Research Paper

Simulation and fabrication considerations of P(VDF-TrFE) cantilevers

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Abstract

This paper presents design and simulation of polyvinylidenefluoride (PVDF) cantilever. However, poly(vinylidenefluoride-trifluroethylene) P(VDF-TrFE) has better piezoelectric properties than PVDF. In view of this, piezoelectric β-phase of P(VDF-TrFE) which is essential for energy harvesting has been investigated. The spin coated films of P(VDF-TrFE) were heat-treated at various temperatures to realize β-phase. The results indicate the presence of β-phase in films heat-treated at 115oC for one hour confirmed using high resolution X-ray diffraction technique. Through Solidworks-simulation software, we show that for a unimorph cantilever with design dimensions 45mm x 30 mm x 3.5 mm and 12mm thick proof mass a fundamental vibrational frequency of 50 Hz (which is required for body energy harvesting) is achievable.

1. Introduction

There has been an increase in wearable devices such as external wearable medical devices, mobile phones, wireless electronic devices etc. due to advancement in wireless technology and low power electronics. Major sources of energy that can be used are environmental vibrations and motion of biological systems; these sources are ideal for piezoelectric materials which have the ability to convert mechanical energy into electrical energy with high conversion efficiency [1]. The concept of utilizing piezoelectric materials for energy generation has been studied greatly over past decades [2, 3]. One ambient vibration energy source is human movement [4], with energy available in breathing, blood pressure/pulse and body movements. Approximately 60–70W of power is consumed during walking and a piezoelectric material in a shoe with a conversion efficiency of 12.5% could produce 8.4W of power. On the other hand, intelligent clothing with flexible piezoelectric materials integrated into fabrics such as gloves [5], may be able to convert a portion of mechanical energy associated with daily activities into electric energy. Converted electrical energy can be used to charge wearable mediums giving greater battery life, or in an ideal scenario, a self-maintaining power supply. Wearable devices will undoubtedly multiply in the years to come due to a constant decrease in size and power requirements of electronic systems.

Smart systems such as wireless sensing nodes etc., can be powered by the energy from the ambient motion of the body, eliminating the need for periodic battery replacements [6, 7]. The power generation in the harvester can be realized by exploiting electromagnetic, electrostatic or piezoelectric effect. The required voltages are generated directly in piezoelectric and electromagnetic conversion mechanisms, while in electrostatic generators, the conversion process is initiated by a separate voltage source. While electromagnetic generators are suitable for generating energy at high frequencies, piezoelectric harvesters can outperform the electromagnetic generators at low frequencies [8]. In Addition, the volume occupied by the piezoelectric generators is smaller than that of the electromagnetic harvesters for a given normalized power density [9]. Hence piezoelectric conversion is a better mechanism to harvest energy at frequencies below 100 Hz.

However, there is a limited choice of piezoelectric materials suitable for low frequency resonator designs [10]. PVDF is an attractive piezoelectric material for harvesters owing to its low elastic stiffness allowing the design of resonators with the fundamental mode of vibration below 100Hz Recently it has been reported that Poly(vinylidenefluoride-co-trifluoroethylene P(VDF-TrFE) has better piezoelectric properties than PVDF. One of the most efficient configurations for a body energy harvesting device is a cantilever with low natural frequency. A piezoelectric harvester with the cantilever configuration having a single layer of piezoelectric material is called a unimorph and that with two layers is called a bimorph [11]. The energy harvester so developed could be integrated with wireless sensor node for in-vitro applications such as monitoring patient health like heartbeat. Energy harvesters have wide ranging potential such as in-vivo applications for powering pacemakers etc. The in-vivo applications though are challenging due to the biocompatibility issues of the energy harvester. Nevertheless, the first set of in-vitro applications appear to be realistic. In this paper, simulation, design and identification of PVDF-TrFE in its piezoelectric phase for the fabrication of unimorph cantilever has been presented.

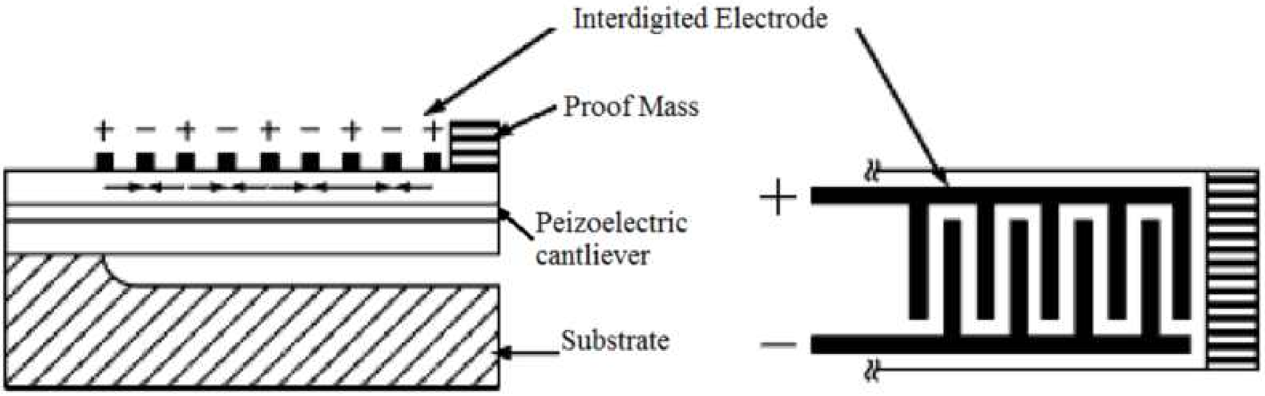


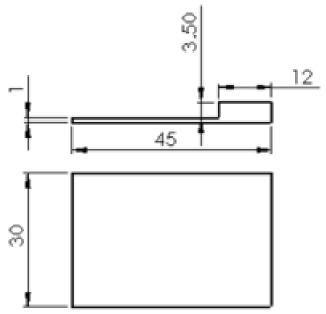
Figure 1. Schematic of d33 mode `of piezoelectric cantilever with metallic interdigitated pattern for energy extraction

Design of unimorph cantilever: In order to harvest the energy from body vibration, d33 mode for the higher voltage power generation from the flexible material PVDF-TrFE is designed and depicted in figure 1.

2. Simulation of the cantilever device

One of the most important design parameters in designing a vibration energy harvesting device is resonant frequency. The power density would be maximum when the vibration frequency of the source matches the resonant frequency of piezoelectric generator. The power density decreases when source frequency deviates from the resonant frequency [6]. The frequency range of common body vibrations is between 40 Hz and 60 Hz. Moreover acceleration decreases with higher modes of frequencies [6]. Therefore, fundamental mode is considered in designing the cantilever.

We use the natural frequency of the proposed cantilever as 75 Hz, which nearly matches with the body vibrations at certain points. Preliminary results are obtained with simulations of the piezoelectric cantilever device using Solidworks-simulation software. The design parameters are as shown in figure 2. The mode list and material parameters are shown in Table 1-2. The simulated cantilever vibrational frequencies are shown in figure 3a-b. In order to identify the vibrational frequencies and amplitudes at a given point on the body, measurements have been carried out using inbuilt accelerometer in i-phone. For this we used i-phone app downloaded from Real vibrations database (realvibrations.nisplab.org) and is shown in figure 4.



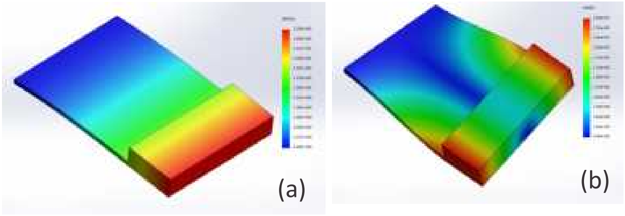


Figure 2. Basic cantilever design parameters (dimensions in mm) for PVDF used for simulation

Figure 3. PVDF Cantilever device designed with numerical simulation for frequency 50Hz (a) Frequency 1-Amplitude-Amplitude1, (b) Frequency 1-Amplitude-Amplitude2

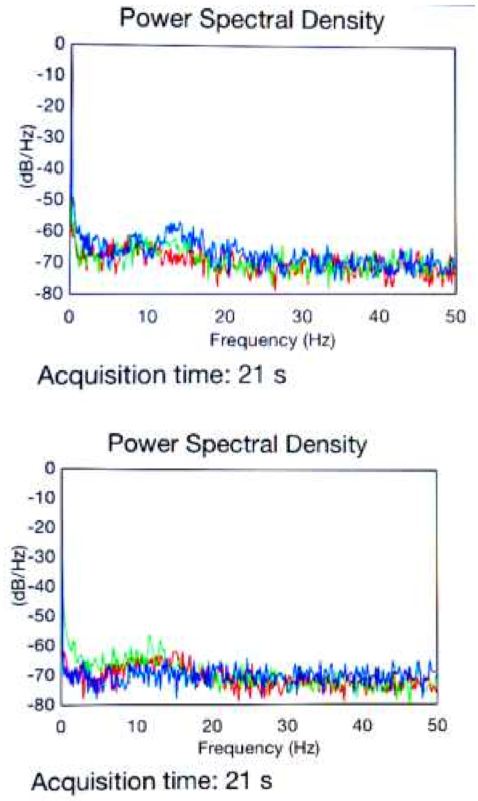


Figure 4. Vibrational frequencies and amplitudes at two points on the body obtained by inbuilt accelerometer in i-phone using NISP lab - real vibrations database app[http://realvibrations.nipslab.org/node/178].

Table 1: Mode list

Frequency Number	Rad/sec	Hertz	Seconds
1	316.28	50.338	0.019866
2	1350.3	214.9	0.0046533
3	3001.1	477.64	0.0020936
4	7823.4	1245.1	0.00080313
5	8903.5	1417	0.0007057

Table 2: Material Properties

Model Reference	Properties	Components
	Name: PVDF Model type: Linear Elastic Isotropic Tensile strength:52 N/mm^2 Mass density:1770 kg/m^3 Elastic modulus:2450 N/mm^2 Poisson's ratio:0.18	SolidBody 1 (Boss-Extrude1) (PVDF_cantilever)

3. Sample preparation

P(VDF-TrFE) 70:30 is purchased from solvay chemicals. 10 wt% P(VDF-TrFE) solution has been prepared using N, N dimethyl acetamide as solvent. The solution is ultrasonicated for 2hours. 2 inch quarter wafers cleaned with RCA and coated 240nm SiO2 using wet oxidation technique. The wafers were kept on hotplate at 120°C for 30 min to remove all the impurities. P(VDF-TrFE) solution was spun on quarter wafers at 1000 rpm for 30 sec to obtain films. The spun P(VDF-TrFE) samples were heated on hotplate at various temperatures 105°C, 115°C, 125°C and 135°C for 1 hr. The thickness of films was measured using dektak profilometer and found to be approximately 1 micrometer.

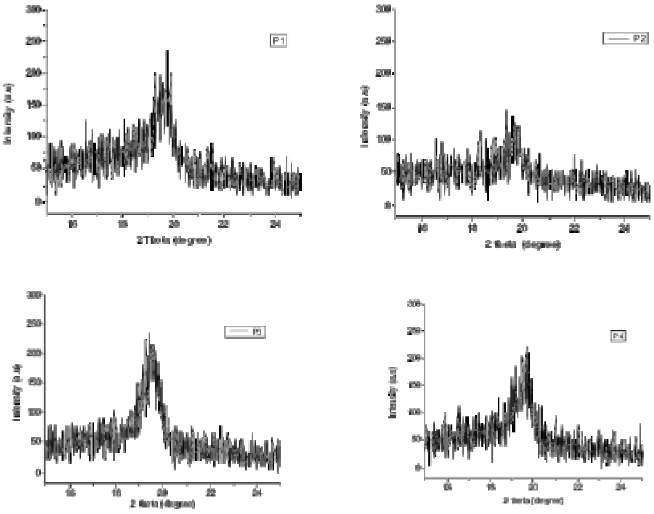


Figure 5: XRD pattern of P(VDF-TrFE) films heat-treated at various temperatures

Piezoelectric Phase identification: To identify the piezoelectric β phase and identify the functional groups of P(VDF-TrFE), high resolution x-ray diffraction (HRXRD) technique is used. XRD spectra of P(VDF-TrFE) films heat-treated at various temperatures are shown in figure 5. A Rigaku diffractometer with monochromated Cu Kα radiation of wavelength 1.54184A was the source of the X-ray generator. The data has been collected in the range of 15 to 25°C.

4. Summary

Design and simulation of PVDF cantilever which has low resonant frequency but high piezo-electric constant has been carried out. The ß-phase of PVDF and P(VDF-TrFE) are essential for realizing piezoelectric properties. This paper presents work on realization ß-phase of P(VDF-TrFE) films obtained by annealing the films in the temperature range 105 to 135°C. XRD results indicate the annealing temperature 115°C is the optimum.

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