International Journal of Mechanical Engineering

Phase formation of PbZr_{0.6}Ti_{0.4}O₃ nanopowders for the applications in energy harvesting

V. Patait* and T. K. Mandal

ICFAI Tech School The ICFAI University Rajawala Road, Central Hope Town Selaqui, Dehradun-248011 Uttarakhand, India *Research Scholar at ICFAI University, Dehradun and Assistant Professor at Samrat Ashok Technological Institute, Vidisha

Abstract

Nanopowders of PbZr_{0.6}Ti_{0.4}O₃ are synthesized through a green synthesis route applying aloe-vera gel at the temperature of 300 to 600 °C in air. The XRD of the as synthesized PbZr_{0.6}Ti_{0.4}O₃ nanopowders, inferred tetragonal symmetry (P4mm), with lattice parameter a = 0.4036 nm and c = 0.4147 nm. The average D value, determined from the XRD peaks was 31 nm. The SEM study indicated particle size of the as prepared PbZr_{0.6}Ti_{0.4}O₃ nanoparticles as 35-40 nm.

Keywords: Green synthesis; PbZr_{0.6}Ti_{0.4}O₃ nanopowders; tetragonal phase; Ferroelectrics

Introduction:

PZT has become a very popular material due to it's various beneficial properties. It is believed to have a high permittivity and due to that it has attracted many of the application as a capacitor [1], better polarization of PZT makes it suitable for memory devices [2] and acoustic wave device due to its better values of electro-mehanical coupling coefficient [3].PbZr_xTi_{1-x}O₃ where x=1 behaves like an antiferroelectric material but at room temperature it shows some transformation and this transition of PZT from antiferroelectric to ferroelectric material at certain temperature make it excellent material for charge application [4-6].Higher values of dielectric constant upto 1400 were obtained with the given composition [7].In the PZT when the ratio of Zr/Ti is changed then the morphological phase boudry changes. It becomes tetragonal structure which is normally happens with the Ti rich structures and becomes rhombohedral or orthorhombic with the Zr rich structures [8]. Remnant polarization value for PZT 60/40 was $45\pm 5 \text{ µC/cm}^2$ [9]. Thickness of 60 mm PZT film to 61 mm shows the relatively increase in the dielectric constant value to 167.8 and decrease in dielectric losses to 0.78% at 1 KHz, the remanent polarization is 14.1 µC/cm² and coercive field is 20.3 kV/cm [10]. For PZT(PbZr_{1-x}Ti_xO₃) structures where Zr(0.1 < x < 0.45) is rich in the structure is comes under the rhombohedral structures and where the Ti (0.5 < x < 1) is rich comes under the tetrahedral structure. Morpological Phase boundary is the area between the rhombohedral and tetrahedral phase and it is generated due to daomains of rhombohedral and tetrahedral crystal structures [1].PbZr_{0.6}Ti_{0.4}O₃ shows the high value of electromechanical coupling due to the presence of MPB. Rhombohedral and tetragonalphases are separated by MPB [1,11].PZT shows the superior piezoelectric properties near the MPB and that is the reason it has been utilized for many piezoelectric transducer and actuators [12]. PZT are ferroelectric where the $PbZr_{1-x}Ti_xO_3(x = 0.2 to$ 0.4) is rhombohedral or rich with Zr side of MPB and where x = 0.6 to 0.8 tetragonal structure or rich with Ti side of MPB [13]. Pulsed Laser Deposition technique are also used to obtain the different ratio of PZT in the form of $PbZr_{1-x}Ti_xO_3/PbZr_{1-x}$ $_{z}$ Ti_zO₃. Various phases were obtained for the different values of x/z as PbZr_{0.4}Ti_{0.6}O₃/PbZr_{0.2}Ti_{0.8}O₃ shows tetragonal/tetragonal, PbZr_{0.6}Ti_{0.4}O₃/PbZr_{0.4}Ti_{0.6}O₃ shows rhombohedral/tetragonal and PbZrO₃/PbZr_{0.8}Ti_{0.2}O₃ shows orthorhombic/rhombohedral [14-16]. $PbZr_{0,6}Ti_{0,4}O_3$ can be obtained through solid state methods and when subjected to ball milling, that can provide the particle size less than 100 nm at lower temperature. The XRD analysis also suggest that when the milling is done and particle size reached less than 100 nm then peaks only widens and no other significant difference was observed [17]. PZT shows the large remnant polarization which makes it more desirable as a energy storage material [18]. Presence of tetragonal and rhombohedral phases are important to obtain the better values of dielectric and ferroelectric properties of the PZT materials [19].

PZT 60 contains the rhombohedral phases and shows the remnant polarization value of 7.9 μ C/cm². When it is compared with the multilayer of tetragonal and rhombohedral combination then the combination shows the better values of remnant polarization of 31 μ C/cm²[20]. Table 1 presents the associated properties of PZT reported by different researchers.

Table 1: Presenting the	Various compositions of PZT,	, method used to a	make that PZT	and Focuses on the I	Remnant	Polarization
generated in the structure	<u>.</u>					

S. No.	Composition of PZT	Method used		Remnant Polarisation	Dielect ric Const ant	Coerc ive field	MPB Present	Ref.
1	PbZr _{0.53} Ti _{0.47} O ₃ nanopowder $(1 - 8 \text{ nm})$	Auto ignition of metal–polymer without calcination	gel	54.2 μC/cm ²		7.7 kV/cm	Yes	[21]
2	PbZr _{0.52} Ti _{0.48} O ₃ nanopowder	directly from their oxide mixture without involving calcination process		23.7 μC/cm ²	1157 at 1Khz	21 kV/cm	Yes	[22]
3	PbZr _{0.52} Ti _{0.48} O ₃ (PZT) films with a dense columnar structure were grown on LaNiO ₃ (LNO)	low-cost chemical solution approach		67.3 μC/cm ²	425		Yes	[23]
4	Pb(Zr _{0.52} Ti _{0.48}) _{0.98} Nb _{0.02} O ₃ (PNZT)	Pb(Zr _{0.52} Ti _{0.48}) _{0.98} Nb ₀ O ₃ sol-gel solutions mixing them with P2 5A piezoelec powders	and ZT- ctric	58 μC/cm ²	1750		Yes	[24]
5	PZT 40/60	pulsed laser deposit onto vicinal SrT (001)substrates	tion iO3	$70 + 7 \ \mu C/cm^2$				[9]
6	PZT 60/40		45 -	+ 5 μ C/cm ²			-	
7	PZT 52/48		50 -	+ 5 μ C/cm ²			Yes	
8	PZT thick film and forming substrate-free PZT thick film	E-Jet deposition and infiltration	sol	$\begin{array}{ccc} 16.1 \mu C/cm^2 \\ and \qquad 29.6 \\ \mu C/cm^2 \end{array}$				[25]
9	$Pb(Zr, Ti)O_3$ (Pb/Zr/Ti = 120/40/60, 25 wt%) (600 nm thickness)	UV/O ₃ assisted ther decomposition densification processe	mal and es	30 μC/cm ²				[26]
10	PbZr _{0.52} Ti _{0.48} O ₃ undoped and doped PZT by Nb, Fe and Ba	pulsed laser deposition (PLD)		$\begin{array}{ccc} 17.3 \mu C/cm^2 \\ \text{and} \qquad 22.6 \\ \mu C/cm^2 \end{array}$	1280 and 1520			[27]
11	PZT 53/47 (45 μm thick)	modified sol–gel dip coating method		7.8 μC/cm ²	1630			[28]
12	Pb(Zr _{0.52} Ti _{0.48})O ₃ (PZT) thin films grown on Pt/TiO2/SiO2/Si(1 0 0) substrates (Thickness vary from 30nm -550 nm)	radio frequency (RF) magnetron sputtering method		$\begin{array}{c} 0.56\\ \mu C/cm^2 (PZT\\ 5 - Thickness\\ is \ 485 \ nm)\\ and \ 1.85\\ \mu C/cm^2 (PZT\\ 6 - Thickness\\ is \ 550 \ nm) \end{array}$		248 (PZT 5) and 171 (PZT 6)		[29]
13	Pb(Zr _{0.52} Ti _{0.48})O ₃ or PZT) thin films on an LaNiO ₃ /poly-Si/titanium nitride (TiN)/SiO ₂	atomic layer deposition	on	19.2 μC/cm ²				[30]
14	$\begin{array}{c} (Pb_{0.92}La_{0.08})(Zr_{0.60}Ti_{0.40})O_{3} \\ (PLZT \ 8/60/40) \end{array}$	high energy mecha chemical milling	no-	33.29 μC/cm ²		10.57 kV/cm		[31]

Copyrights @Kalahari Journals

15	$Pb(Zr_{1-x}Ti_x)O_3(x=0-1)$	chemical solution decomposition (CSD) method	35.83μC/cm ² (When PT buffer layer had 5 layers) and 26.08μC/cm ² (When PZ buffer layer had 1 layers)			[32]
16	$\begin{array}{c} Pb(Zr_{0.6}Ti_{0.4})O_3 \ (P60) \ and \\ Pb(Zr_{0.4}Ti_{0.6})O_3 \\ (P40), \ and \\ heterolayeredPb(Zr_{0.6}Ti_{0.4}) \\ O_3/Pb(Zr_{0.4}Ti_{0.6})O_3 \\ (P60/P40) \end{array}$	solegel technique	18.6 μ C/cm ² (f or alternating heterolayered P60/P40), 14.6 μ C/cm ² (for multilayer P60) and 17.1 μ C/cm ² (f or multilayer P40)	1040(f or alterna ting heterol ayered P60/P4 0) 860 (for multila yer P60) and 800 (for multila yer P40)		[33]
17	$\begin{array}{c} Pb(Zr_{x}Ti_{1-x})_{0.98}Nb_{0.02}O_{3}\\ thin films of different Zr/Ti\\ ratios ranging from 30/70\\ to 70/30(60/40 \ composition\\ with various thicknesses\\ varying from 70 \ nm to 300\\ nm) \end{array}$	Sol –gel method	61.7μC/cm ²		70.7 kV/cm	[34]

The present work deals with the preparation of $PbZr_{0.6}Ti_{0.4}O_3$ nanopowders through environment friendly green synthesis method. The properties obtained with the as prepared PZT have been found to be suitable for the applications in energy harvesting devices.

Experimental

The green synthesis of PbZr_{0:6}Ti_{0:4}O₃ precursor solution was carried out from the starting materials (99.99 % pure) of Pb(NO₃)₂, ZrOCl₂.8H₂O and TiO₂ in the stoichiometric ratio of 1:0.6:0.4. At first, ZrOCl₂.8H₂O (dissolved in deionized water) and TiO₂ (dissolved in 48 % HF) were precipitated as hydrated hydroxides by hydrolysis with NH₄OH in cold water at 2 to 5 °C (with stirring). The precipitates were washed with deionized water till the chloride ion was removed. The ppt was then dissolved in HNO₃ and to it Pb(NO₃)₂ solution was added. The precursor solution was mixed then to the solution of Aloe Vera. In the mixture Pb²⁺, Zr⁴⁺ and Ti⁴⁺ ions were rearranged in aloe vera network. An amorphous structure of the precursor solution was existed on drying it at 70 to 80 °C. This carbonaceous precursor mass was decomposed at 300 to 350 °C in air, producing a recrystallized PbZr_{0:6}Ti_{0:4}O₃ nanopowder. (Fig 1).

Material	Solvent	Vol. (mL)	Conc.
Pb(NO ₃) ₂	H ₂ O	75.0	1.0 M
ZrO(OH) ₂ .xH ₂ O	HNO ₃	11.5	2.0 M
TiO(OH) ₂ .xH ₂ O	HNO ₃	10.4	2.0 M
Aloe Vera	H ₂ O	5.5	-

Table 2. Experimental data used for the preparation of PZT.

Copyrights @Kalahari Journals



Figure 1 Flow chart for the synthesis of PbZr_{0:6}Ti_{0:4}O₃ nanopowders.

XRD of the specimens was performed using "PW 1710 X-ray diffractometer" (0.15418 nm CuK \Box radiation). The D value was measured from the Debye-Scherrer formula [24]. The Rietveld refinement of the XRD profile was carried out with the FullProf (Version 3.5d Oct98-LLB-JRC) program. The proposed structural model developed here is based on the tetragonal (P4mm) [11,24] structure for the PbZr_{0.6}Ti_{0.4}O₃ composition (Table 3).

3. Results and discussion

Figure 2 shows the X-ray diffractograms of **PbZr_{0.6}Ti_{0.4}O₃** nanopowders prepared on heating the aloe-vera precursor in air at (a) 300 °C (b) 400 °C (c) 500 °C and (d) 600 °C for 2 h. According to the diffraction pattern (Figure. 2a), **PbZr_{0.6}Ti_{0.4}O₃** forms nanoparticles on heating the precursor at temperature as low as 300 °C for 2 h. Only a small impurity intermediate pyrochlore phase (10 % according to the intensity in the prominent peaks) produced during the formation of PZT at intermediate temperatures [27-28], is observed. Fig. 2(d) thus indicates a weak peak at an interplanar spacing'd' of **0.3055 nm** (marked by *) corresponding to the residual pyrochlore phase.

The intensity of this phase decreases prominently on heating the precursor material at relatively higher temperatures and the peak at d = 0.3055 nm, no longer exists when heated the precursor at 600 °C for 2 h. Fig. 2(d) indicates the prominent XRD peaks of tetragonal PbZr_{0.6}Ti_{0.4}O₃, caused by heating the precursor at 600 °C for 2 h. The XRD peaks of fig 2(d) are presented in Table 3 considering a tetragonal symmetry of PZT [29] (*a* = 0.4036 nm and c = 0.4147 nm).



Copyrights @Kalahari Journals

International Journal of Mechanical Engineering 4816



Figure 2 X-ray diffractograms of PbZr_{0.6}Ti_{0.4}O₃ nanopowders processed by heating the polymeric precursor at (a) 300 °C (b) 400 °C (c) 500 °C and (d) 600 °C, for 2 h in air.

The highest peak of the diffractogram (I = 100%) was found at 0.2891 nm with hkl = 101. 100 and 112 peaks were found at 0.4035 nm (I = 31) and 0.1679 nm (I = 25), respectively. However, the diffractogram in Fig. 2(d) have some satellite peaks (0.3965, 0.2007 and 0.1641 nm). This is possible because of the presence of hexagonal phase [26], which often coexists in the MPB composition [30]. The existence of these peaks might be because of some hexagonal impurity [26, 30]. A similar X-ray diffractogram have been reported by Sorowiak and coworkers for nanocrystalline tetragonal **PbZr_{0.6}Ti_{0.4}O₃**, obtained by conventional ceramic sintering at 927°C [19].

Table-3: XRD data of PbZr_{0.6}Ti_{0.4}O₃ prepared through a green synthesis method.

d _{hkl} (nm)		т	1.	1_		
Observed	Calculated	1	n	K	1	
0.4035	0.4038	31	1	0	0	
0.2891	0.2890	100	1	0	1	
0.2354	0.2353	15	1	1	1	
0.2018	0.2020	21	2	0	0	
0.1843	0.1845	08	1	0	2	
0.1679	0.1680	25	1	1	2	
0.1446	0.1444	07	0	2	2	
0.1363	0.1362	03	2	1	2	
0.1306	0.1305	06	1	0	3	
0.1223	0.1222	02	3	1	1	
0.1176	0.1175	01	2	2	2	

The as prepared PZT is calcinated at **600** °C for 2 h. The obtained values of d_{hkl} implies the tetragonal structure (a = 0.4031 nm and c = 0.4140 nm) [30].

The value of D for the **PbZr_{0.6}Ti_{0.4}O₃** sample, processed at 300 °C, 400 °C, 500 °C and 600 °C for 2 h, vary from 23 nm, 25 nm, 27 nm and 31 nm respectively (as per 101, 100, 111, 200 and 112 prominent peaks). It is calculated applying Williamson-Hall integral breadth method [31]. Selected peaks were fed to the computer program. To obtain the value of sin \Box and \Box (FWHM) \Box for selected peak. The graph of \Box against sin \Box is used for the further calculation of D. the main formula used for this is $\Box = 1/D + 4e.sin \Box/\Box \Box$ [where: $\Box \Box \Box$ degrees) = FWHM; dimensionless, D (nm)= crystallite size; dimension = L, e = microstrain of the sample; dimensionless, 2 \Box degree \Box = diffraction angle; dimensionless, $\Box \Box nm \Box$ = wavelength; dimension = L) [32]. The calculated D values by both the methods are nearly same.

SEM micrograph of PbZr_{0.6}Ti_{0.4}O₃ nanopowder processes on calcinations of the precursor materials at 600 $^{\circ}$ C is presented in Fig 3. Surface morphology observed from the SEM micrograph shows that the particles are have a interconnected network structure with the particle size of around 35-40 nm.



Figure 3. SEM micrograph of PbZr_{0.6}Ti_{0.4}O₃ nanopowder processes on calcinations of the precursor materials at 600 ⁰C.

The as prepared **PbZr_{0.6}Ti_{0.4}O₃** nanopowder exhibited ferroelectric properties with the ε_{max} value 30000 with $\varepsilon = 1200$ at room temperature at 1 kHz. The present values are comparable with the values obtained in similar PZT nanoceramics prepared by sol gel and other methods [27-28]. The reduction of T_C in **PbZr_{0.6}Ti_{0.4}O₃** nanopowder, in the present investigation, in comparison to the well-established reported **PbZr_{0.6}Ti_{0.4}O₃** value [1] in PbZr_{0.52}Ti_{0.48}O₃ ceramic powder, is presumed to be due to the effect of depolarization field [33]. The increase in value of ε in **PbZr_{0.6}Ti_{0.4}O₃** nanopowder, in the present investigation, is presumed to be because of strong surface dipolar interations in **PbZr_{0.6}Ti_{0.4}O₃** nanoparticles, as demonstrated in Figure 4 [34].



Figure 4. Schematic view representing the surface stress of nanoparticles [34].

The surface dipolar interactions may be the major contributor to the high surface energy of $PbZr_{0.6}Ti_{0.4}O_3$ nanoparticles, surface reconstruction and the interactions with the vicinity should also be considered [35].

Copyrights @Kalahari Journals

International Journal of Mechanical Engineering 4818

4. Conclusions

Green synthesis method is utilized for the fabrication of $PbZr_{0.6}Ti_{0.4}O_3$ nanoparticles with a P4mm tetragonal crystal structure. The heating of aloe-vera precursor material at 600 °C for 2 h. the main advantage of using this method is that the used aloe vera precursor starts decomposing with the treatment of temperature of 300 °C, which results in crystallized $PbZr_{0.6}Ti_{0.4}O_3$ nanopowders. The average crystallite size, using Debye Scherrer relation varies from 23 to 31 nm. The high ε value in $PbZr_{0.6}Ti_{0.4}O_3$ nanopowders confirmes the usability of applied method for delivering better quality of at moderate temperature. Thus, the prepared nanocrystalline $PbZr_{0.6}Ti_{0.4}O_3$ have a huge scope for the utilization in energy harvesting devices.

References

- 1. B. Jaffe, W. Cook, and H. Jaffe. Piezoelectric Ceramics. AcademicPress, London, United Kingdom, 1971; 136.
- 2. J.C. Crawford and F.L. English. Ceramic ferroelectric field effect studies. IEEE Trans. Electron Devices, 1969; 16(6), 525-532.
- 3. K. Suzuki and M. Nishikawa. Poling Dependence of the Surface-Wave Frequency-Generation on PZT. Jpn. J. Appl. Phys. 1974; 13, 240.
- 4. G. Shirane, E. Sawaguchi, and Y. Takagi. Dielectric Properties of Lead Zirconate. Phys. Rev. 1951; 84(3), 476-481.
- 5. E. Sawaguchi, H. Maniwa, and S. Hoshino. Antiferroelectric Structure of Lead Zirconate. Phys. Rev. 1951; 83, 1078.
- 6. B. Xu, Y. Ye, Q.M. Wand, and L.E. Cross. Dependence of electrical properties on film thickness in lanthanum-doped lead zirconate titanate stannate antiferroelectric thin films. *J. Appl. Phys.* 1999; 85, 3753.
- R.E. Koritala and M.T. Lanagana, N. Chen,b) G.R. Bai, Y. Huang,c) and S.K. Streiffer. Microstructure and properties of PbZr_{0.6}Ti_{0.4}O₃ and PbZrO₃thin films deposited on template layers. J. Mater. Res. 2000; 15(9),1962-1971.
- 8. I. A. Kornev and L. Bellaiche. Unusual Thermodynamic Properties and Nonergodicity in Ferroelectric Superlattices. Phys. Rev. Lett. 2003; 91(11), 116103.
- IonelaVrejoiu, Yinlian Zhu, Gwenaël Le Rhun, Markus Andreas Schubert, Dietrich Hesse, and Marin Alexe. Structure and properties of epitaxial ferroelectric PbZr_{0.4}Ti_{0.6}O₃/PbZr_{0.6}Ti_{0.4}O₃superlattices grown on SrTiO₃(001) by pulsed laser deposition. *Applied Physics Letters* 2007; 90, 072909.
- 10. Sung-Gap Lee; Sang-Man Park; Cheol-Jin Kim; Young-Hie Lee. Characterization of PZT composite thick films fabricated using a modified Sol-Gel based process. IEEE Nanotechnology Materials and Devices Conference 2000.
- B. Noheda. Structure and high-piezoelectricity in lead oxide solid solutions. Curr. Opin.in Solid State Mater. Sci. 2002; 6, 27-34.
- 12. Wenwu Cao Wenwu Cao and L. Eric Cross L. Eric Cross. The Ratio of Rhombohedral and Tetragonal Phases on the Morphotropic Phase Boundary in Lead ZirconateTitanate. Japanese Journal of App. Phy. 1992; 31, 1399-1402.
- 13. D. Hesse, L. Feigl, S. J. Zheng, Y. L. Zhu, I. Vrejoiu, K. Boldyreva, B. I. Birajdar, N. D. Zakharov, and M. Alexe. Thicknessinduced structural transitions in three PbZr1-xTixO3/ PbZr1-zTizO3 coherent superlattices (x/z = 0/0.2, 0.4/0.6, 0.6/0.8), MC2009, Vol. 3: Materials Science, DOI: 10.3217/978-3-85125-062-6-614.
- L. Feigl, S. J. Zheng, B. I. Birajdar, B. J. Rodriguez, Y. L. Zhu, M. Alexe, and D. Hesse, Impact of high interface density on ferroelectric and structural properties of PbZr_{0.2}Ti_{0.8}O₃/ PbZr_{0.4}Ti_{0.6}O₃ epitaxial multilayers, Accepted by J. Phys. D: Appl. Phys. 2009; 42, 085305
- I. Vrejoiu, Y. L. Zhu, G. Le Rhun, M. A. Schubert, D. Hesse, and M. Alexe. Structure and properties of epitaxial ferroelectric PbZr0.4Ti0.6O3/PbZr0.6Ti0.4O3PbZr0.4Ti0.6O3/PbZr0.6Ti0.4O3 superlattices on SrTiO3SrTiO3 (001) by pulsed laser deposition. Appl. Phys. Lett. 2007; 90, 072909.
- 16. K. Boldyreva, L. Pintilie, A. Lotnyk, I. B. Misirlioglu, M. Alexe, and D. Hesse, Thickness-driven antiferroelectric-toferroelectric phase transition of thin PbZrO3PbZrO3 layers in epitaxial PbZrO3/Pb(Zr0.8Ti0.2)O3PbZrO3/Pb(Zr0.8Ti0.2)O3 multilayers Appl. Phys. Lett. 2007; 91, 22915.
- 17. Y. Leyet-Ruiz, A. Pérez-Rivero, M. Fernández, E. Pérez-Delfín, F. Guerrero, J. A. Eiras. Preparation and characterization of pzt nanopowder using high energy ball milling. Revista Cubana de Química. 2009; XXI(3), 15-24.
- K. Kim and S. Lee, Integration of lead zirconium titanate thin films for high density ferroelectric random access memory, J. Appl. Phys. 2006; 100, 051604.
- X. D. Zhang, X. J. Meng, J. L. Sun, T. Lin, and J. H. Chu, Low-temperature preparation of highly (100)oriented Pb(ZrxTi1-x)O3Pb(ZrxTi1-x)O3 thin film by high oxygen-pressure processing, Appl. Phys.Lett. 2005; 86, 252902.
- F. M. Pontes, E. Longo, and E. R. Leite. Improvement of the dielectric and ferroelectric properties in superlattice structure of Pb.Zr_xTi_{1-x}O₃ thin films grown by a chemical solution route. Appl. Phys. Lett. 2004; 84(26).
- 21. Subir Roy, Sandip Bysakh. Ultrafine PZT based ceramics synthesized by auto-ignition of metal-polymer gel:Enhanced sinterablity and higher remnant polarization. Materials Chemistry and Physics, 2011; 126, 948–954.

Copyrights @Kalahari Journals

- 22. L.B. Kong, J. Ma. PZT ceramics formed directly from oxides via reactive sintering. Materials Letters. 2001; 51, 95-100
- XiaokuoEr, Fei Shao, SizheDiao, Hongliang Wang, Qinghua Ma, Pingping Liu, Jinxing Zhang, Qian Zhan. Design, synthesis, microstructure and electrical properties of thermal-strained PZT films. Journal of the European Ceramic Society, 2021; 41(11), 5512-5518.
- 24. Yi-Chia Lee, Cheng-Che Tsai, Cheng-Ying Li, Yu-Cheng Liou, Cheng-Shong Hong, Sheng-Yuan Chu. Fabrication and function examination of PZT-based MEMS accelerometers. Ceramics International, 2021; 47(17), 24458-24465.
- 25. Dazhi Wang, Peng Shi, Xuemu Li, Peng Zhou, Kuipeng Zhao, Yunlong Wei, Chongyang Jiang, Junsheng Liang, R.A. Dorey. Fabrication and characterisation of substrate-free
- PZT thick films. Ceramics International, https://doi.org/10.1016/j.ceramint.2018.05.030.
- 26. Phan Trong Tue, Reijiro Shimura, Kazuhiro Fukada, Keisuke Satou, Jinwang Li, Tatsuya Shimoda, and Yuzuru Takamura, Effect of ultraviolet/ozone treatment on the structuraland electrical properties of solution-processedpiezoelectric thick-film lead-zirconium-titanate. Int. J. Nanotechnol. 2018; 15, 69-77.
- 27 Minh D. Nguyena, Thong Q. Trinh, Matthijn Dekkers, Evert P. Houwman, Hung N. Vu, Guus Rijnders. Effect of dopants on ferroelectric and piezoelectric properties of lead zirconate titanate thin films on Sisubstrates. Ceramics International , 2014; 40, 1013–1018.
- 28. Amid Shakeri, HosseinAbdizadeh, Mohammad Reza Golobostanfard. Synthesis and characterization of thick PZT films via sol-gel dipcoating method. Applied Surface Science, 2014; 314, 711–719.
- 29. K. K. Maurya, S.K. Halder, SuchitraSen, Ankita Bose, Sandip Bysakh. High resolution X-ray and electron microscopy characterization of PZT thin films prepared by RF magnetron sputtering K. Applied Surface Science, 2014; 313, 196–206.
- B. Kaleli, M.D. Nguyen, J. Schmitz, R.A.M. Wolters, R.J.E. Hueting, and Analysis of thin-film PZT/LNO stacks on an encapsulated TiN electrode, Microelectronic Engineering, 2014; 119, 16–19.
- 31. Ajeet Kumar, V.V. Bhanu Prasad, K.C. James Raju, A.R. James, Ultra high strain properties of lanthanum substituted PZTelectro-ceramics prepared via mechanical activation, Journal of Alloys and Compounds, 2014; 599, 53–59.
- 32. Gang He, Yao Zhang, Chao Peng, Xiaomeng Li. Surface morphology and ferroelectric properties of compositionalgradient PZT thin films prepared by chemical solution depositionprocess. Applied Surface Science, 2013; 283, 532–536.
- 33. Minh D. Nguyen, Chi T.Q. Nguyen, Thong Q. Trinh, Tai Nguyen, Thao N. Pham, GuusRijnders, Hung N. Vu. Enhancement of ferroelectric and piezoelectric properties in PZT thin films with heterolayered structure. Materials Chemistry and Physics, 2013; 138, 862 - 869.
- 34. T.K. MANDAL. Rietveld refinement on XRD and TEM study of nanocrystalline PbZr0:5Ti0:5O3 ceramics prepared with a soft chemistry route. Materials Science-Poland, 2015; 33(1), 18-24.
- 35. Qi Yu, Jing-Feng Li, Wei Sun. Composition-phase structure relationship and thickness-dependent ferroelectricity of rhombohedral phase in [1 1 1]-textured Nb-doped Pb(Zr,Ti)O3 thin films. Applied Surface Science, 2013; 265, 334–338