The acceleration of charged particles in plasma at the separation of charges

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Fast (suprathermal) charged particles were detected in the first experiments on thermonuclear fusion. Their existence was connected with the presence of an accelerating mechanism in plasma. The nuclear fusion in the Sun is realized also on base of the accelerating mechanism [1]. The mechanism of charged particles acceleration in plasma is associated with generation in plasma of electrical domains. The electric domains were first detected in solid-state semi-conductor plasma [2]. Later electric domains were detected in the plasma glow discharge [3] and in the cathode plasma in a magnetically insulated diode of the electron accelerator [4]. Here and hereinafter under the electric domain implied the quasi-neutral in whole system which consists of a region (layer) with surplus negative charge and a region (layers) with surplus positive charge. The distance between these two regions (layers) of the electric domain exceeds the Debye screening length. Generation of the domain in plasma current tube is equivalent to the transformation of an element with an ohmic character of the impedance in the element with capacitive character. The law of changing of charge in time on the plasma "capacitor" plates (layers) is defined by the next expression [4]

$$q(t) = q_0 \exp(-t/\tau), \quad (1)$$

in which τ is characteristic time of charges separation. It determined by the Maxwell relaxation time [5]

$$\tau_M = \frac{\varepsilon}{4\pi e n \mu_e} \quad (2)$$

where ε is a dielectric permittivity and μ_e is a mobility of electrons. It is proportional to the inverse value refined frequency of space-charge waves, defined by [6]

$$\omega_{wsc} = \omega_{pe} - \frac{\omega_{pe}^2}{12\pi\sigma_d} i \quad (3)$$

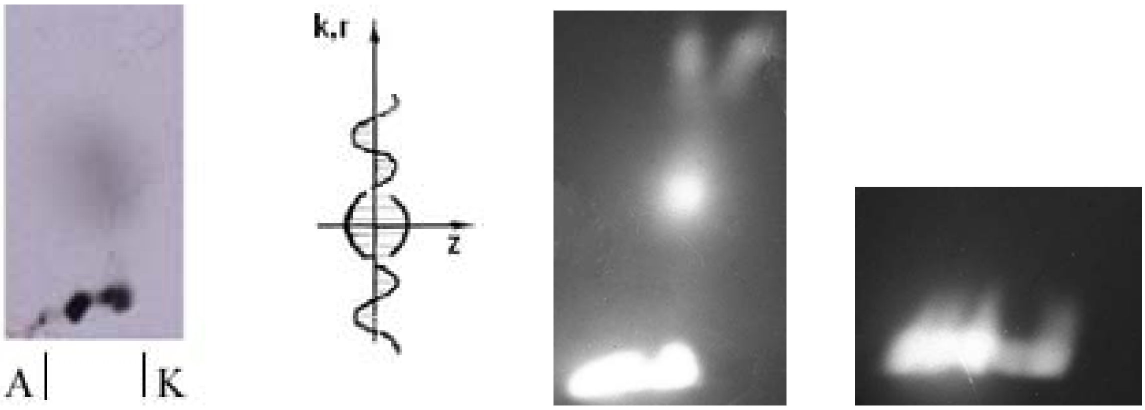
where ω_{pe} is frequency of Langmuir oscillations and σ_d is differential conductivity. Between the regions of the electric domain is always set a strong electric field even for small voltages due to the smallness distance between the regions [7]. The origin of the electric domains in the plasma occurs due to the inequality of electron and ion directional drift flows and is accompanied by the generation of transverse electromagnetic waves [6]. The expression for the frequency of these waves can be written as

$$\omega_{shf}^2 = k^2c^2 + \left(\omega_{pe} - \frac{\omega_{pe}^2}{12\pi\sigma_d}i\right)^2 \tag{4}$$

The presence of a strong field in the area of electrical domain and the generation of a transverse electromagnetic wave during its origin allows to accelerate the particles located between the layers of the electrical domain, and particles near it – as a result of their capture by electromagnetic wave. The displacement of a small group of particles at a distance greater than the Debye screening length leads to a significant potential difference between the layers of the electrical domain. Electrons and ions are formed of the neutral atoms due to the high electric field with intensity exceeding the limit value for the appearance of ionization. The electric domain appears at breakdown in the electrical discharge at high values of derivative of applied voltage dU_{ap}/dt due to the fact that the electron mobility is much higher than the ion mobility ($\mu_e >> \mu_i$). To comply with a phase-matching condition requires that the particle velocity is close to the phase velocity of electromagnetic waves. Value of voltage on the domain are sufficient to ensure that the electrons have a velocity. The particles accelerated in the area of domain by field receive an additional acceleration by means of the transverse electromagnetic wave which generated at the separation of charges. The equation of motion in general form for the charged particles in a homogeneous field of a plane electromagnetic wave is [8]

$$\frac{d\left(m_\alpha \vec{u}_\alpha\right)}{dt} = q_\alpha\left(\vec{E}_z + \frac{\vec{u}_\alpha \times \vec{B}_z}{c}\right), \tag{5}$$

in which: α - a sort of particles, q - its charge, $\vec{E}_z$ and $\vec{B}_y$ - components of the electric and magnetic fields $\left(\vec{E}_z = E_0 e^{i(\omega t+kz)}, \vec{B}_y = B_0 e^{i(\omega t+ky)}\right)$. The charged particles in the field of electromagnetic wave acquire an energy that is significantly higher than the value that corresponds to the applied voltage. The value of acquired energy depends on the values of intensity and induction of fields and time of particles interaction with the wave. Electrical domain performs functions of built-in plasma of microaccelerator of charged particles. Received by the author at the breakdown near surface of a dielectric images of luminosity of plasma are given in Fig. 1. By means of microwave radiation there occurs fast electrons and ions generation. It takes place in the direction which approximately perpendicular to the axis of a discharge cell and dielectric plane.



a **b** **c** **d**

Fig.1. Optical image of luminosity in an initial stage of breakdown –**a**; the qualitative structure generated under origin of the domain of a transversal electromagnetic waves (show only intensity of electrical field)- **b**; luminosity in near-electrode area with secondary V-type formation **– c** and optical image when the flat domain passes between electrodes under breakdown in initial moment of time - **d.** Designations: A-anode, K-cathode, k-wave vector.

The generation of fast particles in the near-electrode space occurs at the moments of time, when the intensity of luminosity grows in the area of electrical domain– see Fig.1(d). The electrical domain moves from the one electrode to the other. The increase of intensity of luminosity is correlated with an increase of applied voltage in the gap. The mechanism of acceleration of charged particles, which is based on the generation of electrical domains, implemented also in the magnetically-insulated diodes with a virtual cathode - vircators. The acceleration of charged particles in plasma on base of electric domain is more efficient than the acceleration on base of laser-plasma interaction. This is due to very low efficiency output of lasers.

References

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