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Loeb's and Streamer-based Mechanism for Negative Corona Current Pulses

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Introduction :

Although a great deal of information on corona phenomena in the technically important electronegative gaseous mixtures has been collected, for negative corona the existing information is more limited than for positive discharge and the complex negative corona mechanism needs further study to be clarified. As a result, in technical literature (see for example,[2]) the traditional Loeb model for negative corona Trichel pulses [2] seems to be yet frequently applied, even when it has been contradicted by numerous experimental and theoretical studies [3-9]. As discussed in [10] the use of the Loeb model hinders a fuller understanding of basic physical mechanism of many important technical applications of negative corona discharges as, for example, in ozone generation, in electrets preparation and in pulse energised electrostatic precipitators.

We suppose than the study of the negative point-to-plane corona in a N_2+CCl_2F_2 mixtures is not only a useful means to provide insight into the basic mechanisms controlling corona phenomena, but it has also some implications of negative corona in plasmachemistry and for high-pressure gas insulation.

Experimental :

Measurements of repetitive negative corona current pulses were carried out in N_2+0.43CCl_2F_2 and N_2+0.85CCl_2F_2 at pressures 15-45 kPa using a negative point-to-plane gap with the stainless-steel cathode curvature of 0.063 mm. and the point-to-plane spacing of 1 cm. The experimental set-up and method used were identical to those described in [9].

A typical train of repetitive negative corona current pulses is shown in Fig.1. Comparing with common regular Trichel pulses observed in air the measured current pulses were less regular in period and shape. In the conditions of our measurements three types of pulse shape were observed, which are exemplified in Figs.2 -3.

Figure 2 illustrates the pulse waveform characterised by a gradual current rise to the pulse maximum with the rise time on the order of 10 ns. The pulse shape in Fig.3 is characterised by the steep pulse leading edge with the rise time roughly 8 ns. Pulses with the shapes similar to that shown in Fig.4. were observed less frequently. In these cases the current firstly gradually rose to a current plateau with the height of some 0.25 mA and ,subsequently, after a delay of 30 ns a sharp current spike riding on the plateau appeared. This sharp current close similar in shape to that shown in Fig.3.

Discussion :

The formation of the pulse shape shown in Fig.2 can be explained in terms of the theory by Loeb 2: In time sequence, the pulse is initiated by electrons ejected from the cathode surface by some mechanisms such as positive ion or excited molecules bombardment and generate primary avalanches. From the primary avalanches further generations of avalanches will result by electron liberation at the cathode mainly due to photo emission feedback. In this way a discharge is produced with positive ions being formed between the cathode and some position where ionisation ceases due to the drop in the laplacian field, and with negative ions being formed further out from this position. The discharge cannot continue indefinitely since the negative ions will create an electric field opposite to the main field which eventually, when a sufficient number of negative ions have accumulated, reduce the field below the level for self-sustained ionisation. The pulse current rise is given mainly by the effectivity of secondary electron photo emission from the cathode surface, and is relatively slow and occurs, as suggested by Alexandrov [11], in two separate stages, the first stage (see current rise in times up to roughly 30 ns in Fig.2) being a slow current rising Townsend phase, and the second phase of short duration (30-50 ns in Fig.2) dominated by an increase of the field near the cathode surface vicinity due to positive ions space charge.

The pulse shape in Fig.3 is remarkably similar to the typical shape of regular Trichel pulses observed using sharp cathodes in air at pressured higher than some 50 kPa (see, for example, [9]). Formation of such fast-rising negative corona current pulse can be explained in terms of the positive-streamer-based model [8, 9, 12] as follows:

The first phase, which is not normally measured, is an initial Townsend phase. If during this initial phase , the critical number (10^8) of positive ions is accumulated in the cathode vicinity, the current rise is drastically increased by the formation of a cathode-directed wave of ionising potential (positive streamer), which results in the formation of steep pulse leading edge. Movement of the streamer head is a phase movement and thus easily can be much faster than the charged particles it contains. The pulse maximum is attained just as the streamer reaches the cathode and, subsequently, the current begins to fall because of a rapid field decrease behind the streamer head. Current signal induced by the streamer arrival to the cathode was analysed by computer simulations in [13].

The most complicated form of the current pulses exemplified by Fig.4 can be explained as follows. Firstly, due to a Townsend ionisation mechanisms a cathode structure similar to that in an abnormal glow discharge was established, and then the positive streamer was formed as a "break-up" of this cathode region. The reader is referred to [12,14] for more details on this phenomenon.

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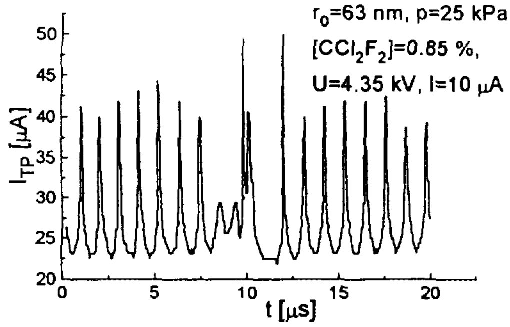

Fig. 1

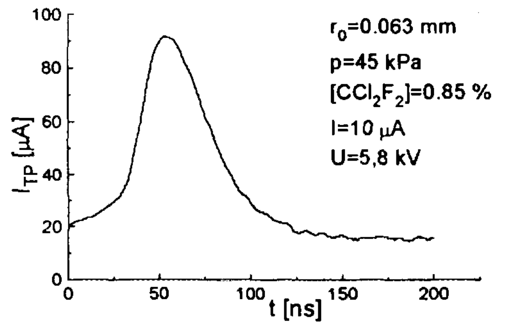

Fig.2

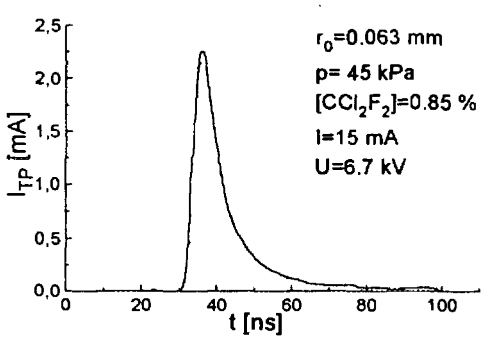

Fig.3

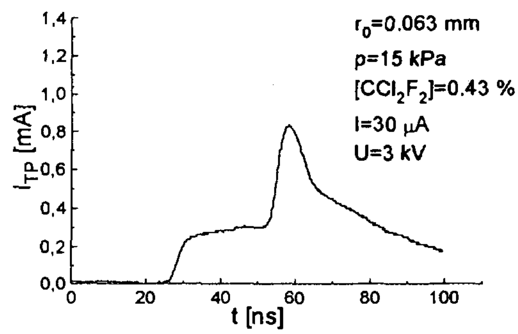

Fig. 4

Fig.1 A train of negative corona current pulses.
Fig.2 Regular current pulse characterized by a gradual current rise.
Fig.3 Regular current pulse characterised by a steep current rise.
Fig.4 Complex form of regular negative corona current pulses.