Influence of nitrogen admixture on characteristics of argon breakdown in a long discharge tube

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Direct current glow discharge in pure argon and in argon with nitrogen admixture was ignited in a long (the length is large as compared with the diameter) cylindrical tube at pressure P = 1 – 5 Torr. Pairs of successive high-voltage pulses were used for breakdown. The breakdown voltage in each pulse was measured and the breakdown voltage in the second pulse was found as a function of the time interval between the pulses. It was observed that addition of even a small admixture of nitrogen (~ 0.02%) to argon resulted in the noticeable change of the breakdown voltage value in the first pulse of a pair as well as in the second pulse.

1. Introduction

It is well known that the preceding discharge pulse has an effect on the breakdown characteristics of the subsequent pulse (see, for example, [1-3]). Qualitatively, this effect can be attributed to the existence of residual electrons (as well as of excited atoms or molecules the collisions of which result in the appearance of electrons) in the discharge gap over a certain time interval after termination of the discharge pulse, which facilitates breakdown in the next pulse.

An influence of the discharge pulse on the breakdown time delay in succeeding pulse ('a memory effect') in nitrogen and rare gases has been studied by Pejović with co-authors (see [1] and references herein) for short discharge gaps. Note that, under the conditions considered in [1], the breakdown occurs in an electric field which is uniform or nearly uniform, so the classical Townsend avalanche mechanism is realized.

The ignition of the discharge in a long discharge tube occurs in a different way. It starts from breakdown of the gap between the high voltage electrode and the adjacent part of the wall and formation of the ionization wave [4]. For finite duration of the pulse leading edge, the memory effect appears as an influence of the discharge pulse on the breakdown voltage in the succeeding pulse. Recently the memory effect in long discharge tubes was studied for discharges in argon [2] and nitrogen [3]. In the present work the influence of nitrogen admixture on the breakdown voltage in argon at pressure P =1 – 5 Torr was experimentally studied.

2. Experimental setup and procedures

The experiments were carried out with a molybdenum glass discharge tube with cylindrical tantalum electrodes at its expanded ends. The inner diameter of the tube was 3 cm, and the distance between the electrodes was 75 cm. The discharge tube was mounted on dielectric holders and spaced at least 8 cm from the metal details of the setup. The working gas was supplied to the discharge tube via glass traps and a copper capillary cooled with liquid nitrogen and was continuously pumped through the discharge tube with a velocity of ~1 m/s.

Discharge pulses of the positive polarity were produced by the high-voltage (up to U_0 = 10 kV) dc power supply. The leading edge of each pulse had the time dependence as $U(t)=U_0[1-\exp(-t/t_0)]$, $t_0 \approx$ 45 μs. Pulse duration (10-30 ms) was long enough to provide the formation of the steady-state glow discharge. The established discharge current was I = 10 mA. The discharge pulses were grouped in pairs with varied time interval, τ, between the pulses of the pair. The repetition rate of the pairs was taken to be f = 0.5 – 0.1 Hz (depending on gas pressure and nitrogen percentage). The breakdown voltage in each pulse of the pair (U_{b1} and U_{b2}, respectively) was measured and the breakdown voltage in the second pulse was found as a function of the time interval between the pulses.

The discharge voltage and current signals *vs* time were recorded. The maximum of the discharge voltage was taken as the breakdown potential value. Emission from the ionization wave, which moved from the anode to the cathode prior to the breakdown, was detected with two optical fibers, and the wave velocity was determined

3. Results and discussion

Results of studies are illustrated by fig. 1(a-b) where the averaged breakdown voltage in the 1st and 2nd pulses is shown in dependence on time interval between pulses. First, let us consider results for pure argon. One can see that the averaged breakdown voltage in the first pulse is independent of τ and has a wide scatter. Note that error bars in fig. 1 show the standard deviations of the average values (averaged over 50 measurements). The full range of the 1st pulse voltage values is between 1.5 and 8.5 kV. The breakdown voltage in the second pulse depends on the time gap τ. For $\tau < \tau_m(\mathrm{Ar}) \approx 350$ ms, U_{b2} is essentially lower than U_{b1} and has no scatter. In this τ interval, U_{b2} is almost constant, apart from the initial period (0.5 – 20 ms), where a local maximum was observed at $\tau_0(\mathrm{Ar}) \approx 7$ ms. For $\tau > \tau_m(\mathrm{Ar})$, the U_{b2} value rises with τ tending to U_{b1} and the scattering of U_{b2} also rises.

In time scale $\tau < \tau_m(\mathrm{Ar})$, a preceding discharge pulse decreases the breakdown voltage and eliminates its scattering in the subsequent pulse. In fact, it means the decrease in the breakdown time delay, partly by eliminating its statistical component. Qualitatively, this conclusion agrees

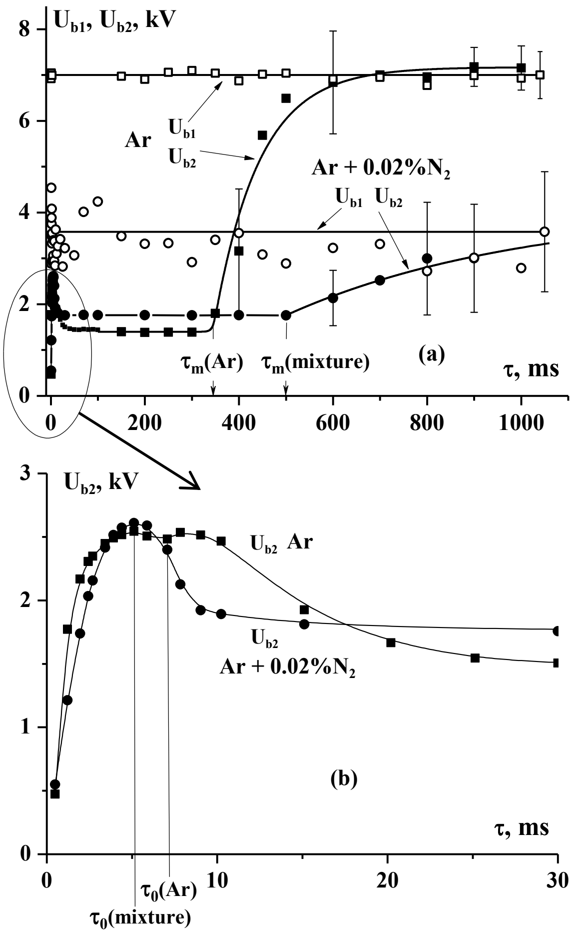

Fig. 1. (a) Breakdown voltage in the 1st and 2nd pulses *vs* time interval between the pulses. P = 5 Torr, f = 0.5 Hz. Error bars are the standard deviations of the average values. (b) Enlarged part of figure (a) marked by the ellipse.

with the results of Pejović et al. [1]. They attribute such an effect to secondary electron emission that is produced by ions or radicals remaining after the preceding discharge pulse.

It was observed that the breakdown in the 1st pulse was always preceded by the propagation of an ionization wave. In the 2nd pulse the ionization wave was detected only at $\tau > \tau_0(\mathrm{Ar})$. Ionization wave velocity varied with breakdown voltage in the range of more than two orders of magnitude (fig. 2).

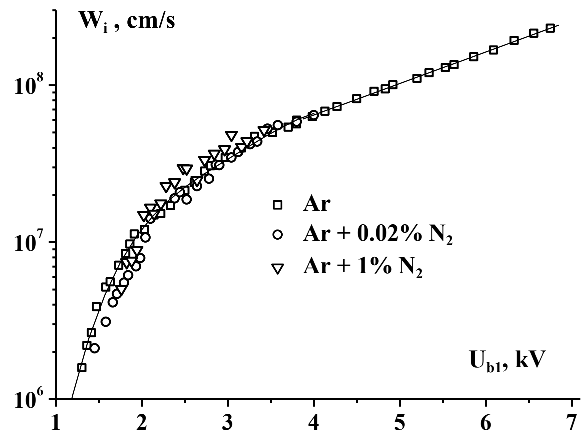

Fig. 2. Ionization wave velocity as a function of the breakdown voltage. P = 5 Torr.

Addition of nitrogen to argon leads to the noticeable decrease in the breakdown voltage in the first pulse (fig. 1). It means the decrease in the breakdown time delay with respect to that in pure argon. Probably, it can be explained by the presence of nitrogen atoms on the tube wall, recombination of which results in the secondary electron emission.

Note also that addition of nitrogen leads to the increase in τ_m and to the decrease in τ_0 values (fig. 1). And the ionization wave velocity as a function of the breakdown voltage in argon-nitrogen mixtures appears to be the same as in pure argon (fig. 2).

This work was supported by the Russian Foundation for Basic Research, # 15-02-06191.

4. References

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