1 Introduction

Polymer nanocomposites with a high dielectric constant have potential applications in energy storage systems and in grading or erosion resistance and DC conductivity, on adding even small amounts of nanofillers to polymer dielectrics [7–11]. However, improvement in complex permittivity does not usually happen. In fact, addition of very small amounts (<1% by volume) of nanofillers viz., Al₂O₃, TiO₂, SiO₂, MgO and ZnO into the polymer matrix has shown a reduction in composite permittivity [7–9]. However, enhancement in the complex permittivity of polymeric dielectrics is reportedly achievable with the addition of nanofillers with high permittivity (e.g. BaTiO₃) [1, 4, 11].

Polymeric materials stressed under high DC field accumulate charge within the volume of material. Accumulated space charge causes local field intensification, leading to aging, and/or premature failure of insulation. A considerable body of literature on space charge behaviour of nanocomposites with various nanofillers, e.g. Al₂O₃, ZnO, SiO₂, MgO, TiO₂ is available [7–9] but lacks consensus in understanding charge transport and trapping [7]. Reports are limited to composites with low filler loading (<2% by volume fraction) and is lacking in studies on BaTiO₃-filled composites. Hence, understanding of space charge behaviour in this high permittivity nanocomposite is crucial, which is done in this paper. Other than the space charge characteristics, the fabricated barium titanate (BaTiO₃ or BT) nanocomposite is characterised in terms of complex permittivity, conductivity and breakdown strength which are crucial properties of a dielectric material. A study of the effect of BT filler loading and surface functionalisation of BT particles before incorporation into the nanocomposite is also done. Moreover, a theoretical case study is also undertaken to evaluate the efficacy of high permittivity nanocomposite in mitigating local electric stress.

2 Experimental

2.1 Materials and methods

Flat specimens of neat epoxy with thickness of 200–300 µm are prepared using epoxy resin (DGEBA: diglycidyl ether of Bisphenol-A), (LY556; density: 1.17 g/cm³ at 25°C) mixed with curing agent (TETA: triethylenetetramine), (HY951; density: 0.98 g/cm³ at 25°C) supplied by Vantico Performance Polymers Pvt. Ltd, India. Nanocomposite specimens are prepared by incorporating barium titanate nanofillers (BaTiO₃) average diameter: 90–100 nm, phase: cubic crystalline, density: 6.08 g/cm³ at 25°C). The nanofillers are surface-functionalised with 3-glycidoxypropyltrimethoxy-silane (GPS; density: 1.07 g/cm³ at 25°C) treatment of the particles is necessary to improve the reactivity of the BaTiO₃ or BT) particles. 2 g of as-received BT powder is taken and 5 mL of H₂O₂ added to it. The mixture is sonicated for 30 min at room temperature.

![Chemical structure of GPS](image)

**Fig. 1** Chemical structure of GPS
temperature. Again, 30 mL of H$_2$O$_2$ is added and the mixture is refluxed for 4 h at 100°C. The nanoparticles are then washed with deionised water under centrifugation at 10,000 rpm for 7 min and then dried in vacuum at 80°C for 12 h.

The optimum amount of GPS for surface functionalisation of BaTiO$_3$ nanoparticle is calculated based on criteria discussed in [12]. Accordingly, 1.937 g of hydrolysed BT particles are added to 5 mL of toluene and sonicated for 30 min at room temperature. 30 mL toluene is added to 0.457 mL silane and sonicated for 30 min. The particle solution is added to the GPS solution and stirred at 100°C for 24 h in a nitrogen environment. The functionalised nanoparticles are washed in toluene as before and vacuum-dried.

Fourier transform infra-red (FTIR) spectra of as-received and surface-functionalised BT nanopowder are shown in Fig. 2. The appearance of a new peak at 1099.33 cm$^{-1}$, after functionalisation, signifies the presence of Si–OH, Si–O–Si and Si–O–Ti bonds [11]. The peak at 1458.40 cm$^{-1}$ is related to the bending vibration of -OCH$_3$ in silane. The appearance of these two new peaks indicates that the BT nanofillers have been successfully modified with silane, through covalent bonding between silane (GPS) with barium titanate (BaTiO$_3$) nanoparticle.

2.3 Preparation of nanocomposite specimens

As-received and surface-functionalised nanofillers are taken in required amounts (determined by the desired filler loading) and dispersed in toluene using an ultrasonic processor for 2 h. After the addition of epoxy resin to the solvent, sonication is required for another 2 h. The solution is magnetically stirred for 4–4 min, and the mixture is poured into glass moulds lined with thin mylar sheets. The test specimen is polarised for 3 h and depolarised for 2 h. The polarisation time was chosen such that all polarisation processes including the slow processes are complete and the current attains a steady value. Similarly, the depolarisation time was chosen such that the current becomes almost zero. At steady state, the conduction current $I_c(t)$ is calculated from

$$I_c(t) = I_p(t) - I_d(t)$$

where $I_p(t)$ and $I_d(t)$ are polarisation and depolarisation currents at time $t$ after switch on or switch off, respectively.

The DC conductivity ($\sigma_{dc}$) is calculated from
\[
\sigma_d = \frac{d \times I_c}{A \times V}
\]  

(2)

where \(d\), \(I_c\), \(A\) and \(V\) are specimen thickness, steady-state conduction current, effective electrode area and applied DC voltage.

### 3.3 Space charge density

Space charge measurements are carried out using a pulsed electro-acoustic (PEA) system supplied by TechImp Italy. The working principle of the PEA system for a flat specimen is discussed elsewhere [15].

When a dielectric material is subjected to a uniform DC field, space charge accumulates in the volume through either injection at the interface or internal generation processes. Above a certain critical field, the current-field relation is no longer linear and begins to be dominated by the space charge accumulated in the bulk of the material (space charge limited current). The electric field at which this transition occurs is regarded as the threshold electric field for space charge accumulation. This can be estimated through different techniques viz., conduction current measurements, space charge mapping and electroluminescence measurements [16]. In this work, the threshold electric field for space charge accumulation of various samples is measured by conduction current method [17].

Before starting new measurements, the test specimen is grounded for 10,000 s to completely deplete any residual space charge. The test specimen is placed between two electrodes and energised with DC voltage such that the applied field is above the threshold electric field for space charge accumulation. An electric pulse of short duration is applied to the test specimen via a decoupling capacitor. This perturbs the charge, resulting in the generation of an acoustic wave at the space charge location. Acoustic waves travel through the test specimen and earth electrode. A piezoelectric sensor placed at the earth electrode converts the acoustic wave into an electrical signal. The amplitude of this signal is proportional to the space charge density of the test specimen. To obtain the space charge profile, a deconvolution technique is necessary. A calibration process is adopted to map the corresponding voltage signal at the oscilloscope to a spatial map of the space charge within the specimen. The calibration is based on a known charge distribution at the earth electrode. The deconvolution and calibration procedures are discussed in detail elsewhere [18–21].

For calibration and deconvolution, prior knowledge of the acoustic impedance of the test specimen is required. The acoustic bulk of the material (space charge limited current). The electric energised with DC voltage such that the applied field is above the ground for 10,000 s to completely deplete any residual space charge measurements are carried out using a pulsed electro-acoustic (PEA) system supplied by TechImp Italy. The acoustic impedance of the test specimen is calculated as

\[
Z_{OLYMPUS} = \frac{\rho \times \nu}{\alpha \times \beta}
\]

(3)

where \(\rho\) and \(\beta\) are mass density (kg/m³) of the material and speed of sound (m/s) in the material medium, respectively [18].

The acoustic impedances of epoxy and its nanocomposites are seen to be close. A marginal increase in acoustic impedance with filler concentration is seen in Table 1.

### Table 1 Acoustic impedance (kg/m²s) of epoxy and its nanocomposites

| Specimen | Nanocomposites (with as-received fillers) | Nanocomposites (with surface-functionalised fillers) |
|----------|------------------------------------------|--------------------------------------------------|
| epoxy    | 3.21 \times 10^6                        | 3.21 \times 10^6                                  |
| 1 vol. % | 3.22 \times 10^6                        | 3.22 \times 10^6                                  |
| 2 vol. % | 3.24 \times 10^6                        | 3.25 \times 10^6                                  |
| 5 vol. % | 3.26 \times 10^6                        | 3.28 \times 10^6                                  |
| 10 vol. %| 3.31 \times 10^6                        | 3.32 \times 10^6                                  |

Both epoxy and its nanocomposite samples are polarised for 10,000 s and depolarised for 4000 s. The polarisation time (10,000 s) is chosen such that all polarisation processes including the slow processes are complete. Similarly, the depolarisation time (4000 s) is chosen such that the current becomes almost zero. While this is adequate for nanocomposites with low filler loadings (up to 2 vol. %), longer depolarisation times (at least 72 h) are required at 5 and 10 vol. %.

The mean magnitude of the accumulated volume charge density in the sample at time \(t\) of depolarisation, \(q(t; E_p)\), is calculated by using the following expression [21]

\[
q(t; E_p) = \frac{1}{T} \int_0^T q_d(x, t; E_p) \, dx
\]

(4)

where \(E_p\) and \(T\) represent polarisation field and specimen thickness, respectively. The space charge measurement of epoxy and its nanocomposites are performed at a field of 20 kV/mm.

### 3.4 Short-term AC dielectric strength

The electrode assembly as per ASTM-D149 is used for short-term dielectric breakdown strength measurements [22]. The electrodes are made of brass. The test specimen and the electrode assembly are immersed in transformer oil during the test to avoid surface flashover. More than 20 samples are chosen from each batch of neat epoxy and its nanocomposites. Measurements are made at room temperature (25°C) and RH of 40–45%. Weibull distributions are used to characterise the breakdown data. The cumulative failure probability \(P(E)\), is expressed as

\[
P(E) = 1 - \exp\left(-\left(\frac{E}{\alpha}\right)^\beta\right)
\]

(5)

where \(E\), \(\alpha\) and \(\beta\) are breakdown field, scale parameter and shape parameter, respectively. \(\alpha\) and \(\beta\) values are positive and finite. The parameter \(\alpha\) is denoted as the nominal field strength corresponding to a failure probability of 63.2% and the parameter \(\beta\) is a measure of the spread of the data.

### 4 Results and discussions

#### 4.1 Permittivity

The real and imaginary components of complex permittivity of epoxy and its nanocomposites (prepared from as-received BaTiO₃ fillers) are shown in Fig. 4. It is seen that complex permittivity (both real and imaginary components) increases with filler loading. The increase is significant beyond 2 vol. % as shown in Fig. 4. A similar increase with filler loading has been reported in the literature [1, 4, 11].

In nanocomposites with 1 vol. % loading, nanofillers are well-dispersed when prepared with as-received fillers. Hence, there is no significant difference observed in real and imaginary relative permittivity of composites prepared with as-received and surface-functionalised nanofillers. However, in the case of nanocomposites with as-received nanofillers, at higher loadings viz., 5 and 10 vol. %, nanofillers tend to agglomerate. Improvement of dispersion is achieved by using surface-functionalised nanofillers. This manifests in a significant difference in the real relative permittivity of nanocomposites with as-received and surface-functionalised fillers at a filler loading of 5 vol. %, and above as shown in Fig. 5a.

Surface-functionalising the particles before use results in a greater increase in the real permittivity of the nanocomposites (Fig. 5a). At higher filler loadings viz., 5 and 10 vol. %, the imaginary relative permittivity of the nanocomposites shows a shift in the peak frequency and a change in peak shape as we go from an as-received nanocomposite to a surface-functionalised one shown in Fig. 5b). This may be attributed to better uniformity of dispersion (and consequently, greater interfacial volume) and/or better bonding of particle to matrix.
Existing literature is divided on the effect of incorporation of fillers on the composite permittivity. Addition of fractional wt. % of nanofillers viz., SiO$_2$, TiO$_2$ into polyvinyl chloride (PVC), was reported to show a reduction in relative permittivity [23, 24]. However, significant improvement in permittivity of nanocomposites were observed with functionalised nanoparticles at higher filler loading. Maity et al. [25] found that incorporation of 1 vol. % of alumina (Al$_2$O$_3$) nanofillers (with relative permittivity $\simeq 10$) in an epoxy, yields a composite which has a relative permittivity less than that of the base epoxy.

More importantly, several groups have documented [7, 25] that the conventional mixing rules (viz., Lichtenker formula, Wiener's bound, Maxwell–Garnett equations) which have traditionally been applied to polymer composites do not necessarily provide meaningful results when used in nanocomposites. This anomaly has led researchers to believe that the nanocomposite is a three component material with the third component being the interphase/interface/interfacial region around each nanoparticle. The interface may have properties (e.g. relative permittivity) which are different from the properties of polymer and nanofillers and significantly influence the overall properties of nanocomposites.

4.2 DC conductivity

The typical polarisation and depolarisation currents in neat epoxy resin at an electric field of 2 kV/mm are shown in Fig. 6. Similarly, measurements are repeated for nanocomposites with different filler concentrations (1 to 10 vol. %). Measurements are conducted with applied electric fields of 1–5 kV/mm to study the field-dependent DC Conductivity. Field-dependent DC conductivity of neat epoxy and its nanocomposites prepared with as-received BaTiO$_3$ fillers at different filler concentrations is shown in Fig. 7. It is seen that up to a filler loading of 2 vol. %, addition of nanofillers reduces DC conductivity. A decrease in conductivity was similarly observed in the epoxy filled with Al$_2$O$_3$ nanofillers (up to 1 vol. %) by Pandey and Gupta [26]. Several groups have studied [7] the mechanism of DC conductivity of polymeric materials like LDPE, EP, PVC, filled with different nanofillers viz., TiO$_2$, SiO$_2$, ZnO and observed a reduction in DC conductivity due to addition of nanofillers. On an
increase in filler concentrations to 5 vol.% and higher, conductivity increase beyond that of neat epoxy (shown in Fig. 7). The significant increase in conductivity at higher filler loading may be attributed to percolation. If we assume that there is an interfacial region with conductivity higher than the base matrix around each nanoparticle [7, 8], then in highly filled nanocomposites (i.e. 5 and 10 vol. %), there are a large number of overlapping interfaces through which a continuous path might be obtainable for easy movement of charges (shown in Fig. 8).

Usage of surface-functionalised fillers results in a smaller increase in conductivity, especially at high loading. In composites with surface-functionalised fillers, better uniformity in dispersion possibly reduces the area of overlap and therefore limits the increase in conductivity with filler loading as shown in Fig. 9.

4.2.1 Estimation of threshold electric field for space charge accumulation: Space charge threshold characteristics for neat epoxy and its nanocomposites (1 vol. %) are shown in Fig. 10. The threshold electric field for epoxy and its nanocomposites are found to be 18 and 16 kV/mm, respectively. The estimated threshold fields for nanocomposites with different filler loadings are listed in Table 2.

It is seen that the threshold electric field decreases with increase in filler concentration. This fact may be explained as follows. During synthesis of the nanocomposites, some physical and chemical defects might be introduced in the weakly bonded regions of the interface around each nanoparticle, and these would encourage charge trapping thereby reducing the threshold electric field [27].

4.3 Space charge density

Space charge measurements on epoxy and its nanocomposites are performed at an electric field of 20 kV/mm (higher than the threshold electric field, to ensure space-charge accumulation). Fig. 11a shows the space charge profile of neat epoxy and its nanocomposites prepared with as-received BaTiO$_3$ nanofillers at 1 vol.% loading. It is seen that the accumulated space charge density in a nanocomposite with low filler loadings (viz., 1 vol. %) is lower than that in neat epoxy. The space charge accumulated near the electrodes is homopolar in nature as in epoxy. Reduction in space charge due to addition of nanofillers has been reported by other researchers [7]. Pandey and Gupta [26] observed that the space charge density in epoxy filled with 1 vol.% Al$_2$O$_3$ nanofillers is less than in neat epoxy. Lower space charge density in nanocomposites is attributable to the lower charge injection at the electrodes and lower mobility of charge carriers within the volume.

![Figure 7](image7.png) DC conductivity versus electric field of epoxy and its nanocomposites (prepared with as-received BaTiO$_3$ fillers) at different filler loadings

![Figure 8](image8.png) Schematic diagram showing movement of charge carrier in nanocomposite at higher filler loading with overlapping interfaces

![Figure 9](image9.png) Comparison of DC conductivity of nanocomposites prepared with as-received and surface-functionalised BaTiO$_3$ nanofillers at loadings of 2 and 10 vol. %

![Figure 10](image10.png) Conduction current density versus electric field of epoxy and its nanocomposites at 1 vol.% loading of as-received BaTiO$_3$ filler

| Table 2 | Threshold electric field (kV/mm) of nanocomposites |
|---------|--------------------------------------------------|
| Filler loadings, vol. % | Nanocomposites (with as-received fillers) | Nanocomposites (with surface-functionalised fillers) |
| 1       | 16      | 17      |
| 2       | 14      | 15      |
| 5       | 13      | 14      |
| 10      | 11      | 12      |

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For higher filler concentrations viz., 2–10 vol. %, the space charge density is higher than in neat epoxy, and increases with filler concentrations as shown in Fig. 11. It is seen that the accumulated space charge is predominantly negative at both the electrodes.

During depolarisation, when the electric field is removed and electrodes are short-circuited, space charge is depleted. At higher filler loadings viz., 5 and 10 vol. %, depletion of charge accumulated may take considerably more time than at lower concentrations (approximately, 20 h for 5 vol. % and 72 h for 10 vol. % loading). This would indicate that the charges are trapped in deeper trap levels.

The space charge profiles of nanocomposites filled with both as-received and surface-functionalised nanofillers at different concentrations (2 and 10 vol. %) are shown in Fig. 11. At 2 vol. % loading, composites with surface-functionalised nanofillers show homopolar charges, whereas heterocharge is observed in composites with as-received filler (shown in Fig. 12). At higher loading viz., 5 and 10 vol. %, space charge is predominantly negative at both the electrodes in nanocomposites (prepared with as-received and surface-functionalised fillers).

The average accumulated space charge density of epoxy and its nanocomposites (prepared with both as-received and surface-functionalised fillers) with different filler loadings are shown in Fig. 13. It is seen that average space charge density is lower in composites prepared with surface-functionalised nanofillers than with as-received. This may be attributed to local chain conformation at polymer-filler interfaces [7, 8].

The charge polarity in the different nanocomposites might be explained in terms of its DC conductivity. In nanocomposites with lower filler loadings, DC conductivity is lower than in neat epoxy (shown in Figs. 7 and 9). Due to low mobility, injected charge is trapped close to the electrodes [26]. In highly filled nanocomposites (viz., 5 and 10 vol. %), DC conductivity is higher than in neat epoxy and the accumulated space charge is predominantly negative as shown in Figs. 11 and 12. Due to higher conductivity at higher filler loadings, charges do not accumulate before travelling to the opposite electrode, leading to negative charge accumulation [7].

4.4 Short-term AC dielectric strength

The Weibull probability distribution of the short-term AC dielectric strength data of epoxy and its nanocomposites with different filler concentrations is shown in Figs. 14a and b. Comparison of AC breakdown strength is made on the basis of filler loading and pre-processing of nanofillers. The scale and the shape parameters for neat epoxy and its nanocomposites prepared with as-received and pre-processed BaTiO₃ nanofillers are listed in Table 3.

It is seen that the addition of 1 vol. % of as-received BaTiO₃ nanofillers into neat epoxy reduces dielectric strength. Reduction in breakdown strength on an addition of nanofillers has earlier been reported in the literature [7, 8, 10]. This might be attributed to the local field intensification due to the difference in large permittivity contrast between BaTiO₃ nanoparticles, i.e. 150 and epoxy, i.e. 3.5, [28] at a frequency of 50 Hz. Such a reduction has also been reported with even a small disparity between the bulk and filler, e.g. Nelson et al. in epoxy-TiO₂ [7, 8] and Patel et al. [10] in epoxy filled with Al₂O₃ nanofillers. A further decrease in dielectric strength is observed when filler loading is increased to 2 vol. % and beyond.
It is worth noting that the reduction in dielectric strength is mitigated by the use of surface-modified nanoparticles at the same filler concentration. A similar improvement in dielectric strength was observed by Abdel-Gawad et al. [23, 24] in PVC-TiO$_2$ and PVC-SiO$_2$ nanocomposites with surface-modified particles. An increase in Weibull shape parameter $\beta$ with surface functionalisation signifies greater predictability of the breakdown strength value. The shape parameter also increases with filler loading (up to 5 vol. %), signifying an improvement in homogeneity and reliability of composites when prepared with surface-functionalised nanofillers. This might be attributed to a better dispersion of nanoparticles on surface functionalisation.

The dielectric properties (viz., permittivity, DC conductivity, space charge density, and breakdown strength) of epoxy and its nanocomposites, prepared with as-received and surface-functionalised BaTiO$_3$ nanofillers, are summarised in Table 4.

![Fig. 14 Weibull probability plot of epoxy and its nanocomposites prepared with BaTiO$_3$ fillers at different filler loadings of (a) As received, (b) Surface functionalised](image)

### Table 4 Comparison of dielectric properties of epoxy and its nanocomposites with as-received and surface-functionalised BaTiO$_3$ fillers

| Properties | Epoxy | Nanocomposites prepared with as-received BaTiO$_3$ fillers (AR) | Nanocomposites prepared with surface-functionalised BaTiO$_3$ fillers (SF) |
|------------|-------|---------------------------------------------------------------|---------------------------------------------------------------------|
| permittivity | $\simeq 3.5$ at frequency $50$ Hz | increases (higher than neat epoxy at $1\%$ loading) | increases (higher than neat epoxy and AR at $2\%$–$10\%$ loading) |
| DC conductivity at electric field of $1\, \text{kV/mm}$ | $10^{-13}$ (S/m) | increases is significant at higher loading (viz., $5$–$10\%$) | difference in AR and SF is significant at $5$–$10\%$ loading |
| space charge density | threshold electric field for space charge accumulation is $18\, \text{kV/mm}$ | threshold electric field is lower than neat epoxy and decreases with increase in filler loading ($1$–$10\%$) | decreases (lower than neat epoxy for $5$–$10\%$) |
| Breakdown strength scale parameter ($\alpha$) | increases (higher than neat epoxy for $1$–$2\%$) | decreases (lower than neat epoxy for $5$–$10\%$) | decreases (lower than neat epoxy but lower than AR for $5$–$10\%$) |
| Breakdown strength shape parameter ($\beta$) | homopolar charge is seen near electrodes | homopolar charge appears near electrodes | homopolar charge up to $2\%$ and after that hetero-polar charge is seen near electrodes |
| | space charge density value at electric field of $20\, \text{kV/mm}$ | space charge density in AR is less than neat epoxy at $1\%$ loading | similar to AR strong dominance of negative charge is seen in the bulk of composites |
| | $= 1.16\, \text{C/m}^2$ | for filler loading $>1$ vol.% Hetero-polar charge is seen near both the electrodes at higher loading (viz., $5$–$10\%$) | space charge density in SF is lower than AR and is pronounced at higher filler loading ($5$–$10\%$) |
| | | strong dominance of negative charge is seen in the bulk of composites | |
| | | | |

It is worth noting that the reduction in dielectric strength is mitigated by the use of surface-modified nanoparticles at the same filler concentration. A similar improvement in dielectric strength was observed by Abdel-Gawad et al. [23, 24] in PVC-TiO$_2$ and PVC-SiO$_2$ nanocomposites with surface-modified particles. An increase in Weibull shape parameter $\beta$ with surface functionalisation signifies greater predictability of the breakdown strength value. The shape parameter also increases with filler loading (up to 5 vol. %), signifying an improvement in homogeneity and reliability of composites when prepared with surface-functionalised nanofillers. This might be attributed to a better dispersion of nanoparticles on surface functionalisation.
mm thickness) of high permittivity material placed on the mounting flange.

The bushing is modelled in COMSOL to obtain the electrostatic field distribution along the surface of bushing (shown in Fig. 15b). The dielectric constant of the epoxy-nanocomposite with 10 vol. % loading of BaTiO$_3$ nanofillers (surface-functionalised) measured at 50 Hz (obtained from the data in Fig. 5) is used in computation. It is seen that the addition of BaTiO$_3$ nanofillers can effectively result in a composite with high permittivity of 5.0. The electric field is highest near the mounting flange. In Fig. 16, the solid line shows the variation of the electric field along the surface of the flange. The dotted line shows the corresponding stress profile when the nanocomposite is used instead. It is clearly seen that the stress in the critical region (first 40 mm from the ground flange) is relieved. At 25 cm, the high permittivity shield on the bushing ends (as shown in Fig. 15), due to which a discontinuity is seen in the electric field stress at this point. The field efficiency factor, which is a measure of the electric stress uniformity (defined as average electric field/maximum electric field), reduces from 55.14 to 32.05%.

6 Conclusions
The nanocomposite synthesised in this work shows improved permittivity, and at power frequency is theoretically shown to be employable in electric stress mitigation in regions of high local field enhancement in high-voltage insulation. The dielectric is also characterised in terms of other relevant properties. The modified dielectric properties of nanocomposites show that surface-functionalisation of nanofillers plays an important role in controlling the morphological structure of the surrounding polymer and improved particle dispersion in nanocomposites, thus influencing its dielectric properties to a certain extent.

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