JOURNAL OF MATERIALS SCIENCE 25 (1990) 424–430

Dielectric properties of low-fitting $Pb(Mg_{1/3}Nb_{2/3})_{1-x}Ti_xO_3$–$Bi_2O_3/Li_2O$ ceramics

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Dielectric properties of low-firing $Pb(Mg_{1/3}Nb_{2/3})_{1-x}Ti_xO_3$–$Bi_2O_3/Li_2O$ ceramics are studied in this work. With the addition of Bi_2O_3/Li_2O eutectic composition, the sintering temperature of $PMN_{1-x}PT_x$ could be lowered to 900° C. Relaxor behaviour of $PMN_{1-x}PT_x$ is enhanced by the incorporation of Bi_2O_3/Li_2O due to the substitution of Bi^{+3}/Li^+ into the $PMN_{1-x}PT_x$ framework. Bi_2O_3/Li_2O eutectic composition is used as a fluxing agent, Curie shifter and depressor. Evaporation of Bi_2O_3/Li_2O and PbO during firing is checked and examined via energy dispersive spectrometry (EDS) and X-ray diffraction (XRD) is used to clarify the Curie shifting and depressing effect of Bi_2O_3/Li_2O.

1. Introduction

It is well known that lead magnesium niobate-based ceramics [1] are promising dielectric materials for capacitors due to their high dielectric constant, small grain size, broad dielectric maximum and high insulation resistivity. Besides, PMN-based relaxors have also been proven to be promising materials for electrostrictive transducers with excellent positional reproducibility and low ageing rate but a lower electrostrictive coefficient than that of PZT [2–4]. To obtain a large electrostrictive strain, a modified plate-through type multilayered actuator has been developed.

The problems encountered in the preparation of $Pb(Mg_{1/3}Nb_{2/3})_{1-x}Ti_xO_3$ (abbreviated to $PMN_{1-x}PT_x$) are the appearance of a pyrochlore phase and the poor reproducibility in consequence [5]. Control of the PbO atmosphere is also critical to prevent the formation of pyrochlore phase [6] and preserve the stoichiometry of the desired solid solution, since the sintering temperatures of $PMN_{1-x}PT_x$ are as high as 1200 to 1300° C [7]. In order to eliminate the appearance of pyrochlore phase and lower the sintering temperature of $PMN_{1-x}PT_x$ to prevent PbO evaporation and to make it possible to use a high silver-content conductor as the internal electrode of multilayered actuator or multilayer ceramic capacitor, a new processing technique instead of conventional oxide-mixing method was developed.

In the work of Swartz and Shrout [5] the "novel" fabrication technique accompanied with the addition of excess MgO was first proposed in preparing pure perovskite $PMN_{1-x}PT_x$. Lejune and Boilot [6] used a conventional oxide-mixing process with the addition of lead oxide to prepare pyrochlore-free $PMN_{1-x}PT_x$, using lead oxide as a liquid fluxing agent. $PMN_{1-x}PT_x$ prepared by this method could be sintered at 900 to 1000° C.

The purpose of this work is to lower the sintering temperature of $PMN_{1-x}PT_x$ ($0 \leqslant x \leqslant 0.2$) with the addition of Bi_2O_3/Li_2O, where Bi_2O_3/Li_2O with a melting point of about 700° C is the eutectic composition of Bi_2O_3 and Li_2O. A similar method to the so-called "novel" fabrication technique accompanied with the addition of 0.2 wt % MgO was used to prepare pyrochlore free $PMN_{1-x}PT_x$ [7].

2. Experimental procedure

2.1. Preparation of $PMN_{1-x}PT_x$–Bi_2O_3/Li_2O

The raw materials used in this work were all reagent-grade oxides such as PbO, MgO, Nb_2O_5, TiO_2, Bi_2O_3 and Li_2O. $MgNb_2O_6$ columbite was first prepared by calcining the mixture of MgO and Nb_2O_5 at 1000° C for 4 h. PbO, $MgNb_2O_6$, TiO_2 and excess 0.2 wt % MgO were weighed in appropriate proportionality and then ball-milled together in acetone for 8 h. Subsequent calcination of $PMN_{1-x}PT_x$ with $0 \leqslant x \leqslant 0.2$ were all carried out at 800° C for 4 h.

The fluxing agent, Bi_2O_3/Li_2O, was obtained by first mixing Bi_2O_3 and Li_2O in a molar ration of 89 : 11 and then the dried slurry was calcined at 620° C for 2 h. After pulverizing the calcined $PMN_{1-x}PT_x$ and Bi_2O_3/Li_2O, respectively, 2 to 10 wt % Bi_2O_3/Li_2O and $PMN_{1-x}PT_x$ were ball-milled together in acetone for 8 h. The dried powders were then mixed with 5 wt % distilled water and pressed in a steel die 1.27 cm in diameter. Six stacked disks were fired in a covered alumina crucible. The soaking time of all the firing processes in this work was fixed at 2 h.

2.2. Examination of evaporated low melting-point phases

To check if the added Bi_2O_3/Li_2O or other low melting point phases might evaporate during sintering, an alumina (96% Al_2O_3) substrate was covered above the pressed ceramic powder and used as a collector for the evaporated phases during firing, as shown in Fig. 1. The composition of the ceramic sample was $PMN_{0.85}PT_{0.15}$ added with 4 wt % Bi_2O_3/Li_2O. Low

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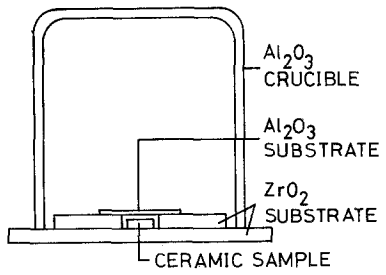

Figure 1 Arrangement for the collection of the evaporated phase from $PMN_{0.85}PT_{0.15}$ with 4 wt % Bi_2O_3/Li_2O added.

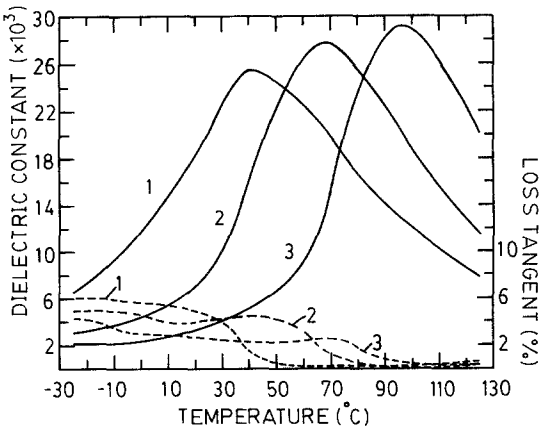

Figure 2 Temperature dependence of dielectric constant (——) and loss tangent (– – –) of 1270° C-fired $PMN_{1-x}PT_x$. (1) $x = 0.1$; (2) $x = 0.15$; (3) $x = 0.2$.

melting phases were then evaporated under the stress of 850° C for 2 h. The evaporated film on the Al_2O_3 substrate was analysed qualitatively with the help of the energy dispersive spectrometer (EDS) and X-ray diffraction (XRD) method.

2.3. Measurement of dielectric properties

Dielectric properties were measured from the 1 mm-thick disk-type specimens with silver electrodes fired on both sides. The dielectric constant and loss tangent were obtained from an HP4192A LF impedance analyser at 1 KHz with 1 V r.m.s. Insulation resistance was measured with a TOA SM-5E super megohm meter 2 min after applying 1000 V d.c.

3. Results and discussion

3.1. Dielectric properties of $PMN_{1-x}PT_x$ with $0.1 \leqslant x \leqslant 0.2$

Figure 2 shows the temperature dependence of dielectric constant and loss tangent of 1270° C-fired $PMN_{1-x}PT_x$ with $0.1 \leqslant x \leqslant 0.2$. The apparent Curie temperature of $PMN_{1-x}PT_x$ for $x = 0.1$, 0.15 and 0.2 are 40, 69 and 98° C, respectively. From the decrease of the loss tangent maximum with the molar ratio x, it is believed that the degree of order of cation ions increased with the content of $PbTiO_3$. Composition of $PMN_{1-x}PT_x$ with x less than 0.1 is suitable for capacitor use, because of its lower Curie temperature, broader dielectric maximum region and lower electrostrictive coefficient. Composition of $PMN_{0.9}PT_{0.1}$ with Curie region centred around room temperature exhibited superior electrostrictive properties to that of $PMN_{1-x}PT_x$ with x larger than 0.1 in positional reproducibility, since the phase of $PMN_{1-x}PT_x$ with x larger than 0.1 at room temperature was dominated by ferroelectric phase [2–4]. This would induce inverse hysteresis, which is inadequate for electrostrictive use. But from the power consumption point of view [8], $PMN_{1-x}PT_x$ with a small x value, was not suitable for the actuator material application because of its high dielectric constant. For the purpose of electrostrictive use, some compromise between the above arguments have to be made and the composition with lower dielectric constant and broad dielectric maximum centred around room temperature is desired if positonal reproducibility and power consumption are both taken into consideration.

In our previous work, Bi_2O_3/Li_2O was used as a fluxing agent, depressor and Curie shifter [9]. To make the resultant $PMN_{1-x}PT_x$ a promising dielectric and electrostrictive material with the incorporation of Bi_2O_3/Li_2O flux agent, $PMN_{1-x}PT_x$ with x less than

TABLE I Effect of firing temperatures and Bi_2O_3/Li_2O content on the properties of $PMN_{0.85}PT_{0.15}$

	Bi_2O_3/Li_2O (wt %)								
	4			6			8		
	Firing temperature (° C)								
	900	925	975	900	925	975	900	925	975
Density ($g cm^{-3}$)	7.48	7.49	7.28	7.63	7.32	7.18	7.62	7.37	7.2
Dielectric constant	7643	8333	10721	5113	7546	8063	4764	6122	7064
Loss tangent (%)	2.2	2.2	2.68	1.69	1.0	0.99	1.17	0.81	0.68
Curie temperature (° C)	33	31	24	26	11	13	20	8	7
Variation of capacitance (%) (at −30, 85 and 125° C)	−46.4 −18.6 −42.6	−45.3 −23.8 −44.7	−48.9 −29.9 −52.5	−38.1 −15.7 −32.9	−36.3 −25.0 −44.9	−41.2 −29.9 −49.1	−33.3 −16.7 −34.4	−28.5 −22.1 −40.1	−34.6 −27.5 −44.4
Insulation resistivity ($\times 10^{12}\ \Omega$ cm)	0.20	2.33	1.41	0.026	2.60	2.05	0.032	2.85	1.16

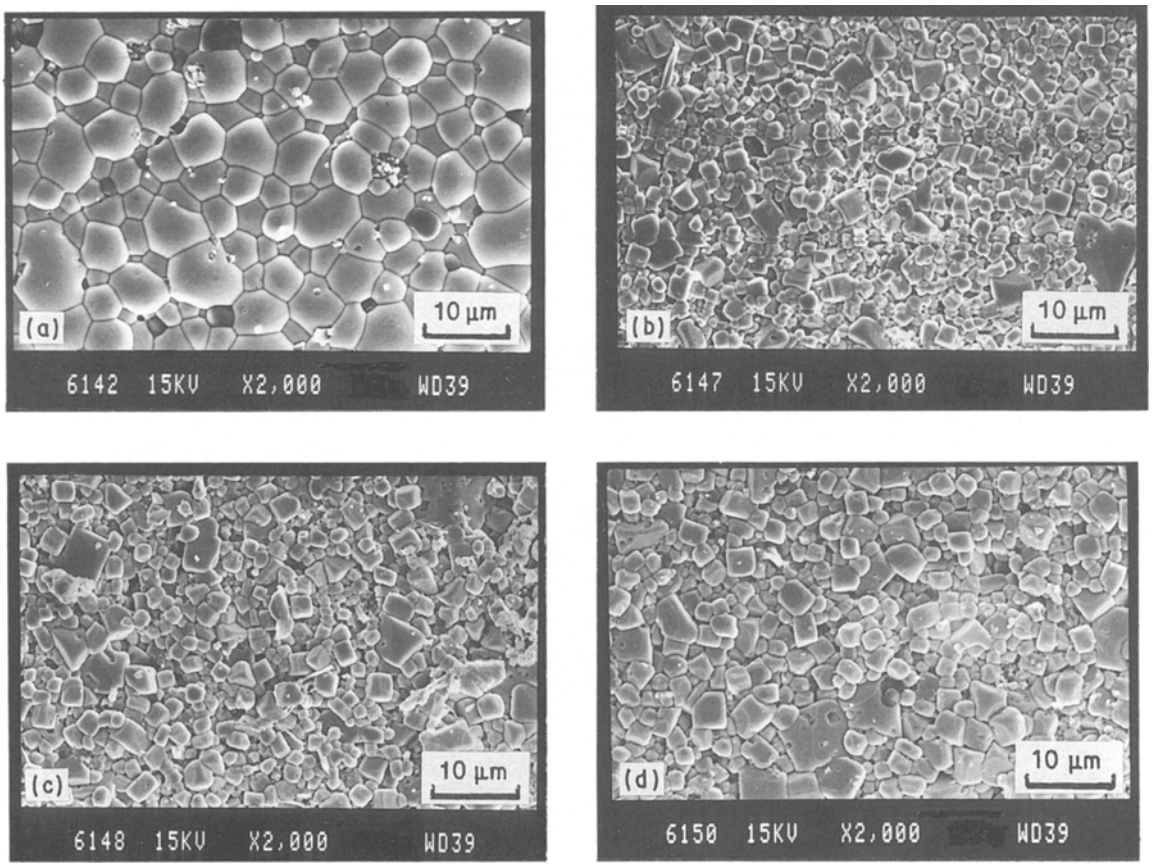

Figure 3 Free surface observation of (a) $PMN_{0.85}PT_{0.15}$, (b) $PMN_{0.85}PT_{0.15}$ with the addition of 2 wt % Bi_2O_3/Li_2O, (c) 4 wt % Bi_2O_3/Li_2O and (d) 8 wt % Bi_2O_3/Li_2O.

0.2 was selected as the candidate compositions based on the above mentioned compromise, since the Curie temperature of $PMN_{1-x}PT_x$ with x less than 0.2 could be restricted in the range of -30 to 50° C (to be seen in the following).

3.2. Typical dielectric properties of $PMN_{0.85}PT_{0.15}$–Bi_2O_3/Li_2O

Table I lists the typical properties of $PMN_{0.85}PT_{0.15}$ incorporated with different amounts of Bi_2O_3/Li_2O. Correlations between sintering temperature and the measured properties are also summarized in Table I. As can be seen in Table I, 0.85PMN–0.15PT can be fired at 900° C with the addition of 4 wt % Bi_2O_3/Li_2O. The density obtained in this case was 7.48 g cm^{-3}, while the theoretical density of 0.85PMN–0.15PT is 8.08 g cm^{-3}.

The composition of $PMN_{0.85}PT_{0.15}$–Bi_2O_3/Li_2O covers the desired Curie ranges for both dielectric and electrostrictive uses. The composition of $PMN_{0.8}PT_{0.2}$ incorporated with Bi_2O_3/Li_2O is only suitable for electrostrictive use because its Curie temperature is about 40° C.

3.3. Fluxing agent of Bi_2O_3/Li_2O

The scanning electron micrograph (SEM) of $PMN_{0.85}PT_{0.15}$ with different amounts of Bi_2O_3/Li_2O added are shown in Fig. 3, where the sintering temperature of pure $PMN_{0.85}PT_{0.15}$ and Bi_2O_3/Li_2O added $PMN_{0.85}PT_{0.15}$ are 1270° C and 925° C, respectively. With higher Bi_2O_3/Li_2O content, a denser microstructure with a larger grain size are observed. From the density measurements of Table I and SEM examination of Fig. 3, the fluxing effect of Bi_2O_3/Li_2O is obvious.

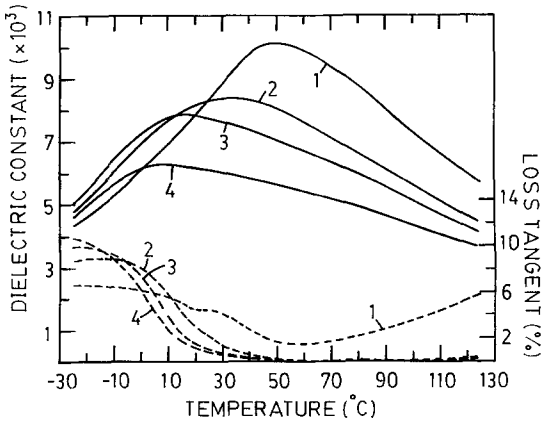

Figure 4 Temperature dependence of (——) dielectric constant and (– – –) loss tangent of 925° C-fired $PMN_{0.85}PT_{0.15}$ with different amounts of Bi_2O_3/Li_2O added. (1) 2 wt %; (2) 4 wt %; (3) 6 wt %; (4) 8 wt %.

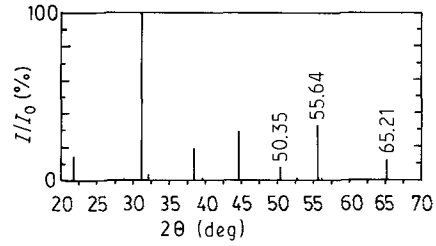

Figure 5 X-ray diffraction pattern of 1270° C fired $PMN_{0.85}PT_{0.15}$.

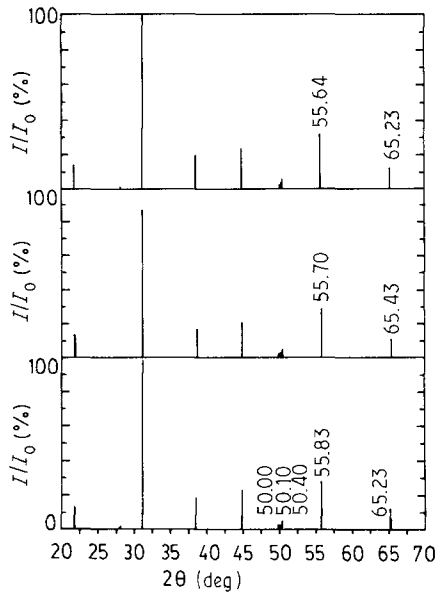

Figure 6 X-ray diffraction pattern of 925° C fired $PMN_{0.85}PT_{0.15}$ with different amounts of Bi_2O_3/Li_2O added.

3.4. Depressing and broadening effect of Bi_2O_3/Li_2O

Figure 4 shows the temperature dependence of the dielectric constant and loss tangent of $PMN_{0.85}PT_{0.15}$ with different amounts of Bi_2O_3/Li_2O, where the sintering temperature is 925° C. As can be seen in Fig. 4, 2 wt % Bi_2O_3/Li_2O is not sufficient to lower the sintering temperature to 925° C, justified from its poor loss tangent against temperature characteristics. The maximum dielectric constant of $PMN_{0.85}PT_{0.15}$ is depressed from 27600 to 10137, 8442, 7620 and 6280 with the addition of 2, 4, 6 and 8 wt % Bi_2O_3/Li_2O, respectively. The depressing effect of Bi_2O_3/Li_2O may be ascribed to the modification of bulk composition or the segregation of Bi_2O_3/Li_2O along the grain boundary (to be discussed in the following).

The X-ray diffraction pattern of 1270° C fired $PMN_{0.85}PT_{0.15}$ and that of $PMN_{0.85}PT_{0.15}$ added with different amounts of Bi_2O_3/Li_2O are shown in Figs 5 and 6, respectively. By comparing the results of Figs 5 and 6, changes of both the bulk composition and the phase of $PMN_{0.85}PT_{0.15}$ by the substitution of Bi^{3+}/Li^+ can be understood from the split of the diffraction peak of $PMN_{0.85}PT_{0.15}$ at 50.35° into 50, 50.1 and 50.4° after incorporation of 8 wt % Bi_2O_3/Li_2O into $PMN_{0.85}PT_{0.15}$. The shift of the diffraction peak can be visualized as the shift of d-space and thus the change of the lattice constant of $PMN_{0.85}PT_{0.15}$ due to the modification of $PMN_{0.85}PT_{0.15}$ by Bi_2O_3/Li_2O.

Figure 7 shows the X-ray diffraction pattern of

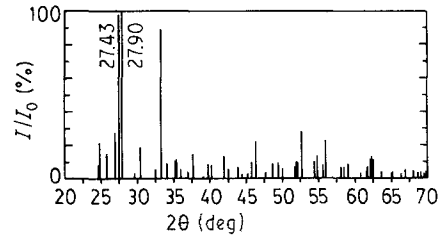

Figure 7 X-ray diffraction pattern of eutectic Bi_2O_3/Li_2O.

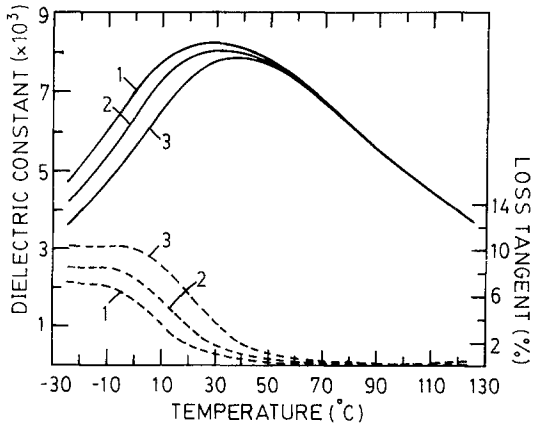

Figure 8 Relaxor behaviour of 900° C-fired $PMN_{0.9}PT_{0.1}$ with 2 wt % Bi_2O_3/Li_2O added. (1) 1 kHz; (2) 10 kHz; (3) 100 kHz. (——) Dielectric constants; (- - -) loss tangents.

680° C calcined Bi_2O_3/Li_2O. The X-ray diffraction pattern of Bi_2O_3/Li_2O is similar to tht of Bi_2O_3 except the relative intensity of diffraction peaks, i.e. the eutectic composition of Bi_2O_3 and Li_2O is formed by the substitution of Li_2O into the matrix of Bi_2O_3. The first two maximum diffraction peaks of Bi_2O_3/Li_2O were 27.4 and 27.9°, respectively. By checking the result of Fig. 6, there are no such diffraction peaks if the content of Bi_2O_3/Li_2O in $PMN_{0.85}PT_{0.15}$ is less than 8 wt %. But for 8 wt % Bi_2O_3/Li_2O added $PMN_{0.85}PT_{0.15}$, there are two diffraction peaks at 27.8 and 28°, similar to that of the Bi_2O_3/Li_2O phase. This result suggests that excess Bi_2O_3/Li_2O may segregate along the grain boundary.

One interesting thing observed in Fig. 4 is that Bi_2O_3/Li_2O shows a significant effect on the degree of order of the cations arrangement. As shown in Fig. 4, the peak value of loss tangent and the Curie region are increased and broadened, respectively, with increasing Bi_2O_3/Li_2O content, i.e. the relaxing characteristics of $PMN_{1-x}PT_x$, and the diffuse phase transition is enhanced with the incorporation of Bi_2O_3/Li_2O. The enhancement of the diffuse phase transition could be explained as the substitution of Bi^{3+}/Li^+ into $PMN_{1-x}PT_x$. The relaxor behaviour of 2 wt % Bi_2O_3/Li_2O-added $PMN_{0.9}PT_{0.1}$ is illustrated in Fig. 8.

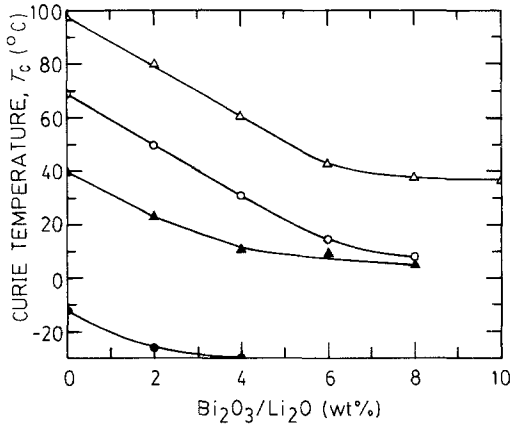

Figure 9 Effect of Bi_2O_3/Li_2O contents on the shifting of Curie temperature of $PMN_{1-x}PT_x$. (●) $x = 0$; (▲) $x = 0.1$; (○) $x = 0.15$; (△) $x = 0.2$.

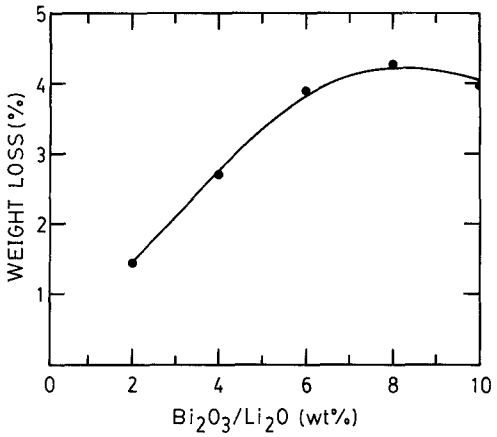

Figure 10 Weight losses of 925° C-fired $PMN_{0.8}PT_{0.2}$ with different amounts of Bi_2O_3/Li_2O added.

3.5. Curie shifting effect of Bi_2O_3/Li_2O

As can be seen in Fig. 4, the Curie temperature of $PMN_{1-x}PT_x$ is shifted from 69° C to 48, 33, 11 and 8° C with the addition of 2, 4, 6 and 8 wt % Bi_2O_3/Li_2O, respectively. It is evidenced that Bi_2O_3/Li_2O could be used as Curie shifter of $PMN_{1-x}PT_x$. The effect of Bi_2O_3/Li_2O on the shifting of the Curie temperature of $PMN_{1-x}PT_x$ is shown in Fig. 9, where the sintering temperature was 925° C. Curie temperature of $PMN_{1-x}PT_x$ is first decreased almost linearly with the content of Bi_2O_3/Li_2O and then approaches to a stable value with further increments of Bi_2O_3/Li_2O. For $PMN_{0.8}PT_{0.2}$ added with 8 and 10 wt % Bi_2O_3/Li_2O, the Curie temperatures are 38° C and 37° C, respectively, i.e. the dissolving of Bi_2O_3/Li_2O into the $PMN_{1-x}PT_x$ grains would not be increased with further increments of Bi_2O_3/Li_2O. Excess Bi_2O_3/Li_2O may segregate along the grain boundary or evaporate due to its low melting point of about 700° C.

Figure 10 shows the weight loss of 925° C-fired $PMN_{0.8}PT_{0.2}$ incorporated with different Bi_2O_3/Li_2O contents. The trend of weight loss with Bi_2O_3/Li_2O content is similar to that of Curie temperature. Weight losses are first increased almost linearly and then

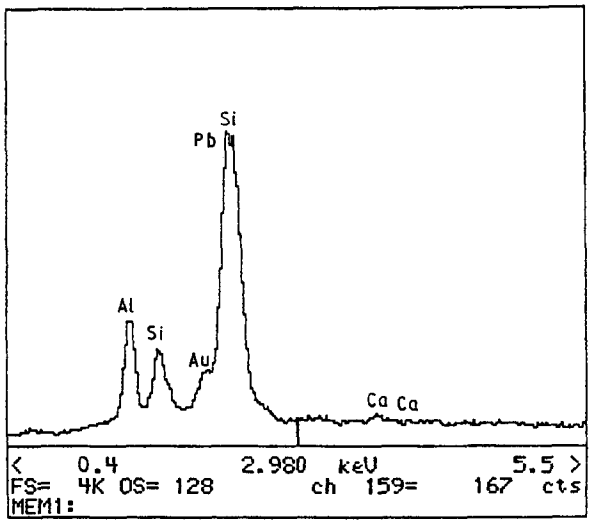

Figure 11 Energy dispersive spectrum of collected phases from the evaporation of 850° C-fired $PMN_{0.85}PT_{0.15}$ with 4 wt % Bi_2O_3/Li_2O added.

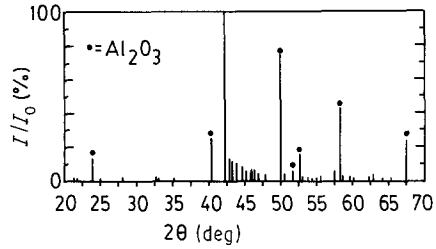

Figure 12 X-ray diffraction pattern of the evaporated film on Al_2O_3 substrate.

increased slowly with further increments of Bi_2O_3/Li_2O. The insignificant variations of both weight loss and Curie temperature imply that excess Bi_2O_3/Li_2O is segregated along the grain boundary. In Fig. 10, the weight loss of 8 wt % added $PMN_{0.8}PT_{0.2}$ is about 4.3 wt % i.e. there is at most 3.7 wt % in $PMN_{0.8}PT_{0.2}$. From this, the solubility of Bi_2O_3/Li_2O in $PMN_{0.8}PT_{0.2}$ could be estimated to be not more than 3.7 wt % at the sintering temperature of 925° C.

3.6. Identification of evaporated low melting-point phases

The energy dispersive spectrum (EDS) of the evaporated film on the Al_2O_3 substrate is shown in Fig. 11. The elements in the evaporated film on Al_2O_3 substrate are identified as Al, Si, Ca, Au, Pb and Bi. Al, Si and Ca came from the 96% Al_2O_3 substrate. Au is the evaporated gold film on the specimen surface for SEM observation. Pb and Bi originate from the phase of PbO and Bi_2O_3/Li_2O, respectively. This confirms the possibility of evaporation of Bi_2O_3/Li_2O during firing. Both the X-ray diffraction pattern and scanning electron micrograph of the evaporated film are shown in Figs 12 and 13, respectively. In addition to the diffraction peaks of Al_2O_3, another residual unknown single-crystal-like diffraction peak is neither that of PbO nor Bi_2O_3/Li_2O. According to the result of Fig. 11, this unknown phase is believed to be a solid solution of PbO and Bi_2O_3/Li_2O. However, whether this solid solution is formed before being evaporated on to alumina surface or after is not clarified in this work.

3.7. Variation of capacitance with temperature

Figure 14 shows the temperature dependencies of capacitance variations for $PMN_{0.85}PT_{0.15}$ incorporated with different amounts of Bi_2O_3/Li_2O, where the sintering temperature is 925° C. As can be seen in Fig. 14, capacitance variations are restricted within the range of 2.6 to 40% from −25° to 125° C with the addition of 8 wt % Bi_2O_3/Li_2O. This composition could be used as dielectrics for capacitor with stable temperature characteristics. An electrostrictive material with stable temperature characteristics, low power consumption and excellent positional reproducibility could be achieved with the aid of Bi_2O_3/Li_2O. For low content Bi_2O_3/Li_2O-added $PMN_{1-x}PT_x$, the broadening of the capacitance temperature characteristics may be attributed to the change of bulk composition by the substitution of Bi^{3+}/Li^+ into $PMN_{1-x}PT_x$. For higher

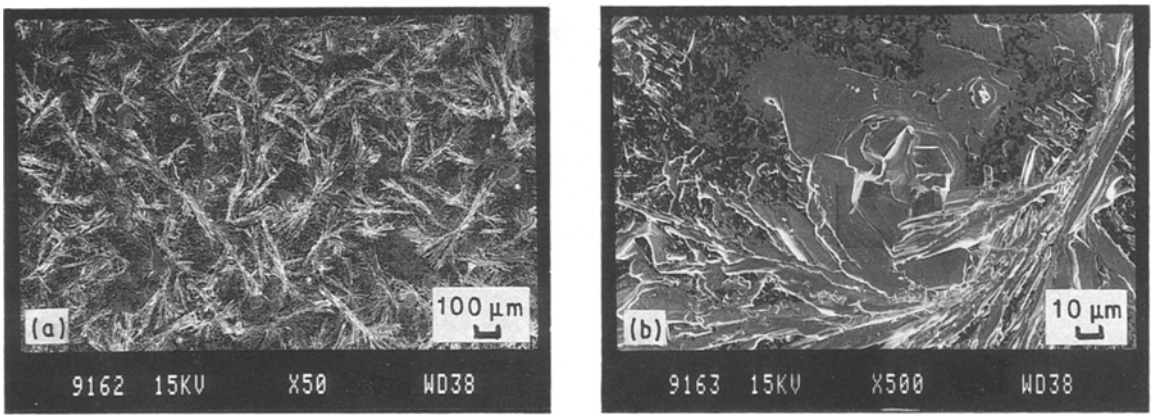

Figure 13 Scanning electron micrograph of the evaporated film on Al_2O_3 substrate with magnification of (a) × 50 and (b) × 500.

content Bi_2O_3/Li_2O-added $PMN_{1-x}PT_x$, the broadening of capacitance against temperature characteristics might result from the segregation of Bi_2O_3/Li_2O.

3.8. Effect of sintering temperature on the dielectric properties of $PMN_{1-x}PT_x$–Bi_2O_3/Li_2O

Figure 15 shows the temperature dependence of dielectric constant and loss tangent of 4 wt % Bi_2O_3/Li_2O-added $PMN_{0.85}PT_{0.15}$ fired at different temperatures. With increasing sintering temperature, more Bi_2O_3/Li_2O may dissolve into the $PMN_{1-x}PT_x$ grain. Curie temperature is thus decreased with firing temperature. The change of Curie temperature and weight loss of 8 wt % Bi_2O_3/Li_2O-added $PMN_{0.8}PT_{0.2}$ against firing temperature are delineated in Fig. 16.

Weight loss increased with firing temperature, but Curie temperature does not change significantly with firing temperature. This confirms the fact that dissolving of Bi_2O_3/Li_2O into the $PMN_{1-x}PT_x$ grain is compensated by the evaporation of Bi_2O_3/Li_2O. Under higher firing temperature such as 1000° C, dissolving of Bi_2O_3/Li_2O into the $PMN_{1-x}PT_x$ grain become insignificant. Consequently, Curie temperature is shifted back to higher temperature at 1000° C.

Figure 17 shows the temperature dependence of the capacitance variations of 4 wt % Bi_2O_3/Li_2O-added $PMN_{0.85}PT_{0.15}$ fired at different temperatures. The higher the firing temperature, the greater the evaporation of Bi_2O_3/Li_2O. As a result, possible segregation of Bi_2O_3/Li_2O could not take place at a higher firing temperature. There is an abrupt capacitance change of about 10% at 125° C due to the lack of Bi_2O_3/Li_2O along the grain boundary when the firing temperature increased up to 975° C.

4. Conclusion

The sintering temperature of $PMN_{1-x}PT_x$ could be lowered to 900° C via liquid phase sintering by adding the eutectic Bi_2O_3/Li_2O. In addition to the fluxing effect of Bi_2O_3/Li_2O, Bi_2O_3/Li_2O also could be visualized as a depressor and a Curie shifter. By comparing the relationships of weight loss against Bi_2O_3/Li_2O content and Curie temperature against Bi_2O_3/Li_2O content, the depressing effect under low Bi_2O_3/Li_2O content is ascribed to the substitution of Bi^{3+}/Li^+ into the bulk grain, which is the same reason as for the shifting of the Curie temperature. The depressing effect under higher Bi_2O_3/Li_2O content may be correlated to the segregation of Bi_2O_3/Li_2O along the grain boundary. The shift of the Curie temperature back to a higher temperature is relevant to the evaporation of Bi_2O_3/Li_2O.

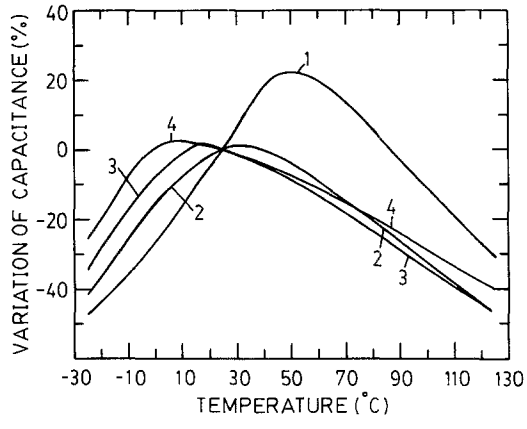

Figure 14 Temperature dependence of the capacitance variation for $PMN_{0.85}PT_{0.15}$ with different amounts of Bi_2O_3/Li_2O added. (1) 2 wt %; (2) 4 wt %; (3) 6 wt %; (4) 8 wt %.

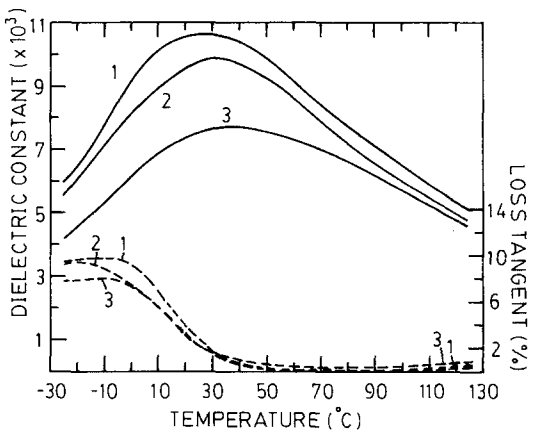

Figure 15 Temperature dependence of dielectric constant and loss tangent of 4 wt % Bi_2O_3/Li_2O-added $PMN_{0.85}PT_{0.15}$ fired at different temperature. (1) 975° C; (2) 950° C; (3) 900° C. (——) Dielectric constants; (– – –) loss tangents.

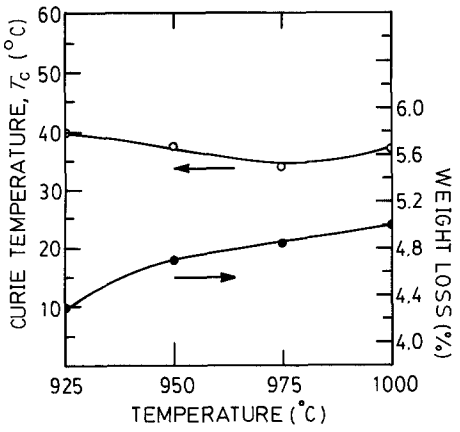

Figure 16 Firing temperature dependence of Curie temperature and weight loss of 8 wt % Bi_2O_3/Li_2O-added $PMN_{0.8}PT_{0.2}$.

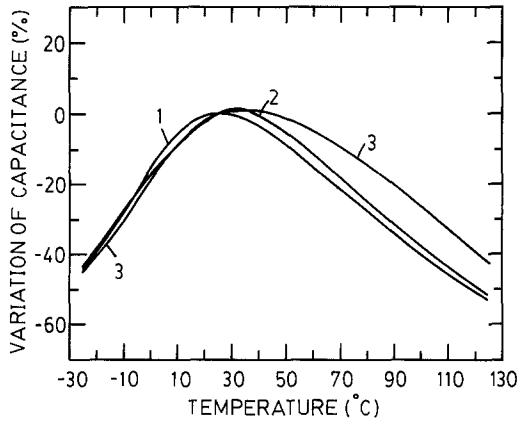

Figure 17 Temperature dependence of the capacitance variation of 4 wt % Bi_2O_3/Li_2O-added $PMN_{0.85}PT_{0.15}$ fired at different temperature. (1) 975° C; (2) 950° C; (3) 900° C.

Resultant composition would be suitable for the dielectric uses with stable temperature characteristics and high resistivity. $PMN_{1-x}PT_x$–Bi_2O_3/Li_2O may also be used as electrostrictive material with stable temperature characteristics, low power consumption and excellent positional reproducibility.

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Received 27 September 1988
and accepted 13 April 1989