Chapter 8

CONCLUSION AND FUTURE SCOPE

8.1 SUMMARY OF IMPORTANT FINDINGS

Through experimental and simulation studies, this thesis delves deeply into the interphase and its effect on the dielectric and thermal properties of epoxy and epoxy alumina nanocomposites. On a more detailed level, the effect of nanofillers on dielectric and thermal properties is explored in terms of their surface treatment. Conduction current measurement, dielectric spectroscopy, and breakdown test are conducted to elicit information on dielectric properties. Thermogravimetric analysis (TGA), thermal conductivity measurements, and differential scanning calorimetry (DSC) are performed to investigate the thermal properties of epoxy alumina nanocomposites. Likewise, FTIR spectroscopy and XRD analysis are used to characterize nanofiller, and nanofiller reinforced polymers chemically and structurally.

The following are the most significant findings from the thesis:

- Experimental evidence indicates that nanocomposites synthesized with surface-treated nanofillers have significantly different dielectric characteristics than neat polymers and nanocomposites (formed with untreated nanofillers). Characteristics information received from thermogravimetric analysis and dielectric properties measurements insinuates a change in chemistry and molecular mobility at the filler matrix interfaces. Using the chemical structure of different constituent phases and FTIR spectroscopic analysis, a chemical interactive model is presented to elicit interphase formation in composites. The impact of interfacial interaction on long-term performance of the nanodielectrics is examined by conducting endurance tests under divergent ac stress. Nanocomposites exhibit a clear superior erosion resistance over the neat polymer. Under the application of cyclic non-uniform ac stress, progressive erosion is likely to initiate and grow from high-stress region. Nanofillers may act as an obstacle and force the eroded channels to move through a zig-zag path. Additionally, surface-treated nanofillers owing to their strong chemical bonding with polymer matrix expected to retard the damage process by alleviating fatigue and distributing electromechanical stress between filler and polymer matrix.

- Extensive experimental work is presented to substantiate interphase development and to provide feasible inputs for altering the dielectric characteristics of PNCs via changing interfacial interaction (chemically or physically).

- The interphase in epoxy alumina nanocomposites is quantified using numerical model and dielectric spectroscopic data. For epoxy alumina nanocomposites, a bisection-based algorithm is devised to determine the interphase extent and its permittivity. The interphase in epoxy alumina nanocomposites is seen to extend up to 100 nm in length and has a relative permittivity slightly less than the effective permittivity of the composites.

- A comprehensive investigation using experimental data and numerical modeling suggests that the interphase in epoxy alumina nanocomposites has a thermal conductivity considerably higher than that of pure epoxy. The interphase exhibited lower direct current conductivity (dc) than pure epoxy. The aligned polymer chains at the interfaces of the filler matrix may be responsible for the interphase's high thermal conductivity. The alignment of the polymer chain reduces phonon scattering, hence increasing the efficiency of heat transfer.

- While the nanofiller content determines the thermal properties of nanocomposites, the interphase volume fraction determines their dielectric properties. As a result, the filler concentrations with the highest interphase volume percentage optimize dielectric and thermal properties. Beyond this optimal filler concentration, increased thermal conductivity is possible at the tradeoff of reduced dielectric properties.

8.2 FUTURE SCOPE

- The present research utilizes alumina particles to synthesize the NC materials. Alumina filler was chosen due to the long history of industries using micron-sized alumina particles for enhancing the mechanical stiffness of epoxy insulation. NCs produced with various nanofillers, such as boron nitride (BN), aluminum nitride (AN), magnesium oxide (MgO), silicon oxide (SiO_2), barium titanate ($BaTiO_3$), and zinc oxide (ZnO), could be investigated for their interphase properties. This enables us to predict numerically the potential benefits of nanocomposites formed with hybrid fillers.
- The purpose of this work was to construct a numerical model to evaluate the effect of filler forms, sizes, and concentrations on dielectric and thermal properties. A practical approach for orienting fillers to achieve directional features yet to be devised. Additionally, the numerical model results must be validated experimentally.

- In this study, a numerical model has been developed for calculating the thermal conductivity, dc conductivity, and permittivity of nanocomposites. Similar, numerical models can be developed to predict other properties viz. breakdown strength and mechanical properties.
- Finally, nanocomposites need to be evaluated extensively for their long-term performance via multi-stress aging experiments.