

Dielectric Properties of Liquid Crystalline Polymers and BaTiO₃-SrTiO₃ Composites for Embedded Matching Capacitors

Jin Cheol Kim, Jun Rok Oh

eMD Center, Central R & D Institute, Samsung Electro-Mechanics Co. LTD., 443-743 Suwon, Korea

Phone: 82-31-218-2714, Email: ecjin.kim@samsung.com

Abstract

We manufactured Liquid Crystal Polymer (LCP) and (1-x)BaTiO₃-xSrTiO₃(BST) ceramic composites and investigated dielectric properties to use as embedded capacitor in printed circuit boards and replace LTCC substrates. The dielectric properties of these composites are varied with volume fraction of BST and ratios of BT/ST. Dielectric constants are in the range of 3~28. In addition, we could get low TCC and High Q value that could not achieve in other ceramic-polymer composites. Especially, in composite with x=0.4 and 50vol% BST, the dielectric constant and Q-value are 27 and 300, respectively. And more TCC is -116~145ppm/°C in the temperature range of -55~125 °C. We think that this composites can be used high-Q substrate material like LTCC and embedded temperature compensation capacitor in printed circuit boards.

Keywords: LCP, BST, embedded capacitor, LTCC

1.0 INTRODUCTION

Miniaturization is a great concern in all electronic equipment. Among them, mobiles are required to be smaller and are the convergence for multi-functions. In order to solve these problems, embedding of passive components (capacitor, resistor, inductors, etc.) in organic substrates and boards is becoming an important strategy in printed circuit boards and module substrates. [1, 2].

Among these passives, capacitors are the most important things because of their great usage. Capacitors are divided into two major parts according to their applications. One is for decoupling (noise cancellation) with characteristics of high capacitance and low inductance, the other is for temperature compensating with thermally stable dielectric constants and low loss. Many studies of embedded capacitors focused on decoupling with ceramic-polymer composite and thin films, but small capacitance is a big obstacle of this embedded capacitor.

On the other hand, polymer and composite is one of the promising dielectric materials for the temperature compensating embedded capacitor because it needs just a few picofarad capacitances. However, in general polymers have a high loss and large temperature coefficient of capacitance (TCC) than the conventional COG-typed Multi Layer Ceramic Capacitor (MLCC). The loss and TCC are very important parameters of mobile components. Any deviation of TCC specifications can affect the channel/frequency selection characteristics and high loss also affects insertion loss of filter/resonator circuits in the Radio Frequency module. So, we need more thermally stable polymer material having low loss. Liquid Crystalline Polymer(LCP) is a promising thermoplastic resin with good heat resistance, low hygroscopicity, a low coefficient of hygroscopic expansion, a low coefficient of thermal expansion(CTE), and good dielectric properties[3~5]. Many studies are

conducted using LCP films for embedded passives in organic substrates. Among these passives, LCP is very suitable for capacitors of filter and balun because of their low loss and frequency stable capacitance in the GHz range. We can infer that LCP is very suitable material for embedded capacitors in the RF module. But, in order to minimize RF module size, we need higher dielectric constants and low TCC. However, there are no reports about LCP-ceramic composites and variations of dielectric properties with thermal change.

Therefore, in this study we investigated dielectric properties of LCP and composite material -LCP and BST- to obtain dielectrics which have high dielectric constants, low loss and low TCC.

2.0 EXPERIMENTAL PROCEDURES

(1-x)BaTiO₃-xSrTiO₃(BST) was selected as filler. The reason is that the BST is a well-known ceramic material which has high dielectric constants. And more BST has an opposite slope of TCC to LCP. Therefore, we can conclude that BST can reduce TCC of LCP and low loss composites. To control TCC of composite, we varied the mole fraction(x) of BST ceramics. In this study, we make five compositions of BST with x=0.1, 0.2, 0.3, 0.4, 0.5. BST powders were suspended in a solution consisting of a dispersant and solvent. The suspensions were then milled for 1hr. LCP was selected as the polymer matrix. LCP-BST composites with different ceramic filler loading (30 and 50vol %) were formulated by adding different amounts of filler to the LCP suspensions. After milling them for 2hrs, the mixed slurry was coated on copper foils with a method of tape casting. To measure dielectric properties, we laminated 12um thick copper foil onto composite film at 300 °C using a vacuum press. The TCC was measured by HP 4284A LCR meter between -55~125 °C in the frequency range of 1KHz~1MHz.

3.0 RESULTS AND DISCUSSION

Fig. 1 is the XRD patterns of BST ceramics. All the peaks from the BST are indexed as perovskite structure. Fig.2 is the dielectric constant of BST powder as a function of temperatures. It is well known that as Strontium increase in BST the curie temperature of BST decrease. We will investigate change of dielectric constant of composite with temperature.

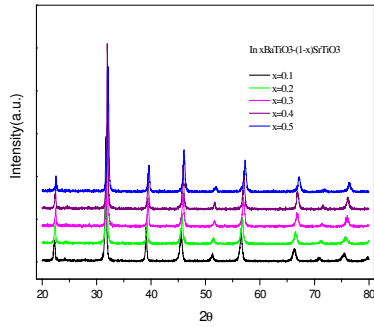


Figure 1: XRD patterns of BST filler

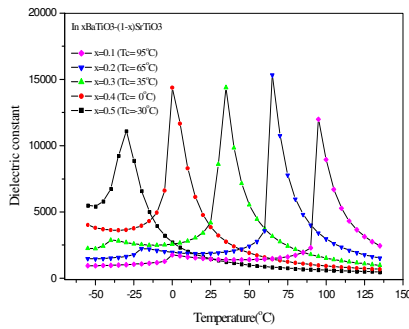


Figure 2. Dielectric constant of BST filler with temperatures

Fig. 3 shows cross-section of all-layer LCP substrate and composite films. This 4 layer substrate consists of woven glass cloth LCP Core and LCP-BST composite as build up layers in both sides. From Fig. 2(a), you can see that composite layer well laminated on LCP core with uniform thickness. Fig 2(b) is the SEM micrographs of composite film. The BST particles are uniformly dispersed in the LCP matrix. Aggregation of BST particles in the films was not noticed, which indicates good compatibility between the LCP and the BST particles with dispersant. In particular, we can see extraordinary phenomena in Fig. 2(a). Generally, in epoxy-based substrates, the second and third Cu layer is located on the core layer, and then the build-up layer occupied vacant space between Cu trace. However, LCP is a thermoplastic resin. The flow ability of resin depends on melting points and amounts of filler loading in dielectric films. As can you see from figure, the LCP resins in the core layer occupy a vacant space between Cu trace instead of the composite layer. It is due to the low flow of the composite layer having higher loading

amounts of filler than the core layer. Because of this, the thickness of the composite layer is very uniform than any other case.

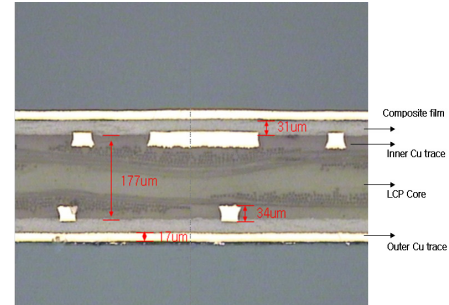


Figure 3(a): Cross-sectional view of all-layer LCP substrate (4L)

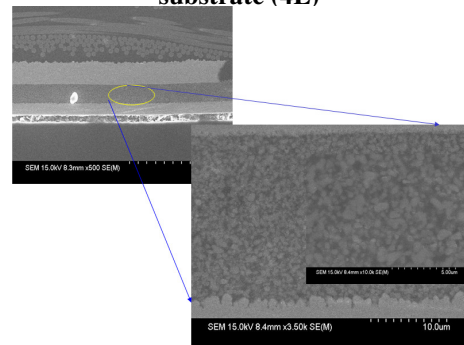
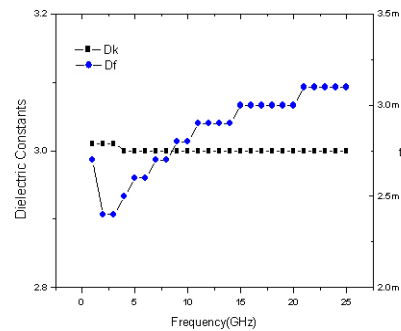
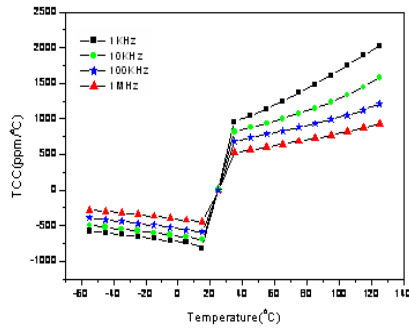


Figure 3(b): Cross-sectional view of LCP-BST composite films

Fig. 4(a) shows the dielectric properties of LCP films in GHz range, and 4(b) is the TCC measurement at 1KHz~1MHz and 1Vrms in the temperature range of -55~125 °C. As is well-known, dielectric constant and dissipation factor of LCP film are about 2.9~3.1 and 0.0024~0.0031 in the range of 1~25GHz. The capacitance of LCP films increases with measuring temperatures. The slope of TCC below room temperature is smaller than that above room temperature. The TCC range of LCP film is -450~+930ppm/°C in the temperature range of -55~125 °C measured at 1MHz. Also, the TCC of composites decreased from -577~+2050 to -450~+930ppm/°C with increasing measuring frequency from 1KHz to 1MHz. These characteristics are very useful in GHz frequency with very small TCC.



(a)



(b)

Figure 4(a): Dielectric properties of LCP films in GHz range (b): TCC characteristics of LCP films at various frequencies

Fig. 5 shows the dielectric properties of composite films as a function of mole fraction of Sr in BST measured at R.T. From these results, we can see that the dielectric constant of the composite did not influenced by dielectric constant of filler. From figure 2, dielectric constant of BST significantly varied with Strontium mole fractions. However, composites have similar values.

The dielectric loss is varied with Sr mole fractions. With increasing Sr fraction, the loss of composite decreased. The Highest Q of 750 was obtained for the composite with 50 mole % of Sr in BST. These Q values (below 0.01 in all composition) are much lower than the widely reported BT-epoxy composites with the same ceramic filler loading[6], and BCB polymer composites[7]. It is due to having low loss filler in composite.

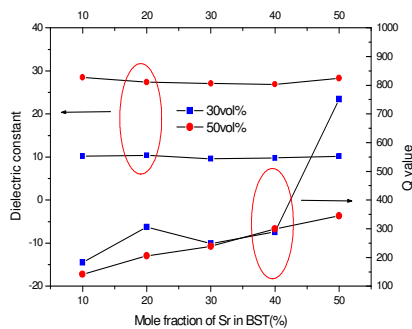
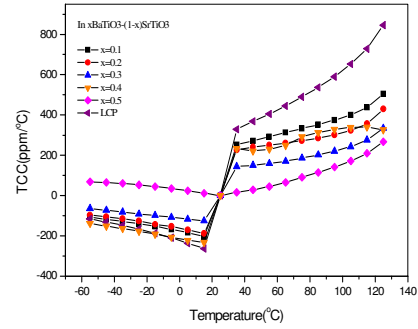
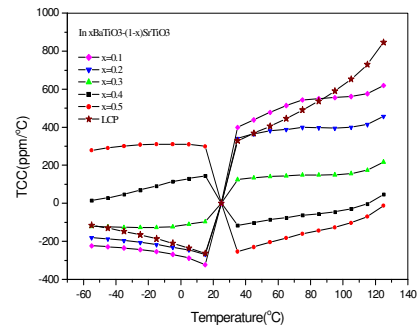


Figure 5: Dielectric constants and Q of composite as a function of mole fraction of Sr in BST filler

The TCC of composites are shown in Figure 6. The measuring frequency is 1MHz in every case. As you can see in these figure 6(a), the TCC decreases very slightly with increasing Sr mole fraction. The shape of TCC curve did change at $x=0.5$. In this case, TCC range of this composite is $0 \sim 266 \text{ ppm}/^\circ\text{C}$. However, In Figure 6b, the TCC decreases significantly. The shape of TCC remains until $x=0.3$. TCC range of $x=0.3$ is $-130 \sim 217 \text{ ppm}/^\circ\text{C}$. However, in case of $x=0.4$, the shape of TCC abruptly changed. As you can see from figure 6(b), TCC range of $x=0.4$ is $-116 \sim 145 \text{ ppm}/^\circ\text{C}$. From these results, we can conclude that it is possible to control TCC range of composite with proper filler.



(a) 30vol%



(b) 50vol%

Figure 6: The TCC characteristics of composite with volume fraction of filler

4.0 CONCLUSIONS

This paper reports the attempt to make low TCC and loss of composite dielectric for embedded RF capacitors. The TCC of the composite was significantly influenced by the TCCs of its constituents (polymer matrix and ceramic filler) and could be controlled by combining a positive TCC resin with negative TCC ceramics. In our LCP-BST composite, the positive TCC of LCP was compensated by the negative TCC of BST filler, leading to positive, zero, negative TCC values by adjusting the volume fraction of the ceramic filler and filler composition. With composite dielectric materials, depending on the fillers or matrices used, the capacitor can be easily designed to have a low or desired TCC. In conclusion, we can obtain composite with 10 dielectric constant and 750 of Q-value, and 27 dielectric constant and 300 of Q-value. In addition, TCC of composite is $-116 \sim 145 \text{ ppm}/^\circ\text{C}$. Its TCC is bigger than that of COG-typed MLCC ($\pm 30 \text{ ppm}/^\circ\text{C}$). However, the TCC of LCP films decreases with increasing frequency. Therefore, our composite can meet characteristics of COG-typed MLCC.

5.0 REFERENCES

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