THE STRUCTURE AND PRODUCTIVITY OF THE BARRIER DISCHARGE

V.I.Gibalov, P.S.Novikov, A.T.Rakhimov, V.B.Saenko, and A.B.Saveliev

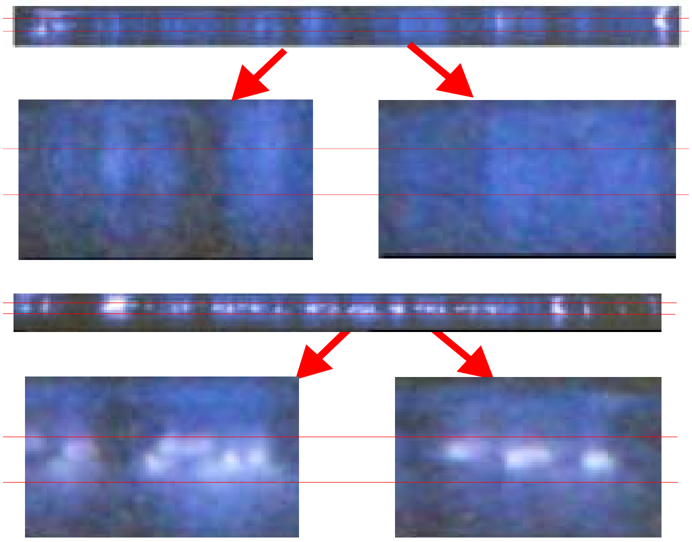
Moscow State University, Chemical Department, 119899 Moscow, Russia; valentin@gibalov.chem.msu.su

1 Abstract

The correlation between discharge structure and ozone yield has being investigated. Pictures of the discharge region proved that discharge is more homogeneous if the anode is conductive. The transferred charge values are different for negative and positive semicircle of the applied voltage in oxygen and air of normal pressure. Depending on the discharge conditions the charge transfer into discharge region takes place in distinct channels as well as in practically uniform discharge structure. The efficiency of the ozone synthesis are influenced by these conditions as well.

2 Introduction

The barrier discharge of any arrangement happens between two electrodes if one of them, at least, is covered by dielectric. The charge transfer takes place in short current impulses with duration of about 10–50 nsec. During this time interval electrons cross the discharge gap, have achieved "borders" of discharge region and leave the gas gap (if the border is a conductive electrode) or accumulate on dielectric surface. This time interval isn't enough for ions to leave the discharge region.
The charge transfer has are two distinguish forms: homogeneous or filamentary spatial structured. The mechanism of the transition of the barrier discharge from first form to the second one is not clear so far. But it was proved experimentally that at certain conditions there is a homogeneous discharge [1] in nitrogen. The discharge, which is close to the homogeneous form was fond in electronegative gas, Fig.1. (The width of the illuminated area is wider then discharge gap value because of the light reflection from the electrode surface) Spatial structure of this discharge depends on the polarity of the conductive electrode.



a)

b)

Fig.1 Pictures of the discharge region. Lines show the discharge gap. Polarity of applied voltage: conductive electrode is an anode -a) and the cathode – b). Air of 1 bar, discharge gap - 0.7 mm.

If the conductive electrode is an anode the charge transfer in the discharge region takes place into a wide columns, which practically homogeneously fill the discharge region, Fig.1. The well known filamentary structure registered at opposite polarity.

So different spatial structure of the discharge development proves that surface characteristics influence on stability of charge transfer in discharge gap, in particular, on discharge contraction.

3 Experimental set-up

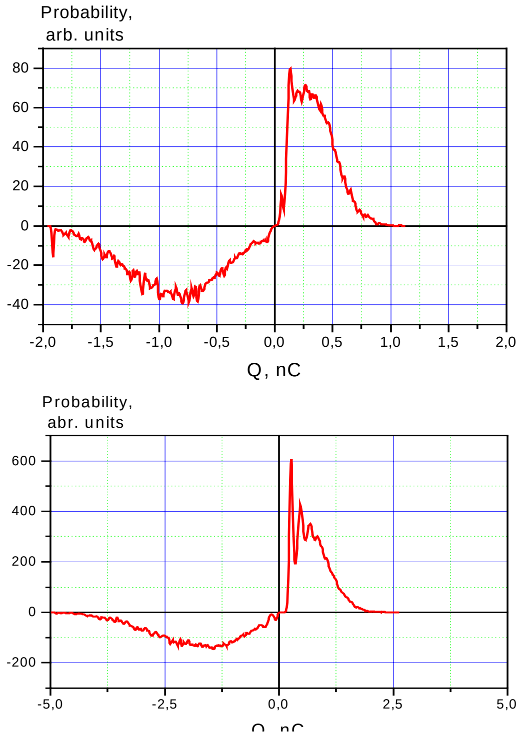
The barrier discharge of the volume arrangement (VD) was taken as experimental discharge cell. It consists of two flat round electrodes with diameters of about 15 and 100 mm. Discharge gap is varied in range of 0 -1.7 mm. Charge transfer into gas gap of discharge cell courses the current "jumps" at external circuit. Voltage "jump" was measured and treated by appropriate equipment and, finally, accumulated by PC. Each voltage jump relates with several individual discharge channels. Because of this the charge transfer value obtained from this jump is a sum of charges transferred into each channel. To obtain a proper result the set of some 100000 of voltage jumps accumulated and treated.

Several power supplies were used during this undertaking. Power supply with industrial frequency (50 Hz) was used for charge measurements. For ozone yield the power supply with very low frequency (0.1-0.02 Hz) is necessary in order to “wash” the gas system from ozone produced by previous semicircle. Voltage amplitude varied from zero till 14 kV.

Experiments were carried out with air and oxygen of normal pressure.

4 Transferred charge value and discharge channels

The method used allows measure value of charge, which is transferred in a single discharge current impulse, with time resolution not better than a few microseconds. For VDs current impulse in this time scale consists of a several micro-discharge current impulses. Results of these measurements were assembled as a histogram where X-axis is a charge value, Y-axis – number of current impulses with same amplitude.

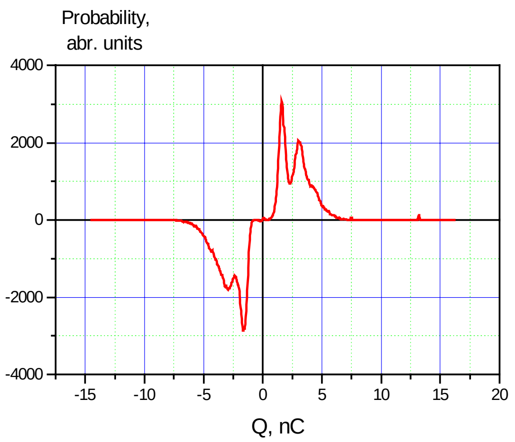


a)

b)

Fig. 2 Distribution of transferred charge value at oxygen. Glass with relative permittivity 5, thickness – 4 mm, discharge gap: a) – 0.58 and b) – 1.4 mm

Distributions of transferred charge value into external circuit obtained by this method are presented at Fig.2 and Fig.3. It’s obvious, that these values are rather different for positive and negative voltage. (The term “positive” or “negative” polarity relates to the polarity of dielectric electrode of discharge cell). Some evidence of this phenomena was mentioned in [3].
If a glass with relative permittivity of 5 units is used, value of transferred charge at positive voltage is several times lower that the same for negative polarity, Fig.2. The distribution at positive polarity has a fine structure (Fig.2, right side) with several maximums. This structure becomes more obvious at bigger gas gaps, Fig.2b. In general, there is a certain probability of appearance of current impulse, which consist of one, two or three …etc micro-discharges. Right side of curves (Fig.2) reflects these ideas. Current impulses, which consist of two to four-five micro-discharges, looks more probable then others. Difference between position of any two close maximums is charge value, which is transferred by sole micro-discharge.



This value is about 0.07 nC mm for discharge gap of 0.58 mm and enlarges till 0.4-0.5 nC at 1.68 mm, Fig.2. Micro-discharge structure with well reproduced charge value, which is transferred into each channel, can be found at positive polarity only. Current impulses at negative polarity are bigger and haven’t noted “channel” structure, Fig.2, left side.

Fig. 3*:* Distribution of transferred charge value. Ceramic, thickness – 6 mm, relative permittivity – 150 units, discharge gap - 0.18 mm.

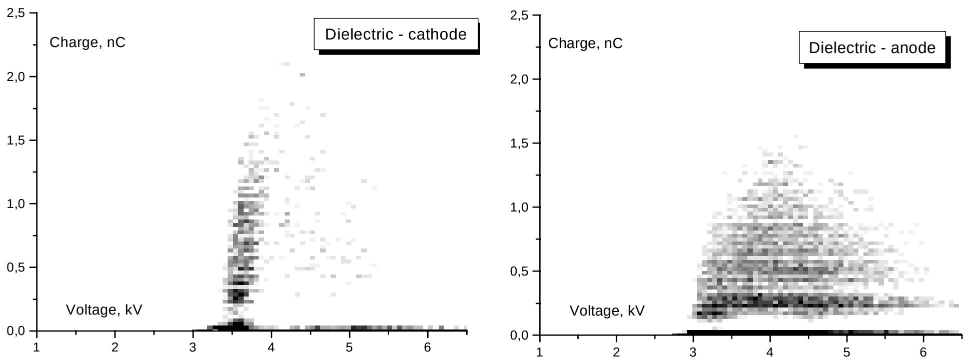
This structure appears at negative polarity if specific capacity is increased, Fig.3. Curve becomes much more symmetric, charge value is about two orders higher. Together with enlargement of the gas gap the micro-discharges number into current impulse decreases for both permittivities. If glass is used as dielectric this value is about 5-7 channels at 0.58 mm discharge gap, while at higher permittivity even at 0.18 mm there are only two channels into discharge gap, Fig.3.

Thus, in increasing of discharge “power” (the intensive parameters are gas gap and pemittivity values) discharge processes become more symmetric, channel structure appears at both polarities and channel number density decreases.

In any case, total charge value, which is transferred in external circuit at one polarity, must be equal to the same value at opposite polarity. But mechanism or structure of this transfer at certain conditions depends on polarity of applied voltage.

5 Temporal distribution of transferred charge value

Except charge transferred value the moment of current impulse appearance (or electrode’s actual voltage value) was registered at experiments too. Histograms of this data are presented at Fig.4. Experimental conditions for this figure are the same as for Fig.2. This histogram reflects the relation between charge value, which is transferred by current impulse and actual voltage (moment of appearance of this impulse).
The polarity of applied voltage effects on shape of these histograms. For both polarities discharge appears into discharge gap at same voltage which correlates with breakdown one. It means that first current impulse appears into discharge gap at this voltage. While applied voltage is rising the following impulse appears too. But, at positive polarity the following current impulses are distributed practically uniformly, from breakdown till peak voltages, Fig.4b. At negative polarity it is most probably that main part of charge is transferred near the breakdown voltage. During following voltage rise there are only a few current impulses, Fig.4a. For both polarities the breakdown impulse has higher amplitude if it takes place a bit later.



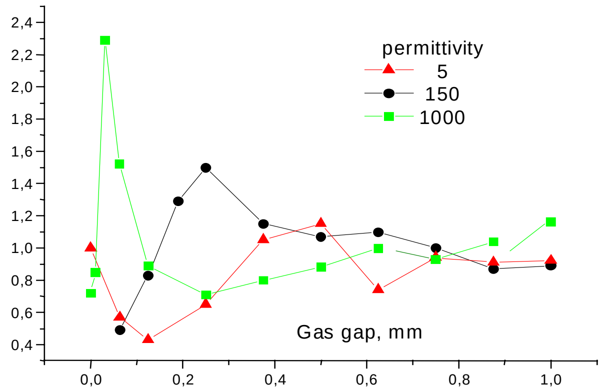
a) b)

Fig.4 Transferred charge via voltage value. Glass, thickness – 4 mm, relative permittivity – 5; discharge gap – 1.2 mm

Distributions on Fig.4 have a fine structure, too; especially, at positive polarity, Fig. 4b. It's just the same mechanism as discussed earlier: the sole current impulse consists of a certain number of micro-discharges and each micro-discharge transfers a certain charge value.
The increasing of specific capacitance (permittivity was increased up to 150 units) decreases number of micro-discharges into sole current impulse (Fig.3, two micro-discharges at positive and negative voltages). Moreover, from available data (Fig.3) follows that charge transfer at both polarities becomes practically identical [2]. Contrary to Fig.4, at this case microdischarges are distributed practically homogeneously from breakdown voltage till its peak values. There are only two maximums in amplitude of transferred charge value, which are near 1 and 2 nC. It means that, firstly, the most probable current impulse consist of two micro-discharges and, secondly, charge value transferred into sole micro-discharge is well reproducible and is about 1 nC at these conditions.

6 Ozone yield

Experimental set-up allows measuring an ozone yield from different voltage polarity separately. First of all it was proved that ozone outputs at different polarity are not the same. This phenomenon was found in [4]. Moreover, this value depends on discharge gap value and this dependence isn’t linear. The discharge energy released during each semicircle of applied voltage must be and is the same So, the relation of ozone output at different polarity is a measure of related efficiency of ozone synthesis. This value is presented on Fig.5.
It is obvious that at bigger values of discharge gap (of about 1 mm, Fig.5) the efficiency of ozone synthesis at both polarities are practically equal. There are two extremums at less values of discharge gaps. While the discharge gap is near the zero, negative polarity at the dielectric is more effective in ozone synthesis then the positive one. In increasing of discharge gap the noted efficiency at positive polarity at the dielectric becomes equal to the same value at negative polarity. Later on the positive polarity becomes more effective, Fig.5. Actual



position of these extremums depends on parameters of dielectric electrode, first of all, the permittivity. In general, at higher permittivity extremums appear at less discharge gaps, Fig.5.

Fig.5 Relation of the ozone synthesis efficiency at positive polarity on the dielectric to the same value at negative polarity via to the discharge gap.

7 Discussion

Discharge process into gas gap of barrier discharge has a transitional form. There are a certain number of discharge phases, which can be reached depending on external conditions. Discharge starts at conditions, which are close to breakdown one. Electron movement and multiplication disturbs field distribution and streamer or ionising wave appears into discharge region. The well ionised channel appears backward of the streamer. When streamer reaches the cathode a “normal” cathode layer appears. Further phase of discharge development results in widening of discharge region (channel) and further charge accumulation on dielectric surface. Final phase of barrier discharge connects with surface charge too. At certain level of surface charge density mean field strength drops down and discharge switch “OFF”.

The "depth" of discharge process development depends on external conditions. The most important parameters, which effect on the process are specific capacitance of dielectric barrier and gas gap value (for VD arrangement of barrier discharge). In general, discharge development can be stopped at any stage. Results, presented in this paper prove that there is an additional parameter, which influences on this process too. This is an asymmetry of the external conditions, or other words, the nature of electrodes: whether it is conductive or dielectric.

If conductive electrode is an anode, electrons leave the discharge region. Total charge density in discharge region becomes more positive and, probably because of this, charge value, which is transferred into micro-discharge, becomes higher. Amplitude of current impulse is higher too [3]. Number of current impulses, which is necessary to charge the dielectric surface to stop the appearance of following current impulses, decreases. Moreover, breakdown current impulses are enough to re-charge dielectric surface and it's unlikely that some more impulses appear till voltage peak.

If anode is dielectric, electrons accumulate on dielectric surface and effect directly on electric field. Transferred charge value decreases and it needs significantly more micro-discharges to charge dielectric surface. These micro-discharges distribute practically uniformly till peak voltage.

Spatial reconstruction of the discharge region results in changing of the mean field strength into the region of main charge transfer. And, by this, it changes the ozone synthesis efficiency.

This difference in charge transfer mechanism disappear if charge transfer value increases. The parameter, which influences on transferred charge value is specific capacitance of dielectric.

References

[1] P.Segur, F.Massines, Proc. Of XIII Int.Conf. on Gas Disch. and their Appl., Glasgow, (2000), p.15-24

[2] V.I.Gibalov, P.S.Novikov, A.T.Rakhimov, V.B.Saenko and A.B.Saveliev, Proc. Of XIII Int.Conf. on Gas Disch. and their Appl., Glasgow, (2000), p.291-94

[3] C.Heuser and G.Pietsch, 6^{th} Int. Conf. On Gas Disch. and their Appl., 1980, Edinburg, IEE Conf. Publ., 189, Part 1, p.98-101

[4] G.Mechtersheimer,B,Eliasson,U.Kogelschatz, Proc. 18^{th} Int.Conf. on Phenomens in Ionized Gases, Swansea, 1987, p.522-23