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DESIGN AND FABRICATION OF PIEZOELECTRIC β-POLY(VINYLIDENE FLUORIDE) MICROACTUATORS FOR MICROFLUIDIC APPLICATIONS

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β-poly(vinylidene fluoride), acoustic streaming, microfluidic applications.

ABSTRACT

This paper reports on a fabrication method for producing piezoelectric poly(vinylidene fluoride) films in their electroactive β-phase that features controlled thickness, smooth and flat surface, and high transparency. These films are suitable for being used as integrated microactuators, such as piezoelectric pumps and/or mixers, in microfluidic applications. β-PVDF films with a thickness of about 25 μm were deposited by spin-coating. It was concluded that the processing parameter that mostly affect the films quality is their drying temperature. Indeed, the drying temperature of 30 ºC proved to be the most suitable for obtaining non-porous and transparent films with a β-phase content of 75%.

INTRODUCTION

Rapid driving and mixing of small amounts of fluidic species are very important for many biomedical applications (Squires et al. 2005). However, these tasks are challenging for microfluidic systems due to the small channel dimensions involved (Yaralioglu et al. 2004). In such channels, the interactions between the fluid and the walls become dominant and, as a result, the Reynolds numbers involved are usually below 100. Therefore, the laminar flow dominates and the mixing of fluidic species occurs only by diffusion which can involve long transit and mixing times (Ottino et al. 2004). In order to improve the efficiency of both transport and mixing of fluids, several mechanisms have been developed. The use of valves and pumps (with moving parts) are attractive solutions due to the chaotic motion generated into the flow. However, most of these systems are difficult to miniaturize, which makes difficult their integration in a microfluidic device. Moreover, they usually need complex control systems that will increase the cost of the device and, more important, due to the strong forces acting on the fluid, they can damage sensitive parts of the device (Yaralioglu et al. 2004).

A piezoelectric material integrated into the microfluidic device can be an interesting solution for overcoming the previously mentioned limitations. The application of an A.C. electrical signal to its contacts causes the generation of acoustic waves which promote the fluid motion in the direction of the acoustic propagation and attenuation, phenomenon called acoustic streaming (Riley et al. 1998). Furthermore, the use of a piezoelectric polymer, such as the poly(vinylidene fluoride) – PVDF on its electroactive β-phase, which allows its deposition by spin-coating with a specific thickness on the desired substrate, represents an advantage compared to ceramic piezoelectric materials (Harrison et al. 2001). On the other hand, due to the possibility of obtaining transparent films, it can be integrated into microfluidic devices with optical detection. The only requirement is the deposition of transparent conductive oxide (TCO), acting as electrodes. Accordingly, this work reports on a non-contact transport and mixing mechanism based on a transparent piezoelectric β-PVDF film that can be implemented in many different applications.

PROCEDURE AND RESULTS

Sample preparation

PVDF powder and DMF solvent were purchased from Solef® 110 and Merck, respectively. The solution of PVDF/DMF was prepared with a mass ratio of 20/80. The polymer was dissolved in the solvent until a homogeneous and transparent solution is obtained. Then, the thin-films were deposited by spin coating on a glass substrate. Three successive depositions were necessary for obtaining a polymer film with thickness of 25 μm. The objective is to study the influence of the post-heating both on the surface morphology of the film, which determines its porosity and transparency, and on the β-phase content, that defines the efficiency of the piezoelectric microactuator.

Identification of crystalline phases

Fig. 1 shows several Attenuated Total Reflection Fourier Transform Infrared (FTIR-ATR) spectra for the PVDF multi-layer films (after three depositions) with the last layer dried at different temperatures. The tests were performed using a FTIR Spectrum 100 with a resolution of 4 cm^{-1}.

A method introduced by Salami et al. [19] was used to calculate the fraction of β-phase present on the PVDF spectra.

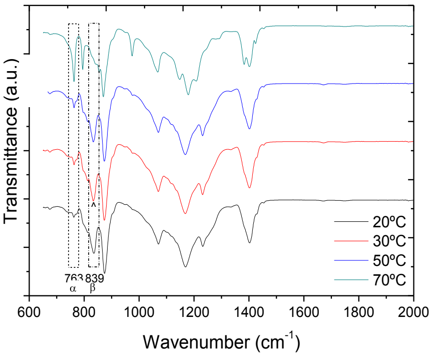


Fig. 1. FTIR-ATR spectrum of PVDF multi-layer films dried at different temperatures.

The results are shown in Table 1. During the deposition, the shear and elongation forces exercised will stretch the polymer chains, leading to preferential formation of β-phase (Ramasundaram et al. 2008). The higher the drying temperature, the faster the evaporation of the solvent and, consequently, lower the contraction of the chains which leads to the formation of α-phase. However, a higher drying temperature results also on the preferential formation of α-phase (Gregorio et al. 1999), being the film completely α at a drying temperature above 80 ºC. This latter factor shows a predominant effect, as can be seen by the obtained results.

Table. 1. Variations of the α and β-phase at different drying temperatures.

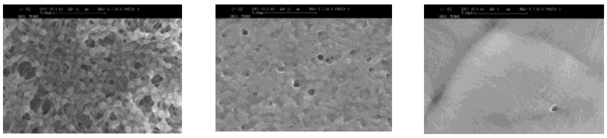
Temperature (ºC)	α-phase content (%)	β-phase content (%)	Error
20	20.7	79.3	2.8
30	26.3	73.7	2.3
50	28.7	71.3	3.6
70	80.9	19.1	1.6

Film quality

A key feature for electromechanical application is the quality of the film, including a uniform thickness and a flat and smooth surface. Moreover, achieving a transparent film largely increases its possible applications, as referred previously. Therefore, after characterizing the crystalline phase of the films, transmittance and morphology studies using a Shimadzu UV-2501 spectrophotometer and a NanoSEM-FEI Nova 200, respectively, were carried out.

For a drying temperature of 20 ºC, the obtained film was white and opaque, contrary to transparent films obtained by drying at higher temperatures. The transmittance of the films dried at 20 ºC is very low (<20%) when compared with the films dried at higher temperatures (>70%). This is due to the porosity and consequent high roughness of the film, which causes the diffuse reflection of visible light (Fig. 2(a)).

The films dried at 30ºC and 50ºC showed similar transmittance spectra and similar smooth and flat surface structures. The SEM micrographs of the film dried at 50 ºC (not shown) is very similar to the one obtained at 30 ºC (Fig. 2(b)), and shows a drastic decrease in porosity comparatively to the films dried at 20 ºC, which results in a substantial increase in the transmittance. The slight difference between the films dried at 30 ºC and 50 ºC compared to the films dried at 70 ºC is due to the thermally induced α to β phase transformation (Fig. 2(c)).



(a) (b) (c)

Fig. 2. SEM image of the PVDF multi-layer films dried at (a) 20 ºC, (b) 30 ºC, and (c) 70 ºC.

CONCLUSIONS

PVDF piezoelectric thin-films produced by spin-coating were reported. According to the results, a drying temperature of 30 ºC proved to be the most appropriate for electromechanical applications, once it allows obtaining suitable electroactive β-phase contents in combination with a high surface quality and transparency of the film.

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