Characterization of piezoelectric materials as a power source for electronic implantation devices

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Abstract

Piezoelectric materials are attractive as a power source for implanted nanoelectronic systems using the energy generated by weaves alive and physiological or biophysical processes. The study of a piezoelectric thin film sensor and its behavior as mechanical to electrical energy converter is discussed. A piezoelectric polymer—PVDF—was characterized and its physical parameters measured. Besides, the development of a PVDF-based 2.5μW power source activated by mechanical vibrations and efficiencies around the 5% is presented.

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1. Introduction

The aim is to establish whether a source of piezoelectric energy that converts mechanical energy—generated through the cardiac contractions or the sanguine flow—to electrical energy can be used as electrical supply for medical implanted devices of low power consumption and small size [1]. The characterized material is the so-called polymer polyvinylidene fluoride (PVDF). It is very flexible, light and resistant to processes of engineering.

2. Theory

The response of a piezoelectric material to a mechanical action is determined by the piezoelectrical constants and the physical dimensions of the material. In thin film devices, relatively small longitudinal forces create very large stresses within the material and the compressive forces are converted into much larger longitudinal extensive forces. In fact, this effect tends to predominate in most circumstances since most substances are compliant to some extent and the ratio of effective sensitivity in the 1 (length) vs. 3 (thickness) directions is typically 1000:1 [2].

For a material with geometrical form (cantilever) as shown in Fig. 1 [3].

\[ S_1 = s_{11} T_1 + d_{31} E_3, \] (1)

\[ D_3 = d_{31} T_1 + e_{13}^T E_3. \] (2)

The application of a bending force \( F \) to a piezoelectric in a cantilever of length \( l \) generates a voltage [4]:

\[ V = \frac{g_{31} 6l t_p}{\omega_s l_s^2} F = k_1 F, \] (3)

where \( g_{31} \) is the piezoelectric voltage coefficient, \( t_p \) is the thickness of the piezoelectric film supported on a substrate of thickness \( t_s \) and width \( \omega_s \). The charge density developed without applied voltage (short circuit) is given by

\[ Q = \frac{d_{31} 6l_o \omega_p l_p}{\omega_s l_s^2} F = k_2 F. \] (4)

Here, \( \omega_p l_p \) is the film area and \( d_{31} \) is the piezoelectric constant.

The charge and the voltage generated by the application of joint force \( F \) also depend on a piezoelectric intrinsical property and on the sensor’s geometry. The total energy
stored in the piezoelectric sensor is given as

\[ E_{\text{stored}} = \frac{QV}{2} = k_1k_2 \frac{F^2}{2}. \]  

(5)

3. Experimental

A PVDF 10\,\mu m thick sensor and 0.48 cm\(^2\) of area was mechanically excited with a 7 cm diameter loudspeaker, 1\,W nominal power and typical efficiency of 0.5\% for a power density of 130\,\mu W/cm\(^2\).

4. Results and analysis

The measured voltage vs. force and charge vs. force characteristics are shown in Graph 1, where a linear behavior is observed, in the measured range (weak forces). Of the obtained curve slopes and sample dimensions, the constant piezoelectric’s \(g_{31}\) and \(d_{31}\) were determinate to be \(56 \times 10^{-3}\) Vm/N and \(8 \times 10^{-12}\) C/N, respectively.

The transient response of the sensor and the Fourier’s analysis has shown a fundamental frequency of 85 Hz. Graph 2 shows the behavior of the piezoelectric sensor as a power source for different frequencies. With a sinus driving force applied to the loudspeaker, the attached sensor was able to light on a red LED (forward voltage 2\,V), to a maximal continuous current value of 1.5\,\mu A at the resonance frequency (72 Hz). Of the curve of resonance is observed a maximum generated power of 3\,\mu W with a loss factor of 30\%. Taking into account the specifications of the speaker, the area of the sensor finds itself that the efficiency in the conversion of energy is close to 4\%.

5. Conclusions

The characterization of the piezoelectric polymer—PVDF—showed that this is an attractive material to be used as a power source in medical implantation devices due to its flexibility and high voltage generation capability by small deformations. The measured efficiency of the studied sensor shows that it can supply a direct current of 2\,\mu A at 2\,V and a pacemaker needs 20\,\mu A at 2.5\,V. In conclusion, it is possible to develop power generators based on the existent materials whose performance could be optimized through an adequate design. Long, thin and narrow sensors seem to be more suitable for a highly efficient conversion of mechanical energy to electric.

References