A.I. Gerasimov, I.V. Gerasimov, T.P. Kopeikina

GAS ANALOGUE OF THE GANNA EFFECT IN CONDITIONS OF TWO-ELECTRODE DISCHARGE OF CONTINUOUS CURRENT

Kostroma State University,
1 May Str.14, Kostroma, 156961, Russia, igor_valerger@mail.ru

Introduction

The action of strong electrical field of constant value by means of ohmic contacts on the semiconductor volume of any orientation give rise to fluctuations of the current through the semiconductor (effect of Gann, 1963 [1–5]). The nature of these fluctuations [5, 6] – process of periodic movement through of the sample of the area of the strong electrical field – domain, which arises nearby to the cathode of the sample. The period t_D of these fluctuations was approximately equal the time of the electrons flight from the cathode to the anode. The repeated cycle of appearance of the new domain and its movements in volume of the semiconductor occurs only after elimination of the previous domain on the anode. The new domain arises only then, when the time of its formation t_F is less than time t_L of the leaving of electrons in the anode from the place of formation of the domain, i.e. at $t_F < t_L = L/\vartheta_E$. Here L – distance the cathode - anode, $\vec{\vartheta}_E$ – velocity of electron-drift in the field (about 10^5 ms^{-1}) at which formation of the domain begins.

In a long model of the semiconductor the domain can arise in various areas of its volume, i.e. in this case L is distance from the anode of birth – place of the domain. Density of the current through the exemplar, in which the domain moves, $\vec{j}_E = en_E\mu_E\vec{E}_{K-A}$, μ_E – mobility of electrons, $\vec{E}_{K-A}$ – field outside of the domain. The result of consecutive repetition of the processes of appearance of domains and their subsequent elimination on the anode becomes the reason of generation of fluctuations of the current in the circuit of the cathode - anode with frequency $f_D = t_D^{-1} = \vec{\vartheta}_D/L$.

In semiconductors devices the movement of electric charges is located only in the area of $p-n-p$ (or $n-p-n$) transitions, while in work of Gann devices all volume of semiconductors elements takes part. It explains, in particular, the high power of such devices.

1. Experimental setup

In rarefied gas the mode similar to effect of Gann in semiconductors is realized by supplied of regulable direct voltage in $600-4500\,V$ to electrodes of five discharged tubes of various internal diameter ($3.8;\ 6.6;15.5;20.1$ and 25.8 mm). One of the ends of all tubes (with equal distance between electrodes 510 mm) with common vacuum system (the range of pressure p of the forevacuum, $10^{-3} \div 10$ Torr) is joined; the second electrode of all tubes is earthed, fig.1. Four accumulating condensers ($300\ \mu F$) were joined to an output of the source of the constant voltage. At realization of the periodic discharge they were joined either in parallel, in series [7, 8].

For registration of time of longitudinal moving of domains were used (fig. 2) of the circuit with two photo cells (or photomultiplier tube). One of them was placed near an electrode with negative high-voltage potential; the second photo cell – was mobile, it moved along a surface tube. The signals from both photo cells acted on two channel memorizing oscillograph and on frequency meter, working in a mode of measurement of intervals of time. The change of temperature of gas in a longitudinal direction of volumes of tubes were estimated of the thermopair removable on external surface of glass wall of tubes.

2. Experimental results

In experiments the area of existence of the periodic mode of breakdown of gas was established in coordinates $V(p)$ (the dependence similar by the curve of Pashen $V(p)$ for the discharges of the constant current [9]), fig. 3. The experiments have shown, that character of this dependence as a whole same, as well as the curve of Pashen $V(p)$ for the discharges of the constant current and for the discharge of unipolar breakdown of gas (UBG) [10, 11]: with reduction of the diameter of tubes $2r_{TUB}$ the border of breakdown of

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gas is displaced in area of the large valuations p and V. However the threshold of breakdown on the maximum of pressure practically is identical for all radiuses of tubes. The dependence of frequency of appearance of domains from pressure $f_D(p)$ has a maximum, which (for all significations of diameters of tubes $2r_{TUB}$) was related to the area of pressure $p = 0.1 \div 0.3$ $Torr$, fig. 3, curve 6.

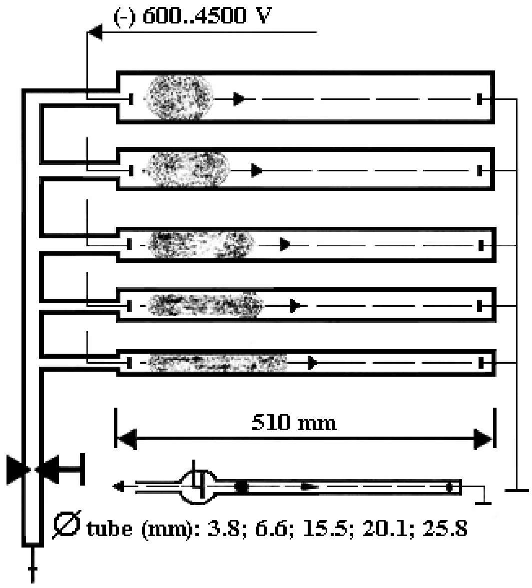

Fig.1. The block of the discharge tubes for research of a periodic mode of the discharge

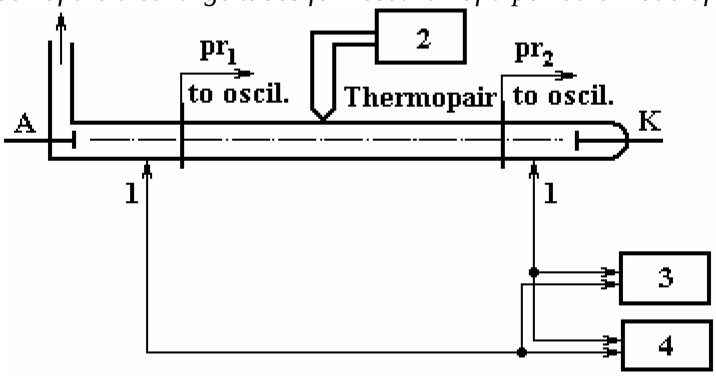

Fig.2. Setup for registration of longitudinal moving of domains. 1 – Photoelectric detector; 2 – plotter; 3 – oscillograph; 4 – frequency meter

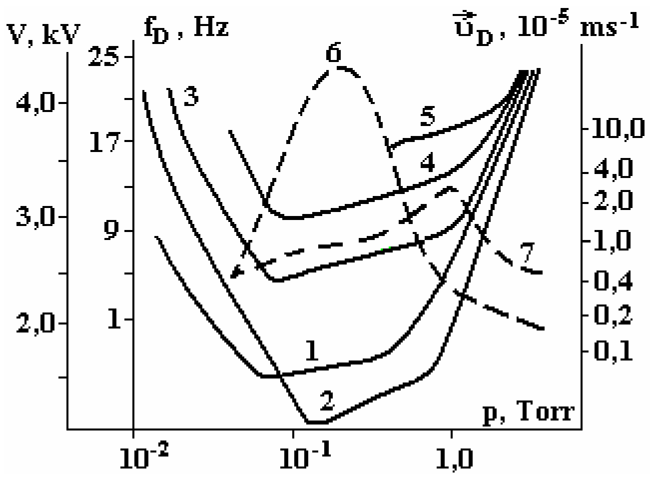

Fig. 3. Dependence $V(p)$ determining area of existence of a periodic mode of the discharge at its various parameters. The curves 1–5 concern to dependences for tubes with a diameter $2r_{TUB} = 25.8; 20.1; 15.5; 6.6; 3.8$ *мм*, *accordingly*

In the same coordinates - $V(p)$ - the frequency f_D of formation of the domain near the cathode was determined; the dependence from voltage V on electrodes and duration of process of the time of flight of the domain on fixed distance (i.e. time of its displacement t_D, its velocity $\vec{\vartheta}_D$) was established; the dependence of frequency f_D of formation of the domain from length L_D of volume of a tube with the discharge and from its diameter $2r_{TUB}$ was defined; the temperature parameters of gas volume at moving of the domain were measured.

The maximum velocity of moving of the domain between electrodes is displaced to border of the greater pressure of area of existence of the pulse mode of breakdown of gas in coordinates, fig. 3, curve 7. On fig. 4 are shown the results of measurement of time of flight of the domain at fixed distance between photocells in 505 mm from duration of process, and from voltage on electrodes.

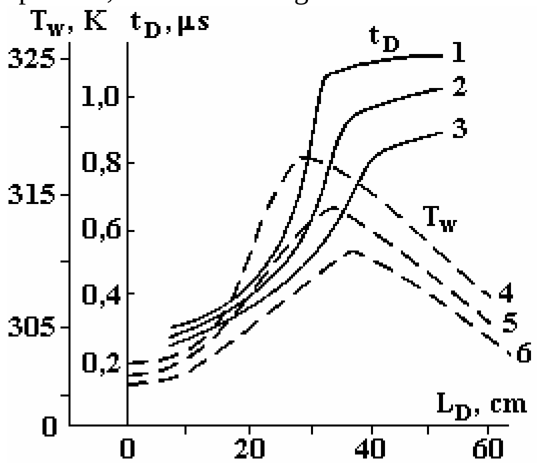

Fig. 4. Time of moving of domains on length of tubes and the temperature of their walls at various value of negative potential on the cathode. 1 – 4,3; 2 – 3,7; 3 – 4,3 kV. ∅ = 6,6 mm; f_D = 0,7 Hz; p = 0,8 Torr

The velocity $\vec{\vartheta}_D$ of displacement of domains becomes maximal $(\approx 4.0 \cdot 10^6\ ms^{-1})$ on some distance from the cathode; it not changing at further longitudinal movement of domens (the inclination of the curve 1.2.3 fig.4 to an axis of distances was constant and rather small). The results of fig. 4 are received at $p = 0.8$ Torr and for frequency of formation of domains $f_D = 0.7$ Hz.

Through 6.5 minutes after the beginning of process of formation of domain (dependence $t_D(t)$, curve 1, fig. 5) the velocity of displacement of domains of $\vec{\vartheta}_D = 1.44 \cdot 10^6\ ms^{-1}$ is observed.

In ~ 50 minutes from the beginning of process the velocity of movement of the domain $\vec{\vartheta}_D$ is increased up to $\approx 4.4 \cdot 10^6$ ms^{-1} remaining further without change.

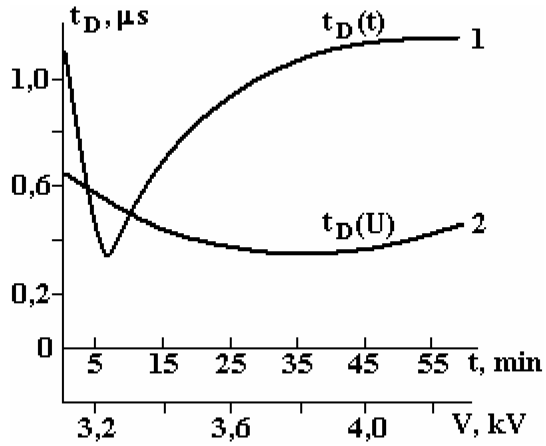

Fig.5. Dependence of the duration of process of the movement of domains from their periodic occurrence and from the value of negative potential on the cathode. L_D = 50,5 cm; p = 0,7 Torr

The area of maximal temperature of gas in volume of tube (the temperature of its wall was measured) is observed on distance at $25-35$ cm from an electrode with negative potential, – in the field of the maximal speed of moving of domains $\vec{\vartheta}_D$ (curves 4 and 6 fig. 4, for $4.26\ kV$ and $3.4\ kV$, accordingly; they are received at the same parameters of the discharge, as curve 1,2.3 same fig.).

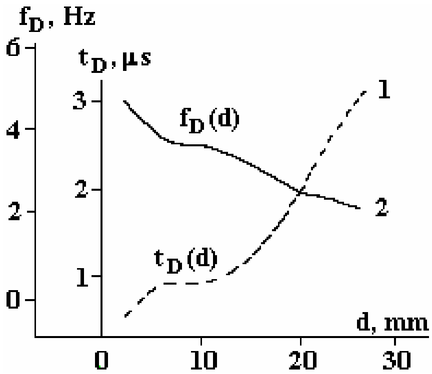

Fig. 6. Dependence the frequency of appearance of domains from a diameter of tubes and time of their moving. L_D = 28 cm; V = 4,3 kV; p = 1,8 Torr

The increase of diameter of tubes from 3,8 mm up to 25,8 mm (at preservation of constant other parameters of the discharge: $V = 4.255\ kV$, $p = 1.8\ Torr$ and $L_{DIS} = 28.5\ cm$) reduced: 1) the velocity of moving of domains (curve 1 fig. 6) with $\vec{\vartheta}_D = (0.285/5\cdot10^{-7}) = 5.7\cdot10^5\ \mathrm{ms}^{-1}$ up to $\vec{\vartheta}_D = (0.285/3\cdot10^{-6}) = 9.5\cdot10^4\ \mathrm{ms}^{-1}$; 2) the frequency f_D of formation of domains – with 5.0 up to $2.5\ Hz$, curve 2 fig. 6.

The frequency of appearance of domains f_D depends on the time interval t from the beginning of process of their formation, fig. 7. The maximal value f_D was observed ~ from 9 minutes of the moment of appearance of the periodic mode. In subsequent (the time interval 50 minutes) frequency of fluctuations f_D fell down up to value which was less than initial, curve 1 fig. 7 ($p = 1.7$ Torr, $L_{DIS} = 28.5$ cm).

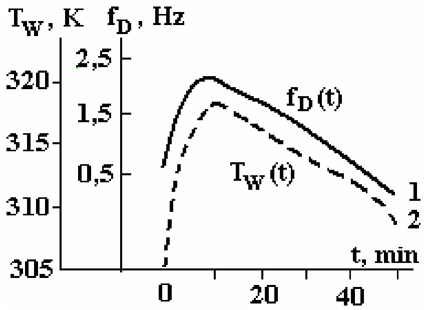

Fig.7. Dependence of temperature of walls of tubes and the frequency of formation of domains from duration of a periodic mode of the discharge. V = 4,3 kV; L_D = 25 cm

Local temperature of a wall of the discharge chamber T_W, K (curve 2 fig. 7, $V = 4.255\ kV$) varies in the same way, as well as f_D. Initial volume of the domain V_D near to the cathode and during its displacement to the anode was fixed in two ways: 1) mobile pair photodiodes - on border of its luminous covering from ionizated and exited molecules of gas; 2) two mobile ring probes – on sharp change of potential on the surface of tube. On certain distance from the cathode L_{MAX} volume of the driven domain V_D was increased up to maximal. Distance L_{MAX} decreased with increase of radius of tube. At the $V = 4.255\ kV$ and diameter of tube $2r_{TUB} = 6.6$ mm – $L_{MAX} = 21-23$ cm; at $2r_{TUB} = 25.8$ mm - $L_{MAX} = 5-6$ cm.

3. Discussion and conclusion

By electrical probes on surface of discharged tube the negative charge inside of tube was fixed in time about several microseconds, oscillograms of fig. 8. These charged volumes were inside of tube from the moment of formation of the domain nearby to cathode and beginning of its passage inside of tube. The same information from probes were too at their input inside of volume of tube. The signals of the probes were fixed too recession of the positive charge of the ions which have arisen under of percussion action of field of the domains $\vec{\nabla}\vec{E} = \rho/\varepsilon_0$ on atoms and molecules of gas [12, 13] (the top piece of oscillograms a fig. 8).

On oscillograms of fig. 8 the changes in volume of the domains are clearly visible during of their removal from the cathode (change of duration $t_{(-)}$ of the signal of negative polarity), i.e. the volume of the domain at its moving to the anode in tube with radius r_{TUB} with velocity $\vec{\vartheta}_D$ is defined from $V_D = \pi r_{TUB}^2 \times L_D = \pi r_{TUB}^2 \times \vec{\vartheta}_D \times t_{(-)}$.

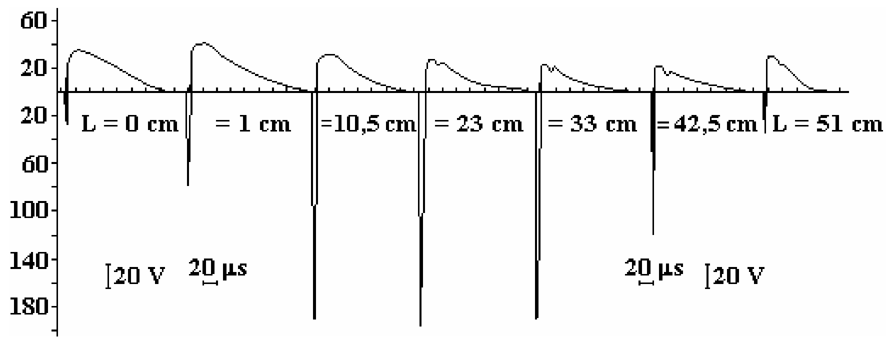

Fig. 8. Change of the form of oscillograms from probes at movement of volumetric charges (domains) on length of volume of tube

The experiments with the pulsed-periodic discharge have shown, that:

– the borders of moving volumes of domains rather precisely are fixed optical (photo-cells, multiplier phototubes, photodiodes) and by electrical methods of researches (by electrical probes inside and on the surface of the discharge tubes), i.e. the charge of the negative sign is located in borders of the moving domain, [13,14];

– in the discharge tubes with various radius, but with the equal square of the surface of the potential electrode and equal pressure of gas (maximal for the pulsed-periodic mode of the discharge in the tube with minimal radius), the maximum primary volume of domains was equal also, fig. 1;

– the form of the domain looked like of ellipsoid of rotation; at small radius of tube the width of the domain in direction of its moving was less, than for the tube with large radius;

– the spherical form of domain is observed only under a border of existence of the periodic discharge at the maximal pressure and only at the square of surface of potential electrode much more exceeding the square of cross section of the discharged tube (the circuit in the bottom of fig. 1), i.e. the appearance of the domain in the form of sphere required simultaneous realization of the following conditions: 1) of the well-defined value of pressure of gas; 2) of the fixed minimal value of potential of negative polarity on the cathode; 3) of the large surface of the cathode - greater, than square of cross section of tube;

– the frequency of formation of domains near the cathode increased proportionally of the growth of negative potential of the cathode and decreased with increase of the diameter of the tube and with growth of duration of discharge process;

– volume of domains increased proportionally of growth of value of potential of negative polarity on the cathode; but the time of formation of domains was decreased and the velocity of their passage from the cathode increased (up to $\approx 6.59 \cdot 10^6$ ms^{-1}).

On the whole the experiments have shown too, that the periodic mode of the discharge was eliminated at switching-off of condensers; after that the usual stratified discharge of a constant current is observed. From here conclusion: the condensers connected to an output of a source, carry out a role of storage device of such quantity of a negative electrical charge, which provide its continuous and inseparable filling of such part of volume of rarefied gas of the discharge tube, at which the electrostatic field of the volumetric negative charge (which has appeared in rarefied gas) itself stops the further process of continuous filling of a negative charge in volume of gas inside of tube. This process can will be repeated only through an interval of the time necessary for continuous draining of the charge, which was entered into gas volume, through of the earthed electrode.

Is obvious, that the frequency of reiteration of this process in experiments, depends: 1) from an possibility of accumulation in condensers of the certain value of a charge (i.e. from value of potential on an output of the source and the value of electrical capacity of condensers connected to its output); 2) from pressure of gas in tube and from its volume: defined value of the charge of negative sign, which have of continuous spatial localization in rarefied gas of a tube requires, firstly, of the defined square of a surface of the potential electrode which participates in continuous filling of energy of electrical pulses in rarefied gas; secondly, is required the fixed volume for the opportunity of allocation of the defined value of the negative charge in rarefied gas which depends on its pressure and from its total volume i.e. from the sizes of the tube; 3) the moving of the volumetric negative charge in rarefied gas in a condition of its indissoluble, continuous spatial localization occurs by resistance on the part of molecules of gas, which results in its heating; 4) the electrical circuit of the earthed electrode should provide minimally possible time of continuous running-off of a volumetric negative charge on ground.

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Summary

The existence of a mode of periodic movement of the volumetric charge of a negative sign from an electrode with negative potential $\left(600-4500\ V\right)$ in the direction of other earthed electrode was discovered. The experiments were carried out with the discharge of a constant current in the presence of the pressure of air $\left(10^{-3}\div 10\right)$ Torr in tubes with various internal diameter ($3.8;\ 6.6;\ 15.5;\ 20.1;\ 25.8\ \text{mm}$), but with identical $\left(510\ \text{mm}\right)$ distance between electrodes. The opportunity of appearance of a mode of the periodic discharge was provided with connection to a potential output of a source of several condensers of large capacity (300 μF). Is supposed, that the discovered periodic mode of the gas discharge is similar to the Gann effect − movement of the volumetrically charge of a negative sign at volume of the semiconductor.