Multi-layer Tunable Capacitors Fabricated by Thick Film Processes

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Abstract

Multi-layer cofired tunable capacitors (MLCTC) were fabricated with MLCC thick film technology. $(Ba,Sr)TiO_3$ (BST) has been utilized as a tunable material. We compared the tunability of BST plate sample with that of MLCTC. Though the tunability of BST plate sample was about 80% at 5V/µm, that of MLCTC suddenly decreased at 3V/µm. This might be caused by stray capacitance of MLCTC because of high dielectric constant of via layers. In this paper, basic concepts of MLCTC and properties of tunable capacitors which have been fabricated with thick film processes are described, and further discussion to decrease stray capacitance will be discussed.

Key words: MLCC, ferroelectric, $(Ba,Sr)TiO_3$, Tunable, Thick film.

1. Introduction

Recently frequency agile technologies have much attention due to the development of mobile telecommunication system. Smart phones have rapidly expanded around the world. According to those developments, radio systems of mobile phone have become complex more and more. Many kinds of radio systems, such as a cell phone, Wi-Fi, FM radio and GPS etc., are built into the small hand set. As a result, more than ten RF-frequency bands are utilized in the most advanced smart phone. So demands are increasing to simplify RF-circuits of multi-functional smart phone system. In this point of view, C-MOS, MEMS and ferroelectrics are proposed as a frequency tunable device. Ferroelectric materials have a large dielectric loss, due to the domain wall movement, and they have a large dielectric dispersion at microwave frequencies. However, above Curie temperatures (Tc), ferroelectric material enters a para-electric state, and the ensuing dielectric loss drastically decreases while the materials retain a large permittivity. Thus ferroelectric materials are very promising for frequency tunable devices[1]-[5]. On the other hand, new technology has been rapidly developed in the

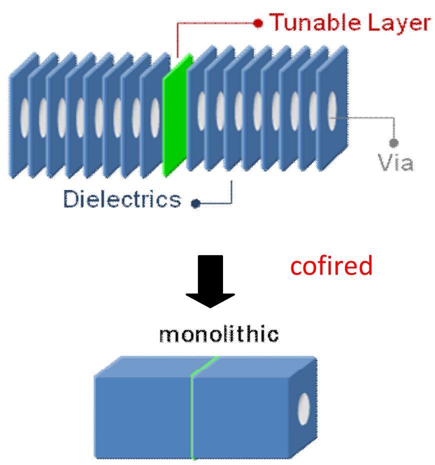

Fig.1 Basic concept of multi-layer cofired tunable capacitor (MLCTC)

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energy application such as a wireless energy transfer technology. In this technology, impedance tuning is very important to control the efficiency of energy transfer. In this case, besides tuning ability such as tunability, loss factors and temperature stabilities, power handling and reliability under high power are required with low cost. So, we have paid attention to tunable capacitors with thick film technology because better power handing ability might be expected than a thin film device[6]-[8]. And in general, devices fabricated by the thick film technology such as MLCC capacitors are known as cost competitive. In this paper, basic concepts of MLCTC and properties of tunable capacitors which have been fabricated by thick film processes are described.

2. Experimental Procedure

Reagent-grade chemicals $BaCO_3$, $SrCO_3$, and TiO_2 were mixed using ball milling to adjust the composition as $(Ba_{0.7}Sr_{0.3})TiO_3$ (BST). After the mixed powder were dried, calcined at 1200°C for 2 hrs. Then, calcined powders were remilled in a ball mill container with distilled water for 20 hrs, dried, mixed with poly vinyl butyral(PVB), and green tape were casted with doctor blade method. The thicknesses of green tape were about 20-30μm. Green tapes were cut into sheets, then, pre-laminated to 0.5mm in thickness. After punched to fabricate via-holes with a laser punching machine, via holes were filled with carbon paste. Then, a pair of green block with via-holes was stacked with inserting a green sheet which is a tunable layer and has no via-hole as illustrated in Fig.1. We are able to choose different materials for via-layers and tunable layers to adjust performance of MLCTC. After cold isostatic pressed, those laminated green blocks were cut into pieces, then,

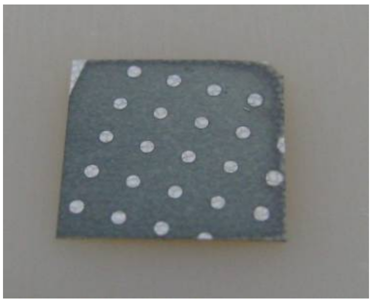

Fig.2 Plate sample of (Ba0.7Sr0.3)TiO3 sintered at 1350°C for 2 hrs. (Electrodes 0.6φ, Ag)

sintered in air at pre-determined temperature. In addition, silver electrodes were put on both side of sintered MLCTC including entire surface of via-hole with paste printing or sputtering method. Silver paste was sintered at 750 °C for 15 min.

On the other hand, BST plate samples were also fabricated in order to investigate dielectric properties of each material. Green sheets were laminated to 0.12 mm in thickness, and cut into 10 mm square, then, sintered in the same condition of multi-layer samples. After sintered, silver electrode was sputtered on entire surface of plate sample. Then, silver electrode which have 0.6 mm in diameter was sputtered on the opposite surface of plate samples as shown Fig.2 The identification of crystalline phases and elemental mapping in a sintered sample were conducted using powder X-ray diffraction analysis (XRD) and wavelength -dispersive electron probe microscopy analysis (WDX), respectively. Dielectric properties at a frequency of 1 kHz were measured using impedance analysis method (Models HP4194 / Hewlett–Packard, and E4980A / Agilent technologies).

$$\text{Tunability (\%)} = (C_0 - C_{bia}) / C_0 \times 100 \qquad (1)$$

where C_0 and C_{bia} are the capacitances with no bias and applied bias voltage, respectively.

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3. Results and discussion

The size of MLCTC was about 1x1x0.5 in mm. The cross sectional image of MLCTC which has been fabricated with BST for via-layers and a tunable layer is shown in Fig.3. BST of the tunable layer is about 30 μm thick and BST of via layers are about 0.45 mm thick. Tunable layer has dense microstructure, and it is confirmed that silver electrodes covered the entire surface of via holes. Measured dielectric results and tangent delta of plate samples in terms of sintering temperature are shown in Fig.4. Dielectric constant was about 5000 to 6000, and tangent delta was about 1-8% respectively. Tunability and leakage current density of plate sample sintered at various temperatures are summerized in Fig.5 and Fig.6 respectively. According to the increase of applied DC voltage, tunability increased, and at about 5 volts per micronmeter tunability seemed to be saturated. Then, tangent delta decreased according to the increase ofapplied voltage. Leakage current densities are small enough. In order to compare with the performance of plate sample and MLCTC, behaviors

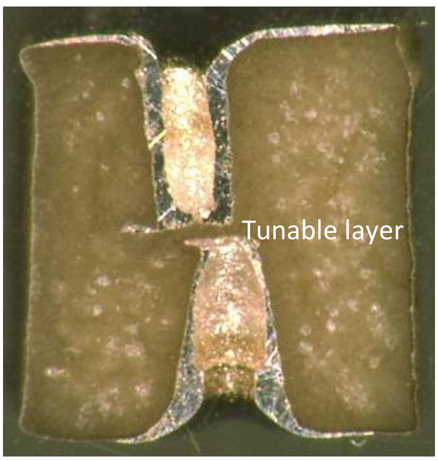

Fig.3 Cross sectional image of MLCTC made with $(Ba_{0.7}Sr_{0.3})TiO_3$ sintered at 1350°C for 2 hrs.

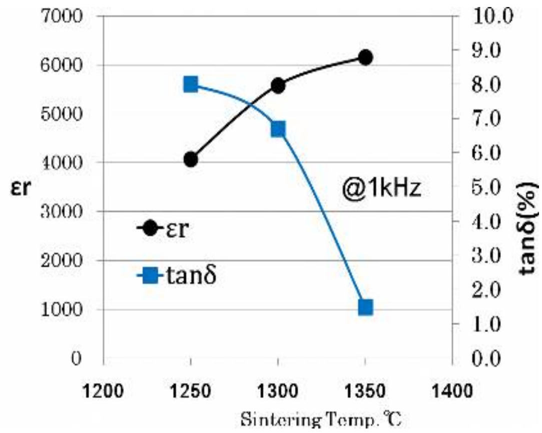

Fig.4 Dielectric properties of $(Ba_{0.7}Sr_{0.3})TiO_3$ plate samples sintered at 1350°C for 2 hrs.

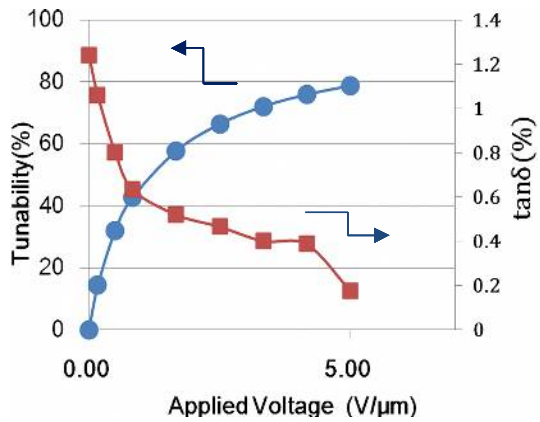

Fig.5 Tunabilities and dielectric lossses of $(Ba_{0.7}Sr_{0.3})TiO_3$ plate samples sintered at 1350°C for 2 hrs in terms of applied voltage..

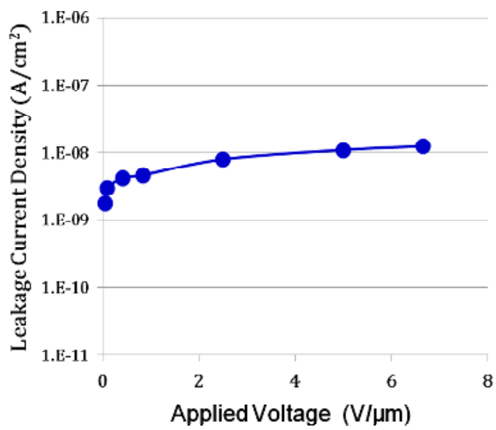

Fig.6 Leakage current densities of $(Ba_{0.7}Sr_{0.3})TiO_3$ plate samples sintered at 1350°C for 2 hrs in terms of applied voltage.

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of tunability with applied voltage are shown in Fig.7. Increase rate of tunability of MLCTC was rapidly decreased at about 3 volts per micron meter. This might be caused by the influence of stray capacitance of MLCC tunable capacitor because of high dielectric constant of via layers. With the increase of tuning voltage, contribution of tunable layer decrease because of large stray capacitance of via layers. On the other hand, leakage current of MLCC tunable capacitor was the same order of plate sample. The most effective way to decrease stray capacitance is to utilize via-layers which have smaller capacitance than that of the tunable layer. In the presentation, the combination of different materials for MLCTC will be discussed.

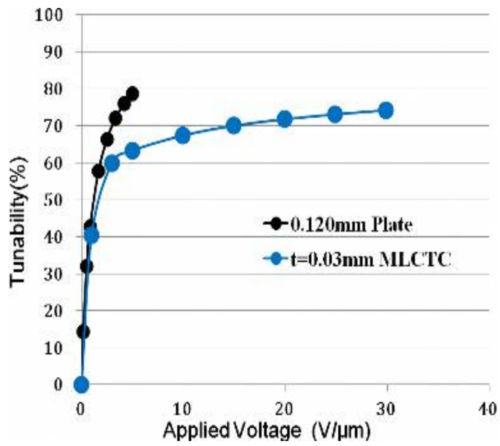

Fig.7 Comparison of tunability with plate sample and MLCTC of $(Ba_{0.7}Sr_{0.3})TiO_3$ sintered at 1350°C for 2 hrs in terms of applied voltage

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