Fast Cathode Processes In Conditioning Of Vacuum Electrodes

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ABSTRACT

High-speed streak photographs of vacuum breakdown show oscillations in light emission at the cathode. Experimental results are presented that show the change in frequency of that oscillation as conditioning progresses. The link between the oscillations and conditioning supports the hypothesis that adsorbed gas removal is the cause of conditioning in vacuum breakdown.

INTRODUCTION

In the last year additional information on the processes involved in vacuum discharges has been obtained. Investigation made in a technical vacuum (10^{-2} to 10^{-6} Pa) have shown that the discharge, of course, begins on the cathode but this event is much more complicated than the description offered in the literature [1,2].

In the first stage of the discharge the cathode event has a cyclical nature with a repetition time of a few ns. Such periodicity is noted both in the case of unbridged [3-7] and spacer-bridged [8,9] vacuum gaps. The major methods used to observe the cathode event involve either an optical system which records light emission or an electrical method which measures various electrical parameters. As yet, there does not exist one universally accepted theory explaining this event.

A number of possible explanations have been proposed. The pulsative event has been linked to: explosive emission [5]; events in cathode plasma and the space charge generated from the plasma [10]; and to events within the strong electric field in cathode contamination layers [2]. It is the purpose of this paper to present new experimental results that can assist in deciding which of the above explanations is correct.

EXPERIMENTAL METHOD

The first stage of the discharge development in vacuum was observed using an Imacon 600 high-speed camera and associated image intensifier. The observations were made in the cylindrical stainless steel chamber with two observation windows. The oil-diffusion pump system achieved a vacuum of 10^{-5} Pa.

The basic electrode system consisted of an aluminum point and plane electrode. The point radius was 0.5 mm, and gap spacing 5 mm. The voltage source was an impulse generator with a standard 1/50 µs wave shape.

The testing procedure involved initially pumping the system for at least four hours. The observations were made during conditioning discharges.

RESULTS

A typical streak photograph of the first stage of breakdown development in vacuum is presented in Fig. 1. This photograph displays the pulsative character of the cathode light. The frequency change during the conditioning process is shown in Fig. 2.

It can be seen that the highest pulse frequency (with a repetition time of ≈4 ns) occurred during the first discharge. With subsequent discharges, the frequency dropped and after about 100 tests the repetition time had increased to 5 ns. In other words, cathode pulse frequency drops with the conditioning of the electrodes. This result shows that the pulse frequency probably is linked to the density of adsorbates on the cathode surface.

It must be noted that the frequency of pulses is inversely related to the breakdown voltage during conditioning.

CONCLUSIONS

The phenomenon of conditioning is well established. The breakdown of a vacuum gap occurs as the result of melting and vaporization under the influence of

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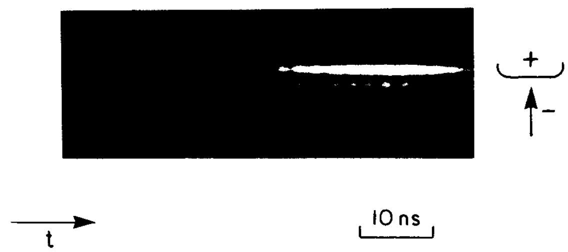

Fig. 1: A streak photograph showing oscillating light emission at the cathode.

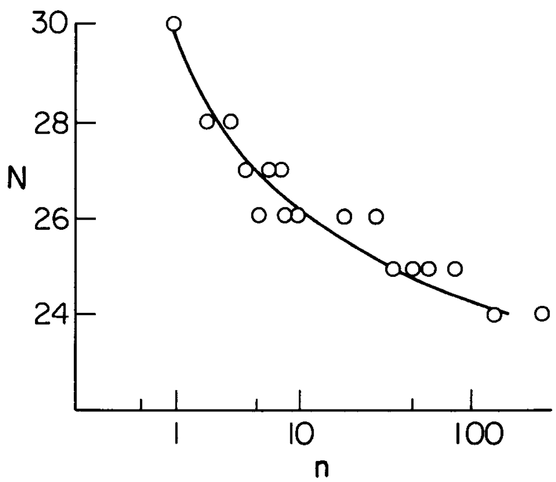

Fig. 2: Changes in the number of cathode pulses N vs the number of conditioning discharges n. The pulses were counted during a 120 ns time interval.

electron bombardment. As the energy for melting and vaporization depends upon the product of electron current and gap voltage, any mechanism that increases electron current will allow breakdown to occur at a lower voltage.

Particles or micro-protrusions on the cathode surface have been invoked as an explanation of conditioning. Initially they enhance the local field and aid field emission, and hence lower the breakdown voltage. Repeated breakdowns are assumed to remove them, leading to an increased breakdown voltage. The fact that conditioning is lost if the electrodes remain field-free in vacuum for some time indicates that particles or micro-protrusions are not the cause of the initial low breakdowns. It is not likely that such defects would reappear when the electrodes are left field-free.

A more likely cause of low breakdowns that could reappear if the electrodes are left field-free is the build-up of adsorbates on the cathode surface. Adsorbates would not contribute to Fowler-Nordheim type field emission but can contribute to electron current in other ways. We suggest that the interaction of field emission current and the adsorbed gas layer lead to a plasma in the region of the cathode surface. The plasma will act as a copious source of electrons leading to anode melting.

Adsorbed gas layers on a cathode surface have been shown to lead to enhanced field emission (EFE), [2]. This very strong emission of electrons occurs without the need of sharp cathode protrusions.

The proposed mechanism of a single pulse is as follows. When the cathode field reaches a critical value, EFE gives rise to a strong emission of electrons from the cathode. The emission process and the field desorb gas molecules, forming a cloud close to the emission site. The velocity of the gas molecules is too low for any significant movement in the times of interest here. The rising field and increasing gas density will rapidly produce conditions in which the emitted electrons ionize enough of the gas molecules to produce a visible plasma, Fig. 3a. The ionization mechanism is discussed in [2]. The creation of the plasma causes a large increase in the emitted current because the electrons in the plasma are rapidly extracted by the field, leaving the heavy, slow moving, ions behind. The positive ions enhance the field at the cathode surface and increase the electron emission, Fig. 3b. The positive ion cloud, almost stationary in position, continues to grow as the increasing emitted electron current passes through the desorbed gas cloud. The positive space charge increases the field between it and the cathode but reduces the field between it and the anode. Eventually the field between the space charge and the anode reverses direction and the emitted electrons, after passing through the plasma region are retarded. Eventually the electrons fall back towards the plasma. At that point the positive space charge can grow no more and the ions collapse into the cathode under the action of the intense field directed towards the cathode, Fig. 3c. The light pulse is terminated and conditions are correct for the process to repeat. An analytical treatment of this model is presented in [10].

The oscillating light emission is the result of periodic variation in the plasma density. The higher the frequency of the oscillation, the more electron current is reaching the anode, therefore the lower the breakdown voltage. As the adsorbates are moved by repeated discharges, the oscillation frequency drops with an associated reduction in electron current and increase in breakdown voltage.

The correlation between decrease in frequency of light emitting events and the increase in breakdown voltage indicates that adsorbed gas removal is responsible for conditioning.

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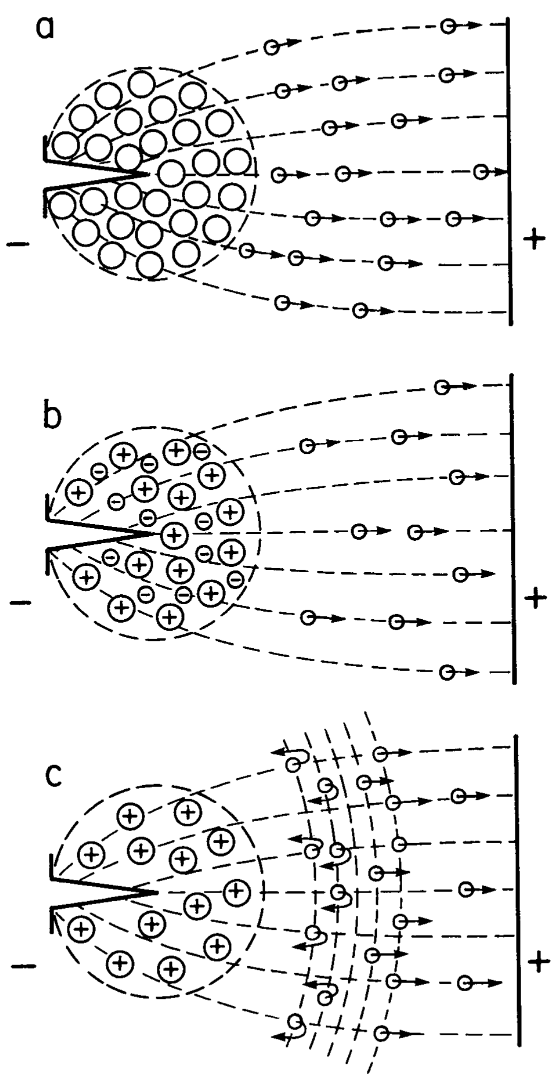

Fig. 3: Mechanism of pulse formation.

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