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Flexible piezoelectric transducer based on electrospun PVDF nanofibers for sensing applications

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Abstract

We present the results concerning the fabrication and characterization of a piezoelectric transducer based on electrospun polyvinylidene difluoride (PVDF) nanofibers. The deposition process was optimized to obtain aligned nanofibers and to maximize the overall piezoelectric effect. The piezoelectric properties were investigated depositing the material on interdigitated metal electrodes implemented on a thin flexible substrate. In order to generate a suitable mechanical stimulation, the device was coupled to an acoustic actuator and its response was recorded at different vibration frequency and during the interaction with humidity and ethanol.

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Keywords: Piezoelectric; Nanofibers; Flexible; PVDF; Electrospinning; Transducer.

Introduction

Piezoelectric polymers are very interesting material for a new generation of applications such as wearable energy harvesting devices and sensors [1, 2]. For these reasons we have investigated a well-known piezo-polymer as polyvinylidene difluoride (PVDF) [3] to develop a piezoelectric transducer for sensing applications. To enhance the device response we have fabricated PVDF nanofibers [4] using a high performance and low cost fabrication

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technology as electrospinning [5, 6]. This technology allows to develop nanofibers from a small amount of polymer solution. In fact, during nanofibres formation the polymer undergoes to a high voltage polarization that acts as a poling process and enhance the piezoelectric properties of the material [7]. In order to study the nanofibers characteristics we have deposited the nanomaterials directly on a interdigitaded electrodes transducer (IDE) implemented on thin flexible substrate (polyimide 50 µm). The generated voltage across the electrodes has been recorded during mechanical stimulations, see Fig. 1. The bending of the flexible substrate is transferred to the fibers, generating a voltage across the electrodes with an amplitude that depends on the piezoelectric coefficient and the induced strain. The results showed a very promising behavior for the use of this transducer in the field of physical sensors such as those for proximity. Furthermore, we have investigated how the well-known interaction of PVDF with some analytes [8] induces changes on the generated voltage. In particular various measures have been carried out in environments with controlled concentrations of humidity and ethanol.

Experimental and results

The PVDF nanofibers were deposited directly on the IDE fabricated on thin flexible polyimide substrate. IDE consisted of 40 pairs of chromium/gold electrodes having a gap of 20 µm, 120 nm thick and of 20 µm width. The deposition was performed by the electrospinning technique that utilizes a high electric field to charge a polymer solution (precursor) and to draw nanofibers from it. This process does not require the use of coagulation chemistry or high temperatures to produce solid structure from solution [9]. In order to prepare the precursor solution, the methyl ethyl ketone (MEK) has been used as solvent for PVDF-TrFE (Polyvinylidene fluoride-Trifluoroetilene) pellets (by PIEZOTECH). In particular the reported results were obtained using 129.4 mg/ml PVDF–TrFE solution, 400 µm of needle diameter, 300 µl/h of feed rate, 5 kV of voltage and 10 cm of the needle-to-rotating collector distance.

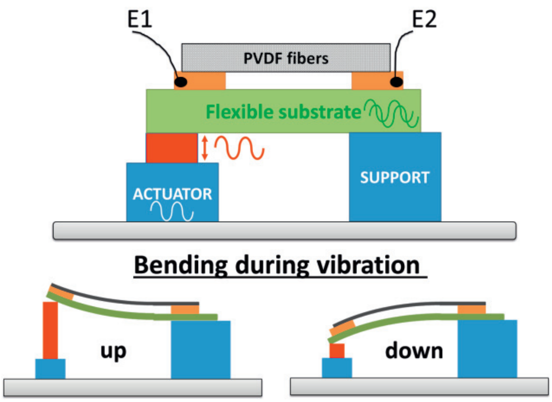

Fig. 1. Sketch of developed device based on PVDF nanofibers. Thin flexible substrate was polyimide 50 µm thick. E1, E2 are the metal(Cr/Au) electrodes (IDE) deposited on the substrate.

Figure 2a reports the AFM images of the electrospun nanofibers, having an average fiber diameter of about 500 nm, deposited on flexible polyimide substrate. During the deposition the IDE electrodes were connected to ground obtaining well aligned nanofibers across the electrodes as evidenced by Fig. 2b. The electrospinning process produces piezoelectric PVDF nanofibers with in situ mechanical stretching and electrical poling. In fact the strong applied electric fields and stretching forces naturally align dipoles in the nanofiber crystal such that the non-polar (α phase: random orientation of dipoles) is transformed into polar-phase (β), determining the polarity of the Electrospun nanofiber. It is well known that untreated PVDF must be mechanically stretched and electrically poled to obtain the β phase necessary for generating piezoelectricity [10].

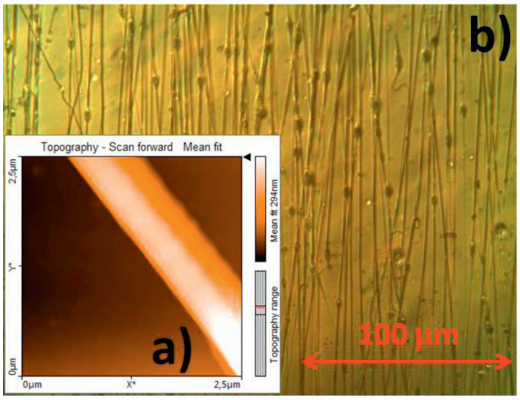

Fig. 2. (a) Atomic force microscope image of a single PVDF nanofibers performed in tapping mode. (b) Optical microphotograph of PVDF electrospun nanofibers on flexible substrate

After the deposition, an extreme of the flexible IDE transducer covered by PVDF nanofibers was fixed to a stable support whereas the other one was connected to the mobile membrane of the acoustic actuator, as depicted in Fig. 1. In this way a vertical mechanical movement of the actuator produce a substrate bending (Up and Down, see Fig. 1) and consequently a voltage across the two electrodes (E1, E2). The actuator was connected to electronic circuit able to control both the amplitude and the frequency of the mechanical stimulation. A sinusoidal movement (in vertical direction) from 100 Hz to 20000 Hz, with constant amplitude, was generated by the actuator. A typical output voltage (V_{OUT}) variations induced by a like sinusoidal movement of the actuator have been reported in Fig. 3a.

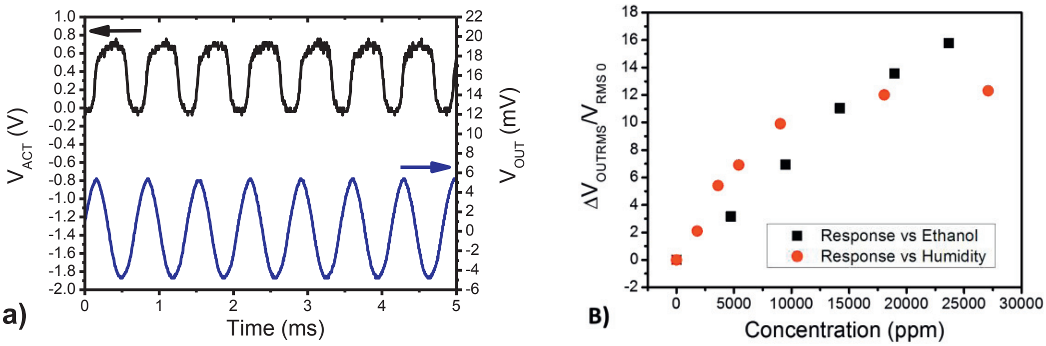

Fig. 3. (a) Voltage across the electrodes (V_{OUT}) during mechanical solicitations (V_{ACT}). In this condition the amplitude was about 8 m V_{pp}. (b) Output voltage change vs ethanol and humidity concentrations

In this case the actuating frequency was about 1450 Hz (near to the device resonance frequency). In order to test the device performances as chemical sensors, we have arranged the fabricated device (Fig.1) in a suitable chamber where it was possible to perform measures under different concentrations of humidity or ethanol. This chamber was connected to a delivering system able to change the inner chamber atmosphere. All the performed measurements were carried out in dynamic conditions using nitrogen as gas carrier (200 sccm of total flow). Figure 3b shows the device performances in terms of percentage of relative voltage changes, $\Delta V_{OUT\ RMS}$ %/$V_{RMS\ 0}$ ($V_{RMS\ 0}$ was the root mean square value of V_{OUT} measured in nitrogen atmosphere), during different humidity or ethanol concentrations.

As highlighted by Fig. 3b the measurement point outs the different PVDF sensitivity versus two kind of important analytes.

Conclusions

A transducer was developed utilizing PVDF as piezoelectric and sensing material. The device was able to detect both humidity and ethanol concentration variations at room temperature. The output measurements put in evidence that, in the case of relative humidity, a saturation phenomenon occurs for concentrations higher than 100000 ppm (about 30%). The developed device can be viewed as a new possible candidate for volatile detection.

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