

Influence of substitution of Nd^{3+} for Bi^{3+} on structure and piezoelectric properties of $\text{SrBi}_{2-\chi}\text{Nd}_\chi\text{Nb}_2\text{O}_9$ ($\chi=0, 0.1, 0.2$ and 0.4)

SUN Lin(孙琳)¹, CHU Jun-hao(褚君浩)¹, YANG Ping-xiong(杨平雄)¹, YUE Fang-yu(越方禹)¹,
LI Ya-wei(李亚巍)¹, FENG Chu-de(冯楚德)², MAO Cao-liang(毛朝梁)²

1. Key Laboratory of Polar Materials and Devices of Ministry of Education,
East China Normal University, Shanghai 200062, China;

2. Shanghai Institute of Ceramics, Chinese Academy of Sciences, Shanghai 200050, China

Received 10 August 2009; accepted 15 September 2009

Abstract: $\text{SrBi}_{2-\chi}\text{Nd}_\chi\text{Nb}_2\text{O}_9$ ($\chi=0, 0.1, 0.2$ and 0.4) bismuth layer-structured ferroelectric ceramics were prepared by the solid-state reaction sintering method. The accurate position of Nd element in $\text{SrBi}_{2-\chi}\text{Nd}_\chi\text{Nb}_2\text{O}_9$ ceramics was determined by the X-ray Rietveld method and Synchrotron radiation X-ray absorption fine structure (XAFS) technology. The partial substitution of Nd^{3+} for Bi^{3+} leads to the decrease in the distortion of NbO_6 octahedron for $\text{SrBi}_{2-\chi}\text{Nd}_\chi\text{Nb}_2\text{O}_9$ ceramics and also lowers the piezoelectric properties of $\text{SrBi}_{2-\chi}\text{Nd}_\chi\text{Nb}_2\text{O}_9$ ceramics. Meanwhile, the temperature coefficient of resonant frequency (TCF) decreases when Nd element partially replaces Bi element in $\text{SrBi}_{2-\chi}\text{Nd}_\chi\text{Nb}_2\text{O}_9$ ceramics.

Key words: bismuth layer-structured ferroelectrics; X-ray Rietveld method; synchrotron radiation XAFS; piezoelectric properties

1 Introduction

Bismuth layer-structured ferroelectrics (BLSFs) have attracted much interest for their fatigue-free properties in nonvolatile ferroelectric thin film random access memory and high temperature piezoelectric devices. BLSFs can be described by the general formula $(\text{Bi}_2\text{O}_2)^{2+}(\text{A}_{m-1}\text{B}_m\text{O}_{3m-1})^{2-}$ ($m=1, 2, 3, 4, 5, 6$). The crystal structure of these compounds consists of fluorite-like $(\text{Bi}_2\text{O}_2)^{2+}$ layers interleaved with $(m-1)$ perovskite-like blocks $(\text{A}_{m-1}\text{B}_m\text{O}_{3m-1})^{2-}$ [1]. $\text{SrBi}_2\text{Nb}_2\text{O}_9$ (SBN) is a member of BLSFs family (i.e. $m=2$, $\text{A}=\text{Sr}^{2+}$, $\text{B}=\text{Nb}^{5+}$), which is composed of Bi_2O_2 layers and perovskite-like SrNb_2O_7 units with double NbO_6 octahedral layers.

BLSFs have been widely studied because of their excellent fatigue-free properties [2–4]. In previous studies, we have found that Pr^{3+} , La^{3+} , Nd^{3+} and Sm^{3+} elements can be introduced into Bi site for SBN ceramics and a relaxor behavior is reduced by the substitution of these lanthanide (Ln) elements for Bi ions [5–8]. However, there are few detailed studies about the

accurate position of the dopant element like Nd^{3+} for these Ln-doped SBN ceramics [9]. On the other hand, SBN is suitable for fine tolerance resonator applications due to its low temperature coefficient of resonant frequency (TCF) value, low electromechanical coupling coefficient (K_p), and high mechanical quality factor (Q_m). In addition, the substitution of Nd^{3+} for Bi^{3+} is most likely to further lower TCF value like the case of Sm-doped SBN [8]. Therefore, in the present work, the accurate position of Nd dopant was investigated by means of the X-ray Rietveld refinement method and XAFS technique and the effects of the Nd dopant on the structure and piezoelectric properties of $\text{SrBi}_{2-\chi}\text{Nd}_\chi\text{Nb}_2\text{O}_9$ ($\chi=0, 0.1, 0.2$ and 0.4) were also studied in detail.

2 Experimental

The conventional solid-state reaction sintering method was used to prepare $\text{SrBi}_{2-\chi}\text{Nd}_\chi\text{Nb}_2\text{O}_9$ ($\chi=0, 0.1, 0.2$ and 0.4) ceramics. Details about the preparation procedure were described elsewhere [7]. The ceramic

samples for piezoelectric measurement were poled in a silicon oil bath at 180 °C under the electric field of about 8–10 kV/mm for 5–15 min.

Phase identification of samples was carried out by X-ray diffractometer (model: Dmax2550 V, Rigaku, Tokyo, Japan) with monochromic Cu K α radiation. Intensities were measured in steps of 0.02° for 1 s in the 2 θ range of 10°–120° at room temperature. Crystallographic and structural parameters were refined by the Rietveld method using the TOPAS software. XAFS measurements at Nd-L $_3$ absorption edge were performed using synchrotron radiation at the National Synchrotron Radiation Laboratory of China. The P – E hysteresis loops were measured by a TF analyzer (Model 2000, aixACCT Systems, Germany) at the temperature of 150 °C with a frequency of 1 Hz. The piezoelectric measurements were performed for 48 h after the poling. The piezoelectric constants, d_{33} , were measured using a quasi-static d_{33} meter (Model ZJ-2, Institute of Acoustics, Chinese Academy of Science). The planar coupling factor K_p and the mechanical quality factor Q_m were determined using the resonance-antiresonance method. Resonance and anti-resonance frequencies in the temperature range from –20 to 140 °C were measured using precision impedance analyzer (Agilent 4294A, USA) combined with a temperature-controlling oven (VT7004, Germany). TCF was calculated using

$$\text{TCF} = \Delta f_r / (f_{r, 20\text{ }^\circ\text{C}} \times 100) \quad (1)$$

where Δf_r is the variation of the resonance frequency within the temperature range from –20 to 80 °C, and $f_{r, 20\text{ }^\circ\text{C}}$ is the resonance frequency at 20 °C.

3 Results and discussion

3.1 Analysis of X-ray Rietveld refinement and XAFS measurement for SrBi $_{2-\chi}$ Nd $_{\chi}$ Nb $_2$ O $_9$

SrBi $_{2-\chi}$ Nd $_{\chi}$ Nb $_2$ O $_9$ ($\chi=0, 0.2$ and 0.4) ceramics powders were carried out by X-ray Rietveld refinement. Fig.1 shows the fitting result of X-ray Rietveld refinement of SrBi $_{1.8}$ Nd $_{0.2}$ Nb $_2$ O $_9$ (i.e. $\chi=0.2$) ceramics powder and Table 1 gives the Rietveld refined structural parameters for this sample. Some previous studies about SBN ceramics powders have been reported that the exchange of Sr $^{2+}$ and Bi $^{3+}$ occurs in SBN[10–12]. So, in our refinement for SrBi $_{2-\chi}$ Nd $_{\chi}$ Nb $_2$ O $_9$, we assumed that some exchange of Sr $^{2+}$ and Bi $^{3+}$ existed for these three samples. The refinement was performed in the orthorhombic space group $A2_1am$. The results of refinement for these samples are presented in Table 1 and Table 2. It can be seen from Table 2 that the refinement parameters for these samples including three reliability factors (R_{wp} , R_{exp} and R_p) are reasonable values, which represent the reliability of the refined structural parameters. Table 1 shows that the exchange amount of Sr $^{2+}$ and Bi $^{3+}$ for $\chi=0.2$ sample is about 16.2%. Similarly, this exchange of Sr $^{2+}$ and Bi $^{3+}$ also happens for $\chi=0$ and 0.4 samples and the exchange amount is 16.7% and 15.1%, respectively, according to their refinement. On the other hand, considering that the radius of Nd $^{3+}$ (0.111 nm, coordinate number 8) is closer to Bi $^{3+}$ (0.117 nm, coordinate number 8) and larger than Sr $^{2+}$ (0.126 nm, coordinate number 8) and both Nd and Bi ions are trivalent, the refinement was performed based on the assumption that Nd $^{3+}$ occupies the Bi-site in Bi $_2$ O $_2$ layers for the Nd-doped SBN samples ($\chi=0.2$ and 0.4). The

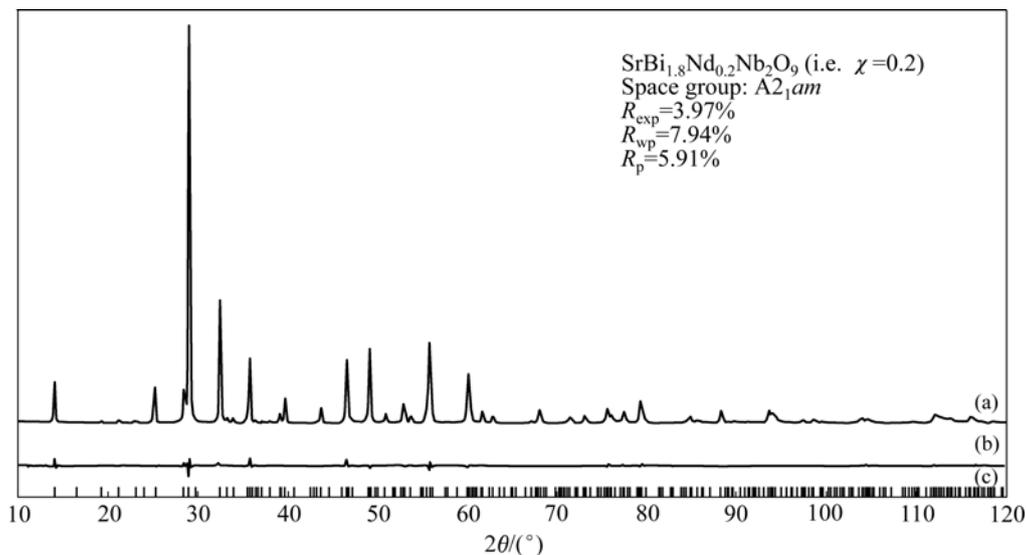


Fig.1 Fitting result of X-ray Rietveld refinement of SrBi $_{1.8}$ Nd $_{0.2}$ Nb $_2$ O $_9$ (i.e. $\chi=0.2$) ceramics powder: (a) Experimental data spectrum; (b) Difference between data points and fitted line; (c) Position of diffraction peaks

Table 1 Rietveld refined structural parameters for SrBi_{1.8}Nd_{0.2}Nb₂O₉ (i.e. $\chi=0.2$)

Site	N_p	x	y	z	Atom	Occupancy	B_{eq}
O1	4	0.952 8(63)	0.784 200(66)	0	O ⁻²	1	0.670(19)
O2	8	0.429 7(42)	0.797 300(43)	0.3391 000(43)	O ⁻²	1	0.670(19)
O3	8	0.262 0(11)	0.996 000(25)	0.2422 000(59)	O ⁻²	1	0.670(19)
O4	8	0.762 8(82)	0.952 200(56)	0.0834 400(55)	O ⁻²	1	0.670(19)
O5	8	0.761 2(75)	0.057 200(52)	0.5719 400(56)	O ⁻²	1	0.670(19)
Sr1	4	0	0.245 500(11)	0	Sr ⁺²	0.837 9(41)	0.890(68)
					Bi ⁺³	0.162 1(41)	0.890(68)
					Sr ⁺²	0.081 0(21)	1.351(32)
Bi2	8	0.498 1(22)	0.733 83(33)	0.201 505(41)	Bi ⁺³	0.819 0(21)	1.351(32)
					Nd ⁺³	0.1	1.351(32)
Nb1	8	0.508 4(21)	0.749 85(85)	0.413 926(56)	Nb ⁺⁵	1	0.375(44)

Table 2 Rietveld refined lattice constants for SrBi_{2- χ} Nd _{χ} Nb₂O₉ ($\chi=0, 0.2$ and 0.4)

Sample	$a/\text{\AA}$	$b/\text{\AA}$	$c/\text{\AA}$	$R_{exp}/\%$	$R_{wp}/\%$	$R_p/\%$	Tilting angle, $\alpha/^\circ$
$\chi=0$	5.515 06(4)	5.513 45(4)	25.098 50(4)	3.57	8.61	6.61	9.72
$\chi=0.2$	5.510 60(7)	5.510 59(7)	25.084 53(4)	3.97	7.94	5.91	9.45
$\chi=0.4$	5.509 40(1)	5.509 50(1)	25.107 14(5)	3.36	6.99	5.28	5.48

reasonable structure parameters obtained by Rietveld refinement reflect that Nd³⁺ replaces Bi³⁺ for SrBi_{2- χ} Nd _{χ} Nb₂O₉ samples.

Table 2 lists the lattice constant of SrBi_{2- χ} Nd _{χ} Nb₂O₉ ($\chi=0, 0.2$ and 0.4) samples and their tilting angle for NbO₆ octahedron, which was obtained by the Rietveld refinement. Compared with those of SBN (i.e. $\chi=0$), the lattice constants a and b decrease by 0.1% and 0.07%, respectively, and the lattice constant c increases by 0.03%. Thus, the structural change mainly occurs in a - b plane when Nd³⁺ partially substitutes for Bi³⁺ in the Bi₂O₂ layer for Nd-doped SBN samples. It should be noted that the tilting angle for NbO₆ octahedron decreases from 9.72° for $\chi=0$ to 9.45° for $\chi=0.2$ and 5.48° for $\chi=0.4$ sample with the increase in the Nd content for Nd-doped SBN samples. The decrease in the tilting angle is related with the 6s² lone-pair electrons of Bi ions in Bi₂O₂ layers[8].

In order to further determine whether the doped Nd³⁺ indeed substitutes for Bi³⁺ in Bi₂O₂ layers or not, synchrotron radiation XAFS technique is used to probe the local environment of doped Nd³⁺ in SBN ceramics. Fig.2 shows the extended-XAFS spectra of Nd-L₃ absorption edge in SrBi_{2- χ} Nd _{χ} Nb₂O₉ ($\chi=0.2$ and 0.4) samples. Since Nd-L₃ absorption edge lies in the 6 208 eV position and Nd-L₂ absorption edge is close to Nd-L₃, the range of selected energy varies from 6 100 to 6 700 eV. As illustrated in Fig.2, some vibration peaks appear near the high energy side of Nd-L₃ edge, which just is attributed to the extended X-ray absorption fine structure.

In addition, It can be seen from Fig.2 that the energy position of Nd-L₃ absorption edge is the same and three little vibration peaks behind Nd-L₃ edge have the similar shape for $\chi=0.2$ and $\chi=0.4$ samples. These observations reflect that the Nd atoms in $\chi=0.2$ and $\chi=0.4$ samples have the same electrovalent structure and the similar local coordination structure[13–14]. Fig.3 gives Fourier transform magnitudes of the Nd-L₃ edge extended-XAFS spectrum of SrBi_{2- χ} Nd _{χ} Nb₂O₉ ($\chi=0.2$ and 0.4) samples. The strongest peak in Fig.3 represents the distance between Nd atom and the nearest coordination atom O (i.e. the first coordination shell peak). It is obvious that the first coordination shell peak of $\chi=0.2$ sample (near 2.2 Å) is the same as that of $\chi=0.4$ sample and both the second coordination shell peaks of $\chi=0.2$ and 0.4 samples appear at about 3.4 Å, which further indicates that the local structures around Nd atoms in $\chi=0.2$ and $\chi=0.4$ samples are very similar. Furthermore, it was ever reported by WACHSMUTH et al[15] that the first and second coordination shell peaks for the Bi atom of Ba_{0.6}Sr_{0.4}Bi₂Nb₂O₉ were near 2.20 and 3.61 Å using synchrotron radiation extended-XAFS technology. More importantly, the configurations of the first and second coordination shell peaks for Nd-L₃ edge of SrBi_{2- χ} Nd _{χ} Nb₂O₉ ($\chi=0.2$ and 0.4) samples are very similar to those of Bi-L₃ edge of Ba_{0.6}Sr_{0.4}Bi₂Nb₂O₉. These results above further indicate that Nd³⁺ really occupies Bi-site in Bi₂O₂ layers for SrBi_{2- χ} Nd _{χ} Nb₂O₉ samples. Therefore, the combination of X-ray Rietveld refinement and synchrotron radiation extended-XAFS

technology strongly confirm that the doped Nd^{3+} successfully substitutes for Bi^{3+} in $\text{SrBi}_{2-\chi}\text{Nd}_{\chi}\text{Nb}_2\text{O}_9$ samples.

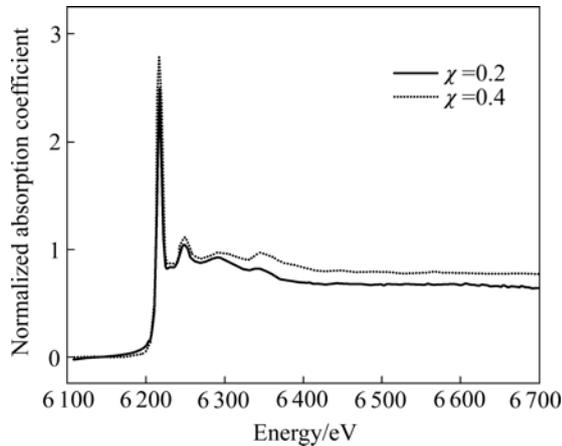


Fig.2 Extended-XAFS spectra of Nd-L₃ edge in $\text{SrBi}_{2-\chi}\text{Nd}_{\chi}\text{Nb}_2\text{O}_9$ ($\chi=0.2$ and 0.4) samples

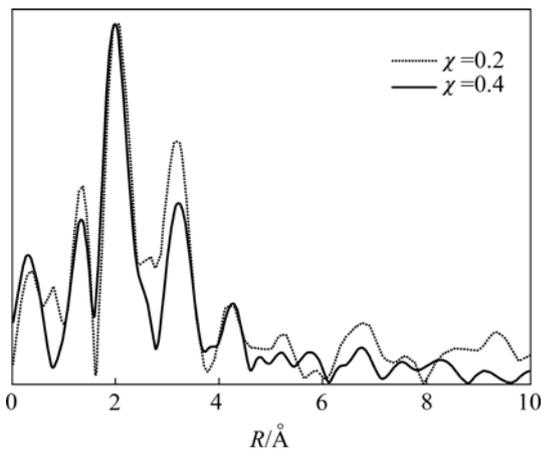


Fig.3 Fourier transform magnitudes of Nd-L₃ edge extended-XAFS spectrum of $\text{SrBi}_{2-\chi}\text{Nd}_{\chi}\text{Nb}_2\text{O}_9$ ($\chi=0.2$ and 0.4) samples (R : interatomic distance between Nd atoms and other atoms)

3.2 Ferroelectric and piezoelectric properties

Fig.4 shows the $P-E$ hysteresis loops of $\text{SrBi}_{2-\chi}\text{Nd}_{\chi}\text{Nb}_2\text{O}_9$ ($\chi=0, 0.1, 0.2$ and 0.4) ceramics measured at $150\text{ }^\circ\text{C}$. The $P-E$ hysteresis loops of all samples approach saturation under the strong external electric field. With the increase in Nd content, both the coercive field ($2E_c$) and the remanent polarization ($2P_r$) gradually decrease. For instance, $2E_c$ decreases from 91.31 kV/cm for $\chi=0$ to 70 kV/cm for $\chi=0.2$ and $2P_r$ also decreases from $15.6\text{ }\mu\text{C/cm}^2$ for $\chi=0$ to $11.90\text{ }\mu\text{C/cm}^2$ for $\chi=0.2$. It may be related to the decrease in NbO_6 structural distortion due to the increase in Nd content for $\text{SrBi}_{2-\chi}\text{Nd}_{\chi}\text{Nb}_2\text{O}_9$ ($\chi=0, 0.1, 0.2$) ceramics. As for $\chi=0.4$ sample, its $P-E$ hysteresis loop is not characteristic of the ferroelectric hysteresis loop because of its low transition temperature ($T_m=75\text{ }^\circ\text{C}$) and it is observed that

both $2P_r$ and $2E_c$ of $\chi=0.4$ sample approach zero. These results indicate that the partial substitution of Nd^{3+} for Bi^{3+} leads to the deterioration of the ferroelectric properties of Nd-doped SBN ceramics.

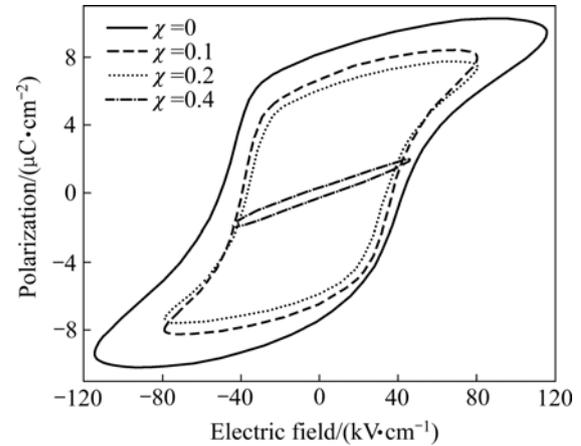
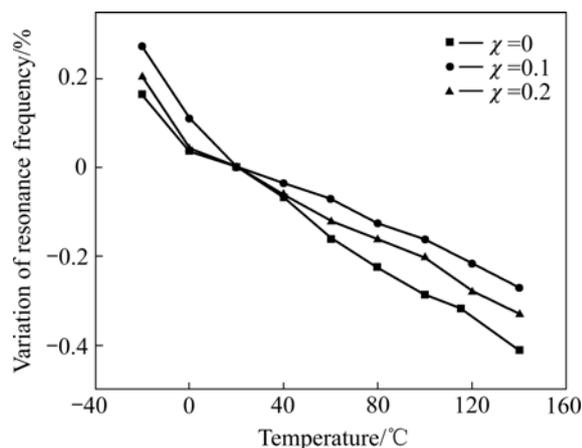


Fig.4 Hysteresis loops of $\text{SrBi}_{2-\chi}\text{Nd}_{\chi}\text{Nb}_2\text{O}_9$ ($\chi=0, 0.1, 0.2$ and 0.4) samples

Table 3 shows the piezoelectric characteristics of $\text{SrBi}_{2-\chi}\text{Nd}_{\chi}\text{Nb}_2\text{O}_9$ ($\chi=0, 0.1$ and 0.2) ceramics. As illustrated in Table 3, Nd-doped SBN ceramics have low dielectric constant ϵ_r , low piezoelectric constant d_{33} , low electromechanical coupling coefficients K_p and high mechanical quality factor Q_m compared with lead zirconate titanate (PZT) ceramics. Furthermore, it should be noted that d_{33} decreases from 11 pC/N for $\chi=0$ to 6 pC/N for $\chi=0.2$ when Nd content (χ) increases gradually in Nd-doped SBN ceramics. This result is consistent with the decrease in $2P_r$ due to the substitution of Nd^{3+} for Bi^{3+} in Bi_2O_2 layers. SBN is expected as the candidate for the fine-tolerance resonator application because it has low ϵ_r , low K_p , high Q_m and low TCF value[16]. However, the TCF value of SBN is not low enough to satisfy the requirement of fine-tolerance resonator application. Thus, the doping-element method was used to decrease the TCF value. For example, there were some research papers which reported that the substitution of Ba^{2+} for Sr^{2+} induced the dielectric relaxor behavior and decreased TCF values for $(\text{Sr}_{1-\chi}\text{Ba}_{\chi})\text{Bi}_2\text{Nb}_2\text{O}_9$ ceramics [16–17]. Considering that the substitution of Nd^{3+} for Bi^{3+} also induces the dielectric relaxor behavior for $\text{SrBi}_{2-\chi}\text{Nd}_{\chi}\text{Nb}_2\text{O}_9$ ceramics[7], it is naturally expected this substitution can lead to lower TCF values. Fig.5 gives the temperature dependence of resonance frequency of $\text{SrBi}_{2-\chi}\text{Nd}_{\chi}\text{Nb}_2\text{O}_9$ ($\chi=0, 0.1$ and 0.2) ceramics in the range from -20 to $140\text{ }^\circ\text{C}$. It can be apparently seen from Fig.5 that TCF values of $\chi=0.1$ and 0.2 samples are lower than that of $\chi=0$ sample. In other words, the substitution of Nd^{3+} for Bi^{3+} decreases the TCF values of SBN ceramics. The reason for it is possibly related to the dielectric relaxor behavior of Nd-doped SBN ceramics[17].

Table 3 Piezoelectric characteristics of SrBi_{2- χ} Nd _{χ} Nb₂O₉ ($\chi=0, 0.1$ and 0.2) ceramics

SrBi _{2-χ} Nd _{χ} Nb ₂ O ₉ sample	ϵ_r (at 1 kHz, RT)	$d_{33}/$ (pC·N ⁻¹)	$K_p/\%$	Q_m
$\chi=0$	145	11	4.5	3 250
$\chi=0.1$	152	7	5	3 960
$\chi=0.2$	155	6	4	3 390

**Fig.5** Temperature dependence of resonance frequency of SrBi_{2- χ} Nd _{χ} Nb₂O₉ ($\chi=0, 0.1$ and 0.2) ceramics

4 Conclusions

1) SrBi_{2- χ} Nd _{χ} Nb₂O₉ ($\chi=0, 0.1, 0.2$ and 0.4) ceramics were synthesized by the conventional solid-state reaction sintering method. The substitution of Nd³⁺ for Bi³⁺ in the Bi₂O₂ layers for SrBi_{2- χ} Nd _{χ} Nb₂O₉ ceramics were determined by the combination of X-ray Rietveld refinement and synchrotron radiation XAFS technique. X-ray Rietveld refinement also indicates that the substitution of Nd³⁺ for Bi³⁺ leads to the decrease in the structural distortion of NbO₆ octahedron, which is described by tilt angle.

2) The substitution of Nd³⁺ for Bi³⁺ decreases the remnant polarization and piezoelectric constant, whereas it decreases the temperature coefficient of resonance frequency values of SBN ceramics. SrBi_{2- χ} Nd _{χ} Nb₂O₉ ceramics can be regarded as one of candidates for fine-tolerance resonator applications.

Acknowledgements

The X-ray absorption spectroscopy of XAFS measurements were performed on synchrotron radiation from beamline U7c at the National Synchrotron Radiation Laboratory in University of Science and Technology of China (USTC). The authors are grateful to PAN Zhi-yun in USTC for discussing the XAFS data and to LIU

Fu-sheng in Shenzhen University for his help and advice on Rietveld refinement.

References

- [1] AURIVILLIUS B, FANG P H. Ferroelectricity in the compound Ba₂Bi₄Ti₅O₁₈ [J]. *Physics Review*, 1962, 126: 893–896.
- [2] ARAUJO C A, CUCHIARO J D, MCMILLAN L D, SCOTT M C, SCOTT J F. Fatigue-free ferroelectric capacitors with platinum electrodes [J]. *Nature*, 1995, 374: 627–629.
- [3] PARK B H, KANG B S, BU S D, NOH T W, LEE J, JO W. Lanthanum-substituted bismuth titanate for use in non-volatile memories [J]. *Nature*, 1999, 401: 682–684.
- [4] WATANABE H, MIHARA T, YOSHIMORI H, ARAUJO A P. Preparation of ferroelectric thin films of bismuth layer structured compounds [J]. *Japanese Journal of Applied Physics*, 1995, 34: 5240–5244.
- [5] HUANG Shi-ming, FENG Chu-de, CHEN Li-dong, WEI Xiao-wei. Dielectric properties of SrBi_{2- χ} Pr _{χ} Nb₂O₉ ceramics ($\chi=0, 0.04$ and 0.2) [J]. *Solid State Communication*, 2005, 133: 375–379.
- [6] HUANG Shi-ming, SUN Lin, FENG Chu-de, CHEN Li-dong. Relaxor behavior of layer structured SrBi_{1.65}La_{0.35}Nb₂O₉ [J]. *Journal of Physics*, 2006, 99: 076104.
- [7] SUN Lin, FENG Chu-de, CHEN Li-dong, HUANG Shi-ming. Dielectric relaxation in layer-structured SrBi_{2- χ} Nd _{χ} Nb₂O₉ ceramics ($\chi=0, 0.05, 0.2, 0.35$) [J]. *Journal of American Ceramic Society*, 2007, 90(1): 322–326.
- [8] SUN Lin, FENG Chu-de, CHEN Li-dong, HUANG Shi-ming. Dielectric and piezoelectric properties of SrBi_{2- χ} Sm _{χ} Nb₂O₉ ($\chi=0, 0.05, 0.1, 0.2, 0.3, \text{ and } 0.4$) ceramics [J]. *Journal of American Ceramic Society*, 2007, 90(12): 3875–3881.
- [9] SUN Lin, CHU Jun-hao, FENG Chu-de, CHEN Li-dong. Analysis of relaxor mechanism and structural distortion for SrBi_{1.6}Nd_{0.4}Nb₂O₉ bismuth-layer-structured ceramics [J]. *Applied Physics Letters*, 2007, 91: 242902.
- [10] BLAKE S M, FALCONER M J, MCCREEDY M, LIGHTFOOT P. Cation disorder in ferroelectric Aurivillius phases of the type Bi₂ANb₂O₉ (A=Ba, Sr, Ca) [J]. *Journal of Material Chemistry*, 1997, 7: 1609–1613.
- [11] ISMUNANDAR, KENNEDY B J. Effect of temperature on cation disorder in ABi₂Nb₂O₉ (A=Sr, Ba) [J]. *Journal of Material Chemistry*, 1999, 9: 541–544.
- [12] KENNEDY B J, HUNTER B A. Cation disorder in Pb-doped SrBi₂Nb₂O₉ [J]. *Chemistry Materials*, 2001, 13: 4612–4617.
- [13] SUNSTROM J E, KAUZLARICH S M, ANTONIO M R. Synthesis, structure and characterization of Ce_{1- χ} TiO₃ (0.0 $\leq\chi\leq$ 0.8; A=Sr, Ba) [J]. *Chemistry Materials*, 1993, 5: 182–191.
- [14] NEVES P P, DORIGUETTO A C, MASTERLARO V R, LOPES L P, MASCARENHAS Y P, MICHALOWICZ A, EIRAS J A. XAS and XRD structural characterization of lanthanum-modified PbTiO₃ ceramic materials [J]. *Journal of Physical Chemistry B*, 2004, 108: 14840–14849.
- [15] WACHSMUTH B, ZSCHECH E, THOMAS N W, BRODIE S G, GURMAN S J, BAKER S, BAYLISS S C. Structure model of Aurivillius compounds: An EXAFS study [J]. *Physical State Solid A*, 1993, 135: 59–79.
- [16] ANDO A, KIMURA M, SAWADA T, HAYASHI K, SAKABE Y. Piezoelectric and ferroelectric properties of the modified SrBi₂Nb₂O₉ ceramics [J]. *Ferroelectrics*, 2002, 268: 65–70.
- [17] ANDO A, KIMURA M, SAKABE Y. Piezoelectric resonance characteristics of SrBi₂Nb₂O₉-based ceramics [J]. *Japanese Journal of Applied Physics*, 2003, 42: 150–156.

(Edited by YANG Hua)