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Lead-Free BCZT-PDMS Piezoelectric Energy Harvester

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ABSTRACT

This article presents the synthesis and characterisation of lead-free BCZT ($Ba_{0.85}Ca_{0.15}Ti_{0.9}Zr_{0.1}O_3$) nanopowder produced by the solid-state reaction technique, employing between four to five cycles of grounding to enhance crystallinity. X-ray diffraction (XRD) and field emission scanning electron microscopy (FESEM) verified that grounding the materials five times yielded a highly crystalline BCZT with a cubic perovskite structure. The BCZT powder was filled into a polydimethylsiloxane (PDMS) matrix at different weight percentages (1%, 3%, 5%, and 10%) to investigate the performance in terms of piezoelectric coefficient and generated voltage. The BCZT-PDMS composites displayed an amorphous form attributable to the polymer matrix. While preserving the functional piezoelectric characteristics of the ceramic filler, the result shows that the 10% wt sample exhibits a higher d_{33} measurement with 45 pC/N, which increased approximately 50% compared to 5% wt. Furthermore, the performance was assessed using d_{33} measurements and voltage production during mechanical excitation, utilising a solenoid with a constant force of 2 N and a frequency of 10 Hz. The findings indicated that the piezoelectric generates voltage well with BCZT-PDMS composite with 10 wt%, yielding a maximum output voltage of 8 V. Finally, the capability of BCZT-PDMS to harvest energy has been presented in this paper.

Keywords: *BCZT-PDMS, piezoelectric coefficient, solenoid tapping technique, energy harvester*

1. INTRODUCTION

Piezoelectric materials are essential in contemporary technology, facilitating applications in sensors, actuators, and energy harvesting devices by converting mechanical stress into electrical energy [1]. Lead-based materials, such as lead zirconate titanate (PZT), have long been used for the outstanding piezoelectric properties, which combine endurance, high piezoelectric coefficients, and thermal stability [2]. However, the environmental and health risks resulting from lead, particularly its toxicity and the possibility of contamination during production, consumption, and disposal, have encouraged research and investigation of safer, lead-free alternatives.

Given the environmental concerns with lead-based piezoelectric materials, significant research efforts have been directed toward discovering lead-free alternatives with equivalent performance. Barium Titanate ($BaTiO_3$) has been widely explored for its outstanding piezoelectric and dielectric properties. It is recognized for achieving one of the highest sensing voltages among lead-free materials [3]. $BaTiO_3$ outperformed ZnO and BNN in terms of mechanical stress, which at 6.09 MN/m^2 at 140 Hz, while the electric potential is 12.2 V, and power dissipation is at 1.86 mW at 100 Hz [4]. Its exceptional energy harvesting capability is primarily attributed to its high piezoelectric coefficients and dielectric constant, which improve its efficiency in converting mechanical energy into electrical energy [5]. The d_{33} coefficient, a piezoelectric charge coefficient, is frequently employed to assess material performance, as it measures the electric charge produced per unit of mechanical stress applied along the same axis, represented in picoCoulombs per Newton (pC/N).

$BaTiO_3$ has significant advantages in piezoelectric capabilities, yet it experiences enhanced crystallite growth at elevated temperatures, making it particularly appropriate for applications requiring larger crystalline structures. Additionally, Barium Calcium Zirconate Titanate (BCZT) demonstrates a reduced crystalline size at increased calcination temperatures. The characteristics of BCZT offer a significant benefit for applications requiring smaller crystalline sizes, as these small crystals can improve certain mechanical and electrical properties by increasing material homogeneity and reducing flaws [6]. The combination of Ca^{2+} and Zr^{4+} into BaTiO3 enhanced energy harvesting efficiency, illustrating the advantages of A-site and B-site doping inside the perovskite structure, so transforming it into BCZT.. Furthermore, BCZT exhibits significant promise as a lead-free material for flexible nanogenerators, yielding superior output voltage and power density relative to traditional $BaTiO_3$ and BZT [7][8]. A polymer matrix was integrated into the BCZT composite to enhance its mechanical flexibility. Polydimethylsiloxane (PDMS) is widely used as the polymer matrix due to its outstanding flexibility, chemical stability, and biocompatibility [9]. The introduction of microelectrodes into the composite gives exceptional mechanical endurance, allowing the material to bend, twist, or fold without experiencing structural damage [10]. The BCZT–PDMS composite has shown efficient energy harvesting from biomechanical activities, including walking and finger tapping, producing output voltages of around 16.8 V during walking excitation testing. This signifies that flexible and wearable devices are crucial for biological applications [11]. While BCZT-based ceramics have attracted significant attention as lead-free substitutes for traditional piezoelectric materials, there is a limitation of information regarding their compatibility with flexible polymer matrices like PDMS, especially in applications with low filler content. Prior research has primarily concentrated on solid state materials, which frequently decrease flexibility and mechanical endurance, or on composites with elevated ceramic content, usually beyond 15% which could limit elasticity and uniform distribution. The influence of ceramic grounding cycles on crystalline structure and subsequent piezoelectric performance remains inadequately investigated. Moreover, whereas PDMS has exceptional mechanical flexibility, its interaction with varying concentrations of BCZT filler and the consequent effects on electrical output remain insufficiently explored.

This study fabricated BCZT ceramic powder via the solid-state reaction method. This approach has considerable benefits because of its simplicity and cost efficiency, facilitating uncomplicated processing with standard apparatus such as a marble mortar and furnace for mixing, grinding, and calcination. The solid state fabrication of BCZT powder produces materials with significant mechanical integrity and a stable crystalline structure, making that appropriate for energy harvesting applications that require enduring performance. The quantity of grinding cycles is essential for enhancing the crystallinity of BCZT powder; an increase in grinding frequency leads to more distinct XRD peaks and a more homogeneous grain shape, thus strengthening piezoelectric capabilities. Additionally, PDMS was utilised as the polymer matrix because of its outstanding flexibility and biocompatibility.
The objective of this research is to study the properties of BCZT powder and the BCZT-PDMS composite. To analyse the effectiveness of the BCZT-PDMS for energy harvesting. This study presents a novel method for enhancing the crystallinity of BCZT ceramic with several grinding cycles, followed by the integration of the refined powder into a PDMS matrix at low weight fractions of 1% to 10%. The efficiency of the BCZT-PDMS composites is assessed by performing biomechanical activities through a solenoid-based tapping mechanism to evaluate the piezoelectric energy harvesting potential.

2. METHODS AND MATERIAL

This project focuses on the development of flexible lead-free piezoelectric material using BCZT as the piezoelectric component. To enhance the material's flexibility, PDMS is combined with BCZT powder. The research includes the fabrication of BCZT powder, the preparation of the BCZT–PDMS composite, and analysis of the piezoelectric samples regarding the composite structure and output voltage performance. These methods are carefully executed to guarantee that the final material possesses both advantageous piezoelectric characteristics and mechanical flexibility, making it appropriate for energy harvesting applications. The methodology includes precise control over the material and testing preparation, ensuring consistent sample characteristics for testing and evaluation. Each step in the fabrication is carefully explained to ensure the final product can be produced without any mistakes and to ensure the quality of the product. The BCZT ceramics powder consists of Barium Carbonate ($BaCO_3$), Calcium Carbonate ($CaCO_3$), Zirconium (IV) Oxide (ZrO_2), and Titanium (IV) Oxide (TiO_2) from Sigma Aldrich (St. Louis, Missouri, United States) composite was weighed using a stoichiometric composition of $Ba_{0.85}Ca_{0.15}Zr_{0.1}Ti_{0.9}$. Then, the composites are mixed and poured into a mortar for the grounding process. A small amount of acetone is used to mix the composite until a uniform BCZT ceramic powder is synthesized. The ceramics powder is then heated at 80^0C for 15minutes to remove the residual moisture from the ceramics powder and make sure it is thoroughly dried. Based on a previous study, the repeatable grounding process is needed to get the fine crystal structure of BCZT [6]. The grounding and drying process is repeated four and five times to achieve homogeneity in the material. Lastly, the dried ceramics powder is poured into a crucible to be calcined by heating again at 1200^0C for 5 hours. The temperature of 1200^0C is used since it is an optimum temperature for BCZT ceramics powder to crystallize [6]. The BCZT sample was then synthesized for material properties using X-ray Diffraction (XRD) (RIGAKU/D/MAX-2000/PC, Akishima, Tokyo, Japan) and FESEM(JEOL, JSM-7600F, Akishima, Tokyo, Japan) to observe the crystalline and surface morphology.

Then, the PDMS solution serves as a polymer matrix to enhance the flexibility of the BCZT ceramic powder. To fabricate the BCZT-PDMS composite, BCZT ceramic powder is weighed to the desired weight percentage, from 1%, 3 %, 5% and 10% as depicted in Figure 1 (b). Based on previous studies, the optimum performance is observed at 15%, with the test being made between 10% and 20%. Therefore, in this research, the weight percentage was intentionally kept below 15% [12]. These percentages are calculated based on the weight of the PDMS solution. Then, the PDMS solution and its bonding agent (silicone elastomer curing agent) were weighed in a 10:1 ratio. The reason a bonding agent is added to the PDMS solution is to enable the hardening process to transform the PDMS solution into a solid and flexible material. After that, the BCZT powder that has been weighed according to the wanted percentage, added to the PDMS solution and mixed vigorously to ensure even distribution. To eliminate the air in the mixed solution, the mixture was put into a vacuum chamber for 15 minutes. Lastly, the solution is cured by heating the mixture in the furnace for 45 minutes to produce a BCZT-PDMS thin film. The thin film cools down to room temperature before peeling off the BCZT-PDMS sample from the petri dish.

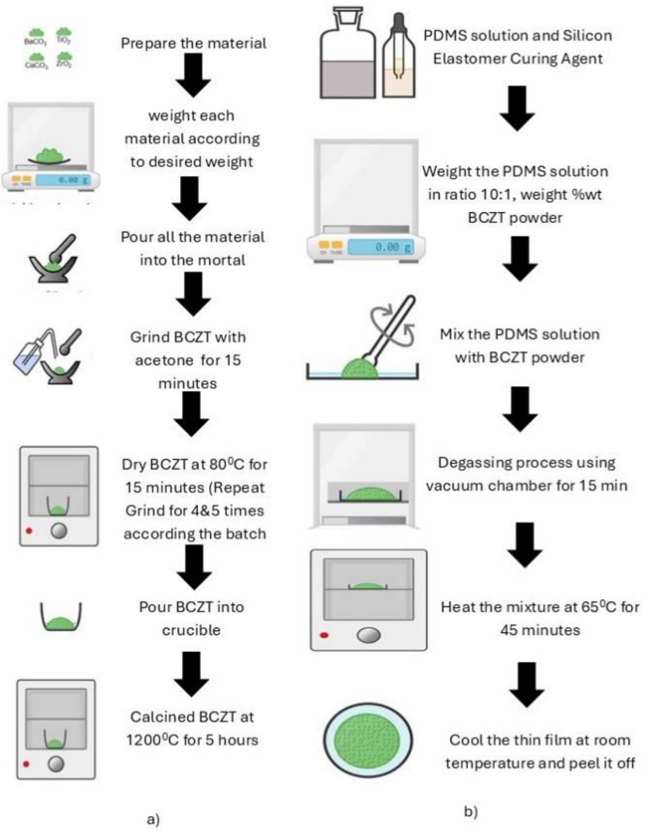

Figure 1. The fabrication process, a) BCZT fabrication, b) BCZT-PDMS thin film fabrication.

The BCZT-PDMS composite requires conductive components such as copper tape and jumper wires to exhibit the electrical charge. The preparation of the sample for the testing process is shown in Figure 2. The sample preparation begins by cutting the BCZT-PDMS thin films into 2 cm x 1 cm sizing. Then, the copper tape is attached to the samples. A 2 cm x 1 cm copper tape is attached to the top, which indicates the positive side of the sample, while a 1cm x 1cm copper tape is attached at the bottom to indicate the negative side of the sample. Copper wires are then connected to both sides of the samples to ensure proper electrical contact. Lastly, the sample is sealed with a plastic cover and tape to secure it.

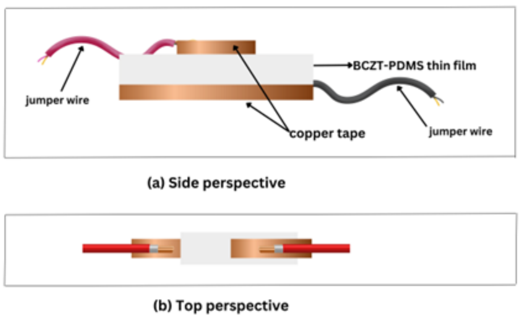

Figure 2. The device consists of a BCZT-PDMS composite thin film placed between two copper tape electrodes.

2.1. Piezoelectric Coefficient

The piezoelectric coefficient (d_{33}) has been constructed using a d_{33} meter to evaluate the performance of BCZT-PDMS composite through the integration of mechanical force and precise electrical measurement. Firstly, the sample is properly positioned between the upper and lower probes of the testing equipment to ensure a constant pressure application on the sample. The applied force can be controlled using the force head, while for precise measurement of the mechanical force exerted can be adjusted using the knob. The mechanical energy generated by the pressure applied can lead to the production of electrical charges in the piezoelectric material. The upper and lower probes function as electrodes to capture the electrical charge generated by the samples. The undesired noise will be filtered by applying the signal conditioning to the electrical signal; therefore, the processed data is accurate and appropriate for analysis. The data was subsequently transmitted to the readout chassis, where the piezoelectric coefficient results were calculated and displayed in picoCoulombs per Newtons (pC/N), allowing direct observation for analysis. The experiment is conducted again for the samples with 1%, 5%, and 10% weight percentage of BCZT. Based on the previous study, the optimal percentage was found to be 15% [12].

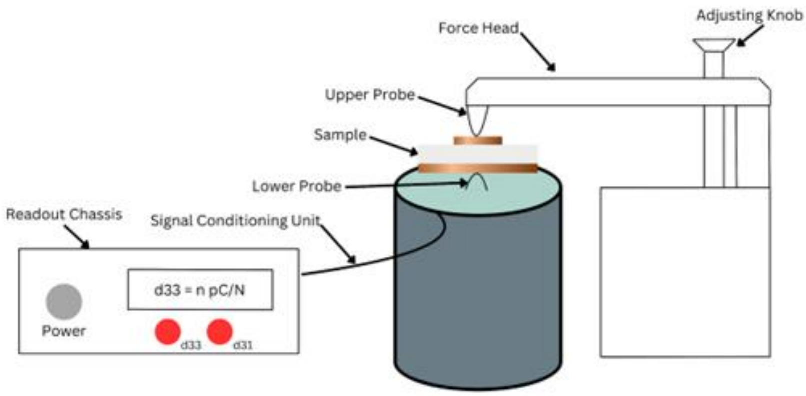

Figure 3. Piezoelectric Coefficient Testing Set up.

2.2. Voltage Output

To evaluate the piezoelectric performance, experiments were conducted using solenoids that operated at a fixed frequency and applied force. In that setup, the solenoid was used as a tapping mechanism, generating a mechanical force of 2 N at a frequency of 10 Hz, resulting in a displacement of about 2 mm and an actuation period of 50 ms each cycle. This controlled periodic impact was applied constantly to simulate mechanical stress conditions for assessing energy harvesting performance, as shown in Figure 4. Oscilloscope (KEYSIGHT/DSOX2022A, Santa Rosa, California, U.S)

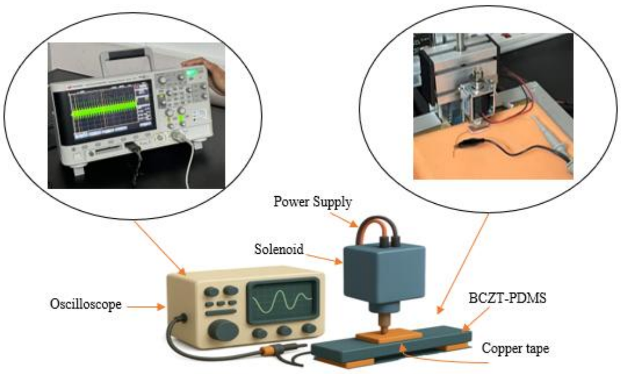

Figure 4. Characterisation setup.

3. RESULTS AND DISCUSSION

The atomic structure, phase purity, and quality of fabricated BCZT ceramic powder can be determined by X-Ray Diffraction (XRD) analysis. The pattern shown in Figure 5 demonstrates the comparison between four to five times ground process, which shows the sharp and well-defined peaks of the synthesized BCZT powder, indicating the BCZT powder is well-synthesized. The BCZT powder possesses a high crystalline structure due to the presence of high intensity peaks at 2-theta values, particularly the prominent peak at approximately 32^0 shows that the cubic crystal structure of BCZT was formed in the calcination temperatures of 1100°C, and the diffraction peaks match the patterns expected for perovskite structures, which represent the crystal structure of BCZT ceramics [6]. Figure 5 presents the diffraction pattern of the sample ground five times, exhibiting significantly sharper and more intense peaks compared to the sample subjected to four grounding cycles. This indicates that the higher number grounded process possesses a higher crystal structure and a well-defined crystal structure. Perovskite structure exhibits high phase purity, with no additional or unexpected peaks, indicating that the sample is solely BCZT with minimal impurities. The crystallite size of BCZT was determined using the Scherrer equation based on the XRD peaks at 2θ = 31.500° for the sample ground five times, and at 2θ = 31.440° for the sample ground four times. The results indicate an approximate size of 263 Å = 26.3 nm for the five-time ground sample, and 304 Å =30.4 nm for the four-time ground sample. This nanometric grain size is indicative of fine crystallite formation, which is desirable in piezoelectric ceramics for enhanced electromechanical properties. A quantitative comparison of peak broadening was performed via Full Width at Half Maximum (FWHM) analysis. The FWHM of the main peak for BCZT ground was found to be lower than that of BCZT ground four times, which is 0.298^0 and $0.342^{0,}$ suggesting a relatively larger crystallite size and/or lower micro strain in the five times ground sample. Observation indicates improved crystallinity, which could lead to better ferroelectric and piezoelectric properties. The narrowing of peaks in the XRD profile suggests that the reaction conditions are optimum for uniform grain development and well-defined phase formation. Impurities, on the other hand, might disturb the crystal structure and reduce the total piezoelectric response, so reducing these qualities. Since the capability of converting mechanical energy to electrical energy is dependent upon the crystallinity of BCZT, a high-crystallinity structure facilitates better interaction with the polymer in the composite, thereby enhancing the performance of the BCZT-PDMS composite in energy harvesting applications. The XRD pattern proves the results align with the expected properties of BCZT materials, hence validating the effectiveness of the synthesis process in producing the crystalline material.

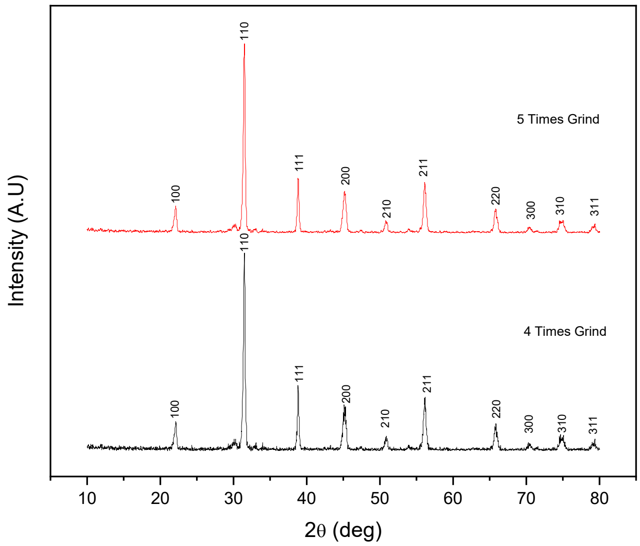

Figure 5. XRD comparison results between the five-times and the four-times ground process for BCZT powder.

The surface morphology, microstructure, and topography of materials with high resolution of BCZT powder are characterized using by characterization technique. Field emission scanning electron microscopy (FESEM) is utilized to ascertain these characteristics of the materials. The FESEM demonstrates a granular morphology that possesses a rough and grainy structure, exhibiting particles of irregular shapes and sizes, which is a typical characteristic of synthesized powders [13]. Figure 6 (a) displays a rough, granular morphology with a wide distribution of particle sizes. The presence of both fine and coarse particles suggests incomplete particle breakdown and partial agglomeration, likely due to insufficient grounding or the high-temperature calcination step. The irregular forms and rough textures of the particles discovered are typical characteristics of ceramic powders post-synthesis. Figure 6(b) illustrates that, although obtained at similar magnification, the micrograph reveals bigger, faceted grains with distinct crystalline boundaries, signifying improved crystallinity. Alternatively, Figures 6(c) and 6(d) illustrate the microstructure of powders that have undergone five grinding cycles. Figure 6(c) illustrates particles that are smaller and more uniformly distributed, exhibiting enhanced dispersion and less agglomeration, features that facilitate improved sintering behaviour and compositional homogeneity in composites. Figure 6(d), acquired at increased magnification, displays densely arranged, distinctly defined crystalline grains with smoother surfaces, demonstrating enhanced particle homogeneity and crystallinity due to the prolonged grinding process.

The particle sizes of the four times and five times ground BCZT powders were assessed using FESEM images for quantitative comparison. The average crystallite size of the BCZT sample exposed to five grinding cycles was approximately 6.1 nm, in contrast to 6.6 nm for the sample ground four times, hence supporting the observed reduction in particle size with enhanced grinding. Nonetheless, surface roughness was not assessed in this investigation, as Atomic Force Microscopy (AFM) or surface profilometry measurements were not conducted. As the comparison in XRD, the grain size for the five times grounded process is smoother and uniform compared to the four times grounded process, in line with the theoretical. Based on the FESEM data, it also shows that the number and the intensity of grounding steps affect the grain size of BCZT. However, over-grinding may introduce defects or contamination from the mortar or pestle, which can affect the grain boundary behaviours. These morphological characteristic matches the requirement for piezoelectric applications due to direct impact on the material's ability to convert mechanical energy into electrical energy. The crystalline and homogeneous structure of BCZT particles enhances the performance of the final BCZT-PDMS composite for energy harvesting.

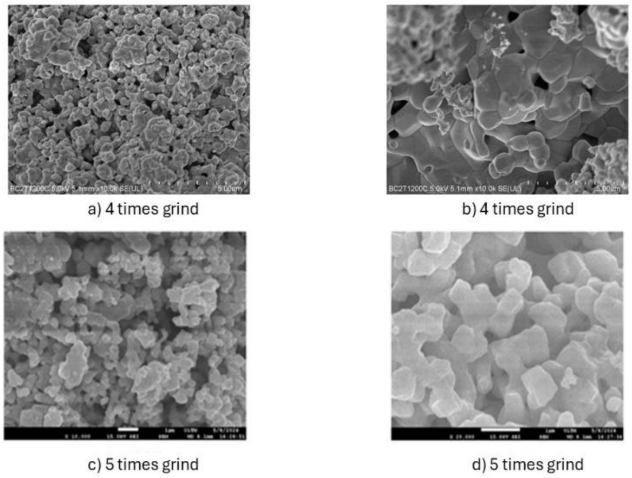

Figure 6. The structure of BCZT powder under FESEM: a) four times ground, b) four times ground, c) five times ground, d) five times ground.

Table 1 Summary of results for four times and five times ground BCZT

Parameter	4× Ground	5× Ground
2θ (main peak)	31.440°	31.500°
Crystallite size (Scherrer)	304 Å (30.4 nm)	263 Å (26.3 nm)
FWHM	0.3420	0.2980
Morphology (FESEM)	Larger, irregular grains	Smaller, more uniform grains
Estimated grain size (FESEM)	6.6 nm	6.1 nm
Crystallinity	Lower, more agglomerated	Higher, better phase purity

Table 2 FESEM-Based Microstructural Comparison of BCZT

Parameter	Mureddu et al. [17]	Sharma et al. [16]	This Research
Grounding method	**Attrition milling** (1× and 2×)	**Ball milling for 6 hours** using zirconia balls	Manual grinding (4× and 5× cycles)
Grain Size (FESEM)	Not quantified; described as *fine*, dense grains	2.9–3.5 µm (micron-sized grains)	6.6 nm (4× ground) vs 6.1 nm (5× ground)
Grain Morphology	Densely packed, uniform microstructure	Large, faceted grains with clear boundaries	Granular, more uniform with 5× grinding
Microstructure Summary	Dense and homogeneous	Coarse-grained, typical of sintered bulk ceramics	Fine and homogeneous (5× ground)

The structural characteristics of the BCZT–PDMS composite must be examined prior to testing to evaluate its suitability for further application. X-ray diffraction (XRD) analysis was conducted on composite samples with varying BCZT weight percentages. The pattern of XRD for BCZR-PDMS sample exhibits a broad and low intensity peak, with a prominent diffraction peak observed at 11.34°(2θ). The crystallite size is approximately 3013nm, which corresponds to the full width at half maximum (FWHM) PEAKS AT 0.03°. This indicates a high degree of crystallinity and minimal lattice distortion. The narrow FWHM suggests well-defined crystal domains, confirming the structural integrity of the ceramic component within the composite. The crystalline peak from BCZT can be observed in Figure 7. The overall XRD pattern displays a broad, low-intensity profile between 10° and 30° (2θ), characteristic of an amorphous or semicrystalline structure. This is attributed to the dominant PDMS material, which is inherently amorphous. Compared to pure BCZT powder, which exhibits sharp and intense diffraction peaks, the reduced peak intensity in the composite indicates that the BCZT particles are dispersed in a non-crystalline form within the PDMS matrix. This dispersion may suppress the crystalline contribution but can still enable uniform particle distribution. Such dispersion, even in the absence of sharp crystalline peaks, can enhance the piezoelectric response of the composite by ensuring consistent stress transfer under mechanical deformation.

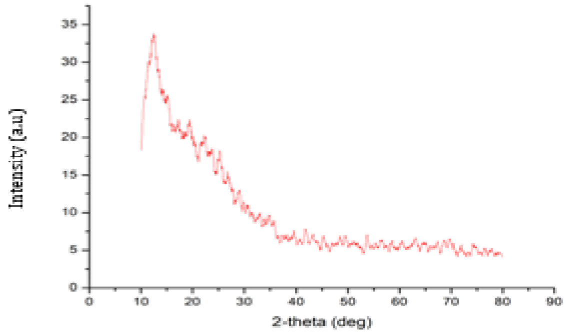

Figure 7. X-Ray Diffraction of BCZT-PDMS.

3.1. Piezoelectric Coefficient d_{33} Measurement

The piezoelectric response is crucial for piezoelectric material to evaluate the material's capability to generate electrical charge under mechanical stress. The trend graph of piezoelectric coefficient (d_{33}) against the percentage of BCZT composite materials is shown in Figure 8. With an increase in the weight percentage of BCZT, the d_{33} values increase, resulting in higher efficiency in the conversion of mechanical energy into electrical charge. The maximum peak on the graph is observed at a BCZT concentration of 10%, which produced a value of 45 pC/N. According to the theory, the pure BCZT ceramics usually have higher d_{33} compared to composited BCZT, which can exceed 100pC/N due to its dense, crystalline structure, but it lacks flexibility. In contrast, flexible BCZT-PDMS composites typically achieve lower d_{33} values but offer mechanical compliance desirable for wearable and soft electronic applications [15]. The graph trend indicates that increasing the BCZT concentration could improve the piezoelectric response and its ability to generate electrical charge when mechanical stress is applied. It has been proven that the BCZT-PDMS composite exhibits great piezoelectric response. At lower concentrations of BCZT, the amount of active material is insufficient for exhibiting a significant piezoelectric effect. Meanwhile, at higher concentrations of BCZT in the thin film, there is a notable enhancement in the alignment of piezoelectric domains, leading to improved d_{33} values.

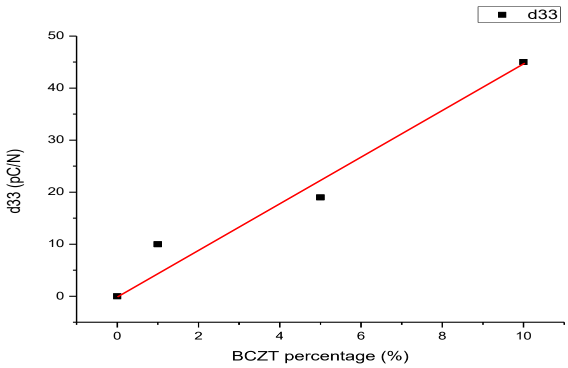

Figure 8. Piezoelectric Coefficient (d_{33}).

3.2. Testing and Experimental

The analysis of the graph emphasizes the identification of peak values of output voltage and the output signal stability. The force is set to 2 N, and the frequency is at 10 Hz. The voltage-time graph of the BCZT-PDMS thin film demonstrates periodic voltage spikes when the nanogenerator applies the mechanical excitation to the thin film under various BCZT weight percentages, indicating the successful generation of electrical signals. The presence of the voltage spikes shows piezoelectric properties, which means the BCZT-PDMS thin film is converting mechanical energy into electrical energy. The consistency of the peaks shows the composite film is responsive to the applied mechanical stress (tapping) and showcases its piezoelectric behaviour.

The variation in the peak voltage varies with different weight percentages of BCZT powder in the thin film. The higher peak indicates the stronger energy conversion of mechanical stress into electrical charges. At 1% weight percentage of BCZT, the output voltage is very minimal, which is approximately 2.5V, due to the low concentration of BCZT powder. As the weight percentage of BCZT increases to 3%, the output voltage slightly increases to approximately 4.5V. While at 5%, the output voltage is 6 V, which is lower than at 10 %. The output voltage reaches approximately 8V at 10%, suggesting that the concentration provides an optimal balance between particle distribution and mechanical coupling within the composites. When BCZT content increases to 10 wt%, as shown in Figure 8(d), the composite still maintains good flexibility and allows efficient stress transfer to the BCZT particles, resulting in the highest voltage output. However, for a concentration of 5 wt%, the composite may not provide enough interconnected piezoelectric regions to effectively convert mechanical stress into electrical energy. As a result, the output voltage of the 5 wt% sample is 25% lower than the output voltage for the 10 wt% sample.

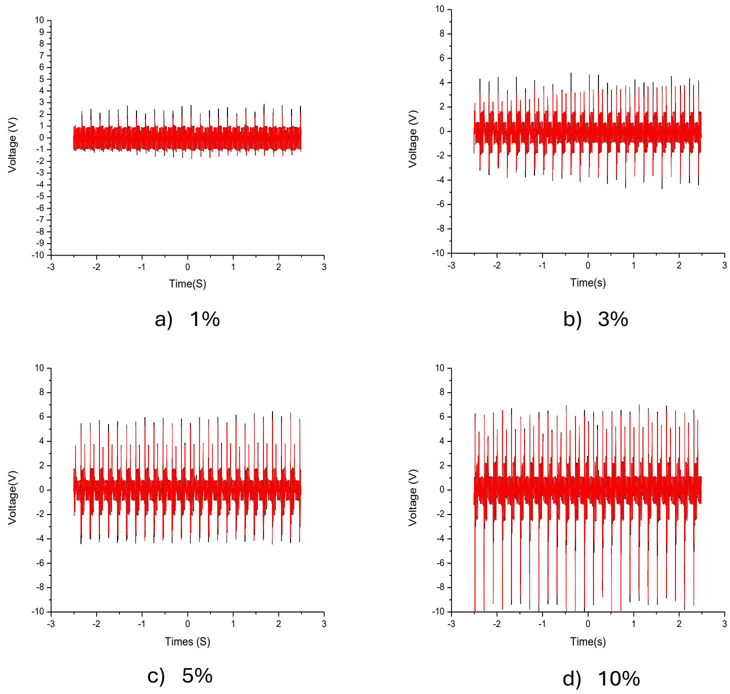

Figure 9. Voltage output using solenoid tapping.

Table 3 Summary of the Output Performance of Piezoelectric Nanogenerators Fabricated Using Various Piezoelectric Materials

Study	Bczt content	d_{33} (pC/N)	Voltage (v)	Material
This work	10 wt%	45	8	BCZT (solid-state, lab-synthesized), PDMS
Gao et al.	8 vol%	6	28.8	BCZT (solid-state), PDMS (Sylgard 184)
Buatip et al.[7]	15 wt%	Not reported	13	BCZT + MCNT, PDMS
Missaoui et al.[8]	15wt%	Not reported	13	BCZT + MCNT, PDMS

4. CONCLUSION

In this study, BCZT ($Ba_{0.85}Ca_{0.15}Ti_{0.9}Zr_{0.1}O_3$) powder has been successfully fabricated and synthesized using the solid state reaction method by varying the grounding cycle from 4 and 5 cycles. Based on XRD and FESEM analysis confirmed that the five times grounding of the precursor materials improves the crystallinity of the BCZT, which contributes to a well-defined cubic perovskite structure. Then, BCZT-PDMS is fabricated by varying the weight percentage (1%, 3%, 5%, and 10%). The structural analysis observed that the BCZT-PDMS composites exhibit an amorphous peak due to the polymer matrix dominance. For piezoelectric performance is evaluated using the piezoelectric charge coefficient (d_{33}) with 45pC/N. Furthermore, an output voltage generation under a consistent mechanical stimulus with the setup of 2 N force and 10 Hz frequency via solenoid tapping is measured, with the result that 10% BCZT-PDMS has the highest output voltage, 8V, compared to other compositions. Therefore, a 10 wt% BCZT loading in PDMS is identified as the optimal composition for achieving high piezoelectric output in flexible energy harvesting applications. Finally, the application of BCZT-PDMS is well defined as a promising candidate for self-powered electronic devices for various applications, like wearable health monitoring, smart footwear energy harvesting based on the flexibility of the devices.

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