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Materials Science and Engineering B99 (2003) 425–427

MATERIALS SCIENCE & ENGINEERING B

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Research on the manufacture of laminated $BaTiO_3$-based thermistor by roll forming

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Received 17 June 2002; accepted 10 September 2002

Abstract

New laminated $BaTiO_3$-based positive temperature coefficient thermistors prepared by roll forming have been studied. Through changing the factors that influence the roll forming process, thick film positive temperature coefficient (PTC) $BaTiO_3$ green sheets with good plasticity, uniformity, compactness and smoothness were obtained. After the films sintered at high temperature in the air and electrodes screen printed, laminated PTC thermistors, which possess many good features, such as small size and lower room resistivity and larger current flux, can be obtained. It is the first time that such laminated PTC thermistors are reported. The lamination technology and electrical behavior of PTC thermistors were also investigated.

Keywords: $BaTiO_3$-based semiconductor ceramic; Laminated PTC thermistor; Roll forming

1. Introduction

With the development of surface mounted technology, laminated $BaTiO_3$-based positive temperature coefficient thermistors, which possess the advantages of small size, lower room resistance and larger current flux, has become the research emphasis [1–4] in the sensitive ceramic area. As the laminated PTC thermistors widely used in many fields for temperature measurement, temperature control, surge suppression, overcurrent protection of the circuit, the demand for it is rising. The research on the laminated PTC thermistor rightly acclimates this development trend. Presently there are many shaping methods for thick films, such as slipcasting, gelcasting, roll forming [5,6]. As roll forming is a very mature molding technique to shape ceramic green sheets, which once was in great deal used to roll the green bodies of chip capacitor and laminated capacitor, resistor, electrocircuit substrate etc. it is used to shape $BaTiO_3$ PTC green sheet of laminated PTC thermistor in the experiment. It has many merits, such as easy manipulation, lower costs, high efficiency, small intensity, little pollution [7,8]. The laminated PTC thermistors manufactured by roll forming behaves better electric properties. This is the first paper to report on manufacturing laminated PTC thermistor by roll forming (Table 1).

2. Experimental procedure

The ceramic green sheets are prepared by roll forming using high purity powder of $BaCO_3$, TiO_2, $SrCO_3$, $CaCO_3$, Y_2O_3, $Mn(NO_3)_2$, SiO_2 as the raw materials. The quantities of binder (polyvinyl alcohol) and plasticizer (glycerol) added in the powders for roll forming, which volatilized in the beginning period of sintering, are approximately 30 and 4–5%. The concentration of binder is 15–18%. The thickness of rolled $BaTiO_3$ films is 0.2–1.0 mm. The green sheets were first separately sintered at high temperature in the air, and then electrodes were screen printed. By the lamination of sintered ceramic sheets, the laminated PTC thermistors can be obtained. The sintering temperature of 1310 °C/30 min was used in followed experiments.

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doi:10.1016/S0921-5107(02)00450-6

Table 1
Electrical properties of single layer and laminated PTC thermistors

Content	Terminal size (mm)	Room temperature resistance (Ω)	Resistance temperature coefficient α (%/°C)	Rising resistance ratio β
$N=1$	$14.50 \times 8.40 \times 0.50$	32.9	11.54	1.9×10^5
$N=3$	$14.60 \times 8.54 \times 1.60$	12.0	11.95	2.5×10^5

The resistivity versus temperature characteristics of laminated PTC thermistor was measured by $R-T$ auto-testing system, SEM was used for analyzing the microstructures of the electrode constructure.

3. Results and discussion

3.1. Microstructures

Laminated PTC thermistor construction consisting of a number of single ceramic thermistors connected in parallel is shown in Fig. 1. This laminated PTC thermistor, which was manufactured by the method of lamination after single green sheet sintered at high temperature in the air and electrodes screen printed, has good inner contact, as shown in the Fig. 2.

In Fig. 2, the black is ceramic PTC sheet and the white is aluminum electrode. As seen from Fig. 2, the electrodes can contact tightly with the ceramic sheets.

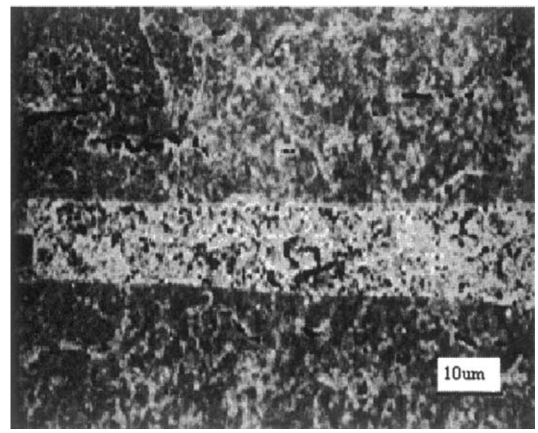

Fig. 2. SEM of a cross section of laminated PTC thermistor.

This is due to the same oxygen atmosphere of every ceramic sheet during sintering.

3.2. Resistivity versus temperature characteristics of laminated PTC thermistor

The resistivity of laminated PTC thermistor versus temperature characteristics and the influence of different numbers of layers on the electronic properties are given in Fig. 3. The room temperature resistivity is greatly decreased when the number of layers increases; meanwhile the resistance temperature coefficients of laminated PTC thermistors are all slightly higher than that of single layer, but they have no regular relation with the number of layers (see Table 1).

The magnitude of ρ_{max}/ρ_{min} of both single layer and laminated PTC thermistor is over 10^5. Moreover, it also has no relation with the number of layers (see Table 1).

3.3. Theoretical model of laminated thermistors

According to Ohm's laws, the total resistance (R_L) of laminated thermistors is

$$R_L = \frac{1}{\sum_{i=1}^{N} 1/Ri} \tag{1}$$

where the N is the number of layers, Ri is the resistance of layer i.

Theoretically,

$$R_L = \frac{1}{N} R_S \tag{2}$$

where R_S is the resistance of a single layer.

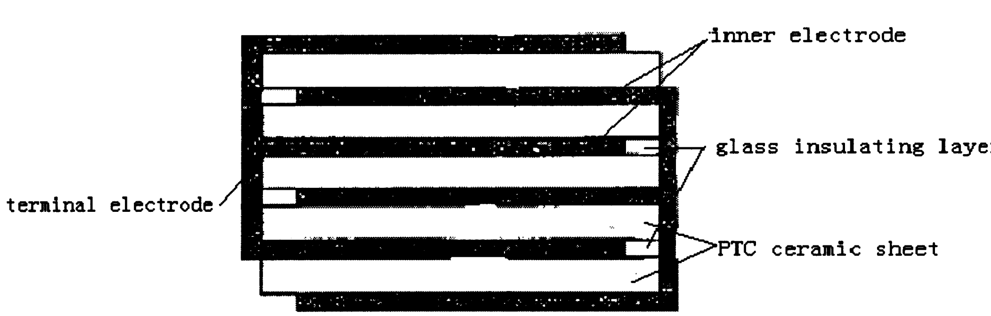

Fig. 1. Schematic of the laminated PTC thermistor.

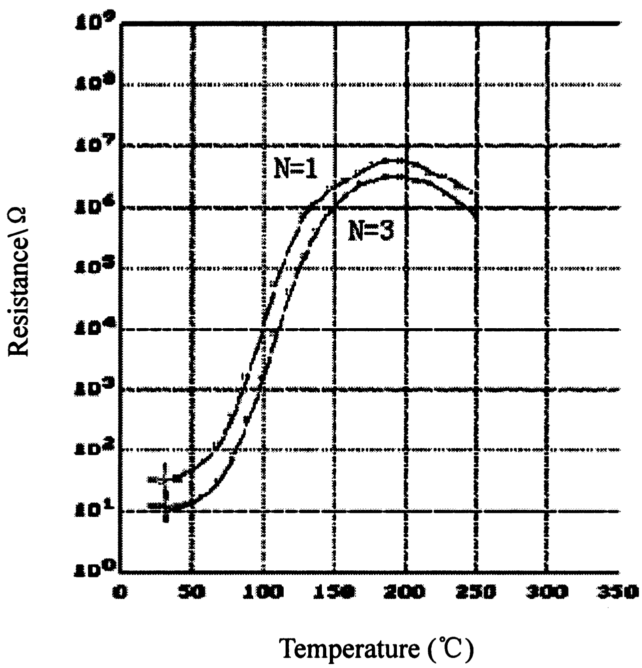

Fig. 3. Resistivity vs. temperature characteristics of laminated PTC thermistors ($N = 1$ means single layer).

According to the experiment, $Ri = 32.9\ \Omega$, $N = 3$ (see Table 1). The theoretical resistance of laminated PTC thermistor is,

$$R_L = \frac{1}{\sum_{i=1}^{3} 1/Ri} = \frac{1}{3(1/32.9)} = 10.97\ \Omega \quad (3)$$

which is very close to the experiment data $R_L = 12.0\ \Omega$ (see Table 1).

4. Conclusion

After the green sheets sintered at high temperature in the air and then laminated after electrodes screen printed, the laminated PTC thermistors were obtained, which can effectively decrease the room resistance, and raise the resistance temperature coefficients and the magnitude of ρ_{max}/ρ_{min}. This $BaTiO_3$-based laminated PTC thermistors can be used under high temperature. Laminated PTC thermistors have a vital role to play as passively smart materials. The following fields of interest, as well as many new developing areas, will greatly benefit by their introduction: the automotive, consumer electronics, integrated circuit, and large scale integration fields. Reliability is a major requirement in a laminated thermistor. It is important to strictly control the macro defects, pores and delaminations placed into the single layer during the lamination manufacture microstructures.

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