INFLUENCE OF VOLTAGE PULSE DURATION ON IGNITION OF GLOW DISCHARGE IN AIR

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The effect of the duty cycle coefficient on the pulsed discharge ignition in air has been studied in experiment. It has been found that the highest breakdown voltage values are required for igniting the discharge with short pulses possessing moderate values of the duty cycle coefficient *D*. On increasing the pulse duration the strongest changes of the breakdown voltage are observed at low gas pressure to the left of the breakdown curve minimum. With the *D* quantity growing and the gas pressure fixed the breakdown voltage first decreases and then it experiences saturation that corresponds to the breakdown in the constant (not pulsed) electric field ($D = 1$). In the region to the right of the breakdown curve the range of the breakdown voltage variation against the duty cycle narrows.

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INTRODUCTION

Glow discharge is widely used in different technological plasma processes. One of the most important parameters that must be known when optimizing plasma processes is the dependence of the breakdown voltage on the pressure (or other parameter characterizing the gap), in other words, the conditions for the plasma to be created in a gas-discharge chamber. The most widely used is the DC glow discharge with constant (non-pulsed) voltage (its ignition has been researched, for example, in the papers [1-15]) and radio-frequency capacitive discharge (see [13, 16-24]). However, these commonly used types of gas discharge possess some drawbacks. For example, excessive heating of the processed samples and arc formation are possible in the glow discharge, while the use of RF discharge requires cumbersome and expensive RF generators and matchboxes.

Unlike dc and RF discharges, microsecond pulsed discharges have been studied much less, including their ignition [25-28]. An advantage of the pulsed discharges is the possibility of changing the duty cycle, the fraction of the pulse period during which a voltage is applied to the electrodes. In this paper, the influence of the duty cycle on the ignition of unipolar low-pressure pulse discharge is investigated. Note that DC voltage is a special case of a pulsed voltage, for which the duty cycle is 1.

1. EXPERIMENTAL

Unipolar pulsed discharge was ignited in the chamber, a block diagram of which is shown in Fig. 1. Flat anode and cathode made of stainless steel are placed at the ends of the chamber. The internal diameter of th discharge tube is 56 mm, distance between the electrodes is 15 mm. The pulsed unipolar voltage is applied to the electrodes from a high-voltage pulse generator with maximum amplitude of 1200 V. The pulse frequency was equal to 20 kHz, while the duty cycle varied from 3 to 89 %. Oscilloscope PCS500 (Velleman Instruments) was used to measure the voltage between the electrodes and the discharge current, and the signals from it were fed to the personal computer. Experiments were conducted in the air in the pressure range from 0.08 to 8 Torr.

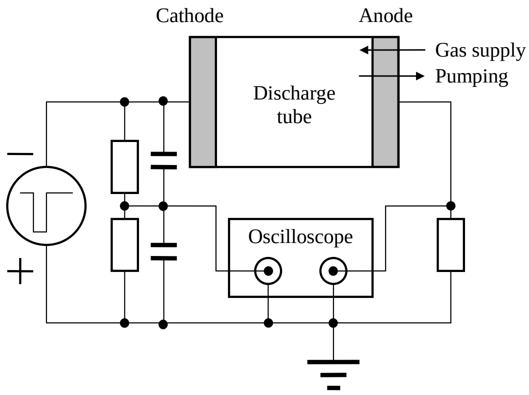

Fig. 1. The scheme of the experimental setup

The method of measuring the breakdown curves was as follows. At a fixed gas pressure, the value of the duty cycle was set and then the voltage amplitude on the electrodes was slowly increased until the ignition of the discharge. In the absence of discharge the displacement current passes between the electrodes, that occurs due to the change in the electric field in the chamber. We considered the moment of discharge ignition as a moment of deviation of the shape of the current signal from the case when ionization is absent. At low gas pressure and small duty cycles an abrupt increase in voltage leads to a pulse of the capacitive current, which then rapidly decreases to zero. If during the rest of the pulse the current begins to grow by exponential law, then this voltage can be taken as a breakdown voltage. Note that in such conditions, the discharge glow is not observed yet. However, at sufficiently high values of pressure and duty cycle the breakdown appears in different form: when the breakdown voltage is reached, rapid formation of the discharge is observed with the appearance of bright glow and high current.

2. EXPERIMENTAL RESULTS

It was noted above that the method for measuring the breakdown curves was different at low and high values of gas pressure. At low pressure (to the left of the breakdown curve minimum), two different modes of unipolar pulse discharge can be observed. In the case of short voltage pulses ($D \approx 0.4$), a low-current mode appears first with the current increasing during the

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pulse. The increase in the discharge current begins after a short time after the voltage pulse beginning (Fig. 2,a).

The discharge current in the low-current mode increases according to the exponential law, and the growth rate increases with the voltage increase. The discharge in this mode glows very weakly and resembles the obstructed mode of DC glow discharge, whose gap between the electrodes is too small to fit even a cathode layer.

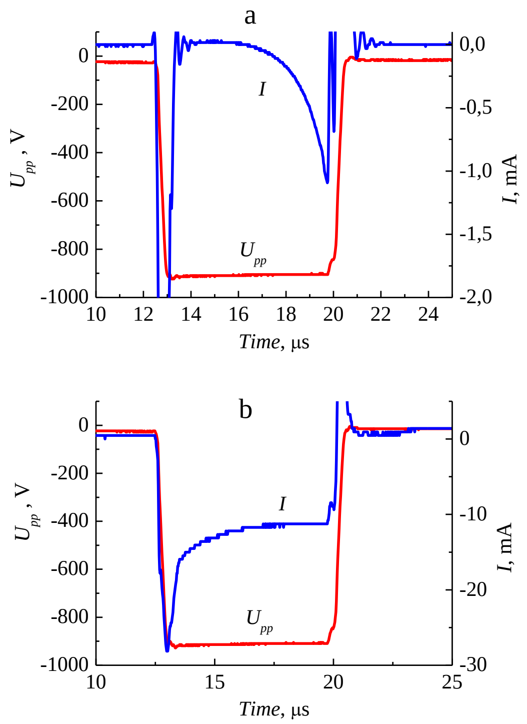

Fig. 2. Voltage and current oscillograms for low-current (a) and high-current (b) discharge modes. p = 0.1 Torr, D = 0.15, voltage amplitude is 923 V

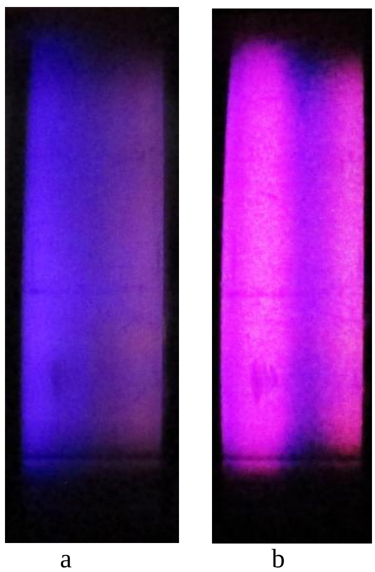

Fig. 3. Photos of low-current (a) and high-current (b) discharge modes. p = 0.1 Torr, D = 0.15, pulse voltage amplitude is 923 V

Each time when the voltage pulse begins, the breakdown of the gap appears and the formation of the discharge current starts from zero level. Apparently, in the low-current mode, during the voltage pulse, the discharge current does not have enough time to reach a value sufficient to form an uninterrupted pulsed discharge. The exponential increase of current over time is associated with multi-avalanche ionization process, when a slightly higher number of positive ions appears after passing of the next avalanche from the cathode to the anode. Further increase of the amplitude of the voltage leads to the transition of the low-current regime to high-current mode (Fig. 2,b and Fig. 3). However, with the duty cycle increase in (that is, at a longer pulse) the achievement of the breakdown voltage leads immediately to the formation of the high-current mode with the magnitude of the discharge current of units or tens of milliamperes.

The measured breakdown curves of the pulsed discharge are shown in Fig. 4 for different values of duty cycle *D*. One can see from the figure that the highest breakdown voltage is required to ignite the discharge by short pulses, with a small *D*. With the pulse duration increase the most significant changes in breakdown voltage are observed at low gas pressure, to the left of the minima of the breakdown curves (Fig. 5). In particular, with increasing *D* at a fixed gas pressure, the breakdown voltage initially decreases rapidly, and then goes to saturation, which corresponds to a breakdown in a constant electric field (D = 1). At the gas pressure near and to the right of the minimum, the behavior of the breakdown voltage remains similar, but its change with increasing *D* becomes less than at low pressure. The right branches of the breakdown curves for different *D* are close to each other and to the curve for the DC glow discharge.

Therefore, we see that at low pressure (less than 2 Torr) high voltage is required to ignite the discharge with short pulses, the lowest voltage corresponds to the breakdown in a constant (not pulsed) electric field. That is, the decrease of duty cycle (pulse width) initially does not affect substantially the ignition of the pulsed discharge, and only with short pulses the breakdown voltage sharply increases. At high pressure (see in Fig. 5 this corresponds to a pressure of 5 Torr), the amplitude of the breakdown voltage practically does not change in the whole range of *D*.

CONCLUSIONS

The experimental studies of the duty cycle effect on the ignition of a pulsed discharge in the air in the range of pressure 0.08…8 Torr have shown that at low pressure (to the left of the minimum of the breakdown curve) two different modes of the discharge burning can be observed. In the low-current mode (which is similar to the obstructed mode of glow discharge) the current increases in exponential law. In this mode each time when the voltage pulse is applied, the breakdown of the gap and the formation of a low-current mode occur newly. When the voltage is increased, the low-current discharge transits to the high-current form. At large duty cycle values the low-current mode is not observed, and the discharge immediately goes to the high-current mode.

It is found that the highest breakdown voltages are required for ignition of discharge with short pulses, that is with small values of *D*. With the pulse duration increase the most significant changes in breakdown voltage are observed at low gas pressure, to the left of the minima of the breakdown curves. With *D* increase at a fixed gas pressure, the breakdown voltage initially decreases, and then goes to saturation corresponding to the breakdown in a constant (non-pulsed) electric field (*D* = 1). In the region to the right of the breakdown curve minimum the range of breakdown voltage variation depending on the duty cycle is narrowed.

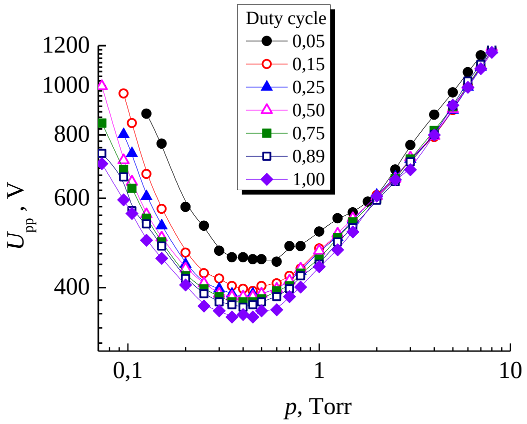

Fig. 4. Breakdown curves of unipolar pulsed discharge in air for different duty cycle values

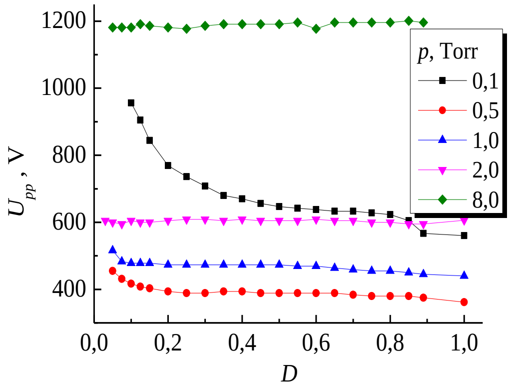

Fig. 5. Dependences of breakdown voltage of pulsed discharge on duty cycle D at various air pressures

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ВЛИЯНИЕ ДЛИТЕЛЬНОСТИ ИМПУЛЬСА НАПРЯЖЕНИЯ НА ЗАЖИГАНИЕ ТЛЕЮЩЕГО РАЗРЯДА В ВОЗДУХЕ

В.А. Лисовский, П.П. Платонов, С.В. Дудин

Экспериментально исследовалось влияние коэффициента заполнения на зажигание импульсного разряда в воздухе. Было обнаружено, что самые высокие значения напряжения пробоя требуются для зажигания разряда короткими импульсами, имеющими небольшие значения коэффициента заполнения D. При увеличении длительности импульса самые сильные изменения пробойного напряжения наблюдаются при низком давлении газа слева от минимумов кривых зажигания. При увеличении величины D и фиксированном давлении газа пробойное напряжение сначала уменьшается, а затем оно выходит на насыщение, что соответствует пробою в постоянном (не импульсном) электрическом поле (D = 1). В области справа от минимума кривой зажигания сужается диапазон изменения пробойного напряжения на зависимости от коэффициента заполнения.

ВПЛИВ ТРИВАЛОСТІ ІМПУЛЬСУ НАПРУГИ НА ЗАПАЛЮВАННЯ ТЛІЮЧОГО РОЗРЯДУ В ПОВІТРІ

В.О. Лісовський, П.П. Платонов, С.В. Дудін

Експериментально досліджувався вплив коефіцієнта заповнення на запалювання імпульсного розряду в повітрі. Було виявлено, що найвищі значення напруги пробою потрібні для запалювання розряду короткими імпульсами, які мають невеликі значення коефіцієнта заповнення D. При збільшенні тривалості імпульсу найсильніші зміни пробійної напруги спостерігаються при низькому тиску газу зліва від мінімумів кривих запалювання. При збільшенні величини D і фіксованому тиску газу пробійна напруга спочатку зменшується, а потім вона виходить на насичення, що відповідає пробою в постійному (не імпульсному) електричному полі (D = 1). У зоні праворуч від мінімуму кривої запалювання звужується діапазон зміни пробійної напруги на залежності від коефіцієнта заповнення.