High Voltage

Special Issue: Interface Charging Phenomena for Dielectric Materials

Guest Editorial: Interface Charging Phenomena for Dielectric Materials

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Interface charge accumulation, leading to unpredictable insulation breakdown, restricts the development and industrialisation of high voltage direct current (HVDC) power equipment. Understanding the mechanism of interface charge transport and interface charge triggered dielectric breakdown is, therefore, of particularly high interest and vital importance. For example, the surface charging of aircraft in space brings damage to board electronic instruments as well as interference to sensing systems. Moreover, the randomly distributed charge clusters on the spacer surface, as shown in the cover page of this Special Issue, is considered as a potential threat to the surface flashover, while the accumulation of space charge within the insulating material poses a threat to the reliability of DC power cables. However, currently we still know very little about the development of charge dynamics in different interfaces, and the related breakdown mechanism of dielectrics induced by charge accumulation is also not very clear.

This Special Issue brings together recent studies of charging phenomena for dielectric interfaces including vacuum-solid interface, gas-solid interface, and solid-solid interface. Nine high-quality papers are accepted for publication in this Special Issue: six papers focusing on gas-solid interface (including one review paper), two review papers focusing on vacuum-solid interface, and one paper focusing on solid-solid interface. A brief discussion of each paper is presented as follows.

Review papers

In ‘Gas–solid interface charge characterisation techniques for HVDC GIS/GIL insulators’ by Zhang *et al.*, the paper reviews the current status, development needs and potential developing orientation of surface charge characterisation techniques. Different surface potential measurement methods and charge inversion algorithms are reviewed regarding the previous studies and future research needs. Drawbacks and outlooks of surface charge measurement techniques are also discussed with the background of laboratory experiment results and on-site measurements.

In ‘Modelling vacuum flashover mitigation with complex surface microstructure: mechanism and application’ by Zhang *et al.*, the paper reviews the influence of surface microstructures on surface flashover in a vacuum. A particle simulation model is constructed to reveal multifactor development under various microstructure shape, size, and distribution. It is shown that anode current decays exponentially with the number of grooves, also trapezoid groove can effectively trap and deflect secondary electrons, thus improving strength of vacuum-insulator interface. Additionally, a theoretical model is proposed to link simulation results with surface charge distribution and flashover voltage. A saturation of groove depth is identified, and optimised groove parameters are given for practical insulator design.

In the paper ‘Improvement of surface flashover in vacuum’ by Li, the article reviews the research progress of surface flashover in vacuum regarding effective methods to improve the surface flashover performance in vacuum, including insulation system optimisation and material modification. The former is beneficial to reduce the electric field distortion, and the latter is able to adjust the surface trap parameters of the material through physical and chemical methods. Meanwhile, the ‘U-shaped' curve is proposed to reveal the relation between surface flashover voltage and surface trap level. Moreover, suggestions are made to build a unified surface flashover model which is suitable to the range from high vacuum to high pressure.

Gas-solid interface charging phenomena

In ‘Surface charge accumulation and pre-flashover characteristics induced by metal particles on the insulator surfaces of 1100 kV GILs under AC voltage’ by Xing *et al.*, the paper establishes a PD detection system with a sensitivity of 0.05 pC for 1100 kV insulators based on the cross-reference pulse current (PC) method. The PD development and flashover characteristics of 5 mm long metal particles on the surface of UHV insulators were studied. It is found that for 1100 kV AC insulators, although the discharges of millimeter-scale particles are low (usually lower than 2 pC), they will still result in charge accumulation on the insulator surface, leading to flashover along the surface. Meanwhile, the discharges with low amplitude is difficult to be detected by traditional PC and UHF methods.

In ‘Influence of humidity on conduction processes in gas-insulated devices’ by Tschentscher *et al*., the paper introduces a highly precise humidity control circuit to analyse the significance of humidity in the range from −25 to −5°C frost-point, which is fully applicable to operating gas-insulated devices. It is found that charge generation from micro discharges at the interfaces substantially increased with increasing humidity. For an electric field of 5 kV/mm, humidity strongly influences the charge provision from technically rough interfaces and potentially contributes to the surface charge accumulation at insulator surfaces. On the other hand, for low-field conduction phenomena, no increase in the ion currents from natural ionisation or electrophoretic conduction was observed.

In ‘Dynamics of surface charge and electric field distributions on basin-type insulator in GIS/GIL due to voltage polarity reversal’ by Luo *et al*., a simulation model is established to study the change of surface charge and electric field distributions under voltage polarity reversal. The surface charge and electric field distributions at different moments are calculated. The influence of reversal time on the transient and steady state is also discussed. The tangential and normal electric fields during the reversal process are analysed to describe the effect of the reversal on the flash characteristics.

The paper ‘Charge accumulation characteristic on polymer insulator surface under AC voltage in air and C_4F_7N/CO_2 mixtures’ by Li *et al.*, studies the charge transport characteristics on insulator surface in air and heptafluorobutyronitrile/carbon dioxide (C_4F_7N/CO_2) mixtures under AC voltage. The results show that with the needle-plate electrode structure, charge distribution on the insulator surface presents a three-tier concentric circle structure both in air and C_4F_7N/CO_2 gas mixtures, while the charge area range of charge distribution on insulator surface in C_4F_7N/CO_2 mixtures is smaller than that in air. It is suggested that the charging property of insulators in C_4F_7N/CO_2 mixtures is related to the larger electron attachment cross section of C_4F_7N gas in a wide range of electron energy distribution.

In ‘Finite-element analysis for surface discharge on polyimide insulation in air at atmospheric pressure under pulsed electrical stress’ by Dong *et al.*, a surface discharge non-equilibrium plasma model of air–polyimide under pulsed electrical stress is established. The temporal and spatial evolution of the microparameters such as charge and electric field distribution during discharge are obtained. The results show that surface discharge develops from needle electrode to ground electrode under both repetitive pulses and single pulse stress. The relationship between the discharge propagation time under repetitive pulses and pulse repetition rate is a 'U-shaped' curve, and the inflection point moves to higher repetition rate region with the increase of voltage.

Solid-solid interface charging phenomena

In the paper 'Improved space charge transport model in bi-layer dielectrics—considering carrier dynamic equilibrium' by Liang *et al.*, the authors propose an improved space charge transport model considering the carrier dynamic equilibrium process in solid dielectrics. The polarisation process of the LDEP/EPDM bi-layer dielectric was simulated by the Maxwell-Wagner model, the bipolar charge transport model and the carrier dynamic equilibrium model, respectively. Influences of parameters on the simulation results were investigated, and comparisons among the simulation results of different models were also made. Compared with the previous models, this improved model performs better in predicting the space charge distribution and the polarisation current.

Summary/conclusion

In summary, this Special Issue reports the most up-to-date researches in interface charging phenomena, and it will be of interest to a wide audience of both fundamental physicists and material scientists, with a background of high voltage engineering and microelectronics, focusing on interface charging problems. We do hope that this Special Issue will provide fruitful, educational and inspiring reading.

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Gilbert Teyssedre, PhD, Senior Researcher of Université de Toulouse. His research activities concern the development of luminescence techniques in insulating polymers with focus on chemical and physical structure, degradation phenomena, space charge and transport properties.


Jinliang He, PhD, Professor of Tsinghua University, IEEE Fellow, IET Fellow. His research focuses on kinds of advanced power transmission technology, such as grounding technology, lightning protection, advanced dielectric materials and sensing technology.