Characterization of Barium Strontium Titanate Nanocomposite Dielectric Inks for RF and Microwave Applications

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Tunable radio frequency (RF) and microwave (MW) devices are keys to reconfigurable and adaptive systems with enhanced capacity and performance. Recently, barium strontium titanate ($Ba_xSr_{1-x}TiO_3$) or BST has been extensively investigated due to its tunable dielectric properties. As previously reported, different types of BST thin or thick films are deposited to develop tunable devices using various techniques such as pulsed laser deposition, chemical vapor deposition and RF sputtering techniques. In our previous work, BST-COC (cyclic olefin copolymer) nanocomposite dielectric ink was used to develop fully printed RF and MW devices on flexible substrates. These inks have been used to develop fully printed varactors for tunable frequency selective surfaces (M. Haghzadeh and A. Akyurtlu, Journal of Applied Physics, 120, 184901, 2016) and phase shifters (M. Haghzadeh, C.Armiento and A. Akyurtlu, IEEE Transactions on Microwave Theory and Techniques, 65, 2030, 2017). Here, we attempt to further investigate the material and improve its performance by miniaturizing the devices or by applying novel sintering techniques compatible with low temperature substrates to reduce the required tuning voltage.

BST has a paraelectric phase above the Curie temperature (T_C), due to the cubic and symmetric crystal structure, with no spontaneous polarization. Below the Curie temperature, BST has a ferroelectric phase due to the spontaneous polarization of non-center symmetric crystal structure. In the paraelectric phase, BST shows the highest microwave dielectric properties such as high tunability, low loss tangent and high switching speed. Therefore, Curie temperature was tailored by adjusting the Ba molar fraction in order to achieve the paraelectric phase of BST at room temperature. The COC thermoplastic polymer was used as the polymer matrix because of the very low loss tangent at radio and microwave frequencies. The size of BST nanoparticles, Ba molar fraction in BST, and BST loading were optimized to achieve the highest dielectric performance of BST-COC dielectric nanocomposite. Copper etched cylindrical capacitors were used as the Device Under Test (DUT) and BST-COC composite was printed inside the gap of the cylindrical capacitor as the Material Under Test (MUT). S_{11}-reflection parameters were measured using a network analyzer, and dielectric constant and loss tangent were calculated.

Previously, BST-COC nanocomposite filled cylindrical capacitors showed a maximum tunability of 10% at 10 GHz with an applied dc voltage of 400 V. However, it is very important to reduce this tuning voltage to practical levels and minimize the total power consumption of the device. Smaller feature sizes using different fabrication processes and a thin BST-COC nanocomposite film (with and without sintering) as a substrate were investigated in order to reduce the operating voltage. Most of the solvent in the BST-COC dielectric ink was evaporated during the printing process. After printing, the dielectric was cured at temperatures below 200 $^{\circ}$C. At such low temperatures, sintering of BST nanoparticles cannot be expected. The Novacentrix PulseForge material processing tool was used for sintering BST nanoparticles at higher temperatures without damaging flexible substrates. Changes of dielectric properties of BST-COC nanocomposites due to sintering, were investigated.