Effect of gamma irradiation on space charge and charge trap characteristics of epoxy–MgO nanocomposites

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Insulating materials used in power apparatus required to be space charge free. Epoxy–magnesium oxide (MgO) nanocomposites were prepared and gamma rays were irradiated for different dosages to understand the dielectric parameters variation, space charge characteristics, surface potential variations, and for getting charge trap characteristics of the material. It is realised that permittivity increases and then reduces when the irradiation level is increased. Tan (δ) marginally increased with increasing dosage of gamma irradiation. Space charge accumulation reduces with increase in wt% of MgO in epoxy resin. 3 and 5 wt% MgO added samples showed stable space charge accumulation and fast decay during depoling, irrespective of irradiation level. Surface potential decay time reduces with irradiated specimens. After irradiation, epoxy nanocomposites showed both shallow trap formation and deep trap formation and found that shallow trap density is high compared to the deep trap density. All the irradiated specimens showed a decrease in the trap energy level compared to the virgin specimens.

1. Introduction: Epoxy resin (ER) is the most commonly used insulant in power apparatus because of its excellent dielectric, thermal, and mechanical properties, and chemical stability [1, 2]. In recent times, the world over, researchers are trying to develop space charge free insulating materials, which can enhance the reliability and life time of power apparatus, during operation. Laghari and Hammoud indicated that high-energy radiation to polymers can cause variation to the electrical, physical, and mechanical properties of the material depending on the type, dose rate, and environmental conditions of radiation [3]. Chen and Davies have studied the influence of γ radiation on formation of space charge in low-density polyethylene (LDPE) and observed that the structural changes in LDPE are directly related to dose and environment of irradiation and concluded that degree of oxidation and monitoring of space charge are measures of aging in insulating materials [4]. It is well reported that with the addition of small weight percentage of the nanoparticles to the base polymer matrix had shown improved properties such as high breakdown strength, low loss, high permittivity, lightweight, good thermal, mechanical, and chemical properties and in addition they have good discharge resistance properties [5–7].

Murakami *et al.* have indicated addition of magnesium oxide (MgO) nanoparticles as filler material to polymeric material have showed improved space charge performance [8]. Takada *et al.* have explained that the induced potential well caused by MgO nanoparticles in LDPE/MgO nanocomposites is the main cause for inhibiting the space charge formation [9]. Andritsch *et al.* studied the dielectric properties and space charge behaviour of epoxy–MgO nanocomposites and observed that addition of low wt% of MgO nanoparticles to the ER showed improved space charge performance and with 0.5 wt% fill grade nanocomposites showed higher short-term DC breakdown strength compared to ER. It was also reported that at elevated temperatures also epoxy–MgO nanocomposites showed better space charge performance compared to neat epoxy [10, 11]. Xie *et al.* examined the space charge behaviour of epoxy–MgO nanocomposites at temperatures ranging from 40 to 200°C and noticed that even though nanocomposites showed reduced glass transition temperature, the increase in permittivity, conductivity, and space charge accumulation was less for nanocomposites compared to neat epoxy [12]. The permittivity, dielectric loss factor, and space charge distribution are important aspects, which decide the performance of electrically insulating material. Addition of MgO nano filler with LDPE material has shown good dielectric properties, even at higher temperatures [13]. In recent times, the ER material is used in nuclear radiation environment. This ionising radiation can cause damage to the polymeric insulating material causing chain scissions, cross-linking, and oxidation, which leads to the variation in charge trap characteristic in surface as well as in the bulk of insulating material [14]. Hence, it is necessary to understand the effect of gamma radiation on the surface potential and charge trap characteristics of epoxy nano–microcomposites.

The effect of radiation on space charge performance of the epoxy nanocomposite insulating materials is scanty. Having known all these facts, a methodical experimental study was carried out to understand the impact of gamma irradiation of epoxy–MgO nanocomposites, which includes (a) the variations in permittivity and tan(δ) of the epoxy nanocomposites; (b) variation is space charge density with epoxy nanocomposites during the poling and depoling period; (c) surface potential variation with nanocomposites and their charge trap behaviour.

2. Experimental studies

2.1. Sample preparation and gamma-ray irradiation: The following step procedures were adopted to prepare nano MgO filled epoxy nanocomposites. In the first step, the MgO nano powder supplied by Nanostructured & Amorphous Materials, Inc., Texas was dried for 3 h at 80°C in a controlled oven in order to remove the traces of moisture present in the nano powder. Dried MgO nanoparticles of required quantity were mixed with solvent (ethyl alcohol) and sonicated for one hour by using high frequency. The processed solvent nano powder solution was then added slowly to the base ER and shear mixed for 30 min and the mixture was sonicated by using ultra-high frequency sonication (frequency – 20 kHz) for 1 h and followed by 6 h high-speed mixture, respectively, to achieve uniform dispersion of nano filler in ER. Then the curing agent (triethylenetetraamine) was mixed and degassed. After degassing, the solution is casted into a sheet of required thickness. The prepared samples were irradiated by ^{60}Co gamma-rays in air environment with a dosage rate of 4.5 kGy/h. The samples were irradiated for 20, 50, and 100 kGy. Fig. 1 shows high-resolution scanning electron microscopy (HRSEM) images of epoxy nanocomposites with different wt% of MgO nano fillers. The average size of nano filler used for the study was 20 nm. It could be realised

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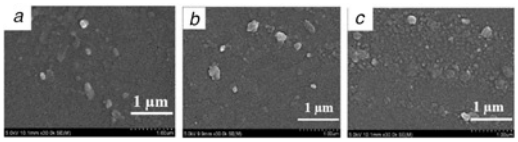

Fig. 1 *HRSEM images of epoxy–MgO nanocomposites*
a 1 wt% specimens
b 3 wt% specimens
c 5 wt% specimens

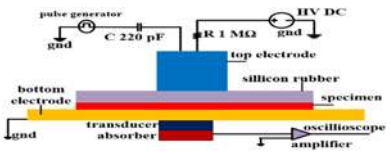

Fig. 2 *Experimental set-up for space charge measurement*

that uniform size particles are distributed and no agglomerated larger particles were observed, which indicates the uniform dispersion of nano fillers in epoxy base.

2.2. Dielectric spectroscopy studies: Dielectric relaxation spectroscopy analysis of the virgin and gamma irradiated specimens was carried out through a broadband dielectric/impedance spectroscopy analyser (Novocontrol Technologies) for understanding the variation of dielectric constant (ε) and dielectric loss (tan δ) of the sample over a wide frequency range from 0.1 Hz to 1 MHz, at room temperature. The test electrode of 30 mm diameter was used for the study.

2.3. Space charge measurement: Pulsed electro acoustic (PEA) method was used for space charge measurement with flat specimens at room temperature. The experimental set-up used for the experiment is shown in Fig. 2. The PEA system consists of a 30 kV high-voltage DC source, a 500 V pulsed generator (with a pulse width of 10 ns) operating at a frequency of about 150 Hz, high-voltage electrodes, a sensor for detection of an acoustic signal generated due to the applied voltage pulse, an amplifier, and an oscilloscope. The polyvinylidene fluoride material is used as a sensor material. The electrode system used is of parallel plane configuration. The top electrode coated with semiconducting (carbon loaded) material and the bottom ground electrode is aluminium material. Sample thickness of 1.5 mm was used in the present study and sample was stressed with an electric field of 10 kV/mm, by applying required DC voltage. During each measurement, the sample surfaces were cleaned with ethanol and ensured clean electrode systems. The poling (voltage-on) and depoling (voltage-off) measurements were performed each for 1 h. The measured signal from the transducer was processed through the amplifier and acquired in an oscilloscope (Tektronix, DPO 5034B, 350 MHz and 5 Gs/s).

2.4. Surface potential decay measurement set-up: The experimental set-up used to measure the decay of surface potential is shown in Fig. 3. Needle (tip radius 0.3 mm) and plane electrode (sliding aluminium sheet) configuration were used for charging the specimen. High-voltage DC was generated by a Trek amplifier (Trek model 20/20C) with its input from the function generator. The needle

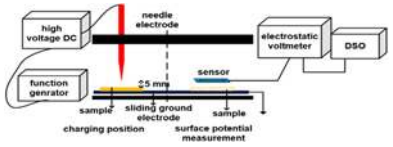

Fig. 3 *Experimental set-up for surface potential decay measurement*

electrode was connected to high voltage and the plane electrode was connected to the ground.

The distance between the high-voltage electrode and the surface of specimen (d) was kept at 5 mm and constant throughout the experiment. Surface potential decay measurements were carried out at room temperature. The DC voltage of ± 12 kV was applied between the high-voltage needle electrode and the plane-grounded electrode. In the present study, the sample was charged for 3 min (charging position). After 3 min of charging, the supply was turned off and the sample was immediately brought under the non-contact kelvin probe connected to an Electrostatic voltmeter (Trek Model 341B) to continuously measure the surface potential. The digital storage oscilloscope was used for recording the surface potential characteristics.

3. Results and discussion

3.1. Discoloration due to irradiation: Fig. 4 shows the variation in the colour of the epoxy–MgO nanocomposites due to the gamma irradiation. The virgin specimen and 1 wt% MgO-added specimen were observed to be transparent but on increase of filler content, it became opaque. A clear change in colour is observed with increase in irradiation level. Among all the specimens, 5 wt% specimen showed less discoloration, irrespective of level of dosage. The cause for it is due to the radiation caused oxidation reactions to epoxy [15].

3.2. Dielectric response analysis: Fig. 5 shows variation in real part of the permittivity (ε') of epoxy–MgO nanocomposite virgin and gamma-irradiated specimen, with increasing frequency. In insulating polymers, relative permittivity is a frequency dependent parameter. In epoxy specimen, the permittivity depends on the number of orientable dipoles present in the system and the capability of the dipoles to orient with the application of electric field [16, 17]. In polymer chain molecules, the covalent bonded atomic groups are present along the chain direction, which are the strongest bonds and molecular groups which are perpendicular to the polymer chain possessing weak intermolecular forces and these bonds are responsible for dielectric relaxation mechanisms. At the lower frequencies of the applied electric field, the functional groups with

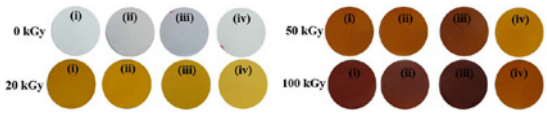

Fig. 4 *Discoloration of different wt% of epoxy–MgO nanocomposites due to different dosage of gamma irradiation (i) 0 wt%, (ii) 1 wt%, (iii) 3 wt %, (iv) 5 wt%*

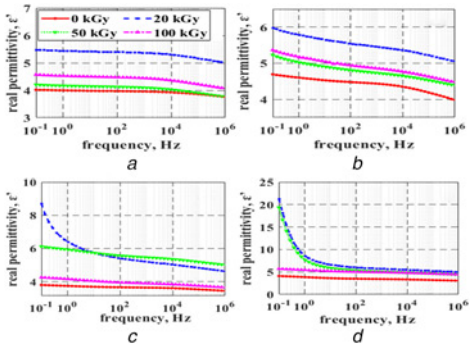

Fig. 5 *Variation in real permittivity at different frequencies of epoxy–MgO nanocomposites with different wt% on gamma irradiation*
a 0 wt%
b 1 wt%
c 3 wt%
d 5 wt%

dipolar nature can orient themselves in the direction of the electric field and results in higher permittivity. With the increase in frequency of supply voltage, the polar entities formed amines and hydroxyls formed from the ring opening of epoxides by amines resisting to rotate in pace thereby reducing the permittivity of the material [18].

With irradiation aging, several internal processes can occur simultaneously, depending on the rate of irradiation, irradiation ambience, and total dose rate. In polymeric materials, the polymers are bound together by weak covalent bonds and are disrupted easily by nuclear radiation [19, 20]. Radiation energy ionises the molecule to give an ion pair. Rupture can take place in the side branch or in the main chain, which creates energetic free radicals (small molecules) that are ready to react by several mechanisms such as crosslinking, chain scission, production of gas, and oxidation. For ER, carbonyl group (C=O) and hydroxyl group (–OH) were reported as reaction products and peroxides by oxidation reaction [21, 22]. With the formation of small molecules (radicals) or by breaking of polymer of chain, which helps in more dipolar orientation under lower frequencies of operation. On further increase in the radiation dosage, the crosslinking of the broken polymer chain molecules can occur [19, 21]. From the dielectric response analysis (Fig. 5), it can be seen that with the initial irradiation dosage of 20 kGy, an increase in permittivity was observed, which can be attributed to the breaking of polymer chain molecules, in all the specimens. Furthermore, it is noticed that with increasing irradiation level to 50 and 100 kGy, 0 and 1 wt% specimen showed reduced permittivity at 50 kGy and further dosage to 100 kGy caused increase in permittivity. In case of 3 and 5 wt% epoxy nanocomposites, a reduction in permittivity with increasing dosage is observed. The cause for it could be due to the fact that in the studied dosage rates, crosslinking predominates at 50 kGy, for 0 and 1wt% specimen. With 3 and 5 wt % MgO nano filler added specimens, crosslinking dominates at 100 kGy. Gao and Du have observed such a variation in the dielectric properties with increased dosage rates [21].

Fig. 6 shows variation in loss tangent of epoxy nanocomposites of virgin and gamma-irradiated specimens. The effect of irradiation on dielectric loss tangent is observed to be less with 0 wt% sample. A reduction in loss tangent is observed with increase in frequency up to a certain value and further increase in frequency causes increase in loss tangent and it was observed with all wt% of MgO in epoxy nanocomposites. The increase in loss tangent with increase in dosages was observed with 0 and 1wt% specimens under all irradiation dosages, consequently with 3 wt% specimen under 20 kGy increase in loss tangent was observed with increase in dosage further caused reduction in loss tangent. In the case of 5 wt% specimen, at 20 and 50 kGy, an increase in loss tangent is observed. On further increase in irradiation dosage, a reduction in loss tangent is observed. In amorphous polymers, three different relaxation processes can occur, which includes α, β, and γ with increasing frequency. In the present study, within the observed frequency range, a broad β relaxation peak was observed at around 10^5 Hz with virgin and gamma irradiated ER material. [16]. In the mid-range of frequency (0.1–100 Hz), with 0 and 1 wt% specimen in Figs. 6*a* and *b* showed a similar response. A reduction in magnitude of the β relaxation peak is observed with an increase in the filler concentration in epoxy nanocomposites. At lower frequencies, increase of dielectric loss is observed in the nanocomposites with increase in filler wt%, due to the interfacial polarisation and increase in conductivity. Especially, 3–5 wt% MgO added epoxy nanocomposites showed additional relaxation peak α, near 1 Hz [23]. In general, at different frequencies, the dielectric loss is high with a gamma-irradiated specimen, irrespective of level of irradiation. From Figs. 5*b* and *c* and Figs. 6*b* and *c*, it can be noticed that the variation in real permittivity and loss tangent with 1 and 3wt% nano filler included specimens with different irradiation dosages in correlation. This behaviour is not observed with 0 and 5 wt% specimens.

3.3. Space charge accumulation: The poling and depoling procedures are employed in order to measure the space charge variation by PEA technique. The average amount of accumulated volume charge density in the specimen was calculated as [24]

$$q(E, t) = \frac{1}{L}\int_{x_0}^{x_1} \left|q_{\mathrm{p}}(x, t)\right| \mathrm{d}x \tag{1}$$

where x_0 and x_1 represent the position of the electrode (induced charges at the electrodes are not taken into account), the absolute value of the charge density is considered in order to provide the information of the cumulative amount of charge. L is the thickness of the specimen. Fig. 7 shows the average amount of space charge accumulated within the bulk volume of epoxy nanocomposite of virgin and gamma-irradiated samples with respect to poling time. It is observed that irrespective of wt% of specimen, the space charge density increases with time. A similar trend is observed with gamma-irradiated specimens. Fig. 6*a* shows variation in space charge density with virgin epoxy nanocomposites with time. It is realised that 3 and 5 wt% MgO added epoxy nanocomposites showed saturated condition, whereas, with lower weight percentage specimens, the space charge density keeps increasing. During the observed poling period, all epoxy–MgO nanocomposites showed less space charge compared to unfilled ER. Among

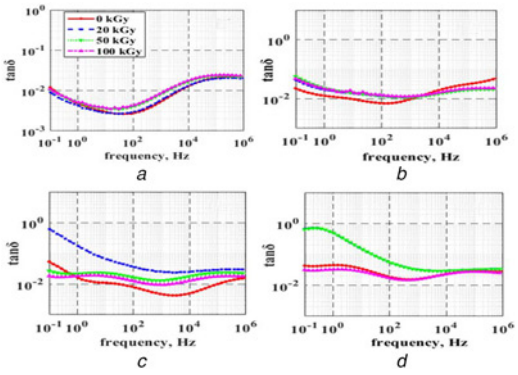

Fig. 6 *Variation in tan δ at different frequencies of epoxy–MgO nanocomposites with different wt% on gamma irradiation*
a 0 wt%
b 1 wt%
c 3 wt%
d 5 wt%

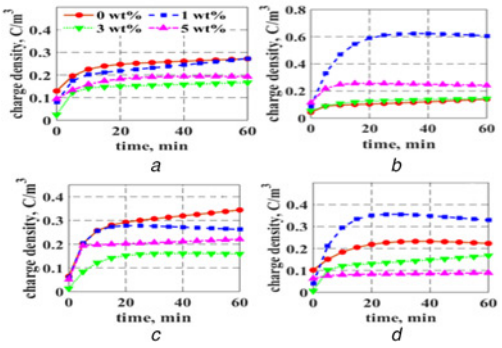

Fig. 7 *Average space charge accumulation with respect to poling time of gamma-irradiated epoxy nanocomposites with different wt% of MgO*
a 0 kGy
b 20 kGy
c 50 kGy
d 100 kGy

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all, 3 wt% nanocomposite showed less space charge accumulation. Figs. 7*b–d* show variation in space charge density for 20, 50, and 100 kGy gamma-irradiated specimens. It is realised that 0 and 1 wt% specimens showed more variation in space charge accumulation dynamics on irradiation, whereas, in 3 and 5 wt% specimens, the space charge accumulation dynamics are relatively constant with respect to irradiation.

As mentioned earlier with radiation aging several internal processes such as chain scission, crosslinking, oxidation, and gas bubble formation can occur simultaneously and the mechanism dominating the others will be responsible for the behavioural performance of the material. Owing to the characteristic changes in the material such as increase or decrease of permittivity, the electrical performance of the materials get altered, which causes the variation in the space charge performance of the radiated specimens [25, 26]. Ning *et al.* have studied the variation in space charge accumulation of epoxy–MgO nanocomposites under ultraviolet (UV) aging and observed that 1 wt% epoxy–MgO nanocomposite showed increased space charge accumulation compared to the other wt% nanocomposites under different hours of UV aging [27]. Overall, within the observed irradiation doses, 3 and 5 wt% epoxy–MgO nanocomposites showed relatively stable and less average space charge accumulation performance.

3.4. Space charge distribution studies: The distribution of space charge over time in the sample for applied electric stress of 10 kV/mm for virgin and gamma-irradiated 0 wt% specimen are shown in Fig. 7. It can be seen from Fig. 8(*i*)*a* for a virgin 0 wt% specimen, accumulation of positive hetero space charge near the cathode occurs immediately on application of voltage and is almost constant during the poling period and distribution of less amount of positive charge is observed within the bulk of the sample. As shown in Fig. 8(*i*)*b* with 100 kGy gamma ray irradiation the space charge distribution in 0 wt% specimen, a large amount of positive hetero charge accumulation can be seen near the cathode and accumulation of positive charge distribution in the middle of the sample and negative hetero charge near anode are observed. The space charge distribution in 3 wt% epoxy nanocomposite specimen for virgin and 100 kGy gamma irradiated specimen is shown in Figs. 8(*ii*)*a* and (*ii*)*b*. It clearly indicates that the level of hetero-charge and space charge accumulation in the bulk volume is not high with nanocomposites. This clearly indicates the use of MgO as space charge-free insulant. The space charge accumulation characteristics are the same as in all wt% of epoxy nanocomposite specimens under various irradiation dosages. It is noticed that with varying dosage rate, the average amount of accumulated charge differs because of the irradiation induced mechanisms. Karpagam *et al.* studied the impact of gamma irradiation on epoxy–clay nanocomposites and observed less space charge density with gamma-irradiated specimens [28].

3.5. Space charge decay: The space charge decay performance of virgin and gamma-ray irradiated epoxy–MgO nanocomposites of 0 and 3 wt% specimens on switching of applied voltage after 1 h of poling, and their charge decay characteristics are shown in Fig. 8. After 1-h of depoling with virgin specimens showed a space charge profile with considerable electrode peaks with a little amount of space charge observed, which are shown in Figs. 9(*i*)*a* and (*ii*)*a*. An irradiated 0 wt% specimen showed considerable charge within the bulk of the sample and a 3 wt% specimen showed that the total charge present in the volume of the sample is almost negligible, which are shown in Figs. 9(*i*)*b* and (ii)*b*. It is also observed irrespective of gamma aging, the hetero-charge can be seen in all specimens. Also, fast charge detrapping is observed in gamma-aged samples, which is mainly because of the radiation-induced chemical changes by degradation or cross-linking. It is well understood that nanocomposites showed fast charge detrapping compared to the polymer matrix [29].

Fig. 10 shows the space charge decay during voltage off period for epoxy–MgO nanocomposites of 0 and 100 kGy irradiated specimens. It can be seen that epoxy nanocomposites 3 and 5 wt% show the fast space charge decay compared to the virgin epoxy specimen and 1 wt% specimen showed slow space charge decay. With 100 kGy gamma irradiation, all epoxy–MgO wt% specimens showed faster space charge decay compared to the epoxy-irradiated specimen. It can be seen under irradiated conditions that epoxy–MgO nanocomposites showed improved space charge decay performance.

3.6. Electric field enhancement: The space charge accumulation within the bulk of the specimen alters the applied electric field and enhances the local electric field within the

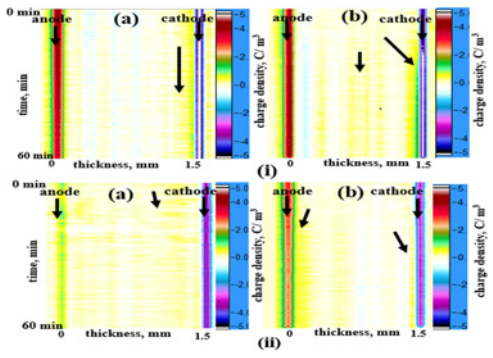

Fig. 8 *Space charge distribution in the bulk of the gamma-irradiated epoxy nanocomposite specimen with respect to poling time (a) 0 kGy gamma irradiated, (b) 100 kGy gamma irradiated*
i 0 wt% specimen
ii 3 wt% specimen

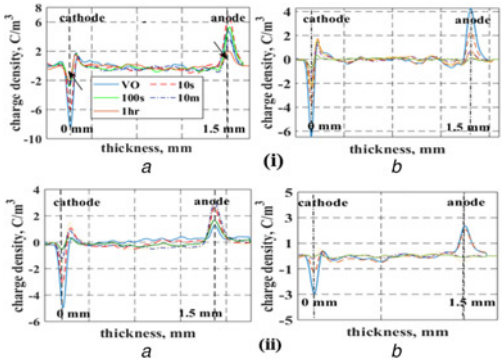

Fig. 9 *Time-dependent space charge decay profiles of the gamma-irradiated epoxy nanocomposite specimen with respect to poling time (a) 0 kGy, (b) b 100 kGy*
i 0 wt% specimen
ii 3 wt% specimen

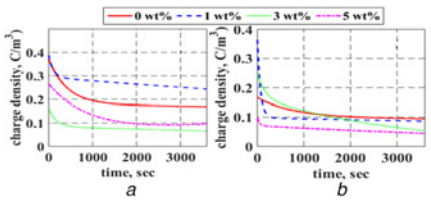

Fig. 10 *Absolute space charge decay during depoling for epoxy–MgO nanocomposites*
a 0 kGy gamma irradiated
b 100 kGy gamma irradiated

specimen. In general, the percentage field enhancement factor can be calculated as

$$\%\mathrm{FE} = \frac{E_\mathrm{m} - E_\mathrm{DC}}{E_\mathrm{DC}} \times 100 \quad (2)$$

where E_m is the maximum electric field after one hour of poling and E_DC is the applied electric field. Fig. 11 shows the electric field enhancement due to space charge accumulation, which is calculated for epoxy and epoxy nanocomposite under different doses of irradiation conditions using field enhancement factor (%FE) as given below. It is observed that the 3 wt% specimen has less electric field enhancement under 0, 50 and 100 kGy irradiated conditions and at 20 kGy irradiated conditions, 3 wt% showed marginally higher field enhancement compared to 0 wt% specimen. In general, at lower irradiation condition, an increase in loss tangent with increased field enhancement due to space charge is observed.

3.7. Surface potential decay and charge trap studies: Fig. 12 shows the surface potential decay characteristics of virgin and irradiated epoxy–MgO nanocomposites on the deposition of charges by corona activity under positive and negative DC voltages. The surface potential decays exponentially, the basic equation governing the decay is

$$V = V_\mathrm{o} \mathrm{e}^{-t/\tau} \quad (3)$$

The surface potential decay rate is less with the 0 wt% specimen and with the addition of nano MgO filler the rate increases for 1 and 3 wt% specimens and on any addition, the decay rate decreases. Table 1 shows the mean life time of the surface potential decay curves of epoxy nanocomposites. A general reduction in decay time is observed up to a certain dosage and above which charge decay process prolongs. Also, gamma irradiation of epoxy nanocomposites showed improved surface potential decay performance with 50 kGy irradiation. Xing *et al.* observed a similar type of characteristic with electron beam irradiated epoxy–AlN nanocomposites and observed that with electron beam irradiation increased the surface flashover voltage of epoxy–AlN nanocomposites under cryogenic temperature [14].

The density of trapped charges ($N(E)$) at different energy levels (E) follows the decay behaviour within the bulk of the material with the variation of trap depth (ΔE), [30], i.e.

$$N_\mathrm{t}(E) = \frac{4\varepsilon_0\varepsilon_\mathrm{r}}{eL^2kT}\left| t\frac{\mathrm{d}V_\mathrm{s}(t)}{\mathrm{d}t}\right| \quad (4)$$

and trap energy

$$\Delta E = E_c - E_d = kT\ln(\nu t) \quad (5)$$

where N_t (in $\mathrm{eV}^{-1}\mathrm{m}^{-3}$) is the trap density; e (in C) is the charge; ε_0 ε_r (in F/m) is the dielectric constant of the material; L (in m) is the thickness of material; k (in J/K) is the Boltzmann constant; T (in K) is the thermodynamic temperature; V_s (in V) is the surface potential; E_t (eV) is the trap energy; ν (s^{-1}) is the attempt to escape frequency.

Fig. 13 shows the trap energy versus $t\mathrm{d}v/\mathrm{d}t$ curves for virgin and gamma-irradiated epoxy–MgO nanocomposite specimens under both polarities of DC voltages. It can be seen that nanocomposites showed less trap depth and the trap decreased for the gamma irradiation. It indicates that the charge of trapping is easy in nanocomposites. After irradiation, epoxy nanocomposites showed both shallow trap formation and deep trap formation and we found that shallow trap density is high compared to the deep trap density, which is the main reason for fast charge detrapping in epoxy nanocomposites. Table 2 shows the level of the highest trap depth observed in epoxy nanocomposites, it can be seen that the trap depth decreased with irradiation up to a certain dosage level and with higher dosages, the trap depth increased slightly.

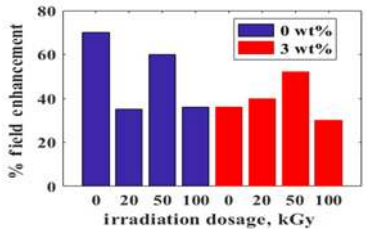

Fig. 11 *Field enhancement due to space charge in 0 and 3 wt% epoxy nanocomposite under different irradiation doses*

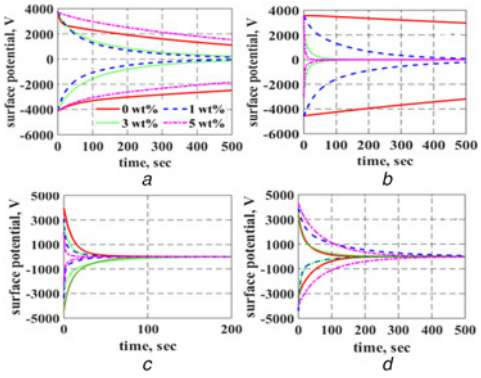

Fig. 12 *Surface potential decay of gamma-irradiated epoxy nanocomposites*
a 0 kGy
b 20 kGy
c 50 kGy
d 100 kGy

Table 1 Mean life time of surface potential decay

Wt%	Mean lifetime (τ), s							
	+DC				−DC			
	Irradiation, kGy							
	0	20	50	100	0	20	50	100
0	386	2896	11.1	23.1	1260	1517	12.3	45.1
1	110	102	3.03	16.3	136	96.6	1.91	9.91
3	124	12.8	8.81	18.1	110	10.8	1.63	12.4
5	560	1.98	1.26	70.7	702	2.63	1.65	75.2

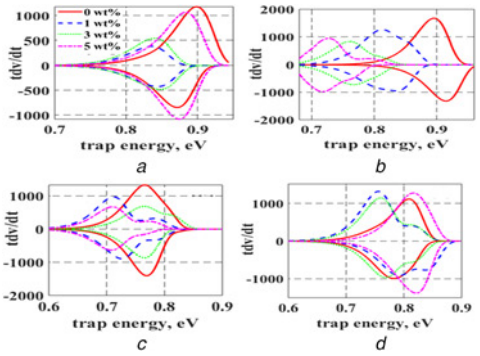

Fig. 13 *Trap characteristics of gamma-irradiated epoxy nanocomposites*
a 0 kGy
b 20 kGy
c 50 kGy
d 100 kGy

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Table 2 Trap energy variation

Wt%	Mean lifetime (τ), s							
	+DC				−DC			
	Irradiation, kGy							
	0	20	50	100	0	20	50	100
0	386	2896	11.1	23.1	1260	1517	12.3	45.1
1	110	102	3.03	16.3	136	96.6	1.91	9.91
3	124	12.8	8.81	18.1	110	10.8	1.63	12.4
5	560	1.98	1.26	70.7	702	2.63	1.65	75.2

4. Conclusion: The important conclusions arrived at based on the present study are the following:

- It is observed that with an increase in irradiation dosage, discoloration of the samples occurs and is the minimum with 5 wt% MgO added epoxy nanocomposites.

- At lower dosages of gamma irradiation, an increase in permittivity is observed and on increasing the dosage a reduction in permittivity is observed. A marginal increase in tan(δ) is observed with epoxy nanocomposites on gamma irradiation.

- Space charge density accumulated during the poling time is less with 3 and 5 wt% epoxy nanocomposite specimens with virgin and gamma-irradiated specimens. A more hetero charge is observed with ER. 3 and 5 wt% MgO in epoxy nanocomposites showed relatively stable space charge accumulation performance.

- Space charge decay is high with epoxy nanocomposites compared to ER, irrespective of the level of irradiation. 3 and 5 wt% specimens showed very fast space charge decay.

- Surface potential decay is high with gamma-irradiated epoxy nanocomposites. Reduction in trap energy is observed with epoxy nanocomposites, which helps in fast charge detrapping. The results of the study confirm depoling characteristics with PEA studies. With irradiated epoxy nanocomposites, both shallow trap formation and deep trap formation is observed and we found that shallow trap density is high compared to the deep trap density. All the irradiated specimens showed a decrease in the trap energy level compared to the virgin specimens.

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6 References

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