p. 118.

[2] L. J. Gibson, M. F. Ashby, Cellular Solids: Structure and Properties, Cambridge U. Press, New York (1999).