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Nanodielectrics in Power Engineering: Review and Prospects

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Abstract

Nano-dielectrics are materials in which filler particles are dispersed to improve material characteristics such as toughness, enhance barrier properties, and increase resistance to fire. Nano-dielectrics, are expected to have improved dielectric properties which can be exploited with simpler manufacturing technologies, but have a wake of disadvantages. The engineering challenge is to maximize the former and minimize the latter. Nano materials are used or likely to be used in the near future in a large variety of applications in power industry, energy storage devices, and microelectronics, rotating machine insulation, electric stress control applications, and outdoor insulation. In this topical review the author discusses the progress achieved so far, challenges and prospectives in the area of electrical power, transmission and Distribution.

Keywords: Cable Bolting, Hangwall, Jumbo Drill, Manganese Ore, SDL

1. Introduction

Nanomaterials are materials in which foreign particles are dispersed to improve material characteristics such as stiffness, toughness, enhance barrier properties, increase resistance to fire, and ignition. Nanodielectrics, a subcategory of nanomaterials, are expected to have improved dielectric properties which can be exploited with relatively less expense and simpler manufacturing technologies[1,2]. The engineering challenge is to maximize the former and minimize the latter. Nanomaterials are used or likely to be used in the near future in a large variety of applications in power industry, energy storage devices, and microelectronics[3], rotating machine insulation, electric stress control applications, and outdoor insulation[4].

Commonly used nanoparticles for research and their physical properties are shown in Table 1.

Lewis[1], Tanaka et al.[5] and Daily et al[6] have proposed theories for the role of nanomaterials in a different parent matrix. model the interfacial structure and visualize it as having multiple layers.

2. Nanodielectrics in Power Industry

One of the major advantages looked for in the application of nanodielectrics to power industry is the improvements in dielectric performance. This criterion includes higher surface and volume

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Table 1. Properties of conducting and insulating nanoparticles[7]

Property	Magnetite Fe_3O_4	Zinc oxide ZnO	Alumina Al_2O_3	Quartz SiO_2	Silica SiO_2
Electrical conductivity (S/m)	1×10^4–1×10^5	10– 1×10^3	1×10^{-12}	1.3×10^{-18}	1.4×10^{-9}
Dielectric constant	80	7.4–8.9	9.9	3.8-5.4	3.8
Relaxation time (s)	7.47×10^{-14}	1.05×10^{-11}	12.2	36.3	5.12×10^{-2}
Dielectric strength (kV/mm)	_	35	10	_	_
Thermal conductivity ($Wm^{-1}K^{-1}$)	4-8	23.4	30	11.1	1.4

resistivity, higher partial discharge inception level, improvements in aging performance under combined thermal and electrical stress, and improved performance in adverse ambient conditions such as pollution, fog and icy conditions. Since no single nanodielectric material is likely to satisfy all these requirements search for materials that satisfy a particular application is likely to yield better results.

3. Polythene and Selected Nanomaterials

Polyethylene, cross linked polyethylene and blends[8] are extensively used in electrical industries. The dielectric properties of polyethylene/aluminum nanocomposites have been investigated Huang et al.[9] as such composites with high dielectric constants are required in wireless communication products.

Figure 1 shows ε' and tan δ as a function of frequency for various constant values of percentage loading. As the loading is increased the interfacial phenomena is thought to increase upto 24%. For higher loadings imperfect filler packing combined with the decrease of the effective area of the interface between polymer matrix and the nanofiller is suggested for lowering ε'. The largest value of tan δ (~ 0.65) is observed at 10 Hz for 24% loading.

4. Epoxy Resin Nanocomposites

Production of embedded passive components like capacitors, inductors and resistors in to the bulk of the printed circuit boards (PCB) rather than mounting them on the PCB is an emerging technology. Various dielectrics, particularly composites have been studied

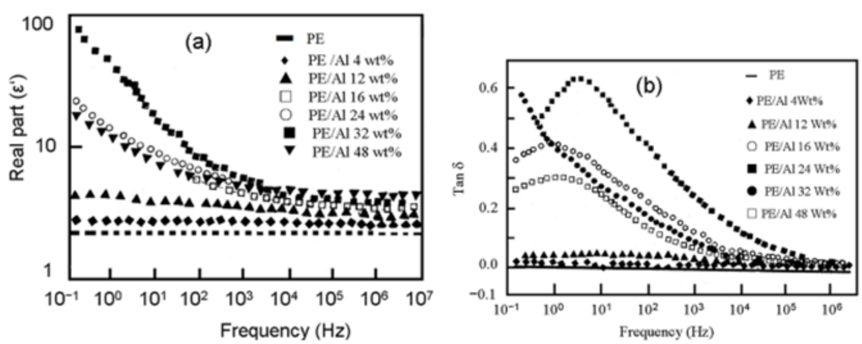

Figure 1. Dielectric constant (ε') and loss tangent in polyethylene/alumina nanocomposite as a function of frequency at various loadings by wt. percentage[10].

for the purpose of producing embedded capacitors in PCBs.

The dielectric constant of many composites considered for this purpose usually have a dielectric constant (ε') of 10 to 100. Gonon and Boudefel[11] have studied the dielectric constant and AC conductivity of epoxy/silver and find that dielectric constant as large as 1000, ten times larger than epoxy/ferroelectric composites. Recall that the AC complex admittance and conductivity are related by:

$$Y^* = G + jC\omega \quad (1)$$

where G and C are the parallel conductance and capacitance respectively, and

$$\sigma^* = \sigma + j\varepsilon_0\varepsilon''\omega \quad (2)$$

$$Y^* = s^* \frac{A}{L} \quad (3)$$

where A and L are the area and length of the parallel capacitor.

Two of the major tools for the study of the dielectric properties of nanocomposites are dielectric spectroscopy and time domain spectroscopy. Dielectric spectroscopy covers three frequency ranges; 10^{-2} Hz to 10^7 Hz and 10^8 Hz to 10^{11}Hz and broad band measurements. Time domain measurements are carried out by measuring DC current in the time range of 10^{-5} s to 10 s.

For power engineering applications one of the commonly used epoxy is Bisphenol-A and nanomaterial dispersions. The fillers are generally speaking, spherical alumina (Al_2O_3), Titania (TiO_2) and zinc oxide (ZnO) powders as received by suppliers or functionalized by simple heating or treating with specific chemicals. A typical preparation procedure for using as received material is given in [12]. The results of dielectric spectroscopic studies are given in [13].

For field tenability ferroelectric barium titanate ($BaTiO_3$) and antiferroelectric lead zirconate (PZ) nanoparticles are promising choices. The latter composite (PZ) demonstrates dielectric constants that increase with higher electric field and higher % loading.

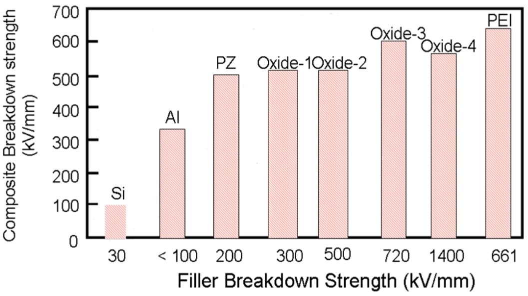

Figure 2. Breakdown strength of PEI nanocomposites with various fillers of about 5wt.% loading. PZ means lead zirconate. Adapted from[14].

The influence of nanoparticles on the dielectric strength of the composites is shown in Figure 2. These results show that the influence of nanoparticles on the dielectric strength should be evaluated with great care as both increase and decrease in the dielectric strength are possible depending upon the matrix-filler combinations.

5. Concluding Remarks

The field of research is rich in exciting possibilities and it is hoped that the topics discussed in this brief review provides the necessary background and specialization for the task.

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