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Modeling the Electrical Conduction in Epoxy–$BaTiO_3$ Nanocomposites

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Epoxy–$BaTiO_3$ nanocomposites are widely used as the dielectric material in embedded planar capacitors. To maximize the effective dielectric constant of this nanocomposite, the loading of $BaTiO_3$ is kept as high as possible, but at high loadings of $BaTiO_3$ the magnitude of undesirable leakage current in the dielectric also increases. This paper investigates the conduction mechanism in epoxy–$BaTiO_3$ nanocomposites. Further, the effects of $BaTiO_3$ loading and the size of $BaTiO_3$ particles on the electrical conduction are investigated and also modeled. To investigate the conduction mechanism, capacitor structures (Cu/dielectric/Cu) with nanocomposite dielectric were fabricated using the colloidal process. The loading and size of $BaTiO_3$ particles were varied in the nanocomposite dielectric. Once the capacitor structures were fabricated, the leakage current was measured across the capacitor dielectric as a function of temperature and voltage. The leakage current data were checked for any consistency with the standard conduction models using regression analysis, and the dominant conduction mechanism was identified. Finally, the activation energy of the dominant conduction mechanism was trended as a function of $BaTiO_3$ loading and particle size both experimentally and theoretically.

Key words: Epoxy–$BaTiO_3$ nanocomposites, electrical conduction, dielectric, embedded capacitor

INTRODUCTION

Epoxy–$BaTiO_3$ nanocomposites are widely used as dielectric materials in embedded planar capacitors.[1,2] Embedded planar capacitors (Fig. 1) are thin laminates that serve both as a power-ground plane and as a parallel-plate capacitor in a multilayer printed wiring board (PWB).[3] These capacitors are generally used in decoupling applications and lead to a reduction in the number of surface-mount capacitors and, hence, PWB miniaturization.[4] Embedded planar capacitors have also been found to reduce high-frequency electromagnetic interference (EMI) as compared with discrete surface-mount capacitors.[5,6] The laminate of an embedded planar capacitor consists of a thin dielectric material sandwiched between copper layers. Epoxy–$BaTiO_3$ nanocomposites are widely used as the dielectric material, since they combine the low-temperature processing of polymers and the high dielectric constant of ceramics.[7,8] Since the dielectric constant of $BaTiO_3$ attains a maximum value when the particle size is around 140 nm (as observed in pure $BaTiO_3$), nanoparticles of $BaTiO_3$ are used in the composite.[9]

To achieve a high dielectric constant of the nanocomposite, the $BaTiO_3$ loading is kept as high as possible. With an increase in the $BaTiO_3$ loading, the dielectric constant of these nanocomposites increases,[10–14] but at the same time the magnitude of the undesirable leakage current in the dielectric also increases.[15] The mechanism of this undesirable leakage current has not been well understood.

The mechanisms of current conduction in ceramics (such as $BaTiO_3$)[16,17] and polymers[18] are well understood, but limited work has been performed to

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