Sensors and Actuators A 263 (2017) 633–638

Contents lists available at ScienceDirect

Sensors and Actuators A: Physical

journal homepage: www.elsevier.com/locate/sna

Poling effects on the performance of a lead-free piezoelectric nanofiber in a structural health monitoring sensor

Sang Hyun Ji [a,b], Jeong Ho Cho [a], Jong-Hoo Paik [a], Jondo Yun [b], Ji Sun Yun [a,*]

[a] Electronic Materials & Component Center, Korea Institute of Ceramic Engineering and Technology, Jinju, Republic of Korea
[b] Department of Advanced Engineering, Kyungnam University, Changwon, Republic of Korea

ARTICLE INFO

Article history:
Received 31 January 2017
Received in revised form 7 June 2017
Accepted 10 July 2017
Available online 12 July 2017

Keywords:
Lead-free piezoelectric nanofiber
Poling effects
Electrospinning
Structural health monitoring sensors
Nanofiber composites

ABSTRACT

This study investigates the poling effects on the performance of a lead-free piezoelectric nanofiber module. The lead-free piezoelectric nanofiber of $0.78Bi_{0.5}Na_{0.5}TiO_3$-$0.22SrTiO_3$ (BNT-ST) and polyvinylidenefluoride (PVDF) is prepared by an electrospinning, and the lead-free piezoelectric nanofiber modules are fabricated with the bottom and top interdigitated electrodes. The poling effects on the performance of the lead-free piezoelectric nanofiber module were investigated by XRD and temperature-dependence dielectric properties. The possibility of a flexible structural health monitoring sensor application is confirmed by measuring the output voltage of the poled and unpoled lead-free piezoelectric nanofiber modules. The flexible lead-free piezoelectric nanofiber modules are directly attached on the structure with various shapes. We expect that this system will improve the efficiency of sensing. Tests on impact detection and the structural health monitoring based on the poled and unpoled lead-free piezoelectric nanofiber modules were carried out. The monitoring results confirm the potential for estimating impact location and problems with the structure, which have been observed more obviously in the poled lead-free piezoelectric nanofiber modules.

1. Introduction

Piezoelectric materials of lead zirconate titanate (PZT) are used for a variety of actuator and sensor applications [1,2], but international environmental regulations, such as Restriction of Hazardous Substances/Waste Electrical and Electronic Equipment, call for development of lead-free alternatives. Therefore, it is necessary to develop lead-free ceramics to replace lead-based ceramics in the piezoelectric industry [3,4], and lead-free piezoelectric material ceramics is being studied by many researchers to replace the lead-based ceramics material used in electronic and electrical products. Bismuth sodium titanate (BNT) ceramic is one important candidate for lead-free piezoelectric materials because of various advantages, for example, its strong ferrelectricity at room temperature and a high Curie temperature of about 320 °C [5]. In addition, to improve strain behavior characteristics and piezoelectric properties, many researchers have proposed modification of BNT systems with various perovskite ferroelectrics, such as $BaTiO_3$ (BT) [6] and $SrTiO_3$ (ST) [7]. ST is especially able to reduce the electric field needed to obtain high strains.

Unpoled piezoelectric ceramics have low piezoelectric properties because the piezoelectric ceramic domains have a random direction. Randomly existing domains are factors that degrade the electrical properties and piezoelectric properties of piezoelectric ceramics, and many researchers have tried to improve electrical properties and piezoelectric effects by aligning the domains present in the piezoelectric ceramic. The poling process is a process of directly applying an external force (high voltage) to the piezoelectric ceramic, and the domains existing in the piezoelectric ceramic are aligned in a certain direction. The domain-aligned ceramics are polarized and the electrical and piezoelectric properties are enhanced. For bulk ceramic or thin films, it has been reported that the poling effect shows better properties [8,9], but the poling effects of the piezoelectric nanofiber have not yet been reported. For piezoelectric nanofibers produced by electrospinning, it is difficult to supply the high voltage in a certain direction because the piezoelectric nanofibers with diameters as small as about 300 nm are difficult to electrospin in a uniform direction.

In this paper, lead-free piezoelectric nanofiber modules were prepared according to our previous study [10], and high voltage was applied to the nanofiber modules for poling the piezoelectric

* Corresponding author.
E-mail address: susubin@kicet.re.kr (J.S. Yun).

http://dx.doi.org/10.1016/j.sna.2017.07.016
0924-4247/

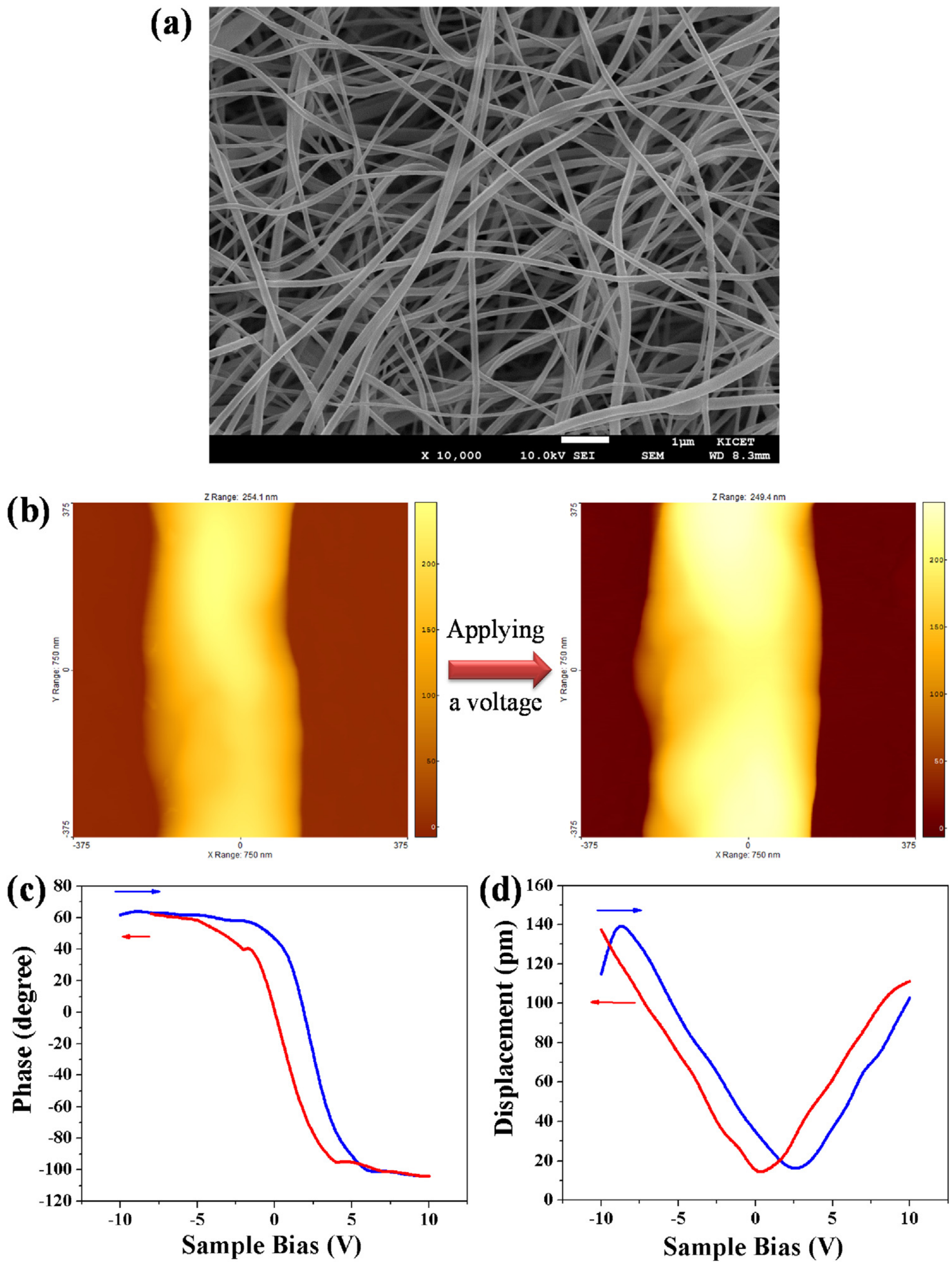

Fig. 1. (a) SEM image, (b) PFM images, (c) PFM phase hysteresis loop, and (d) amplitude hysteresis loop of the BNT-ST/PVDF nanofibers.

ceramic inside the nanofiber module. The sensor characteristics of poled and unpoled lead-free piezoelectric nanofiber modules were measured by simulating several situations for structural health monitoring sensor applications. Structural health monitoring has been extensively studied in various fields such as aerospace, construction and automobile [11]. Although bulk piezoelectric materials are typically used for these industries, bulk piezoelectric materials have limitations for integration of the sensor modules into the structures. In this regard, piezoelectric nano-structtures, such as nanowirers, nanoplates, nanofibers, and nanoparticles, have been recently studied by many researchers [12]. The proposed flexible lead-free piezoelectric nanofiber modules were directly attached to structures with various shapes, and the limitations of bulk piezoelectric materials were overcome. Furthermore, the sensing properties were improved by the poling process.

2. Experimental

Pure lead-free piezoelectric nanofiber modules were prepared according to our previous study [10]. BNT-ST ($0.78Bi_{0.5}Na_{0.5}TiO_3$-$0.22SrTiO_3$) lead-free piezoelectric ceramic powder was synthesized by a solid-state reaction using Bi_2O_3, Na_2CO_3, TiO_2 and $SrCO_3$ (purity >99.9%) supplied by Kojundo Chemical. These materials were weighted with a composition of $0.78Bi_{0.5}Na_{0.5}TiO_3$-$0.22SrTiO_3$, and the composite powder was sieved with a mesh to control the particle size of the powder at less than about 100 μm. In order to prepare the electrospinning solution, P(VDF-TrFE) copolymer powder (Measurement Specialties) with VDF 75% and TrFE 25%, DMF (dimethylformide, Sigma-Aldrich, 99.5%) and acetone (Sigma-Aldrich, 99.5%) were added sequentially. The solution weight ratio of the mixture was as follows: PVDF-TrFE:DMF: acetone = 2:5:5. The whole mixture was magnetic stirred for 24 h at room temperature to obtain a homogeneous solution. After magnetic stirring for