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Anisotropic Thermal Expansion Characteristics of Lead Metaniobate Ceramics Used in the Low-Liquid Level Sensors for Fuel Tanks of Space Launch Vehicles[1]

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Low-liquid level sensors are used to monitor the fuel level in fuel tanks of space launch vehicles. These sensors, which are usually bonded to the bottom surface of the tank, are currently made of lead metaniobate ceramic. Lead metaniobate ($PbNb_2O_6$) is used because it has very stable piezoelectric behavior and a relatively low dielectric constant (<500). Very limited thermal expansion data, especially in the operating temperature range of the space launch vehicles, exist in the literature. This paper provides thermal expansion data for $PbNb_2O_6$ ceramic in both the radial (in-plane) and the thickness (out-of-plane) directions. These results clearly indicate an anisotropic thermal expansion behavior for this ceramic.

KEY WORDS: anisotropy; ceramics; lead metaniobate; thermal expansion.

1. INTRODUCTION

Low-liquid level sensors are used to monitor the fuel level of fuel tanks of space launch vehicles. These sensors, which are usually bonded to the bottom surface of the tank, are currently made of lead metaniobate ceramic. Lead metaniobate ($PbNb_2O_6$) is preferred over other piezoelectric ceramics or single crystals because of its stable piezoelectric behavior and relatively low dielectric constant (<500).

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There is only a limited amount of published information on the thermal expansion of $PbNb_2O_6$-based ceramics near their Curie temperatures (250–550°C) [1]. This paper provides the thermal expansion data in the temperature range of −120 to 180°C for a commercially available $PbNb_2O_6$ ceramic (KEZITE K-83).

2. EXPERIMENTAL

Modified $PbNb_2O_6$ (KEZITE K-83) cermic samples in the form of small disks, approximately 0.5 mm thick and approximately 5 mm in diameter, were used for this investigation. Table I provides some important properties of this material which were obtained from the manufacturer.

A DuPont 943 Thermomechanical Analyzer (TMA) was used to determine the radial direction (in-plane) and thickness direction (out-of-plane) coefficients of thermal expansion (CTEs). The $PbNb_2O_6$ disks had to be sectioned into rectangular form, and the sides of the samples were then polished so that in-plane CTEs could be determined. Experiments were run from −120 to 180°C at $5°C \cdot min^{-1}$ in a nitrogen atmosphere. The mean thickness CTE and the mean radial CTE for two lots of K-83 crystals were determined.

3. RESULTS

Table II provides the radial and thickness direction CTEs for two lots (1987 and 1988 orders) of the ceramic. All the CTE experiments showed a consistently reproducible phase transition around −30°C, as shown in Fig. 1. This phase transition occurred around the same low-temperature region regardless of the number of times the samples were rerun, as shown in Fig. 2. This type of low-temperature transition was reported as early as 1953 by Goodman [2] in his study on the dielectric constant and loss tangent ($\tan \delta$) properties as a function of temperature (from −200 to +800°C) for the $PbNb_2O_6$ ceramic.

Table I. Properties of KEZITE K-83 Lead Metaniobate($PbNb_2O_6$) Ceramic (Obtained from Vendor)

Relative dielectric constant	175
Piezoelectric charge coefficient, d_{33}	$65\ pC \cdot N^{-1}$
Piezoelectric voltage coefficient, g_{33}	$42\ mV \cdot m \cdot N^{-1}$
Density	$4.3\ g \cdot cm^{-3}$
Curie temperature	250–300°C

Table II. Radial-Direction (In-Plane) and Thickness-Direction (Out-of-Plane) CTE of KEZITE K-83 Lead Metaniobate ($PbNb_2O_6$) Ceramic

KEZITE K-83 $PbNb_2O_6$ sample	Radial direction CTE (from 40 to 160°C) (10^{-6} °C^{-1})	Thickness-direction CTE (10^{-6} °C^{-1})
		From 50 to 150°C
Lot 1 (1987 order)	12.0	−11.0
	12.0 (12.3 ± 0.5)	−7.0
	12.8	−14.3
		−12.8
		From 50 to 120°C
Lot 2 (1988 order)	11.7 (11.6 ± 0.2)	−27.0
	11.4	−20.3

Because of the presence of this low-temperature transition, the CTEs were determined above room temperature. The radial CTEs obtained in the range of 40 to 160°C were very consistent and reproducible around 12.3×10^{-6} °C^{-1} for the 1987 order and 11.6×10^{-6} °C^{-1} for the 1988 order (Table II).

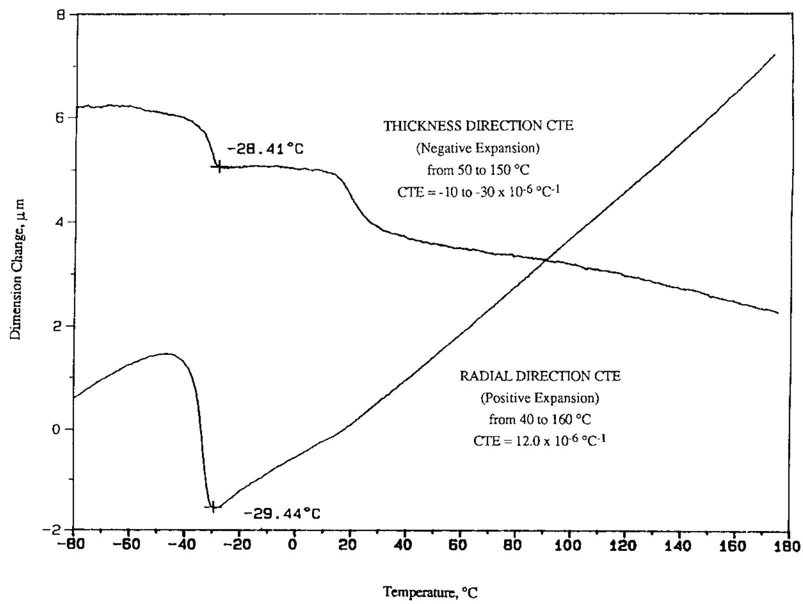

Fig. 1. Radial- and thickness-direction CTEs of KEZITE K-83 $PbNb_2O_6$ ceramic showing its anisotropic thermal expansion behavior.

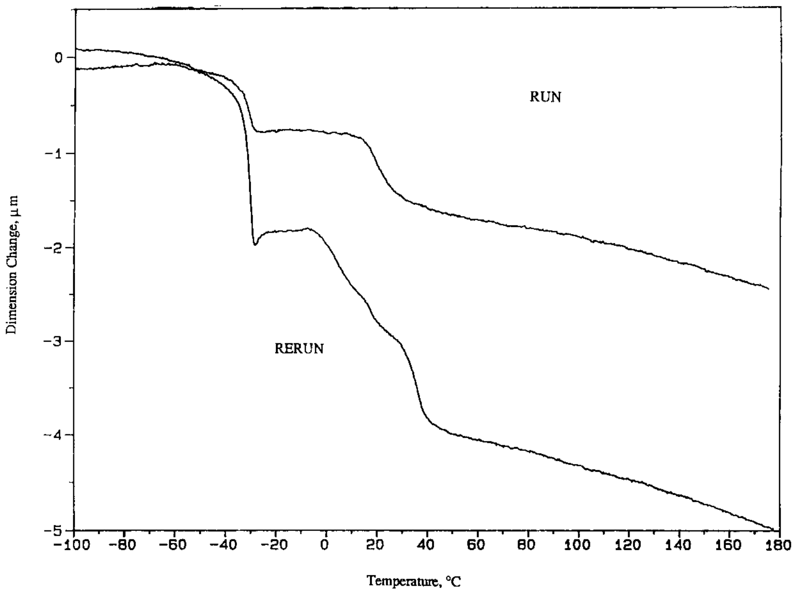

Fig. 2. Thickness-direction CTE measurements of as-received (rung) and aged (fifth-rerun) samples of KEZITE K-83 $PbNb_2O_6$ showing the presence of a consistently reproducible phase transition around $-30°C$.

On the other hand, as Table II shows, the thickness direction CTEs were negative and irreproducible. They ranged anywhere from -10 to $-30 \times 10^{-6}\ °C^{-1}$. This anisotropic thermal expansion behavior can be clearly seen from Fig. 1.

4. CONCLUSIONS

From the CTE measurements obtained in both the radial and the thickness directions of KEZITE K-83 $PbNb_2O_6$ ceramic used in the low liquid-level sensors, the following can be concluded.

(i) The $PbNb_2O_6$ceramic

- has a consistently reproducible phase transition around $-30°C$ and
- shows anisotropic thermal expansion characteristics above room temperature.

(ii) Although the radial CTE is positive and reproducible around $12 \times 10^{-6}\ {}^{\circ}C^{-1}$, the thickness CTE is negative and irreproducible (ranging from -10 to $-30 \times 10^{-6}\ {}^{\circ}C^{-1}$).

REFERENCES

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