Extended Abstracts of the 2018 International Conference on Solid State Devices and Materials, Tokyo, 2018, pp647-648

Sensitivity Enhancement of PVDF Nanofiber based Acoustic Sensors by Downscaling the Substrate Thickness

Md. Osman Goni Nayeem, Sunghoon Lee, Tomoyuki Yokota and Takao Someya

University of Tokyo, 7-3-1, Hongo, Bunkyo-ku, Tokyo 113-8654, Japan
Phone : +81-3-5841-6709 E-mail : nayeem3064@ntech.t.u-tokyo.ac.jp

Abstract

Here, we investigated the effect of substrate thickness on Poly (Vinylidene Fluoride) nanofiber (PVDF NF) based acoustic sensors. First, we investigated the effect of different electrospinning conditions (e.g. solution concentration, applied voltage, and pumping rate) on the formation of electrospun nanofibers to obtain high β-phase content. The electrospun PVDF NF sheet was sandwiched between two substrates with various thicknesses. The peak output voltage and sensitivity of nanofibers based acoustic sensors increased 32 mV to 661 mV and 7.2 mV/Pa to 147.7 mV/Pa respectively, when the substrate thickness decreased from 125 μm to 1.5 μm.

1. Introduction

The ability of piezoelectric materials to convert electrical energy from mechanical deformations and vice versa, attracts much attention from research community over the last few years. Especially, being Lead-free, flexible, stretchable and lightweight, polymer based piezoelectric materials such as Poly (Vinylidene Fluoride) (PVDF) and co-polymers (PVDF-TrFE, PVDF-HFP etc.) are extensively studied for mechanical energy harvesting [1-2], sensing [3-4] and developing self-powered electronics [5]. To enhance the performance of piezo devices fabrication of nanofibers by electrospinning is a common technique as it provides *in situ* stretching and poling and thereby, high piezoelectricity can be achieved [6]. Another important technique is addition of nanofillers such as nanoparticles, graphene, or carbon nanotubes etc. [7] and several groups already reported more than 90% β-phase content in Piezoelectric nanofibers. However, so far focus has been given to improve the β-phase content in Piezoelectric materials. Engineering the substrates can also affect the performance of piezoelectric transducers. Lee, B. S. *et al.* reported the effect of different substrates on piezoelectricity of sound-driven energy generators [8]. Here, we investigated the effect of substrate thickness on the performance of PVDF nanofibers based acoustic sensors. The sensitivity of acoustic sensors with 1.5 μm substrates increased 20 times compared to sensors with 125 μm substrates.

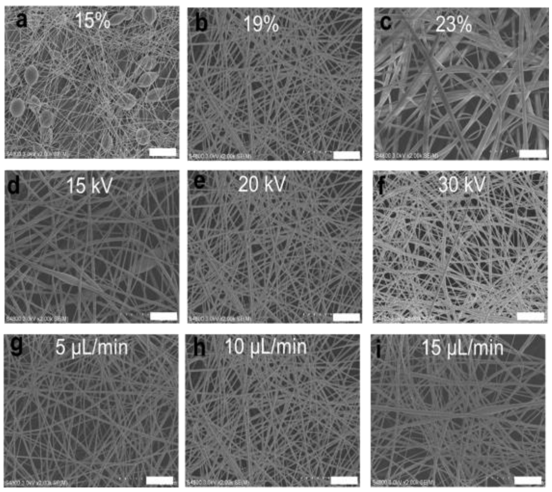

Fig.1: Optimization of PVDF nanofibers by varying electrospinning condition: a, b, c) Variation of solution concentration (20 kV, 10 μL/min); d, e, f) Variation of applied voltage (19wt%, 10 μL/min) and g, h, i) Variation of pumping rate (19 wt%, 20 kV); scale bar = 10 μm.

2. Experimental Results

Fabrication and Optimization of PVDF Nanofibers

PVDF nanofibers were fabricated by electrospinning process (Fuence, ES-2000). Firstly, PVDF pellets (M_W 275,000 gmol^{-1}, Sigma-Aldrich) were dissolved in a solvent mixture of Dimethylformamide (DMF) and Acetone with a mixing volume ratio of 4:6 and stirred at 70 ^{0}C for more than 3 h. The solution was placed in a glass syringe with a metal needle (27 gauge) and nanofibers were collected on a silicone coated paper placed on top of a grounded flat collector. The distance between metal needle tip and grounded collector was maintained to be 15 cm. Three parameters of electrospinning (solution concentration, applied voltage and pumping rate) were varied to optimize the PVDF nanofibers. The morphology of nanofibers was examined by a scanning electron microscopy (SEM). As shown in Fig. 1 (a-c), at lower concentration (constant 20 kV, 10 μL/min), fibers

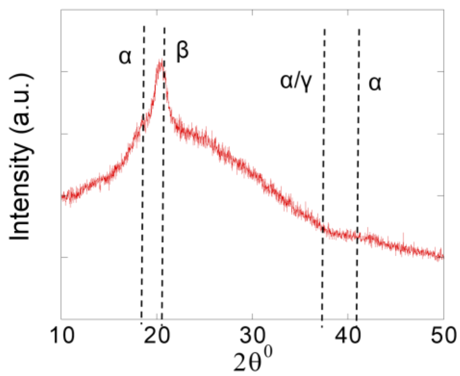

Fig.2: XRD spectra; peak at 2θ ≈ 20.2^0, which corresponds to diffraction in (110) plane and represents the β-phase [4].

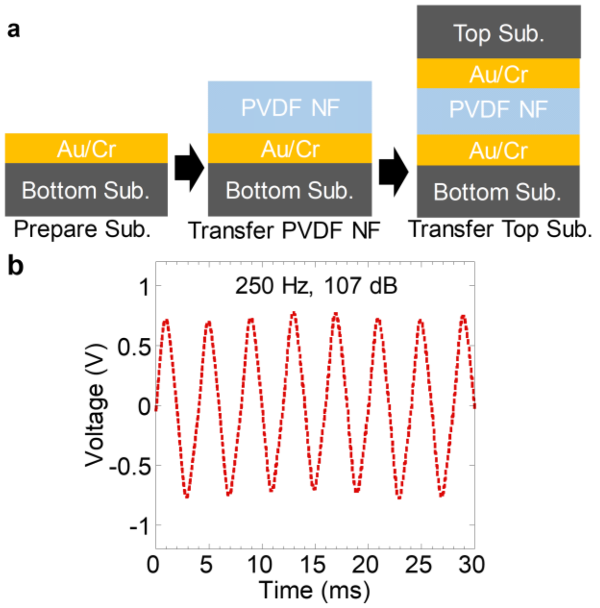

Fig. 3: a) Schematic illustration of fabrication process. The dimension of fabricated acoustic sensors was 2.5×2.5 cm^2. b) Voltage output under sound wave by acoustic sensor with 1.5 μm substrate.

contain lots of beads although the average diameter is less. With the increase of solution concentration, beads disappear but at the same time average fibers diameter increases significantly. At lower applied voltage (constant 19wt%, 10 μL/min), as shown in Fig. 1 (d-f), fibers become thicker and contain beads. With the increase of the applied voltage, fibers become thinner, but if the voltage is too high, solvents instantly evaporated and causes clogging at the needle tip. Fig. 1 (g-i) show the effect of pumping rate, where fibers diameter increase with introducing some beads in fibers. Thus, we optimized the electrospinning condition as 19 wt%, 20 kV and 10 μL/min. The XRD pattern (Fig. 2) has a very high peak at $2\theta \approx 20.2^0$, confirms the high β-phase content of our fabricated PVDF nanofibers.

Fabrication of Acoustic Sensors

Polyimide or Parylene (1.5 μm case) substrates were prepared with varying the thickness of substrates from 1.5 to 125 μm (1.5, 25, 50, 75, and 125μm). 3 nm Cr and 70 nm Au were deposited on the substrates by thermal vapor evaporation process as electrode. The acoustic sensors (area, 2.5×2.5 cm^2) were fabricated by sandwiching PVDF nanofibers layer in between two substrates (Fig 3a).

Characterization of Acoustic Sensors

To characterize sensors, a constant sound waves was applied directly to the sensors and the corresponding electrical voltage signal is measured. A high output peak-to-peak voltage of ~1.58 V was obtained (Fig. 3b), when a sound waves of 250 Hz and 107 dB was applied to a sensor with 1.5 μm substrates.

Effect of Substrate Thickness on Sensors Performance

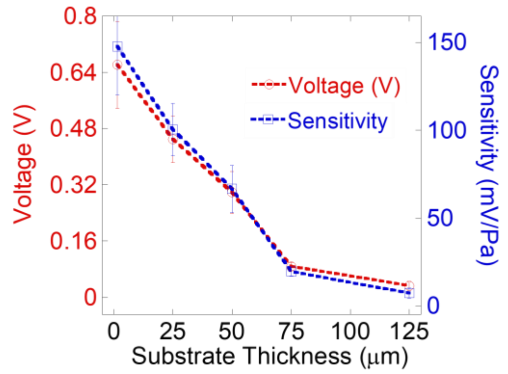

Fig. 4: Output voltage and sensitivity of acoustic sensors as a function of substrate thickness. The error bars represent the standard deviation of the test results of at least three sensors.

Figure 4 shows the voltage and sensitivity as function of the substrate thickness. Output voltage of the acoustic sensors increased from 32 mV to 661 mV with the decrease in substrate thickness from 125 μm to 1.5 μm. This was because, with the decrease in thickness, stiffness of the substrate deceases significantly, which allowed the PVDF nanofibers layer to vibrate more than in case of other thicker substrate conditions. The sensitivity (S) of the acoustic sensors was calculated by equation 1 [3].

$$S = \frac{V}{P} = \frac{V}{P_0.10^{SPL/20}} \qquad (1)$$

where P is the sound pressure, V is the voltage output of the sensors, Po is the reference sound pressure of 2×10^{-5} Pa and SPL is the sound pressure level in dB. The average sensitivity increased 20 times from 7.2 mV/Pa to 147.7 mV/Pa when substrates thickness was reduced from 125 μm to 1.5 μm.

3. Conclusions

We demonstrated PVDF nanofibers based acoustic sensors with varying substrate thickness. The output voltage and sensitivity increases significantly (20 times) when the substrate thickness is downscaled from 125 μm to 1.5 μm.

Acknowledgements

This work was supported by JSPS KAKENHI Grant Number JP817H06149. We would like to thank H. Jin, C. Okutani, and Y. Jimbo from the University of Tokyo for fruitful discussions.

References

[1] Chang C. *et. al.*, *Nano Lett.* **10,** 726–731 (2010).
[2] Cha, S. *et al.*, Nano Lett. 11, 5142–5147 (2011).
[3] Lang, C. *et. al.*, Nat. Commun. 7, 11108 (2016).
[4] Persano, L. *et. al.*, Nat. Commun. 4, 1633 (2013).
[5] Fan, F. R. *et. al.*, Adv. Mater. 28, 4283–4305 (2016)
[6] Chang, J. *et. al.* Nano Energy 1, 356–371 (2012).
[7] Liu, X. *et. al.*, RSC Adv. 6, 106690–106696 (2016).
[8] Lee, B. S. *et al.*, ACS Appl. Mater. Interfaces 6, 3520–3527 (2014).