White Paper: Resistivity and Dielectric Strength of Nanocomposites

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Abstract

The surface resistivity, volume resistivity, and dielectric strength of zirconia nanocrystal/acrylic composites was measured in this study. Native bisphenol A glycerolate dimethacrylate (BPA) was measured as the reference medium, and PixClear® PCPR nanocomposites were tested at 50wt% and 90wt% in the same polymer system.

Introduction

There is growing interest in the use of filler materials to modify the performance of polymers. Due to gentler processing conditions and a demand for rugged electronic devices, polymers are replacing more traditional materials, such as ceramics, for use in flexible electronics applications. Pixelligent's zirconia nanocrystals have been shown to increase the refractive index of polymeric materials, and in this paper we look at their effect on electrical properties. We have previously shown an increase in dielectric constant due to addition of zirconia into polymeric materials. To broaden this study we have investigated surface resistivity, volume resistivity, and dielectric strength. Surface and volume resistivity are important inputs into electrical design, while dielectric strength is important for understanding bulk material tolerances. Dielectric breakdown is the failure of an insulating material under an applied electrical field resulting in mechanical damage and conduction of electricity. While many polymers have breakdown strengths that exceed the tolerances of ceramic materials they generally have lower dielectric permittivity. In this paper we demonstrate minimal degradation to surface and volume resistivity and dielectric strength while significantly increasing the dielectric constant of polymeric materials.

Since dielectric breakdown dramatically decreases with the presence of defects, the filler's chemical and physical compatability is crucial to the material's electrical tolerance. The use of larger micron-sized filler particles is detrimental to material properties due to structural inhomogeneity. Although nanofillers have greatly increased surface area, they have a smaller detrimental effect on the structural properties of the polymeric film if they are uniformly dispersed, and cause the least decrease in electrical performance.[1][2] Pixelligent's PixClear® nanomaterials use surface modification to create high quality dispersions that lead to highly loaded, defect free nanocomposites of various polymers.

In a previous white paper, [3] PixClear® zirconia was shown to increase the dielectric permittivity of acrylic materials from 1.5 to 7.9 when introduced up to 80wt%. Pixelligent's nanocrystalline zirconia particles are small (<10 nm) and uniform, and our proprietary surface capping technology enables the creation highly loaded composites that are free of agglomeration. Capping or the use of surfactants has been shown to lead to better breakdown outcomes compared to uncapped particles according to experiments on nanocomposites using $BaTiO_3$ and $PbZrO_3$ particles.[4]

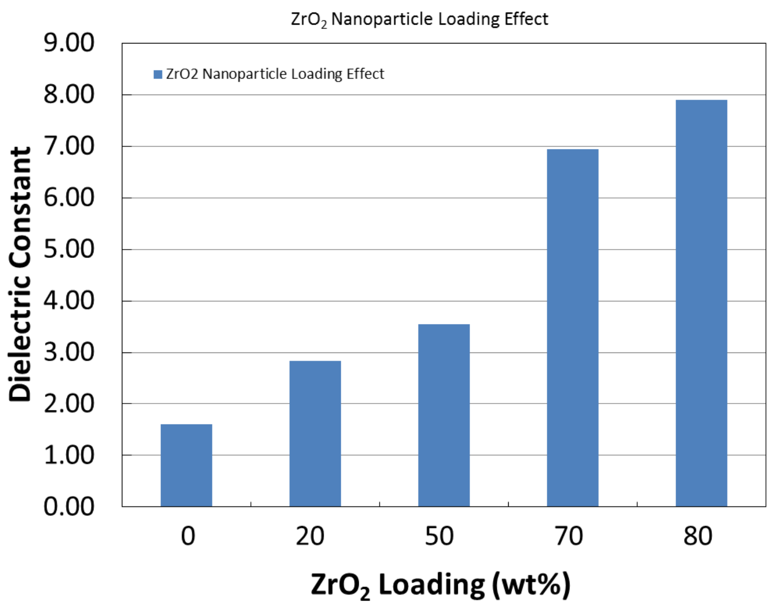

Figure 1. Dielectric permittivity of PixClear® nanocomposites increases with loading [3]

Following our investigation into the enhanced dielectric permitivity, samples at 50wt% and 90wt% were measured for surface and volume resistivity and dielectric breakdown strength.

Methods

Film Preparation

Pure bisphenol A glycerolate dimethacrylate (BPA), 50wt% PixClear® PCPR, and 90wt% PixClear were spin coated onto an aluminum pans to a thickness on the order of hundreds of microns. Each film was conditioned for 40hrs at room temperature and 50% relative humidity.

Dielectric Breakdown and Dielectric Strength Measurement

A cylindrical probe was place in contact with the films and tested with the aluminum substrate in place. Direct-voltage was applied until breakdown or arc over occurred.

Volume and Surface Resistivity Measurement

Each film was placed in a resistivity cell, connected to a high resistance meter. 500 V were applied to the specimen for 60 s.

Results and Discussion

When PixClear® is added to the acrylic medium bisphenol A glycerolate dimethacrylate, the dielectric constant increases to 7.9 at 80wt% loading (Figure 1.).[3] According to measurements on PixClear® nanocomposites at 50wt% and 90wt%, the volume and surface resistivities slightly decrease compared to the native polymer (Figure 2.) despite the gains in dielectric permittivity.

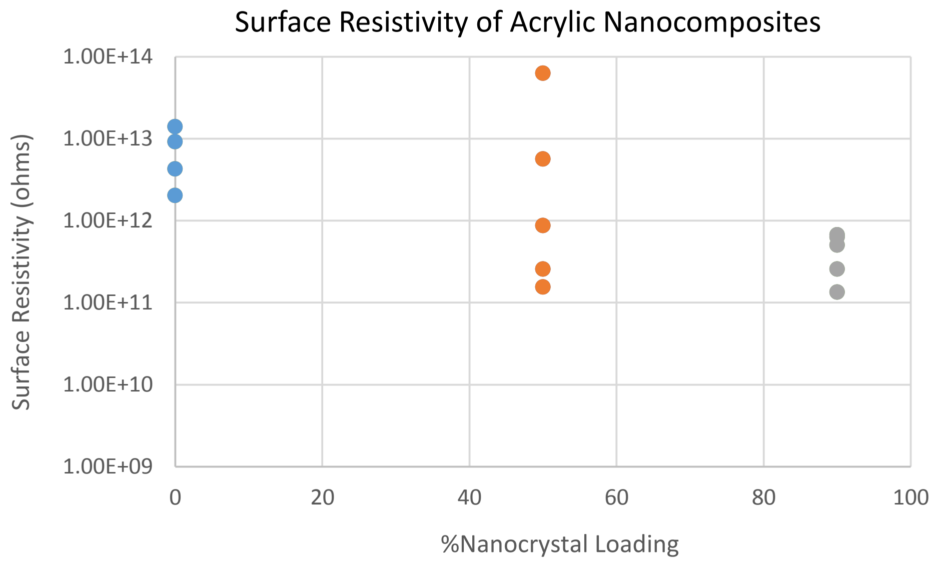

Figure 2. Logarithmic scale plot of the surface resistivity of native acrylic and nanocomposites loaded at 50wt% and 90wt%.

The large variation in surface resistivity measured for the 50% nanocomposite could indicate an uneven surface. In general, both surface resistivity decreases when more nanocrystals are introduced into our arcrylic composites (Figures 2.).

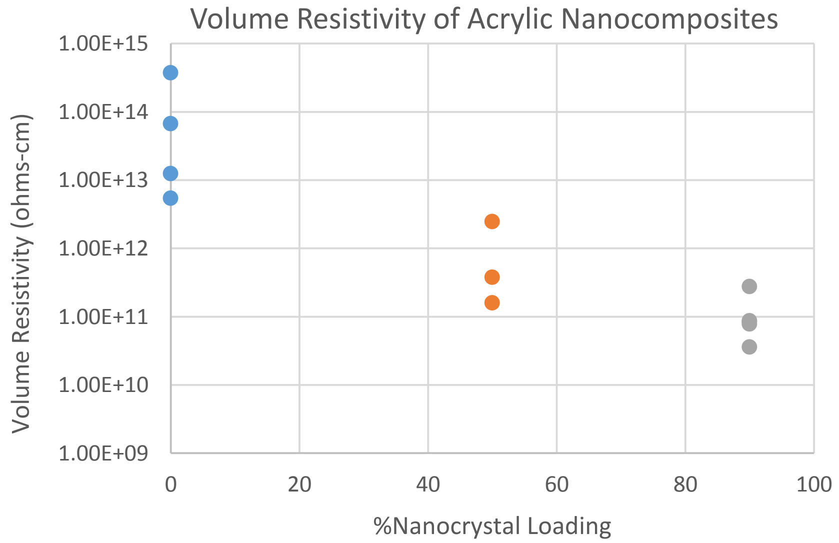

Figure 3. Logarithmic scale plot of the volume resistivity of native acrylic and nanocomposites loaded at 50wt% and 90wt%.

In Figure 3., the volume resistivity data indicates a decrease with greater amounts of nanocrystal loading. This indicates that the added PixClear® decreases the inherent insulation properties compared to native BPA.

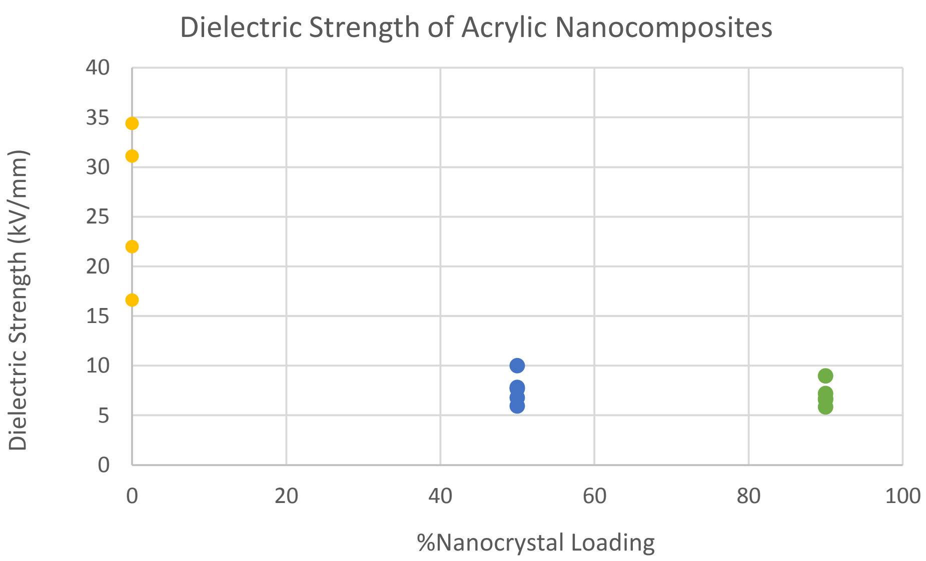

Figure 4. The dielectric strength of native acrylic and nanocomposites loaded at 50wt% and 90wt%.

The PixClear® PCPR nanocomposites have a lower measured dielectric strength compared to the native acrylic polymer. With the average 50wt% and 90wt% dielectric strengths being 7.6 and 7.0kV/mm respectively, there is a very small difference between each nanocomposite. The modest decline in dielectric strength at very high loadings indicates that the addition of PixClear® zirconia creates little to no defects in the composite, otherwise the dielectric strength would decrease even further. In addition, dielectric strength remains appreciable while improving the dielectric constant.

Conclusions

While dielectric permittivity of PixClear® acrylic nanocomposites increases with loading, surface and volume resistivity decreased. The dielectric strength of the nanocomposites was also less than the native polymer, but the similarity between 50wt% and 90wt% nanocomposites indicates that the addition of PixClear® results in high quality, high loading films.

Acknowledgements

We thank Dr. Jian Wang for his work preparing samples and collecting the resistivity and dielectric breakdown data for Pixelligent's nanocomposites.

References

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