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Research Article

Preparation and Characterization of $PbO.ZrO_2.TiO_2$ and $SrO.ZrO_2.TiO_2$ Nanofibers by Electrospinning Method

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Abstract

Lead zirconate titanate (PZT)-based ferroelectric ceramic materials are piezoelectric materials of commercial importance. Strontium zirconate titanate (SZT) perovskite materials also have a wide application area. PZ and SZT starting solutions can be prepared using a variety of suitable methods. Among these methods, the sol-gel process has attracted special attention due to the low temperature requirement, homogeneity and the ability to obtain the appropriate particle size. The electrospinning method is the most effective and widely used method in nanofiber production. Electro-spinning is a method that enables the production of solid and hollow nanofibers in long lengths, homogeneous diameters and various compositions. When the electro-spinning technology is combined with the sol-gel method, continuous nanofibers, nanotubes and filled nanofibers are produced from polymer or ceramic solution under a certain electric field.

In this study, lead zirconate titanate (PZT) and strontium zirconate titanate (SZT) solutions containing Sr and Pb were prepared by sol-gel method. Solutions were prepared using metal salts and alkoxides as the precursor materials. The solutions obtained were fed at flow rates of 1.6, 1.8, 2.0 mL / hour and PZT and SZT nanofibers were formed by electrospinning method at 20 kV voltage rating. Different parameters of the electrospinning device were examined and the SZT and PZT nanofibers were produced with optimum properties. Crystal structure, characterization of morphological surface and chemical properties of the produced nanofibers were done with XRD, SEM and EDX, respectively. XRD results showed that the perovskite structure of PZT and SZT was not damaged during Sol-gel and electrospinning processes. A small amount of beady structure was observed in SEM analysis of PZT and SZT nanofibers. According to EDX analysis of nanofibers, it was observed that the PZT and SZT structure was also formed.

Keywords: PZT, SZT, Sol-Gel Method, Electrospinning Device.

$PbO.ZrO_2.TiO_2$ ve $SrO.ZrO_2.TiO_2$ Nanofiberlerin Elektrospinning Yöntemi ile Hazırlanması ve Karakterizasyonu

Öz

Kurşun zirkonat titanat (PZT) bazlı ferroelektrik seramik malzemeler ticari öneme sahip piezoelektrik malzemelerdir. Stronsiyum zirkonat titanat (SZT) perovskit malzemeleri de geniş bir uygulama alanına sahiptir. PZT ve SZT başlangıç çözeltileri uygun olan çeşitli yöntemler kullanılarak hazırlanabilir. Bu yöntemler arasında sol-jel işlemi, düşük sıcaklık gereksinimi, homojenlik ve uygun partikül boyutunun elde edilebilmesi nedeniyle özel ilgi görmüştür. Elektroeğirme yöntemi nanofiber üretiminde en etkin ve en yaygın kullanılan yöntemdir. Elektroeğirme, katı ve boşluklu içyapılı, uzun boylarda, homojen çapta ve çeşitli bileşimlerde nanofiber üretimi sağlayan bir yöntemdir. Elektroeğirme teknolojisi sol-jel yöntemi ile birleştirildiğinde, polimer veya seramik çözeltiden belirli bir elektrik alan altında sürekli nanofiber, nanotüp ve dolgulu nanofiber üretimi gerçekleşmektedir.

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Bu çalışmada, Sr ve Pb içeren kurşun zirkonat titanat (PZT) ve stronsiyum zirkonat titanat (SZT) çözeltileri sol-jel yöntemi ile hazırlanmıştır. Çözeltiler, öncü malzemeler olarak metal tuzları ve alkoksitler kullanılarak hazırlanmıştır. Elde edilmiş olan Çözeltiler, 1.6, 1.8, 2.0 mL / saat akış hızlarında beslenmiştir ve 20 kV voltaj değerinde PZT ve SZT nanofiberleri elektrospinning yöntemi ile oluşturulmuştur. Elektroeğirme cihazının farklı parametreleri incelenmiş ve SZT ve PZT nanofiberleri optimum özelliklerde üretilmiştir. Üretilen nanofiberlerin kristal yapısı, morfolojik yüzey karakterizasyonu ve kimyasal özellikleri sırasıyla XRD, SEM ve EDX ile yapılmıştır. XRD sonuçları Sol-jel ve elektrospinning işlemleri sırasında PZT ve SZT'nin perovskit yapısının bozulmadığını göstermiştir. PZT ve SZT nanofiberlerin SEM analizlerinde az miktarda boncuksu yapı gözlemlenmiştir. Nanofiberlerin EDX analizine göre PZT ve SZT yapısının da oluştuğu görülmüştür.

Anahtar Kelimeler: PZT, SZT, Sol-Jel Metodu, Elektroeğirme Cihazı

1. Introduction

Development and production of energy generators operating with high efficiency have been needed due to the increasing need for energy in recent years. For this purpose, scientists have carried out many studies on the development of materials with piezoelectric, ferroelectric and pyroelectric properties due to their many application areas [1-3].

When pressure is applied on materials with piezoelectric crystal properties, electricity can be easily obtained by the applied pressure effect. This effect is directly related to the change in polarization density inside the material. If the piezoelectric material is not short-circuited, the applied pressure creates a voltage in the material. Because of this reason, piezoelectric ceramics are enormous materials that can convert mechanical energy into electrical energy. Piezoelectric ceramics are used in the computer industry (inkjet printers, disc drives), automotive industry (alarms, airbag sensors, fuel jets, air flow sensors, parking sensors, seat belt alerts), medical and military systems. It also forms the basis of many scientific techniques (such as STM, AFM, MTA, SNOM, which are scanning probe microscopes) in terms of atomic dissolution [4-6].

While describing the electrical behavior of the material, it is necessary to mention the characteristics of Pyroelectric materials. Pyroelectric materials have the ability to generate a potential difference between their ends when heated or cooled. Even a small temperature change at hundreds of degrees can be detected with pyroelectric materials. For this reason, pyroelectric crystals are commonly used in under-red detectors [7-9].

Ferroelectric materials have permanent polarization by themselves without being exposed to an external electric field. This polarization can be directed by the electric field effect. Ferroelectric materials are used in the production of capacitors with adjustable load storage capacity. These capacitors consist of a ferroelectic layer placed between a pair of electrodes. Ferroelectric materials must be symmetrical in order to show piezoelectric and pyroelectric properties. The combination of piezoelectric, pyroelectric and memory features makes ferroelectric capacitors very useful for sensor applications [10-12].

Lead Zirconate Titanate ($Pb(Zr_{1-x}Ti_x)O_3$ or PZT) is an excellent ferroelectric ceramic material that has perovskite structure,. On the other hand PZT and Strontium zirconate titanate ($Sz(Zr_{1-x}Ti_x)O_3$ or SZT) nanofibers have recently been widely developed by scientists, especially because of their ferroelectric, piezoelectric and pyroelectric properties, efficiency of energy conversion, large remnant polarization and because they have many application areas [13-17]. The most widely used of these are sensors, actuators, ferroelectric memory devices, nano-generators, micro-electromechanical systems (MEMS) and converters [18-20]. On the other hand SZT ceramics have become a research subject in integrated microelectronics, microwave devices and electronic ceramics industry because of its high dielectric permeability, adjustability, low microwave loss, high breaking strength and low leakage current density [21, 22].

The electrospinning method is a simple, cost-effective and versatile process for the production of advanced fiber with varying diameters in micrometer and nanometer sizes in various fields [23-26]. Nanofibers are formed from solution or molten polymeric fluid using a high voltage electrical field.

For the polymer to be transported as fiber, it must be in liquid form or in the form of a polymer solution. The experimental setup required for the electrospinning method basically consists of three important parts as shown in Figure 1.1.

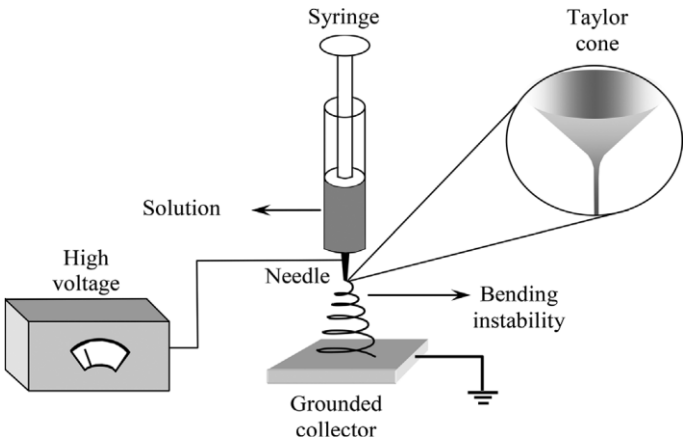

Fig. 1.1 Electrospinning experimental set-up [27].

1. High voltage power supply,

2. Feeding unit (syringe, metal needle, etc.),

3. Grounded collector (conductor plate, rotating cylinder, etc.).

The polymer and solvent are mixed at room temperature and a homogeneous polymer solution is prepared by sol-gel method. Then this solution is injected into the syringe. It is sent from the syringe to the metal needle at a constant speed using a pump. The high voltage source is turned on when the droplet takes the form of a cone at the tip of the metal needle. The polymer droplet is electrified and the induced droplet is evenly distributed

over the collector substrate surface. Many scientests used this method for the production of nanofibers.

In this study, PZT and SZT nanofibers containing Pb and Sr were prepared by sol-gel method using the electrospinning method. Solutions were prepared using metal salts and alkoxides as the precursor materials. Different parameters of the electrospinning device were examined and the SZT and PZT nanofibers were produced with optimum properties. Crystal structure, characterization of morphological surface and chemical properties of the produced nanofibers were done with XRD, SEM and EDX, respectively.

2. Material and Method

Lead zirconate titanate (PZT) and strontium zirconate titanate (SZT) nanofibers are obtained by electrospinning of sol–gel based solutions. PZT solution was prepared from lead Acetate, zirconium Oxychloride, titanium isopropoxide, and SZT solution was prepared from strontium nitrate, zirconium Oxychloride, titanium isopropoxide.

To prepare the solutions of nanofiber ($SrO.ZrO_2.TiO_2$) and nanofiber ($PbO.ZrO_2.TiO_2$), strontium nitrate, zirconium oxychloride, titanium isopropoxide, and lead acetate were choosen as precursors. Chemicals used in the experimental study are shown in Table 2.1.

Table 2.1. Chemicals Used in Experimental Study

Compound Name	Formulas	Properties
Lead acetate	$Pb(CH_3COO)_{2.3}H_2O$	Sigma, 99,9 % Mw= 379.34 g/mol
Strontium nitrate	$Sr(NO_3)_2$	Sigma, 99,995%, Mw=211.6 g/mol
Zirconium oxychloride octahydrate	$ZrOCl_{2.8}H_2O$	Sigma, 99.5%, Mw= 322,28 g/mol
Titanium isopropoxide	$Ti\{OCH(CH_3)_2\}_4$	Sigma, 99.5%, Mw=284.22 g/mol
Polyvinylpyrrolidone	$(C_6H_9NO)_n$	Sigma, M_w ~1,300,000
Absolute ethanol	CH_3CH_2OH	Sigma, 99.8%, Mw=46 g/mol

2.1. Preparation of Nanofiber Solutions ($PbO.ZrO_2.TiO_2$ and $SrO.ZrO_2.TiO_2$)

For the first step in the production of solutions of PZT nanofibers by sol-gel method, 1% of the molecular weight of lead, zirconium and titanium were taken. 5 grams of pure water was added to the Lead Acetate solution, and 3 grams of pure water to each of Zirconium Oxychloride and Titanium Alcohol solutions.

P: 379. 34 g/mol ⟶ 1% 3.79 g/mol + 5 g pure water
Z: 322.28 g/mol ⟶ 1% 1.67 g/mol + 3 g pure water
T: 284.25 g/mol ⟶ 1% 1.36 g/mol + 3 g pure water

And then, production of solutions of SZT nanofibers by sol-gel method, 1% of the molecular weight of strontium, zirconium and titanium were taken. 5 grams of pure water was added to the Strontium nitrate solution, and 3 grams of pure water to each of Zirconium Oxychloride and Titanium Alcohol solutions.

S: 211.63 g/mol ⟶ %1'i 2.11 g/mol + 5 g pure water
Z: 322.28 g/mol ⟶ %1'i 1.67 g/mol + 3 g pure water
T: 284.25 g/mol ⟶ %1'i 1.36 g/mol + 3 g pure water

The mixture was obtained by adding the two solutions into Titanium Alcohol solution. This prepared mixture solution was mixed in a magnetic stirrer at 250 rpm for 4 hours. After this process, 2g of PVP / 10ml of Ethanol were added slowly onto this solution and stirring was continued for 1 more hour. After the mixing process, the top of the beaker was covered with a watch glass and left to age for 1 day. PZT nanofibers were produced by the electrospinning method. The aged solution was drawn into a 10 ml 22 gauge plastic syringe and placed in the syringe pump. The solution was fed at 1.6, 1.8, 2.0 mL / hr flow rates and fibers were formed on aluminum foil at 20 kV voltage. PZT and SZT nanofibers formed on aluminum foil were heat treated at 1100 °C for 1 hour. One of the biggest problems encountered in nanofiber production is the loss of fibers after heat treatment. Three samples, A1, A2 and A3, were separated from the PZT solution. The same experimental steps were repeated to obtain SZT nanofibers. Thus B1, B2 and B3 samples were obtained. Table 2.2 showed that voltage and magnification values of PZT and SZT nanofibers.

Table 2.2. Voltage and magnification values of PZT and SZT nanofibers

Samples	Fibers	Voltage (kV)	Magnification (Kx)
A1	PZT	20	5.00
A2	PZT	20	10.00
A3	PZT	20	10.00
B1	SZT	20	5.00
B2	SZT	20	10.00
B3	SZT	20	10.00

Then the surface morphologies and chemical properties of group A and group B nanofibers have been analyzed in AKU Technology Application and Research Center by scanning electron microscope (SEM) and electron X-ray (EDX) measurements, respectively. The experimental steps are shown in Fig 2.1 and 2.2.

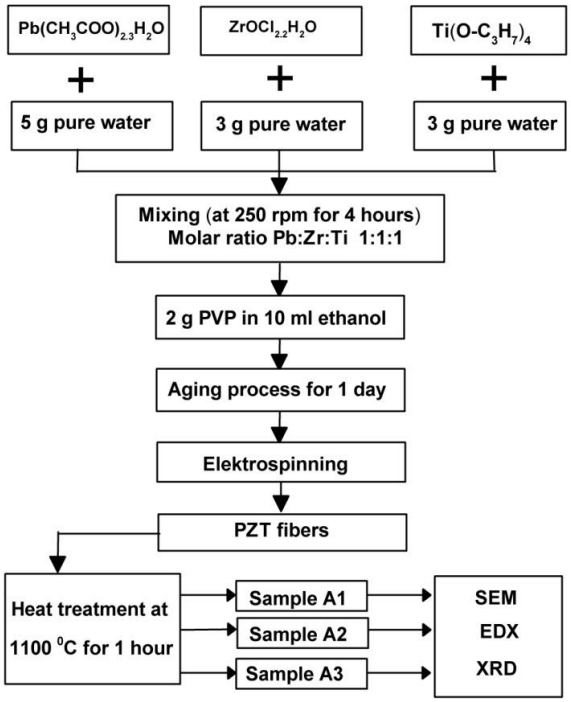

Figure 2.1 Experimental flow chart of PZT nanofibers

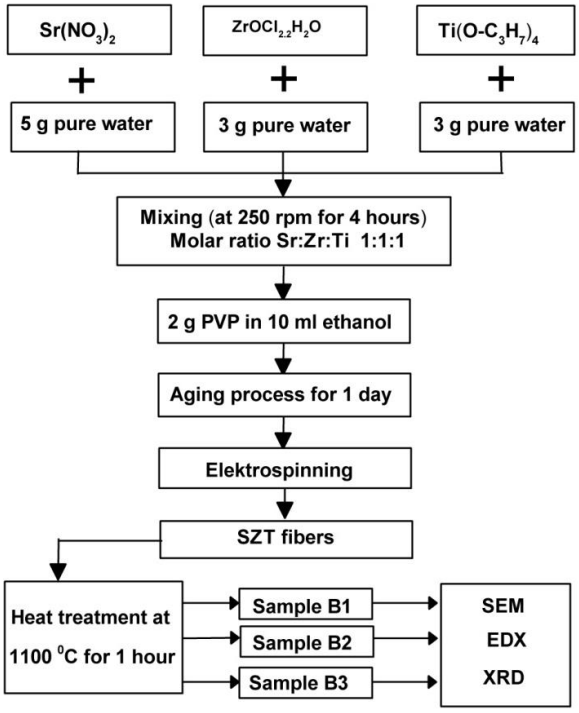

Figure 2.2 Experimental flow chart of SZT nanofibers

3. Results and Discussion

3.1. SEM Analysis of PZT Nanofibers

Figure 3.1 shows the SEM micrographs of PZT nanofibers (a)A1, (b)A2 and (c)A3. A small amount of beady structure was observed in the SEM analysis of PZT nanofibers.

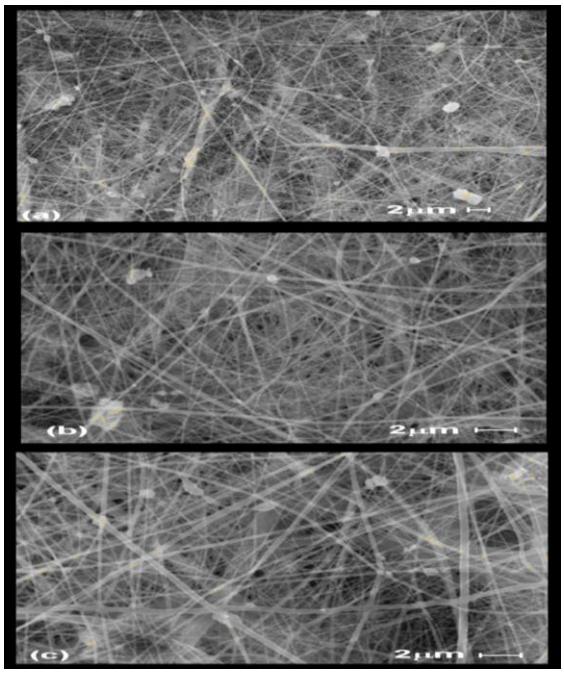

Figure 3.2. SEM Analysis of PZT Nanofibers (a)A1, (b)A2 and (c)A3.

3.2. SEM Analysis of SZT Nanofibers

SEM Analysis of SZT Nanofibers is given in Figure 3.2. A small amount of beady structure was observed in the SEM analysis of SZT nanofibers.

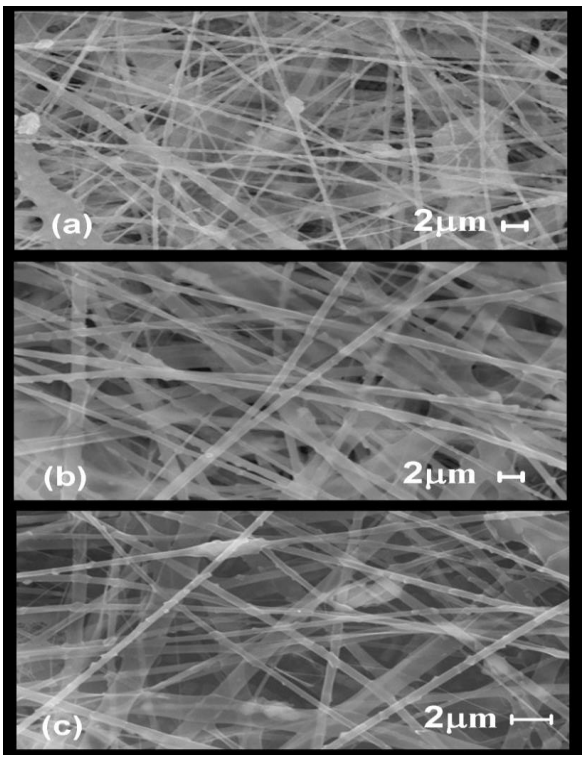

Figure 3.2. SEM Analysis of SZT Nanofibers (a)B1, (b)B2 and (c)B3.

3.3. EDX Analysis of PZT Nanofibers

Figure 3.3 shows the EDX analysis of sample A2. Results of EDX analysis of PZT nanofibers were showed that PZT

structure consisting of 9.62% titanium, 1.32% zirconium, 89.06% lead was obtained.

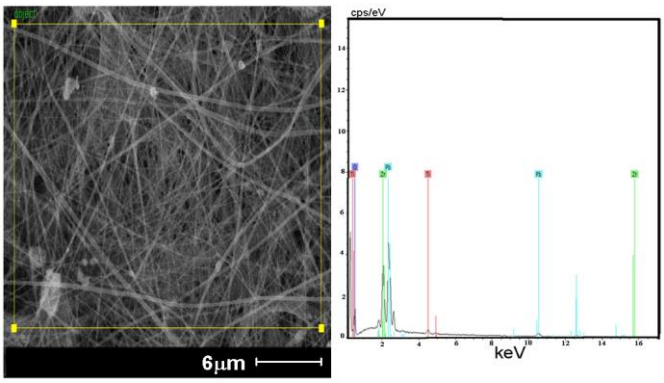

Figure 3.3. EDX Analysis of Sample A2.

3.4. EDX Analysis of SZT Nanofibers

Figure 3.4 shows the EDX analysis of sample B2. According to the EDX analysis of SZT nanofibers, it was observed that the SZT structure was also formed.

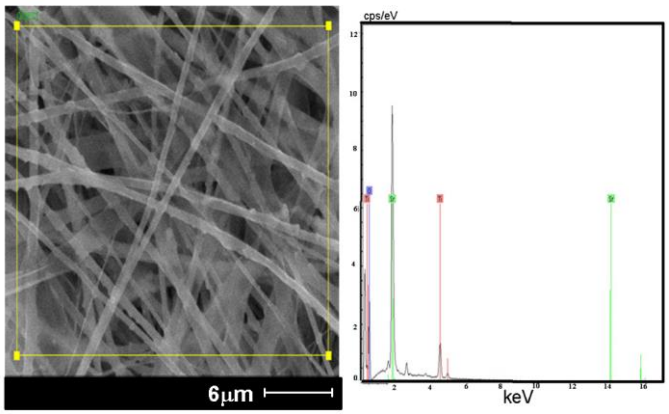

Figure 3.4. EDX Analysis of Sample B2.

3.5. Diameter Analysis of PZT Nanofibers

SEM and diameter analysis of PZT nanofibers are given in Fig. 3.5 (a)A1, (b)A2 and (c)A3 respectively. As a result of the removal of all impurities from the fiber structure after heat treatment, some decrease in the diameter of the fibers was observed.

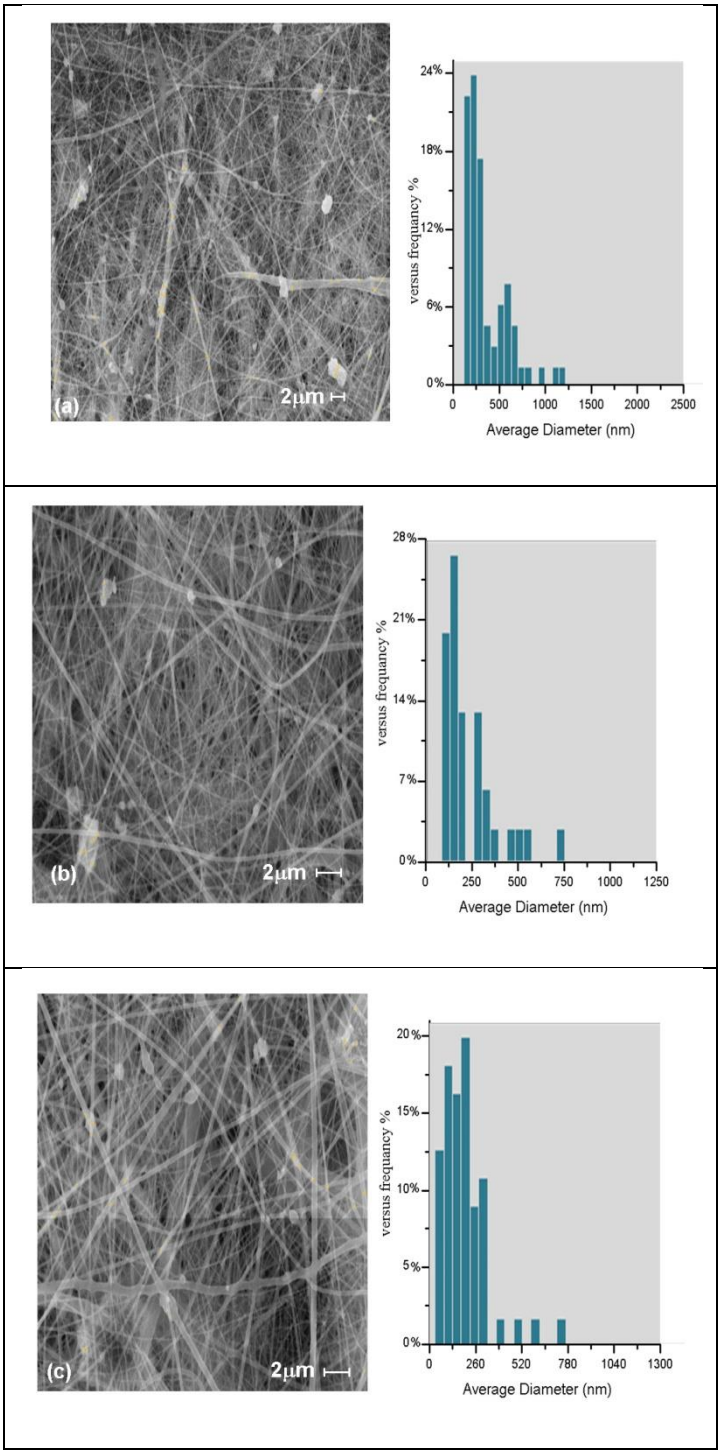

Figure 3.5. Diameter Analysis of PZT Nanofibers (a)A1, (b)A2 and (c)A3.

3.6. Diameter Analysis of SZT Nanofibers

SEM and diameter analysis of SZT nanofibers are given in Fig. 3.6 (a)B1, (b)B2 and (c)B3 respectively. As seen in Mophology and average diameters, all SZT nanofiber samples are in the form of uniform fibers, but their diameters differ. As a result of the removal of all impurities from the fiber structure after heat treatment, some decrease in the diameter of the fibers was observed.

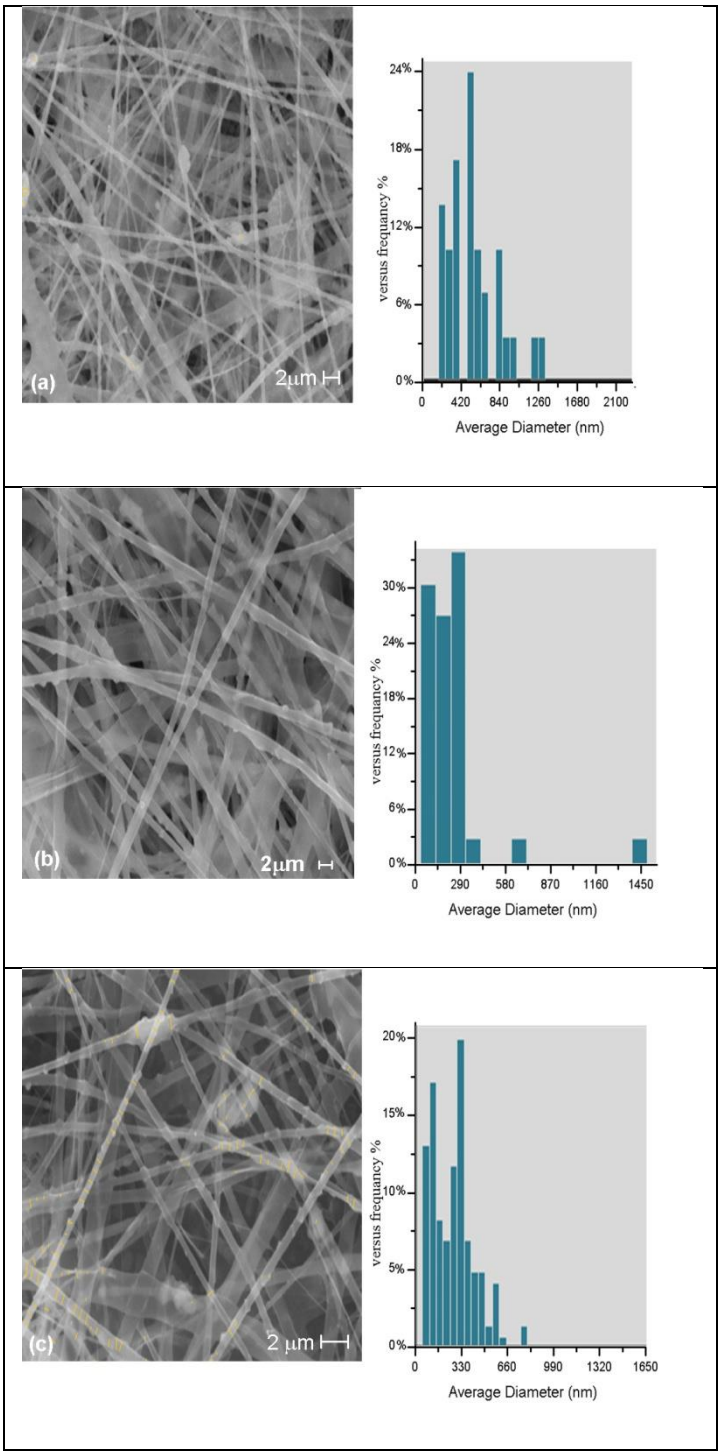

Figure 3.6. Diameter Analysis of SZT Nanofibers (a)B1, (b)B2 and (c)B3.

3.6. XRD Analysis of PZT and SZT Nanofibers

XRD patterns of the A2 and B2 electrospun fibers sintered at 1100 °C for 1 hour are seen in Fig. 3.7. As seen from Fig 3.7, XRD patterns showed that well-defined peaks, indicating crystallinity and phase formation of synthesized compounds. Perovskite structure of PZT and SZT is undisturbed during of sol-gel and electrospinning process.

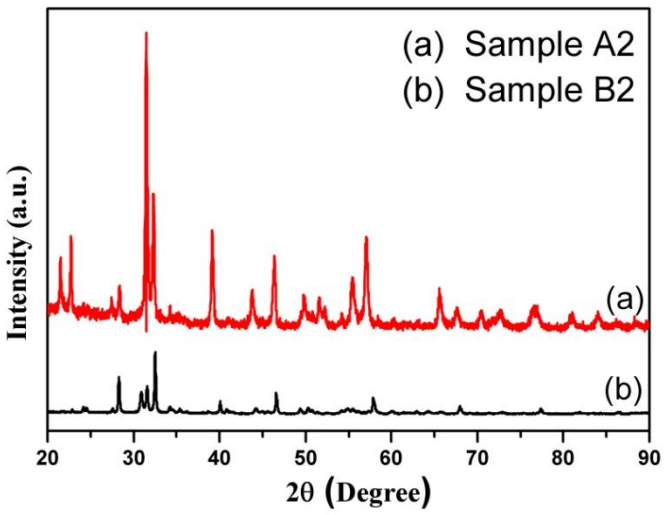

Figure 3.7. XRD patterns of nanofibers of (a) Sample A2 (b) Sample B2.

4. Conclusions and Recommendations

In this study, PZT and SZT nanofibers have been successfully obtained via by electrospinning method and positive results were obtained. The produced PZT and SZT nanofibers were calcined at 1100 ° C for 1 hour. A small amount of beady structure was observed in the SEM analysis of PZT and SZT nanofibers. As a result of the removal of all impurities from the fiber structure after heat treatment, some decrease in the diameter of the fibers was observed.

Results of EDX analysis of PZT nanofibers were showed that PZT structure consisting of 9.62% titanium, 1.32% zirconium, 89.06% lead was obtained. According to the EDX analysis of SZT nanofibers, it was observed that the SZT structure was also formed. As a result of the EDX analysis, SZT structure consisting of 9.62% Titanium, 1.32% Zirconium and 89.06% Strontium was obtained. According to XRD patterns, a complete formation of PZT and SZT perovskite structure was obtained at sintering temperature of 1100 °C for 1 hour.

Acknowledgement

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References

[1] Chamankar, N., Khajavi, R., Yousefi, A. A., saeid Rashidi, A., & Golestanifard, F. (2019). Comparing the piezo, pyro and dielectric properties of PZT particles synthesized by sol–gel and electrospinning methods. *Journal of Materials Science: Materials in Electronics*, *30*(9), 8721-8735.

[2] Berlincourt, D. (1976). Current developments in piezoelectric applications of ferroelectrics. *Ferroelectrics*, *10*(1), 111-119.

[3] Khajelakzay, M., & Taheri-Nassaj, E. (2012). Synthesis and characterization of PB (ZR0. 52, TI0. 48) O3 nanofibers by

electrospinning, and dielectric properties of PZT-Resin composite. *Materials Letters*, *75*, 61-64.

[4] Qiao, X., Geng, W., Sun, Y., Yu, J., Chen, X., Yang, Y., ... & Chou, X. (2020). Preparation of high piezoelectric and flexible polyvinylidene fluoride nanofibers via lead zirconium titanate doping. *Ceramics International*, *46*(18), 28735-28741.

[5] Ramsay, M. J., & Clark, W. W. (2001, June). Piezoelectric energy harvesting for bio-MEMS applications. In *Smart Structures and Materials 2001: Industrial and Commercial Applications of Smart Structures Technologies* (Vol. 4332, pp. 429-438). International Society for Optics and Photonics.

[6] Kornmann, X., & Huber, C. (2004). Microstructure and mechanical properties of PZT fibres. *Journal of the European Ceramic Society*, *24*(7), 1987-1991.

[7] Whatmore, R. W. (1991). Pyroelectric ceramics and devices for thermal infra-red detection and imaging. *Ferroelectrics*, *118*(1), 241-259.

[8] Whatmore, R. W. (2004). Pyroelectric arrays: ceramics and thin films. *Journal of electroceramics*, *13*(1-3), 139-147.

[9] Guggilla, P., Batra, A. K., Currie, J. R., Aggarwal, M. D., Alim, M. A., & Lal, R. B. (2006). Pyroelectric ceramics for infrared detection applications. *Materials Letters*, *60*(16), 1937-1942.

[10] Izyumskaya, N., Alivov, Y. I., Cho, S. J., Morkoç, H., Lee, H., & Kang, Y. S. (2007). Processing, structure, properties, and applications of PZT thin films. *Critical reviews in solid state and materials sciences*, *32*(3-4), 111-202.

[11] Watton, R. (1989). Ferroelectric materials and devices in infrared detection and imaging. *Ferroelectrics*, *91*(1), 87-108.

[12] Lynch, C. S., Yang, W., Collier, L., Suo, Z., & McMeeking, R. M. (1995). Electric field induced cracking in ferroelectric ceramics. *Ferroelectrics*, *166*(1), 11-30.

[13] McKnight, R. E., Kennedy, B. J., Zhou, Q., & Carpenter, M. A. (2008). Elastic anomalies associated with transformation sequences in perovskites: II. The strontium zirconate–titanate Sr (Zr, Ti) O3 solid solution series. *Journal of Physics: Condensed Matter*, *21*(1), 015902.

[14] Chen, X., Li, A., Yao, N., & Shi, Y. (2011). Adjustable stiffness of individual piezoelectric nanofibers by electron beam polarization. *Applied Physics Letters*, *99*(19), 193102.

[15] Yu, Y., & Singh, R. N. (2000). Effect of composition and temperature on field-induced properties in the lead strontium zirconate titanate system. *Journal of Applied Physics*, *88*(12), 7249-7257.

[16] Yu, Y., Tu, J., & Singh, R. N. (2001). Phase stability and ferroelectric properties of lead strontium zirconate titanate ceramics. *Journal of the American Ceramic Society*, *84*(2), 333-40.

[17] Shende, R. V., Krueger, D. S., Rossetti, G. A., & Lombardo, S. J. (2001). Strontium zirconate and strontium titanate ceramics for high-voltage applications: synthesis, processing, and dielectric properties. *Journal of the American Ceramic Society*, *84*(7), 1648-1650.

[18] Chen, X., Xu, S., Yao, N., & Shi, Y. (2010). 1.6 V nanogenerator for mechanical energy harvesting using PZT nanofibers. *Nano letters*, *10*(6), 2133-2137.

[19] Dong, Z., Kennedy, S. J., & Wu, Y. (2011). Electrospinning materials for energy-related applications and devices. *Journal of Power Sources*, *196*(11), 4886-4904.

[20] Hsu, Y. C., Wu, C. C., Lee, C. C., Cao, G. Z., & Shen, I. Y. (2004). Demonstration and characterization of PZT thin-film sensors and actuators for meso-and micro-structures. *Sensors and Actuators A: Physical*, *116*(3), 369-377.

[21] Zhao, J., Wu, X., Li, L., & Li, X. (2004). Preparation and electrical properties of SrTiO3 ceramics doped with M2O3–PbO–CuO. *Solid-state electronics*, *48*(12), 2287-2291.

[22] Parida, S., & Rout, S. K. (2017). Effect of zirconia on the structural and optical properties of strontium titanate ceramic. *Ferroelectrics*, *517*(1), 81-89.

[23] Yun, J. S., Park, C. K., Jeong, Y. H., Cho, J. H., Paik, J. H., Yoon, S. H., & Hwang, K. R. (2016). The fabrication and characterization of piezoelectric PZT/PVDF electrospun nanofiber composites. *Nanomaterials and Nanotechnology*, *6*, 20.

[24] Gevorkyan, A., Shter, G. E., Shmueli, Y., Buk, A., Meir, R., & Grader, G. S. (2014). Branching effect and morphology control in electrospun PbZr0. 52Ti0. 48O3 nanofibers. *Journal of Materials Research*, *29*(16), 1721.

[25] Abd Razak, S. I., Wahab, I. F., Fadil, F., Dahli, F. N., Md Khudzari, A. Z., & Adeli, H. (2015). A review of electrospun conductive polyaniline based nanofiber composites and blends: processing features, applications, and future directions. *Advances in Materials Science and Engineering*, *2015*.

[26] Ponhan, W., & Maensiri, S. (2009). Fabrication and magnetic properties of electrospun copper ferrite (CuFe2O4) nanofibers. *Solid State Sciences*, *11*(2), 479-484.

[27] Evcin, A., Bezir, N. Ç., Kayalı, R., Arı, M., & Kepekçi, D. B. (2014). Indium phosphide nanofibers prepared by electrospinning method: Synthesis and characterization. *Crystal Research and Technology*, *49*(5), 303-308.