Preparation of 0-3 Polymer-based Piezoelectric Composites with (Pb$_{1-x}$, Bi$_x$)(Ti$_{1-y}$, Fe$_y$)O$_3$ Powders
2001年 2月

2001年 2月
1. ................................................................. 1
2. ................................................................. 3
  2.1 ................................................................. 3
  2.2 ................................................................. 5
  2.2.1 ................................................................. 5
  2.2.2 ................................................................. 8
  2.3 ................................................................. 11

3. ................................................................. 13
  3.1 (Pb_{1-x}, Bi_x)(Ti_{1-y}, Fe_y)O_3 powder .................................................. 13
  3.2 (Pb_{1-x}, Bi_x)(Ti_{1-y}, Fe_y)O_3/polymer .................................................. 17
  3.3 ................................................................. 20

4. ................................................................. 22
  4.1 (Pb_{1-x}, Bi_x)(Ti_{1-y}, Fe_y)O_3 powder .................................................. 22
  4.2 (Pb_{0.5}, Bi_{0.5})(Ti_{0.5}, Fe_{0.5})O_3/polymer ........................................... 27

5. ................................................................. 37

- i -
Fig. 2.1. Applications of piezoelectric composites.

Fig. 2.2. Connectivity patterns for a diphasic solid. Each phase has zero-, one-, two-, or three-dimensional connectivity to itself. In the 3-1 composite, for instance, the shaded phase is three-dimensional connected. Arrows are used to indicate the connected directions.

Fig. 2.3. Schematic representation of piezoelectric composites with 0-3, 1-3, and 3-3 connectivity.

Fig. 2.4. The composites consisted of dielectric continuous medium and piezoelectric ellipsoidal particles.

Fig. 3.1. Flow diagram for piezoelectric ceramic preparation.

Fig. 3.2. Sintering condition of piezoelectric ceramics.

Fig. 3.3. Ni plating process.

Fig. 4.1. XRD patterns of the powders treated at various temperatures.

Fig. 4.2. XRD patterns of (Pb\(_{1-x}\)Bi\(_x\))(Ti\(_{1-y}\)Fe\(_y\))O\(_3\) powder (x=y).

Fig. 4.3. XRD patterns of (Pb\(_{1-x}\)Bi\(_x\))(Ti\(_{1-y}\)Fe\(_y\))O\(_3\) powder (x ≠ y).
Fig. 4.4. XRD patterns of each heat-treatment conditions.
(a) 900°C, Pb-atmosphere  (b) 900°C, air-atmosphere
(c) 1000°C, Pb-atmosphere  (d) 1000°C, air-atmosphere

Fig. 4.5. SEM micrographs of (a) ceramic powder sintered at 900°C and
(b) 1000°C, and composite with (c) UP RF1001, (d) KBR1729,
(e) Bakelite powder, and (f) Transoptic powder.

Fig. 4.6. Dielectric properties of each specimens. (1kHz)

Fig. 4.7. Hysteresis loop of specimens: composite with Bakelite powder and (Pb$_{0.5}$Bi$_{0.5}$)(Ti$_{0.5}$Fe$_{0.5}$)O$_3$ calcined at (a) 900°C,
and (b) 1000°C.

Fig. 4.8. Remanent polarizations of the 50vol% of (Pb$_{0.5}$Bi$_{0.5}$)(Ti$_{0.5}$Fe$_{0.5}$)O$_3$ calcined at 900°C composite with each voltage.

Fig. 4.9. Remanent polarizations of the composites with Bakelite powder with each vol% of (Pb$_{0.5}$Bi$_{0.5}$)(Ti$_{0.5}$Fe$_{0.5}$)O$_3$. 

- iii -
Table 3.1. Composition of each \( \text{Pb}_{1-x}\text{Bi}_x \)(\( \text{Ti}_{1-y}\text{Fe}_y \))\text{O}_3 \) powder.

Table 3.2. Polymers used in the present study.

Table 4.1. Tetragonality of each specimen.
Preparation of 0-3 Polymer-based Piezoelectric Composites with (Pb\(_{1-x}\), Bi\(_x\)) (Ti\(_{1-y}\), Fe\(_y\))O\(_3\) Powders

Kyung-Tae Kim

Dept. of Materials Engineering
Graduate School
Korea Maritime University

ABSTRACT

Piezoelectric materials are used extensively in many transducer applications. However, they have limited utility in transducers used under hydrostatic conditions because of their low hydrostatic piezoelectric coefficient (d\(_h\)) have also limited utility in ultrasonic field due to small voltage coefficient (g\(_{33}\)) and large acoustic impedance.

To improve the magnitude of hydrostatic piezoelectric coefficient and voltage coefficient, the composite of piezoelectric materials and polymer with different patterns have been prepared. In addition, these composites having lower acoustic impedance and smaller dielectric constant than those of solid piezoelectric materials, make it easier to obtain good impedance matching with water of the human body.

Because of these advantages, piezoelectric composites would be used in many fields such as measuring instruments, diagnostic ultrasonic transducer, information processing instruments and acoustic devices.

Especially, these composites have advantage of making a shape using ceramic powder that cannot produce by sintering.

In this study, we produced the composites using (Pb\(_{1-x}\), Bi\(_x\)) (Ti\(_{1-y}\), Fe\(_y\))O\(_3\) powder which cannot produce by sintering because of its high
tetragonality that create high inner stress. (Pb$_{1-x}$, Bi$_x$)(Ti$_{1-y}$, Fe$_y$)O$_3$/Epoxy 0-3 piezoelectric composites were prepared for investigating the effects of volume fraction of (Pb$_{1-x}$, Bi$_x$)(Ti$_{1-y}$, Fe$_y$)O$_3$ on the dielectric, piezoelectric properties of composites. (Pb$_{1-x}$Bi$_x$)(Ti$_{1-y}$Fe$_y$)O$_3$ powder, which has high tetragonality and voltage coefficient ($g_{33}$) was prepared from oxide mixture of PbO, Bi$_2$O$_3$, TiO$_2$, and Fe$_2$O$_3$. Then, (Pb$_{1-x}$, Bi$_x$)(Ti$_{1-y}$, Fe$_y$)O$_3$ particles were mixed with epoxy, piezoelectrically inactive species. After poling, dielectric, and piezoelectric properties were investigated.
1. Introduction

1940: The piezoelectric material BaTiO$_3$ was discovered by PZT (lead zirconate titanate), which is a material used in hydrophones (actuators), sonar (hydrophone), actuators, and sonar. Hydrophones are devices that convert sound waves into electrical signals, and actuators are devices that convert electrical signals into mechanical movements.

1973: Pauer and Kyiatama, Banno introduced PZT (lead zirconate titanate) and studied its properties. This work laid the foundation for the development of PZT materials.

1978: Newnham et al. studied the piezoelectric properties of PZT and its temperature coefficient. They found that the temperature coefficient of PZT is lower than that of PbTiO$_3$, which is another piezoelectric material.

Pb(Zr,Ti)O$_3$ is a piezoelectric material that is used in various applications. This material is made by mixing PbTiO$_3$ and Pb(Zr,Ti)O$_3$ in different ratios. This mixture allows for the control of the piezoelectric properties of the material. The matrix phase is usually polyurethane, silicon rubber, chloroprene rubber, eccogel, polyvinyliden fluoride, etc., to improve the mechanical properties of the material.

- 1 -
tetragonality (c/a) - 0 - 3 -
2. 2 2 2

2.1 2 2 2

( polarization ) ( electric field ) ( deformation ) . \(^{1,2}\)

1880年 カリエール キャリオレ 項目 (rochelle salt, KH\_\_2PO\_4, (NH\_4)H\_2PO\_4) に ソーラー電池 太陽電池 を開発 した。1945年 ペロフスキー BaTiO\_3 1000℃ に ソーラー電池 を開発 した。1947年 ロバーツ BaTiO\_3 に ソーラー電池 を開発 した。マッソン PbTiO\_3, CaTiO\_3, PbZrO\_3 に ソーラー電池 を開発 した。 Pb(Zr, Ti)O\_3 に ソーラー電池 を開発 した。カリエールの Curie キャリエールの Curie は 400℃ に ソーラー電池 を開発 した。

計算機 ソーラー 山田 (T), 横 (E), 水 (S), 東 (O) に 依存 した。
\( d = \left( \frac{D}{T} \right)_E = \left( \frac{S}{E} \right) \tau \)

\( e = \left( \frac{D}{S} \right)_E = - \left( \frac{T}{E} \right)_E \)

\( g = \left( \frac{F}{T} \right)_D = \left( \frac{S}{D} \right) \tau \)

\( h = - \left( \frac{E}{S} \right)_D = - \left( \frac{T}{D} \right)_S \)

\[
S = s^E \tau + d \cdot E
\]

\[
D = d \tau + \varepsilon^T E
\]

\[
T = c^E \tau - e \cdot E
\]

\[
D = \varepsilon S + \varepsilon^S E
\]

\[
S = s^D \tau + g \cdot D
\]

\[
E = - g \tau + \beta^T D
\]

\[
T = c^D \tau - h \cdot D
\]

\[
E = - h \tau + \beta^S D
\]

elastic compliance, c\( ^S \) elastic stiffness, \( \varepsilon \), \( \beta \)
2.2 3.4 3.4.

2.2.1 3.4 - 3.4 3.4 - 3.4

(40kHz 3.4) 3.4 hydrophone (40kHz 3.4) 3.4 thermister (40kHz 3.4) 3.4 brittle (40kHz 3.4) 3.4 sheet (40kHz 3.4) 3.4 bulk (40kHz 3.4) 3.4 (10mHz〜10GHz) (40kHz 3.4) 3.4 (10mHz〜10GHz) (40kHz 3.4) 3.4 (10mHz〜10GHz)
- ここに文章がありません。
Fig. 2.1. Applications of piezoelectric composites.(ref. 1)
2.2.2

1978 Newnham (piezoelectric active phase) and (nonpiezoelectric phase) as shown in the figure. (phase) and (connectivity) are shown in Figure 2.2. (connectivity)

Fig. 2.2. (phase) and (connectivity) are shown in Figure 2.2.

1),2),3),4) Skinner, Rittenmyer lost wax plastic spheres 3-3, 1-3, 0-3 impedance matching 1-3, 3-3, 3-1, 0-3, 3-2, 2-2 1-3, 3-3, 3-1, 3-2, 2-2

Harrison PZT powder, PZT rod, spurrs epoxy. 3-3, 1-3, 0-3, 3-2, 2-2 3-3, 1-3, 0-3, 3-2, 2-2

0-3, 3-0, 3-1, 3-2, 2-2
Fig. 2.2. Connectivity patterns for a diphasic solid. Each phase has zero-, one-, two-, or three-dimensional connectivity to itself. In the 3-1 composite, for instance, the shaded phase is three-dimensional connected. Arrows are used to indicate the connected directions.(ref. 1)
Fig. 2.3. Schematic representation of piezoelectric composites with 0-3, 1-3, and 3-3 connectivity.
Fig. 2.3. 0-3, 1-3, 3-3 の MATERIAL は Fig. 2.4 に示されています。T. Yamada の研究 

\[
K = K_1 \left\{ 1 + \frac{nq(K_2 - K_1)}{n K_1 + (K_2 - K_1)(1 - q)} \right\}
\]

ここで、K1 は matrix の弾性率、K2 は dispersoid の弾性率、q は dispersoid の体積率、n は dispersoid の数を表します。
Fig. 2.4 The composites consisted of dielectric continuous medium and piezoelectric ellipsoidal particles.
3. 3.1 (Pb$_{1-x}$, Bi$_x$)(Ti$_{1-y}$, Fe$_y$)O$_3$ powder

3.1 (Pb$_{1-x}$, Bi$_x$)(Ti$_{1-y}$, Fe$_y$)O$_3$ powder.

\[ (Pb_{1-x}, Bi_x)(T_{1-y}, F_y)O_3 \]

\[ x, y = 0.2, 0.3, 0.4, 0.5, 0.8 \]

\[ 700^\circ C \]

15mm

1.13ton/cm$^2$

disc

Fig. 3.1.

10, 12, 13, 14, 15

Table 3.1

\[ \text{Table 3.1} \]

\[ \text{Table 3.1} \]
Table 3.1. Composition of each (Pb$_{1-x}$Bi$_x$)(Ti$_{1-y}$Fe$_y$)O$_3$ powder.

<table>
<thead>
<tr>
<th></th>
<th>x</th>
<th>y</th>
<th>PbO</th>
<th>Bi$_2$O$_3$</th>
<th>TiO$_2$</th>
<th>Fe$_2$O$_3$</th>
</tr>
</thead>
<tbody>
<tr>
<td>0.2</td>
<td>0.2</td>
<td>4.64</td>
<td>1.17</td>
<td>1.6</td>
<td>0.4</td>
<td></td>
</tr>
<tr>
<td></td>
<td>0.5</td>
<td>4.64</td>
<td>1.17</td>
<td>1</td>
<td>1</td>
<td></td>
</tr>
<tr>
<td></td>
<td>0.8</td>
<td>4.64</td>
<td>1.17</td>
<td>0.4</td>
<td>1.6</td>
<td></td>
</tr>
<tr>
<td>0.3</td>
<td>0.3</td>
<td>2.906</td>
<td>1.294</td>
<td>1</td>
<td>0.444</td>
<td></td>
</tr>
<tr>
<td>0.4</td>
<td>0.4</td>
<td>2.933</td>
<td>1.944</td>
<td>1</td>
<td>0.666</td>
<td></td>
</tr>
<tr>
<td>0.5</td>
<td>0.2</td>
<td>2.96</td>
<td>2.92</td>
<td>1.6</td>
<td>0.4</td>
<td></td>
</tr>
<tr>
<td></td>
<td>0.5</td>
<td>2.96</td>
<td>2.92</td>
<td>1</td>
<td>1</td>
<td></td>
</tr>
<tr>
<td></td>
<td>0.8</td>
<td>2.96</td>
<td>2.92</td>
<td>0.4</td>
<td>1.6</td>
<td></td>
</tr>
<tr>
<td>0.8</td>
<td>0.2</td>
<td>1.29</td>
<td>4.67</td>
<td>1.6</td>
<td>0.4</td>
<td></td>
</tr>
<tr>
<td></td>
<td>0.5</td>
<td>1.29</td>
<td>4.67</td>
<td>1</td>
<td>1</td>
<td></td>
</tr>
<tr>
<td></td>
<td>0.8</td>
<td>1.29</td>
<td>4.67</td>
<td>0.4</td>
<td>1.6</td>
<td></td>
</tr>
</tbody>
</table>
Fig. 3.1. Flow diagram for piezoelectric ceramic preparation.
Fig. 3.2. Sintering condition of piezoelectric ceramics.
3.2 (Pb\textsubscript{1-x}, Bi\textsubscript{x})(Ti\textsubscript{1-y}, Fe\textsubscript{y})O\textsubscript{3}/polymer

(Pb\textsubscript{1-x}, Bi\textsubscript{x})(Ti\textsubscript{1-y}, Fe\textsubscript{y})O\textsubscript{3} and its tetragonality \[\ldots\]

XRD\[\ldots\]

Polymer\[\ldots\]

0-3\[\ldots\]

Polymer\[\ldots\]

0-3\[\ldots\]

(Pb\textsubscript{1-x}, Bi\textsubscript{x})(Ti\textsubscript{1-y}, Fe\textsubscript{y})O\textsubscript{3} \[\ldots\] Fig. 3.2\[\ldots\]
Table 3.2: Polymers used in the present study.

<table>
<thead>
<tr>
<th>Polyester resin</th>
<th>Hardening condition</th>
<th>Density (g/(\text{cm}^3))</th>
<th>Composite density (%)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Solid</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Black Bakelite Powder</td>
<td>130~180 °C</td>
<td>1.4</td>
<td>95~98%</td>
</tr>
<tr>
<td></td>
<td>20~30 kN</td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td>10~20 min</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Transoptic Powder</td>
<td></td>
<td>1.42</td>
<td></td>
</tr>
<tr>
<td>Liquid</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>UP RF1001</td>
<td>R·T, 8 hr</td>
<td>1.38</td>
<td>70~80%</td>
</tr>
<tr>
<td>KBR1729</td>
<td>120 °C, 2 hr</td>
<td>1.2</td>
<td></td>
</tr>
</tbody>
</table>
Table. 3.2

<table>
<thead>
<tr>
<th>UP RF 1001</th>
<th>KBR1729</th>
</tr>
</thead>
<tbody>
<tr>
<td>UP RF 1001</td>
<td>KBR1729</td>
</tr>
<tr>
<td>120°C</td>
<td>250°C</td>
</tr>
</tbody>
</table>

Press: black bakelite powder, transoptic powder. 130~180°C, 20~50kN, 10~20kN, 120°C, 50kN. 180°C, 50kN. 120°C, 50kN.

Decigator: black bakelite, transoptic powder. 130~180°C, 20~50kN, 10~20kN, 120°C, 50kN. 180°C, 50kN. 120°C, 50kN.

(Pb$_{1-x}$, Bi$_x$)(Ti$_{1-y}$, Fe$_y$)O$_3$
3.3 Hysteresis loop

- SnCl\(_2\) and PdCl\(_2\) at 80°C for 15 minutes.
- Ni\(\cdot\)µµ±Ý for 5 minutes.

A 4-probe meter was used to measure the resistance. The electric field was 0-3 kV/mm, and the temperature was 100°C.

Dielectric breakdown was observed at 3kV/mm. RT 66A silicon oil (dielectric breakdown) was used.
Ultrasonic cleaning

Removing grease in acetone

Sensitizing
SnCl₂ 90 g/l + HCl 55 ml/l
RT, 5 min

Activating
PdCl₂ 0.2 g/l + HCl 2.5 ml/l
80 °C, 15 min

Ni plating
NiSO₄ 35 g/l + CH₃COONa 10 g/l + NaPH₂O₂ 10 g/l
80 °C, 20 ~ 50 min

Fig. 3.3. Ni plating process.
4.  

4.1 (Pb$_{1-x}$, Bi$_x$)(Ti$_{1-y}$, Fe$_y$)O$_3$ powder

Fig. 4.1. $x \cdot y = 0.5$, $(\text{Pb}_{0.5}, \text{Bi}_{0.5})(\text{Ti}_{0.5}, \text{Fe}_{0.5})\text{O}_3$ powder. $700^\circ\text{C}$ peak tetragonal. $x \cdot y = 0.4$, $c/a=1.104 \pm 0.005$. $0.3 \leq x \cdot y \leq 0.8$, $c/a=1.090 \pm 0.005$. $0.2 \leq x \cdot y \leq 0.8$, $c/a=1.140 \pm 0.005$. Table 4.1. $x \cdot y = 0.2$, $c/a=1.090 \pm 0.005$. $0.8 \leq x \cdot y \leq 0.8$, $c/a=1.140 \pm 0.005$.

Fig. 4.2. $x \cdot y = 0.4$, $c/a=1.104 \pm 0.005$. $0.3 \leq x \cdot y \leq 0.8$, $c/a=1.090 \pm 0.005$. $0.2 \leq x \cdot y \leq 0.8$, $c/a=1.140 \pm 0.005$.

Fig. 4.3. $x \cdot y = 0.2$, $c/a=1.090 \pm 0.005$. $0.8 \leq x \cdot y \leq 0.8$, $c/a=1.140 \pm 0.005$. $0.2 \leq x \cdot y \leq 0.8$, $c/a=1.090 \pm 0.005$.
Fig. 4.1. XRD patterns of the powders treated at various temperatures.
Fig. 4.2. XRD patterns of (Pb$_{1-x}$, Bi$_x$)(Ti$_{1-y}$, Fe$_y$)O$_3$ powder (x=y).
Table 4.1. Tetragonality of each specimen.

<table>
<thead>
<tr>
<th>Chemical formula</th>
<th>Tetragonality (c/a)</th>
</tr>
</thead>
<tbody>
<tr>
<td>((\text{Pb}<em>{0.7} \text{Bi}</em>{0.3}) (\text{Ti}<em>{0.7} \text{Fe}</em>{0.3})\text{O}_3)</td>
<td>1.090 ±0.005</td>
</tr>
<tr>
<td>((\text{Pb}<em>{0.6} \text{Bi}</em>{0.4}) (\text{Ti}<em>{0.6} \text{Fe}</em>{0.4})\text{O}_3)</td>
<td>1.104 ±0.005</td>
</tr>
<tr>
<td>((\text{Pb}<em>{0.5} \text{Bi}</em>{0.5}) (\text{Ti}<em>{0.5} \text{Fe}</em>{0.5})\text{O}_3)</td>
<td>1.135 ±0.005</td>
</tr>
</tbody>
</table>
Fig. 4.3. XRD patterns of \((\text{Pb}_{1-x}, \text{Bi}_x)(\text{Ti}_{1-y}, \text{Fe}_y)\text{O}_3\) powder \((x \neq y)\).
4.2 (Pb$_{0.5}$, Bi$_{0.5}$)(Ti$_{0.5}$, Fe$_{0.5}$)O$_3$ / polymer

(Pb$_{1-x}$, Bi$_x$)(Ti$_{1-y}$, Fe$_y$)O$_3$ / polymer

Fig. 4.4

Fig. 4.5.
Fig. 4.4. XRD patterns of each heat-treatment conditions.
(a) 900°C, Pb-atmosphere  (b) 900°C, air-atmosphere  
(c) 1000°C, Pb-atmosphere  (d) 1000°C, air-atmosphere
Fig. 4.5. SEM micrographs of (a) ceramic powder sintered at 900°C and (b) 1000°C, and composite with (c) UP RF1001, (d) KBR1729, (e) Bakelite powder, and (f) Transoptic powder.
(b) (c) (d) (e) (f) 

Transoptic powder \( \approx 30 \) vol% Bakelite powder

UP RF 1001 \( \approx 20 \) vol% Bakelite powder

30vol% LCR Meter

40vol% Bakelite powder

80% Bakelite powder
Fig. 4.6. Dielectric properties of each specimens. (1kHz)
Bakelite Powder 50vol% ±îÁö÷°¡ÇÑ

Bakelite powder RT 66A hysteresis loop Fig. 4.7. (a) 900°C, (b) 1000°C.

Fig. 4.8. 900°C (Pb₀.₅, Bi₀.₅)(Ti₀.₅, Fe₀.₅)O₃ 50vol% poling Graph.

- 32 -
Fig. 4.7. Hysteresis loop of specimens: composite with Bakelight powder and \((\text{Pb}_{0.5}\text{Bi}_{0.5})(\text{Ti}_{0.5}\text{Fe}_{0.5})\text{O}_3\) calcined at (a) 900°C, and (b) 1000°C.
Fig. 4.8. Remanent polarizations of the 50vol% of \((\text{Pb}_{0.5}\text{Bi}_{0.5})(\text{Ti}_{0.5}\text{Fe}_{0.5})\text{O}_3\) calcined at 900°C composite with each voltage.
Fig. 4.9. Remanent polarizations of the composites with Bakelite powder with each vol% of \((\text{Pb}_{0.5}\text{Bi}_{0.5})(\text{Ti}_{0.5}\text{Fe}_{0.5})\text{O}_3\).
Fig. 4.9 バケライト粉末の平均粒子径とその最小二乗回帰直線

1000°C で 18～20%、900°C で 5～15% の気孔率を示す。500°C での気孔率は約 20% である。

36
5. 

\[ \text{PbO, Bi}_2\text{O}_3, \text{TiO}_2, \text{Fe}_2\text{O}_3, \ldots \] \[ (\text{Pb}_{1-x}, \text{Bi}_x)(\text{Ti}_{1-y}, \text{Fe}_y)\text{O}_3 \] \[ \text{polymer} \] \[ 0-3 \] 

1. \[ \text{PbO, Bi}_2\text{O}_3, \text{TiO}_2, \text{Fe}_2\text{O}_3, \ldots \] \[ (\text{Pb}_{1-x}, \text{Bi}_x)(\text{Ti}_{1-y}, \text{Fe}_y)\text{O}_3 \] 

2. \[ \text{BiFeO}_3 \] \[ \text{PbTiO}_3 \] 

3. \[ x = y \] 

4. \[ x, y = 0.5 \] \[ \text{tetragonality} (c/a=1.135 \pm 0.005) \] \[ \text{BiFeO}_3 \] \[ \text{tetragonality} \] 

5. \[ \text{tetragonality} \] 

6. \[ \text{BiFeO}_3 \] \[ \text{PbTiO}_3 \] \[ 0-3 \] 

7. \[ \text{BiFeO}_3 \] \[ \text{PbTiO}_3 \] \[ 5-15 \% \] 

- 37 -
8. RT66A® hysteresis loop, 6kV/mm, 1000°C, 50vol% Pr=6.355 μ C/μ m².

9. 1000°C, 900°C, 18~20% porosity.
1) ±èÈ£±â, ½Åº´Ã¶, ¾ÐÀü¡¤Àü¿Ö¼¼¶ó¹Í½º -¿ø¸®¿ÍÀÀ¿ë½Ç·Ê -(1991).


15) Yoneda Atsuhiko, Takenaka Tadashi, Sakata Koichiro, ‘Temperature dependence of piezoelectric constants of lithium bismuth (Li0.5Bi0.5)-modified PZT (lead zirconate-lead titanate) ceramics in the vicinity of the morphotropic phase boundary’, Nippon Seramikkusu Kyokai Gakujutsu Ronbunshi 98(8), 890-894. Japan, (1990).

