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Large area microfabrication of electroactive polymeric structures based on near-field electrospinning

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Abstract
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Keywords
electrospinning, polymeric, electroactive, microfabrication, structures, near, area, field, large

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Large Area Microfabrication of Electroactive Polymeric Structures Based on Near-Field Electrospinning

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Abstract

The use of electroactive polymeric materials for sensing and actuating applications is very attractive due to important properties like low operating voltage, low form factor, or high mechanical flexibility. However, its use has been conditioned by the lack of available processing methods for such materials. The deposition of thin layers is very easy by conventional techniques; however obtaining patterned layers is not a trivial task. This paper presents a methodology suitable to fabricate electroactive polymeric microstructures on large area devices. Structures ranging from \textasciitilde1.5 mm to \textasciitilde100 μm width, with a thickness of \textasciitilde12 μm, were obtained.

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Keywords: Polymers Microfabrication; PVDF Patterning; Electroactive Sensors and Actuators; Electrospinning

1. Introduction

PVDF (Poly(vinylidene fluoride)) is an electroactive polymeric material with very interesting properties for sensing and actuating applications [1]. PVDF is transparent, flexible, can be obtained in very thin layers, and can be tailored to almost any surface geometry to work as sensor or actuator. The main problem so far, when using this material, is associated with the ability to pattern it. One method available is based on dry etching [2], which allows for patterning of such material, but only for selected conditions, like flat and rigid substrates. As well, it is not possible to use the dry etching on large areas.

In this work, a new method was developed and characterized to obtain microstructures along large areas, without the use of masks, which is based on a technique known by near-field electrospinning [3].

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2. Fabrication

The fabrication methodology was developed to allow the automatic deposition of PVDF and to form different geometries.

2.1. Fabrication setup

Figure 1-a) shows a photograph of the setup implemented to process A4 sized areas. The setup uses an X-Y table and a PVDF dispenser, both computer controlled.

![Apparatus used for PVDF fabrication](image1)

![Prototype showing the geometries fabricated with this process](image2)

Fig. 1. (a) Apparatus used for PVDF fabrication; (b) Prototype showing the geometries fabricated with this process.

The PVDF is dispensed through a metallic needle on top of a metallic layer, with the help of an electric field applied between the top needle and the bottom metallic layer. The computer controls the X-Y table speed and direction, as well the PVDF flow rate.

This process allows the fabrication of different microstructures and geometries, on very large areas, as shown in Fig. 1-b), depending only on the X-Y table dimensions.

2.2. Processing parameters

Several processing parameters influence the width and thickness of the PVDF structures. The most important that need to be controlled to achieve the desired geometries are X-Y table speed, polymer solution flow rate, voltage between the needle tip and the table, needle diameter, and the PVDF solution, namely its viscosity. After running several experiments, the values on Table 1 were obtained.

Table 1. Processing parameters used to obtain the PVDF structures.

<table>
<thead>
<tr>
<th>Fabrication parameter</th>
<th>Applied value</th>
</tr>
</thead>
<tbody>
<tr>
<td>Applied voltage</td>
<td>3.5 KV</td>
</tr>
<tr>
<td>Dispensing speed</td>
<td>2 ml/hr</td>
</tr>
<tr>
<td>Needle diameter</td>
<td>0.25 mm</td>
</tr>
<tr>
<td>Table speed</td>
<td>10 mm/s</td>
</tr>
<tr>
<td>PVDF solution</td>
<td>PVDF 15%/DMF 85%</td>
</tr>
<tr>
<td>Annealing temperature</td>
<td>10 m at 50º</td>
</tr>
</tbody>
</table>
Using the values of Table 1 as starting point, and varying them, allows the fabrication of structures with dimensions ranging from ~1.5 mm to ~100 μm width, with a thickness of ~12 μm.

3. Material Characterization

To be able to obtain the polymeric PVDF structure with the right dimensions is just the first step. Next step is to make it electroactive. That requires proper material structural characteristics.

3.1. Dimensional characteristics

The parameters of Table 1 allowed the fabrication of structures that can be as small as 100 μm wide and 12 μm thick, as shown in Fig. 2-a).

![SEM photograph of one fabricated PVDF lines. It shows that very small features can be obtained.](image)

From a structural point of view, the obtained structures are sharp and defined. Changing the fabrication parameters on Table 1, it was also possible to obtain larger structures, as shown in Fig. 2-b).

3.2. Structural characteristics

Despite showing the proper dimensions, during the first processing phase the material shows high porosity (Fig. 3-a), not allowing its electrical polarization [4]. The PVDF polarization involves the use of a high electric field applied between both faces of the sample under development. Since the sample is only 12 μm thick, the presence of holes in the material structure will lead to electric discharges between electrodes, destroying the PVDF samples. Therefore, it is not possible to obtain a piezoelectric response of a material with high porosity.

To solve this problem, an annealing procedure was used, using the temperature shown on Table 1. As can be observed in Fig. 3-b), the porosity present in Fig. 3-a) disappeared, being now possible to apply an electrical poling to orient the polymer dipoles in the direction of the electric field, maximize the dipole orientation and therefore obtain a piezoelectric response of the electroactive polymer. After poling, the obtained structures may be used as sensors or actuators.
Fig. 3. (a) SEM photograph of one sample after PVDF deposition. As can be observed, the material shows a high level of porosity, not allowing its polarization; (b) SEM image of the material morphology after annealing.

4. Conclusions

An electrospinning method was used to allow the fabrication of polymeric microstructures. Changing the process variables, this process allows the fabrication of different microstructures and geometries, as shown in Fig. 1-b), on very large areas, depending only on the X-Y table dimensions. This process may allow the development of new sensing and actuating methodologies, since it allows the fabrication of very small structures on large areas, like touch screens, or display panels.

Acknowledgements


References