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PZT and PVDF bimorph actuators

I. CHILIBON, C. DIAS[a], P. INACIO[a], J. MARAT-MENDES[a]
National Institute of Research and Development for Optoelecronics, INOE-2000, PO Box MG-5, 077125, Bucharest, Romania
[a]*Department of Materials Science, Faculty of Science and Technology, New University of Lisbon, 2829 - 516 Caparica, Portugal*

The paper presents the main characteristics of two types of bimorph actuators, such as: PZT and piezoelectric PVDF. Two PZT thick plates about 0.3 mm thickness where fixed together and in between a metallic brass plate as positive electrode. An important result is that the PZT bimorph transducer starts vibrating at low alternative voltage about 5 V, developing more than 2 mm aperture displacement at the plates end. PVDF pre-polarized piezoelectric bimorph structure consists on two PVDF thin films, with 25 μm thickness and 31 pC/N d_{31} piezoelectric coefficient. The PVDF bimorph transducer starts vibrating at low alternative voltage, such as 10 V, developing more than 1 mm aperture displacement at its end. The mechanical resonance frequency of piezoelectric bimorph transducers depends on geometric size (length, width, and thickness of each layer), and the piezoelectric coefficients (d_{31} and s_{11}) of the piezoelectric material. The piezoelectric bimorph actuators can be well suited to be implemented in devices for laser system micrometry displacement, and biological sensor applications.

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Keywords: PZT ceramics, PVDF, Bimorph actuator

1. Introduction

The piezoelectric bimorph actuator is created by laminating layers of piezoelectric ceramic material, namely Lead Zirconate Titanate (PZT) onto a thin sandwich beam or plate [1]. Bimorph actuators consist of two independent flat piezoelectric elements, stacked on top of each other. By driving one element to expand while contracting the other one, the transducer is forced to bend, creating on out-of-plane motion and vibrations.

The bimorph transducer is an electromechanical one and it works on the basis of the reverse piezoelectric effect, converting the electrical power into a mechanical vibration in the range of tens of microns. The piezoelectric bender transducers have two major advantages: (1) the ability to generate electrical signals from mechanical and acoustic sources of low impedance; and (2) the ability to develop relatively large motions and low forces with small electrical excitation [2].

The piezoelectric actuator devices offer a number of benefits for applications in active control devices. Their high stiffness results in isotropic high actuator performance. The actuators are easily controlled, provide fast response, can have small dimension and weight, and can be simply driven by voltage. The piezoceramic materials type PZT with high compliance and electrostrictive coefficients, have a large domain of applications in electromechanical transducers for optoelectronics as: low power bimorph piezoceramic transducers for optical vibrating systems, interferometer with laser, remote commands in optoelectronic systems, bare code systems and micropositioners for laser systems, structural control systems and minimally invasive surgery [3].

The mechanical resonance frequency of piezoelectric bimorph transducers depends on geometric size (length, width, and thickness of each layer), and the piezoelectric coefficients (d_{31} and s_{11}) of the piezoelectric material.

A flexible device (bimorph PZT transducer) having two active PZT layers was designed and realized for a laser system application. When a sinusoidal voltage supplies the device, the transducer starts to vibrate with the entire system and the motion of light of laser beam is scanned on a screen. At resonance frequencies, the system has maximum amplitude of vibration and efficiency. The device has the ability to develop relatively large motions and low forces with small electrical excitations.

PVDF pre-polarized piezoelectric bimorph structure was realized on two PVDF thin films, with 25 μm thickness and 31 pC/N d_{31} piezoelectric coefficient. The PVDF bimorph transducer started vibration at low alternative voltage, such as 10 V, developing more than 1 mm aperture displacement at its end. The piezoelectric bimorph actuators can be well suited to be implemented in devices for laser system micrometry displacement, and biological sensor applications.

2. Bimorph actuators

Bimorph actuators consist of two independent flat piezoelectric elements, stacked on top of the other. By driving one element to expand while contracting the other one, the actuator is forced to bend, creating an out-of plane motion and vibrations. The results look like a miniature diving board that bends up and down with applied voltage (Fig. 1). The output force **F** and displacement **u** are obtained as [4]:

$$u = \frac{3}{4} d_{31} \left(\frac{L}{t} \right)^2 V \tag{1}$$

$$F = \frac{2tW}{L} \frac{d_{31}}{s_{11}^E} V \tag{2}$$

where length (L), width (W) and thickness (t) of each ceramic layer.

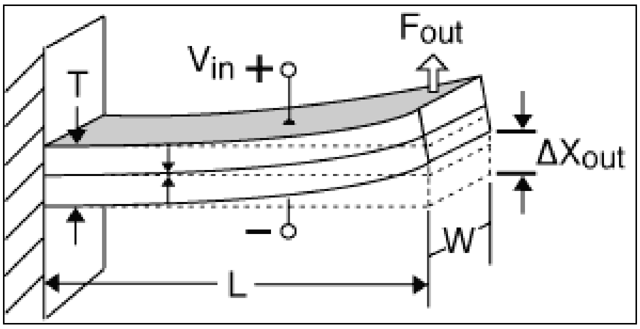


Fig. 1. Schematic diagram of a ceramic bimorph.

Force and stroke are typically specified under quasi-static conditions, meaning that the actuator is operating well below its first resonant mode. The resonance frequency of the fundamental bending mode is expressed as:

$$f_r = 0.08 \frac{t}{L^2} \sqrt{\frac{1}{\rho s_{11}^E}} \tag{3}$$

where s_{11}^E is stiffness, and ρ is density. Compared to a single piezoelectric plate or a multilayered stacked actuator, bimorphs show very large displacements but quite small resonance frequency, low stiffness and low blocking force.

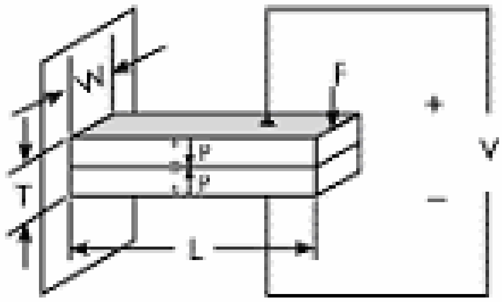
For a vibrating bar clamped at one end the resonant frequency is given by [5],

$$f = a^2 \frac{\pi c k}{8L^2} \quad a = 1.194^2, 2.988^2, 5^2, 7^2 \ldots \tag{4}$$

where c is the velocity of sound in PVDF, L is the length of the bimorph cantilever and k is the radius of gyration given by,

$$k = \frac{t}{\sqrt{12}} \tag{5}$$

Series and parallel operation modes for bimorph actuators are function of electrical connection and the polarization (P) orientation of piezoelectric layers. **Series Operation** refers to the case where supply voltage is applied across all piezo layers at once. The voltage on any individual layer is the supply voltage divided by the total number of layers. A 2-layer device wired for series operation uses only two wires, one attached to each outside electrode (Fig. 2a). **Parallel Operation** refers to the case when a metallic blade is fixed between both piezoelectric layers and connected like in Fig. 2b).



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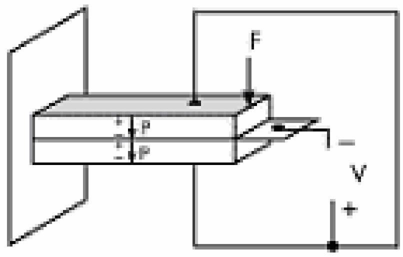

b

Fig. 2. Series (a) and parallel (b) operation modes for bimorph actuators.

Table 1 reviews the properties of piezoelectric materials and PVDF polymer. While PVDF has a relatively low dielectric ratio, $\varepsilon/\varepsilon_0$, compared to piezoelectric ceramics and crystalline materials, this ratio is relatively higher compared to other polymers.

Table 1. Electrical and acoustic properties of some piezoelectric materials [6].

Piezoelectrics	Velocity (cm/sec)	ε_R	d_{33} (10^{-12} m/V)	g_{33} (10^{-3} Vm/n)	Density (g/cm^3)	Acoustic impedance g/cm^3-sec (x10^5)
Barium Titanate	.564	1200	149	14.1	5.55	33.5
PZT-2	.441	450	152	38.1	7.6	31.3
PZT-4	.460	1300	289	26.1	7.5	34.5
PZT-5A	.435	1700	380	24.8	7.75	33.7
PZT-5H	.456	3400	593	19.7	7.5	34.2
Quartz	.566	4.5	2.3	-	6.82	15.2
PVDF	.220	12	33	339	1.78	2.5

Ferroelectric polymers are produced by a variety of techniques, where in the case of PVDF the material is mechanically drawn and polarized in order to form a useful transducer material. The drawing techniques include extrusion and stretching and while processing the film material is subjected to a strong electrical polarization field. Without drawing, PVDF shows a very weak piezoelectric behaviour and the higher the molecular orientation the stronger the resultant response of the polarized film. After polarization, PVDF exhibits considerably stronger piezoelectric response than most other known polymers [7,8,9].

3. Experimental results

3.1. PZT bimorph actuators

The electromechanical PZT bimorph transducer works on the reverse piezoelectric effect basis, converting an electrical power into a mechanical vibration in the range of tens microns. When an electrical field E is applied on the transducer electrodes, the thin PZT plate (polarized in the same direction as E) expands and the other one (polarized on the contrary direction of E) contracts. The experimental studies on the thin PZT plates, with various thicknesses have shown the correspondence between the size and the electrical capacity.

The electrical capacity of PZT plates, function of their thickness is presented in Table 1, where: **L**, **l**, and **h** are respectively the length, width and thickness of the PZT plate and **C** is the plate electrical capacity. The piezoceramic material utilised is type PZT (lead titanate zirconate), realized in laboratory, with various additions (Ni, Bi, Mn) and presents piezoelectric and dielectric characteristics, such as: 7.2 g/cm^3 density, 1100 permittivity, 80 quality factor, 0.55 coupling factor, 20 10^{-12} m^2N^{-1} compliance constant [10].

Table 2. Electrical properties of PZT plates.

PZT plate	L [mm]	l [mm]	h [mm]	C [nF]
1	23.0	13.0	0.29	8.76
2	21.0	13.0	0.32	8.72
3	21.0	13.0	0.35	7.69
4	22.5	13.5	0.36	7.31
5	22.5	13.5	0.37	7.17

As application of PZT bimorph transducer (BPT) we realized a flexible device, consisting in a sandwich of two thick PZT plates about 0.3 mm thickness and a brass blade between them, all together fixed with an epoxy resin. Two rectangular piezoelectric plates and a metallic electrode fixed between them are glued together.

PZT bimorph transducer (1) fixed to a long plastic blade (2), and a small mirror (3), glue to the blade end is presented in Fig 3. This flexible device was implemented into a He-Ne laser system in order to create a scanning image on a screen (Fig. 4). When a sine-wave voltage **u** supplies BPT, the transducer starts to vibrate with the entire system and the mirror moves.

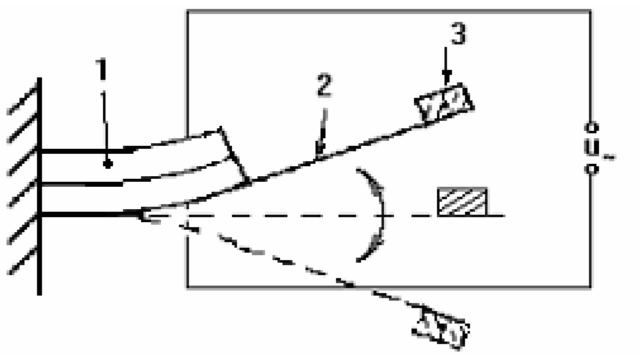

Fig. 3. A flexible device with BPT.

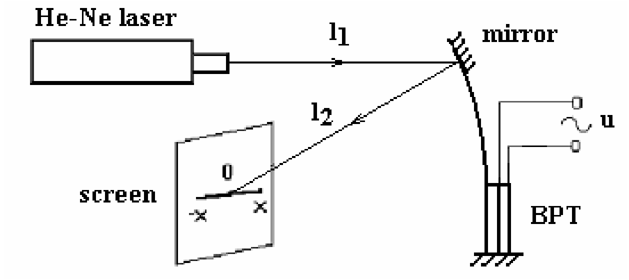

Fig. 4. Laser system with BPT.

Table 3. Resonance frequency of piezo-polymer bimorphs.

Transducer position	Length (mm)	f_{res} (Hz)	Mass (mg)
Horizontal	21	31.0	0
Vertical	21	30.3	0
Vertical (Immobillon)	21	25.9	3
Horizontal	27	18.5	0

A sinusoidal voltage **u** is applied on BPT electrodes with different amplitudes, and the transducer starts to vibrate, together with the blade and mirror. The maximum displacement at the plastic blend end is achieved at the device mechanical resonant frequency. The mirror movement implies the laser light beam trajectory modification, in consequence the screen scanning. The light beam of the laser is propagating on the distance $\mathbf{l_1}$ = 40 cm between the He-Ne laser and the mirror, and $\mathbf{l_2}$ = 140 cm between the mirror and the screen. For different applied sinusoidal voltages we obtained a linear displacement **Δx** - voltage **u** characteristic (Fig. 5).

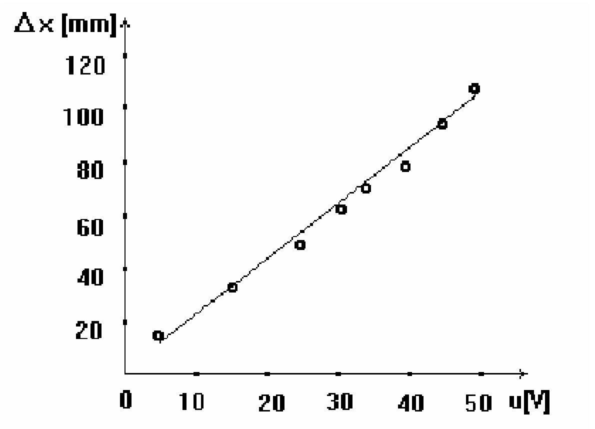

Fig. 5. Displacement – voltage characteristic for the He-Ne laser system.

An important result is that the PZT bimorph transducer starts to vibrate at low alternative voltage about 5 V, and 50 Hz resonance frequency. The flexible device develops more than 2 mm displacement at the blade end. As result, when the bimorph transducer is supplied with 50 V, the He-Ne light beam scans the screen, creating an image with maximum 120 mm width.

3.2. PVDF bimorph actuators

PVDF pre-polarized piezoelectric bimorph structure consists on two PVDF thin films, with a nominal thickness about 25 μm and 31 pC/N d_{31} piezoelectric coefficient (by SOLVAY). After cutting two identical strips of the appropriate dimensions typically 21-27 mm long and 9 mm wide they were glued to one another with a cyanoacrylate adhesive in anti-parallel direction (see Fig. 6). Measurements of the electrical impedance were performed using model 760 QuadTech LCR Bridge, whose measuring frequency range is between 10 Hz and 2 MHz.

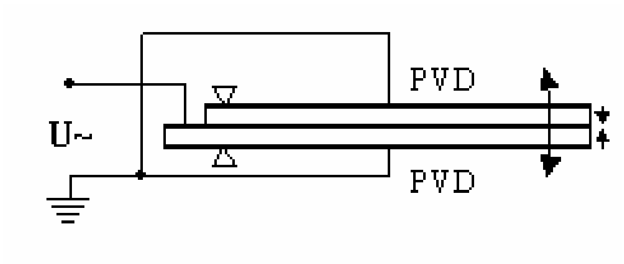

Fig. 6. Electric measurement of the bimorph impedance

In Fig. 7 is a plot of the real part of the electrical impedance Rs of a horizontal bimorph. For this sample one can distinguish a resonance centred around 31 Hz, which results from the mechanical vibration resonance of a PVDF cantilever.

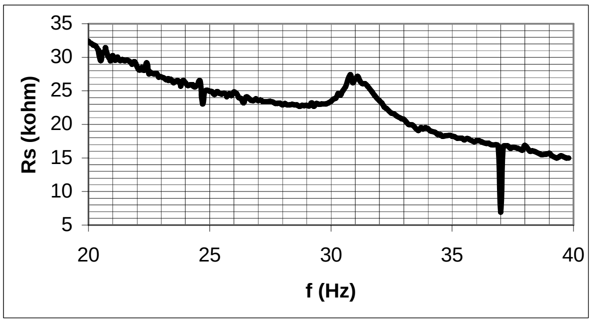

Fig. 7. Real part of the impedance for a horizontal bimorph

In view of the application in mind we have also measured the impedance of the bimorph transducer vibrating in vertical and horizontal position. For instance, the resonance frequency of a bimorph transducer with an immobillon strip 10.5 mm long by 6 mm wide thermally glued to the bimorph was also measured and is listed in Table 3. The bimorph-immobillon structure has mechanical resonant frequency in horizontal position greater than in vertical position (Figs. 7 and 8).

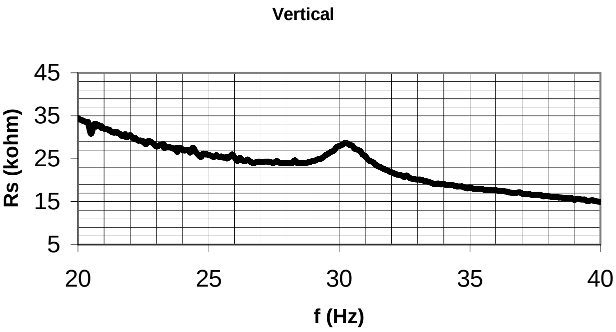

Fig. 8. Real part of the impedance for a PVDF vertical bimorph.

The PVDF properties provided by SOLVAY are: sound velocity c = 2260 m/s and permitivitty $\varepsilon_r = 10$. The layers size is: t = 25 μm thickness, 8 mm width and 25 mm length. As result, the calculated capacitance is 4.3 nF and 20 Hz resonance frequency (see relations (4) and (5)). The calculated capacitance value is lower than the experimental one, due to the interfacial adhesive layer between PVDF strips. The inappropriate adhesive utilization could generate the stiffness increasing of the bimorph structure, comparativelly with single PVDF cantilever. It is also significant that a resonance oscillation could be observed in a bimorph-immobillon structure [11]. The PVDF bimorph transducer starts vibrating at low alternative voltage, such as 10 V, developing more than 1 mm displacement at its end.

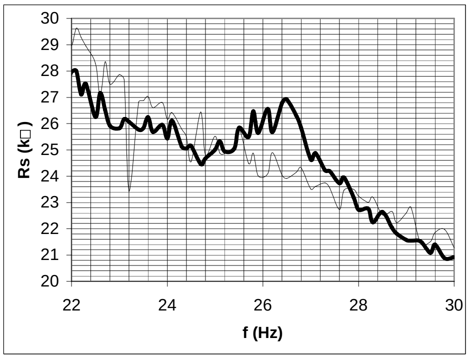

Fig. 9. Real part of the impedance for the vertical bimorph PVDF transducer measured in air (thick curve) and water (smooth curve).

The bimorph-immobillon structure has mechanical resonant frequency in air greater than in water (Fig. 9). The PVDF bimorph transducer started vibrating at low alternative voltage, such as 10 V developing more than 1 mm displacement at its end.

4. Conclusions

Piezoelectric materials like PZT and PVDF are suitable for bimorph transducers applications such as: He-Ne system for light beam scanning, and bimorph-immobillon structure.

The He-Ne system equipped by BPT vibrates starting 5V sinusoidal voltage. The flexible device with BPT has 50 Hz mechanical resonance frequency (due to length of the flexible plate and the total mass). Also, at resonance frequency, the system yields maximum vibration displacement amplitude and efficiency. The BPT has the ability to develop relatively large motions and low forces with small electrical excitations.

The bimorph-immobillon structure behaviour depends on its clamped position (horizontal or vertical) and loading medium (air or water), so the device exhibits different mechanical resonant frequencies in various conditions.

The mechanical resonance frequency of piezoelectric bimorph transducers (PZT and PVDF) depends on the size (length, width, and thickness of each layer), and the piezoelectric coefficients (d_{31} and s_{11}) of the piezoelectric material. The piezoelectric bimorph actuators can be well suited to be implemented in devices for laser system micrometry displacement or light beam scanning and biological sensor applications.

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*Corresponding author: qilib@yahoo.com