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Current distribution of AC surface discharges and associated chemistry

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Abstract

It is shown that AC discharges propagating at an air/dielectric interface, though of planar structure, behave, till a critical voltage V_{crit}, as corona discharges in an air gap, with similar propagation fields for the filamentary discharge components and similar glow components. This leads to consider the surface discharges as gas discharges propagating above the dielectric surface. Beyond V_{crit}, the retention of charges by the dielectric surface becomes ineffective, due to the gas heating in the filamentary channels and to the heat subsequently transferred from these channels to the surface. In return, the surface gives its energy excess back to the discharge, so opening the way, on the surface, to leader-like discharges of higher conductivity, needing about 10 times lower fields to propagate.

Keywords: Surface discharge; Gas/surface interface; Discharge propagation; Surface modification

1. Introductive background

Lichtenberg was the first in 1778 [1] to report observations on surface discharges. His approach consisted in sprinkling a mixture of two powders on dielectric surfaces after exposure to the discharge: red lead oxide positively charged (thus attracted by the negative charges of the surface), and yellow sulphur powder negatively charged (attracted by the residual positive charges). So coloured figures were obtained visualizing not only the expansion limits of the discharge on the surface, but also the distribution of the charges of each polarity remaining on it.

More than 100 years after, Toepler [2,3] also realized observations on discharges developing on a dielectric plate, inserted between the two electrodes of a point-to-plane electrode system. He succeeded with the statement of two empirical rules, still in use under the denomination of first and second Toepler laws:

- the first law stipulates that, for DC-pulsed potentials $V < V_{crit}$, the discharges expand over a circular area looking homogeneous to the naked eye; a particular feature of this area is that its radius r_d increases proportionally with the voltage, with coefficients of proportionality $E = V/r_d$ differing with the polarity of the applied voltage, but not with the characteristics of the dielectric plate: $E = 5.5\,kV/cm$ in ambient air with positive pulsed voltages applied at the point electrode, $E = 11.5\,kV/cm$ with negative pulsed voltages applied at the point electrode.
- the second law defines the critical voltage V_{crit} for which filamentary discharges are seen to develop from the border of the first law circular area and shows that this transition voltage is clearly dependent on the dielectric plate characteristics while only little on the discharge polarity: $V_{crit} = 110(e/\varepsilon_r)^{1/2}$ in positive polarity, with V_{crit} in kV, e the dielectric plate thickness in cm and ε_r its relative permittivity $V_{crit} = 119(e/\varepsilon_r)^{1/2}$ in negative polarity.

A significant breakthrough has been achieved by Hidaka and Murooka [4] and Murooka et al. [5] in the understanding of the first Toepler law discharges phenomena. He introduced the idea that the circular luminous area formed by these discharges is actually formed by a large number of filamentary discharges evenly distributed around the point of contact of an electrode tip with the dielectric surface.

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Our aim is to extend this basic knowledge further, far enough to be able to enter into the physical mechanisms into play. The filamentary discharges evidenced by Murooka et al. stimulated the search for similarities, reported in this paper, between conventional gas discharges (e.g. corona discharges) and surface discharges. General laws depicting the discharge behaviour of gas discharges will be tested with surface discharges. Correlations between the discharge propagation on an insulating surface and the pulsed discharge current will be proposed, whereas the diffuse discharge component will be investigated through its chemical properties. For this purpose, two different experimental set-ups will be used,

(i) one aimed to study the propagation of filamentary discharges on an dielectric surface,
(ii) the other one more specifically designed to study the transport of the gaseous products from a diffuse surface discharge along an insulating surface, in correlation with the hydrodynamic properties of the discharge.

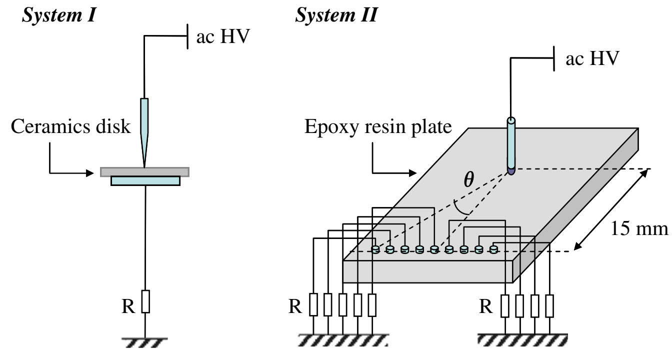

Fig. 1. Electrode systems used for the study of the discharge propagation parameters (system I) and for the analysis of the current and chemical products distributions on the dielectric surface (system II).

2. Experimental

2.1. System I (Fig. 1)

The study of the discharges propagation is performed with a first electrode arrangement consisting of two electrodes, placed on both sides of a dielectric plate, as in systems commonly used for dielectric barrier discharges. The tip of a point electrode (stainless steel, 1 mm diameter, 50 μm tip radius) is in contact with the insulating surface. This electrode is polarized with an AC 16.7 kHz high voltage (measured using a high voltage probe 1/1000 ratio). On the opposite side of the dielectric plate, a metallic disk is connected to ground through a 50 Ω resistor R used for discharge current measurements. The dielectric plate is a Al_2O_3/SiO_2 ceramics disk (smooth surface, 60 mm diameter, 3 mm thickness, fired at 1300 °C). Experiments were performed in synthetic dry air (100 L/h). The revolution symmetry of this system was particularly convenient (i) to visualize the discharges taking place all around the extremity of the point electrode, (ii) to get measurements of their propagation length (photographs) as a function of the voltage and current parameters (oscilloscope recordings of the voltage applied to the point electrode and of the discharge current measured at the grounded electrode) (Fig. 1).

2.2. System II (Fig. 1)

The study of the production of the gaseous products from a diffuse surface discharge and of their transport along an insulating surface is performed using a second electrode arrangement. This time, all electrodes are placed on the same side of the insulating plate. This insulating plate is an epoxy resin sample (5 mm thickness) with or without silica filler. The high voltage electrode is a stainless-steel rod (1.1 mm diameter), perpendicularly directed to the insulating material surface and partially embedded (1 mm depth) in its bulk. This electrode is polarized with 50 Hz AC high voltages. The counter electrode consists of a linear row of nine metallic patches embedded in the insulating material, each of them individually grounded through a 50 Ω resistor R. Discharge current and applied voltage measurement techniques are the same as with system I. The high voltage electrode is located at 15 mm from the central grounded patch (see Fig. 1, system II). Spacing between two successive patches centres is fixed to 6 mm, so determining vertex angles θ from 0° to 58° between the central axis (from the rod basis to the central patch) and the different directions joining the rod basis to the different lateral patches. Experiments with this system were performed in ambient air (~295 K, ~65% RH), its geometry being more suitable than the preceding one for all space resolved investigations concerning the diffuse component of the surface discharges.

The investigations performed with electrode system II are of different kinds:

- using the instantaneous voltage x current method, the mean power P is evaluated; this value, divided by the applied RMS voltage gives the mean active discharge current; another way to measure the mean discharge current is to use a galvanometer in series with the grounded patch(es); this mean discharge current is used for comparison of the laws characterizing the diffuse component of the surface discharge with the laws governing the same component in point-to-plane air gaps (Townsend law relating the total mean current to the applied voltage, Warburg law describing the current repartition inside the discharge gap);
- space-resolved surface energy Ws is simply deduced from measurements of the contact angle α of distilled water droplets (10 μl volume) deposited on the surface after its exposure to the discharge, using the $W_s = \gamma_{LV}(1 + \cos \alpha)$ relation with $\gamma LV = 72.8\,m\ \ J\,m{-}2$ for distilled water;