

## Space charge properties of XLPE and PDMS dual-dielectric with graphene coating

Zhipeng LEI, Davide FABIANI, Fabrizio PALMIERI, Chuanyang LI, Giacomo SELLERI, Marco SPERANZA, Filippo GROLLI; Department of Electrical, Electronic and Information Engineering 'G. Marconi', University of Bologna, (Italy), [leizhipeng@163.com](mailto:leizhipeng@163.com), [davide.fabiani@unibo.it](mailto:davide.fabiani@unibo.it), [f.palmieri@unibo.it](mailto:f.palmieri@unibo.it), [lichuanyangsuper@163.com](mailto:lichuanyangsuper@163.com), [giacomo.selleri2@unibo.it](mailto:giacomo.selleri2@unibo.it), [marco.speranza@unibo.it](mailto:marco.speranza@unibo.it), [filippo.grolli@studio.unibo.it](mailto:filippo.grolli@studio.unibo.it)

Francesco CRISTIANO, Francesco BERTOCCHI; Nanasa S.r.l., (Italy), [francesco.cristiano@nanasa.com](mailto:francesco.cristiano@nanasa.com), [francesco.bertocchi@nanasa.com](mailto:francesco.bertocchi@nanasa.com)

### ABSTRACT

Charge injected from electrode will accumulate in the insulation of High voltage DC insulation systems, which leads eventually to electric field distortion and degradation of insulation. In order to block space charge injection into Cross-linked polyethylene (XLPE) and Polydimethylsiloxane (PDMS) layers, in this paper a graphene coating was used. The graphene was first covered to the outer side of two-layers specimen. Then, the space charge profile of the specimen was measured by means of the pulsed electroacoustic (PEA) technique at 10 kV/mm and 40 kV/mm. Comparing space charge profiles of different graphene coating specimens, the presence of graphene coatings blocks injected charge at cathode, and changes space charge build up at anode and the PDMS/XLPE interface, thus providing a beneficial effect for the electrical insulation thanks to a lower electric field distortion.

### KEYWORDS

Space Charge, Graphene coating, XLPE, PDMS

### INTRODUCTION

For High voltage DC power system, the degradation and ageing of insulation depends on space charge distribution. How to limit charge injection from electrode into the insulation is one of the prime problems needed to be solved. As the insulation materials, Cross-linked polyethylene (XLPE) and Polydimethylsiloxane (PDMS) are widely used in the DC power system, such as in the joint of power cables.

For limiting the injection and accumulation of space charge in insulation system at DC electric field, researchers have presented some methods. Generally, different types of nanoparticles have been added into insulation materials, which can change the conduction and polarization properties of insulation, thus influencing space charge distribution [1]. The surficial fluorination also has been used to change the surface charge accumulation, and further affect the properties of bulk charge buildup [2]. In addition, nano-AgNPs covered by a very thin film of plasma polymer was deposited on the surface of LDPE, which could suppress the charge injection [3].

In order to block space charge injection into the XLPE and PDMS layers, the paper makes use of a graphene coating layer spread over the surfaces of the samples. The space charge profile of the samples was measured by means of the pulsed electroacoustic (PEA) technique at 10 kV/mm and 40 kV/mm. Space charge properties were analyzed for understanding how the graphene coating influences the mechanism of charge accumulation and transportation.

### SPECIMEN PREPARATION

XLPE tapes were obtained from the peeling of a Prysmian HV cable with the thickness of 140  $\mu\text{m}$ . During the specimen preparation, XLPE was cut into a disc with the diameter of 75 mm and pasted on a flat Bakelite substrate. Then, PDMS, 184 Silicone Elastomer from Dow Corning, was manually mixed with curing agent by a weight ratio of 10:1 for 5 min. The mixture was degassed at vacuum for more than 15 min to make sure all bubbles removed. Before the substrate with XLPE was placed into the spin coater, the mixture was evenly poured on the XLPE surface. After that, the substrate was spun at 350 RPM for 120 s. A thin film PDMS with the thickness of about 140  $\mu\text{m}$  was deposited on the XLPE surface. Finally, the specimen was cured at 65  $^{\circ}\text{C}$  for more than 60 min. Figure 1 shows the pictures of PDMS (upper) and XLPE (under). For analyzing the effect of graphene coating on space charge, graphene dissolved in an appropriate solvent was mechanically applied on the side of XLPE or PDMS, and both side of XLPE and PDMS by Nanasa S.r.l.

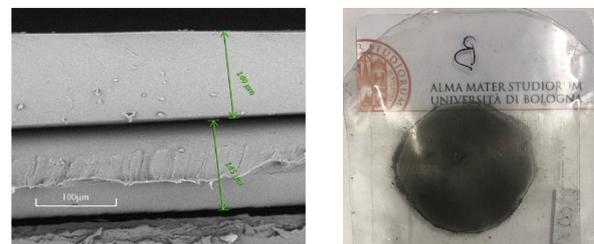
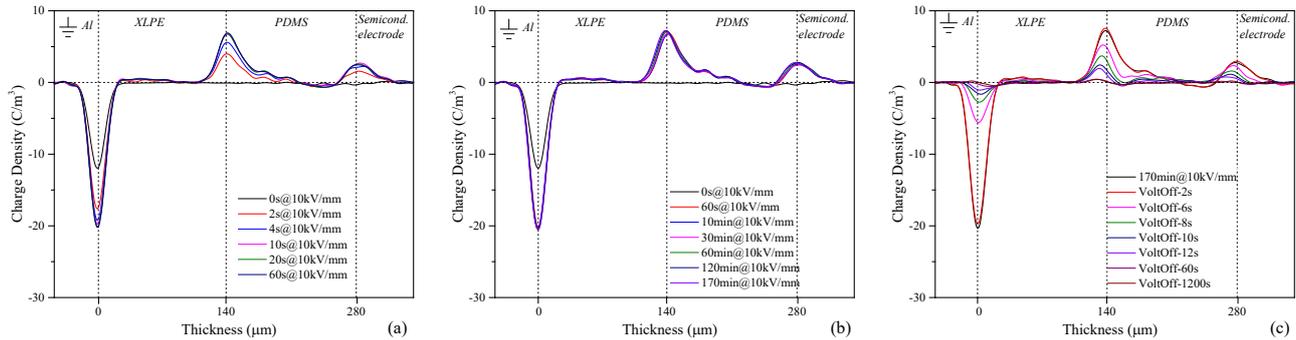


Fig. 1: Pictures of XLPE and PDMS Dual-dielectric

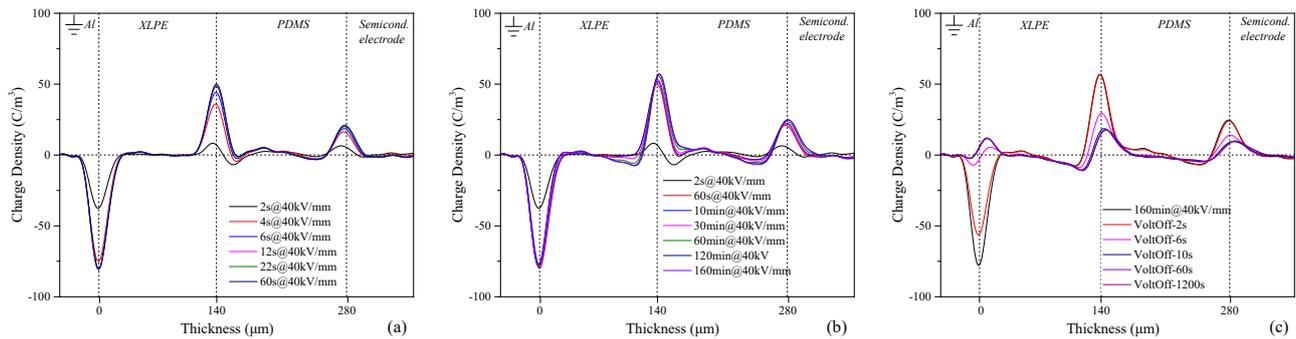
### SPACE CHARGE MEASUREMENT PROCEDURE

The Pulsed Electroacoustic technique (PEA) was used for testing the space charge distribution in the paper [4, 5]. During the test, a semi-conductive material was installed between the upper electrode and the specimen, in order to attenuate sonic impedance mismatch between metal electrode and insulation. Through a coupling capacitor, a voltage pulse with the amplitude of 500 V and the width of 10 ns was applied to specimen. The specimen was poled for 10000 s at 10 or 40 kV/mm, respectively and depolarized for about 1000 s. All PEA tests were carried out at room temperature.

The space charge profiles of same sample at different electric field were recovered by the first waveform acquired at 10 kV/mm. Then the density of space charge was calibrated according to the potential distribution. However, the calibration factor was calculated though the space charge data after volt-on 10 s, because the amplitude of power source took several seconds to reach the steady output after turned on.



**Fig. 2: Space charge profiles of XLPE and PDMS dual-delectric: (a) and (b)poling at 10 kV/mm; (c) depolarization**



**Fig. 3: Space charge profiles of XLPE and PDMS dual-delectric: (a) and (b)poling at 40 kV/mm; (b) depolarization**

## RESULTS AND DISCUSSION

### Space charge of XLPE and PDMS dual-delectric

The space charge profiles of XLPE and PDMS without graphene coating at 10 and 40 kV/mm can be seen in Figure 2 and 3. During first several seconds, space charge profiles rise fast to a stable condition because the permittivity and conductivity of XLPE and PDMS is different, as shown in Figure 2a and 3a. According to Maxwell Wagner theory for the interfacial polarization, the time constant of the stable space charge is

$$\tau = \frac{d_{XLPE} \varepsilon_{PDMS} + d_B \varepsilon_{XLPE}}{d_{XLPE} \sigma_{PDMS} + d_{PDMS} \sigma_{XLPE}} \quad [1]$$

where  $d$  is the thickness,  $\varepsilon$  is permittivity, and  $\sigma$  is conductivity. The relative permittivity of XLPE and PDMS is 2.0 and 2.7, and the conductivity is about  $10^{-15}$  and  $3 \times 10^{-13}$  S/m, respectively.

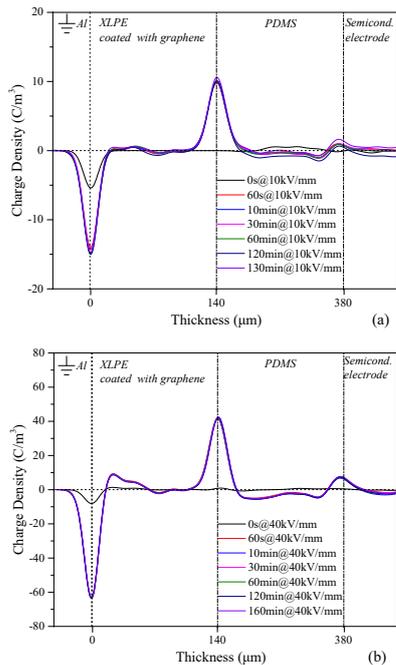
The time constant of XLPE and PDMS dual-material is about 140 s, so the space charge distribution at the interface becomes stable after a few minutes, depending on the conductivity of material. From Figure 2b and 3b, it can be concluded that there is no obvious change with time at 10 kV/mm. At 40 kV/mm, however, negative charges accumulate in both XLPE near the polymer interface and PDMS, which originate likely from migration of injected electrons from cathode. The negative heterocharge at the anode, on the contrary, could be associated to ionic charges originated from impurities' dissociation in PDMS. In addition, the amount of positive charge begins to increase on the side of PDMS near polymer interface, because the permittivity of PDMS is higher than XLPE.

During the depolarization phase, Figure 2c shows that the decrease rate of positive charges of polymer interface in PDMS is higher than that in XLPE, because the conductivity of PDMS is higher than that of XLPE. After poling about 160 min at 40 kV/mm, negative charges blocked in XLPE near the polymer interface can be observed in Figure 3c. At cathode, the charge density of heterocharges from the migration of positive charges in materials is so high that homocharges are difficultly found.

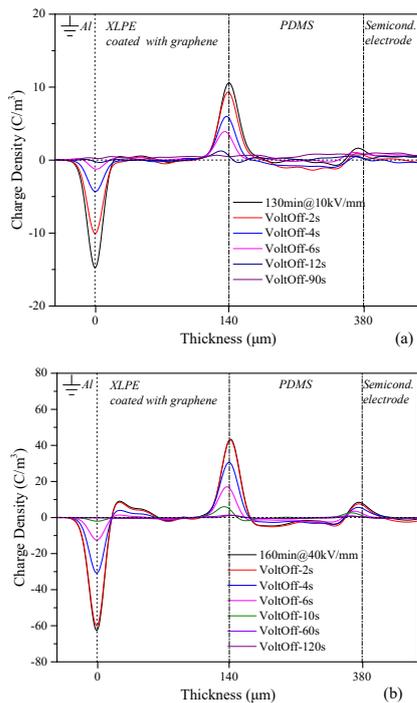
### Space charge of GrXLPE and PDMS

The space charge profiles of specimen coated with graphene on the side of XLPE at 10 and 40 kV/mm is shown in Figure 4. At 10 kV/m, no obvious charge injection can be evidenced. The peak of charge density at cathode slightly increases. At 40 kV/mm, however, heterocharges accumulate near each interface. Especially, the amount of heterocharges accumulating near the cathode indicates that the extraction of space charge from the bulk is blocked by graphene coating as well.

Heterocharges near the anode can come again from the ionic species migration in PDMS as observed also in Figure 4b. Figure 5 shows Space charge profiles of GrXLPE and PDMS dual-delectric during depolarization. Comparing with space charge profiles of specimen without graphene, homocharges accumulating at each interface also decrease to zero after about 120s, and no heterocharge can be found near the cathode. The negative charge also cannot be found in XLPE near the polymer interface, thus suggesting that graphene may suppress charge injection.



**Fig. 4: Space charge profiles of GrXLPE and PDMS Dual-dielectric poling at (a) 10 kV/mm, (b) 40 kV/mm**

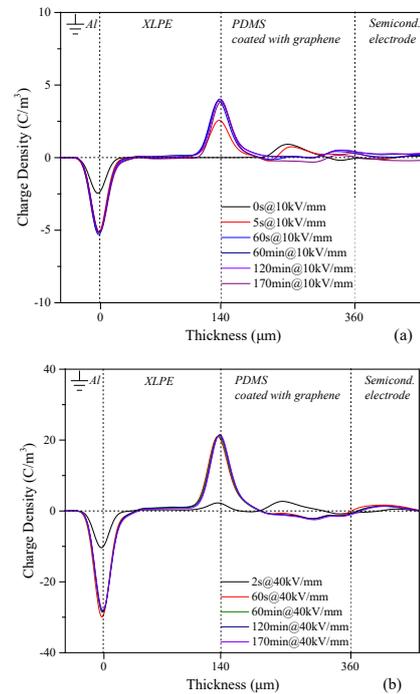


**Fig. 5: Space charge profiles of GrXLPE and PDMS during depolarization at (a) 10 kV/mm, (b) 40 kV/mm**

### Space charge of XLPE and GrPDMS

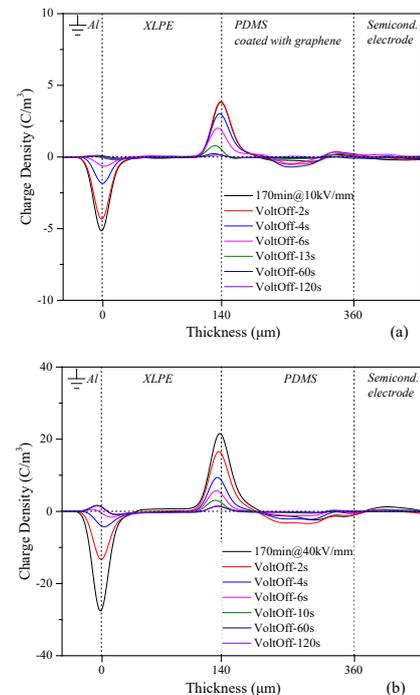
The space charge profiles of specimen coated with graphene on the side of PDMS at 10 and 40 kV/mm is shown in Figure 6. Comparing with at 10 kV/mm, the peak value of charge density at cathode under 40 kV/mm slightly decrease, and a small amount of homocharges are injected into XLPE near cathode. Moreover, the positive charge density of specimen coated with graphene on the side of PDMS is lower than that without graphene coating at both polymer interface and anode. Due to the decrease of the

quantity of positive charge and charge injection from cathode (no graphene coating on that side), there is no heterocharge accumulating near cathode.



**Fig. 6: Space charge profiles of XLPE and GrPDMS during polarization at (a) 10 kV/mm, (b) 40 kV/mm**

The depolarization phase is shown in Figure 7. A significant amount of homocharge can be found near cathode, and heterocharges accumulating near anode which disappear with time.

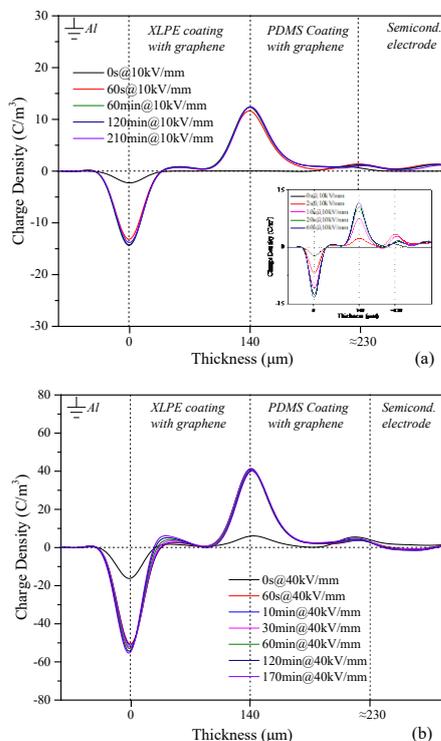


**Fig. 7 Space charge profiles of XLPE and GrPDMS during depolarization at (a) 10 kV/mm, (b) 40 kV/mm**

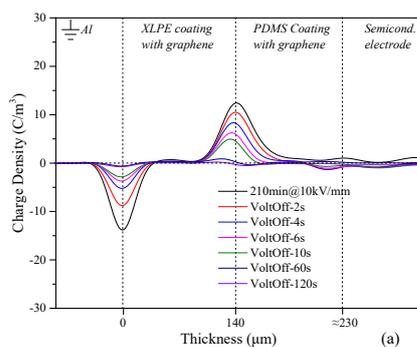
### Space charge of GrXLPE and GrPDMS

Figure 8 and 9 show the space charge profiles of specimen coated with graphene on both sides. During polarization phase, positive charge at anode is seen to decrease after about 1 min as shown in Figure 8a. Heterocharges from the induced charge of polymer interface accumulate near the cathode at 40 kV/mm, which is blocked in extraction by graphene. The charge density at cathode rises with time which indicates no electron injection occurs.

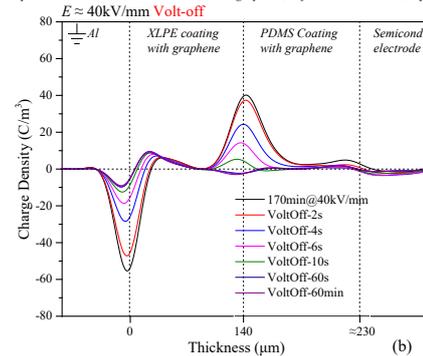
Combining with the depolarization phase shown in Figure 9, it can be found that no heterocharge accumulates near the anode. Because the conductivity of PDMS is higher than that of XLPE, the positive charge in PDMS will move to the polymer interface during depolarization phase, and disappear faster than in XLPE, which results in the heterocharge accumulation near the cathode. During volt off, a part of positive charge will neutralize with negative charge. Other parts will be blocked near the cathode due to the existence of potential energy barrier between graphene and XLPE.



**Fig. 8** Space charge profiles of GrXLPE and GrPDMS during polarization at (a)10kV/mm, (b) 40kV/mm



Specimen E: both XLPE and PDMS coated graphene, Surface resistance  $17k\Omega/sq^{-1}$



**Fig. 9** Space charge profiles of GrXLPE and GrPDMS during depolarization at (a)10kV/mm, (b) 40kV/mm

### CONCLUSION

In the paper, the space charge distribution of layered samples of XLPE / PDMS with and without graphene coating at different DC electric field is analysed. For the specimens without graphene coating, charge injection appears as heterocharge accumulation near the opposite-electrode at high electric field. For specimens coated with graphene, the charge injection into the bulk is prevented and some heterocharge remains blocked near the electrode itself, and the induced charge at polymer interface migrates close to the cathode at high electric field.

### REFERENCES

- [1] D. Fabiani, P. Mancinelli, C. Vanga-Bouanga, M. F. Fréchet, and J. Castellon, 2016, "Effect of graphene-oxide content on space charge characteristics of PE-based nanocomposites." IEEE Electrical Insulation Conference, EIC, vol.1, 631-634.
- [2] L. Lan, Q. Zhong, Y. Yin, and X. Li, 2013, "Effect of surface fluorination on space charge behavior at LDPE/EPDM interface", IEEE International Conference on Solid Dielectrics, ICSD, vol.1, 444-447.
- [3] L. Milliere, K. Makasheva, C. Laurent, B. Despax, and G. Teyssedre, 2014, "Efficient barrier for charge injection in polyethylene by silver nanoparticles/plasma polymer stack", Appl. Phys. Lett. vol. 105, 122908.
- [4] T. Maeno, T. Futami, H. Kushibe, T. Takada, and C. M. Cooke, 1988, "Measurement of spatial charge distribution in thick dielectrics using the pulsed electroacoustic method", IEEE Trans. Dielectr. Electr. Insul. vol. 20, 433-439.
- [5] R Bodega, PHF Morshuis, and JJ Smit, 2006, "Space charge measurements on multi-dielectrics by means of the pulsed electroacoustic method", IEEE Trans. Dielectr. Electr. Insul. vol. 13, 272-281.