DYNAMICS OF MICRO PLASMA FOCUS FORMATION IN VACUUM-SPARK DISCHARGES

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Abstract

The results of 2D computer simulation of micro plasma focus formation during low voltage vacuum discharges induced by picosecond laser beams are represented. This processes are accompanied by matter transition into extreme states (with maximum pressures about of 100-200 Mbar and specific internal energies up to few $10^,$s MJ/g) and X-ray radiation generation.

1. Introduction

As at first it had been predicted and shown in computer simulation [1-4], the X-ray radiation can take place in laser-induced vacuum discharges under comparatively small applied voltages. Recently it was confirmed in natural physical experiments [5]. The soft X-ray radiation is generated due to overheating instability on nonlinear stage of cathode torch evolution, after the "shooting solitons" generation [1-4]. The hard X-ray radiation can be generated in result of plasma interruption near the anode region (as well as in plasma focus system [6]), when in micro volumes of plasma torch   the electrical potential reaches a high values (few kV and more higher [2]).

In this paper some new results of matter transition into extreme states during vacuum discharges under comparatively small applied voltages about of 150 V (accompanied by X-ray radiation) are represented. A mathematical model of vacuum breakdown induced   by picosecond laser beam (with the same parameters as in experiments [5]) in the presence of electric fields is based on the 2-D electro-hydrodynamic and heat transfer equations [7,8], including self-consistent calculations of the electric field and current distributions. The system of hydrodynamic equations was solved by using method of „big particles" [9] and completed by equations of state in a wide range [10]. The calculation of heat transfer were produced by using method [11] (with taken into account radiative heat transfer and cooling, electron emissive energy loss on the boundary of hot matter). Thermal and electrical conductivity were calculated by using model [12] including effects of strongly coupled plasma, as well as an empirical formula [13] for solid and liquid copper.

2. Discussion

Computer simulations have been carried out for the following conditions of experiments [6]: applied voltage $U_0 = 150$ V , active resistance of external circuit Rc = 0.03-150 Ω , inductance

L = 0-150 nH and electrode gap distances D_g = 50-150 μm. The initial temperature T_0 of hot spot (with thickness about of 6 μm and diameter 40 μm) has been varied from 3 eV to 20 eV, depending on the intensity of heating laser beam. It should be noted, that in the peak of laser intensity the electron temperature of laser-produced plasma can exceed a few hundreds eV . Nevertheless, at the end of the laser pulse the temperature of hot spot reduces to mentioned above value owing to the radiating of absorbed energy and electron-ion relaxation in the dense plasma. As well as in [8] the doubly calculations have been produced : one time without taken into account the Child-Langmuir current density limitation and another - with them. In both represented here cases the calculations were produced for U_0 =150 V, T_0=20 eV, D_g = 50 μm, R_c =0.03 Ω, L=0 nH. Let us consider the first case (namely in this case we have earlier [4] the best agreement with experiments). The most interesting results of present calculation are: the formation of micro plasma focus (MPF) under contact collapse, the generation of extreme states of matter and X-ray radiation, which are confirmed by experiments [5]. The main plasma parameters for the time t=2.0 ns are represented in Fig.1-3. As it has been observed for t> 2.0 ns the formation of MPF takes place when cathode plasma torch riches the anode. In the contact point-like region near the anode the decreasing of plasma density (but not mass density, see Fig.1a and Fig.2a), temperature (Fig.1 b) and conductivity (due to the phase transition from the metal to the non-ideal plasma) and increasing of electric potential (Fi.g.3a) take place. Then in the periphery of plasma torch the temperatures and pressures are sharply growth due to current self-focusing (Fig.3 b), which usually is preceded before the overheating instability [4,8]. We have a fine picture (Fig.4 a) at time t=2.05 ns, when two propagated in opposite direction shock waves have a hemisphere-like forms, and later the maximum pressure riches up to 200 Mbar (Fig.4 b). Such processes can be repeated a few times during vacuum discharge [4,8]. Then logically we can anticipate that generation a set of short (10- 100 ps) pulses of X-ray emission must take place from considered discharge, because of the current self-focusing and overheating processes are ultra fast processes and have aperiodic character. Note, that in considered case the mean temperature equals to 5 eV, but the maximum temperature reaches up to 5 keV.
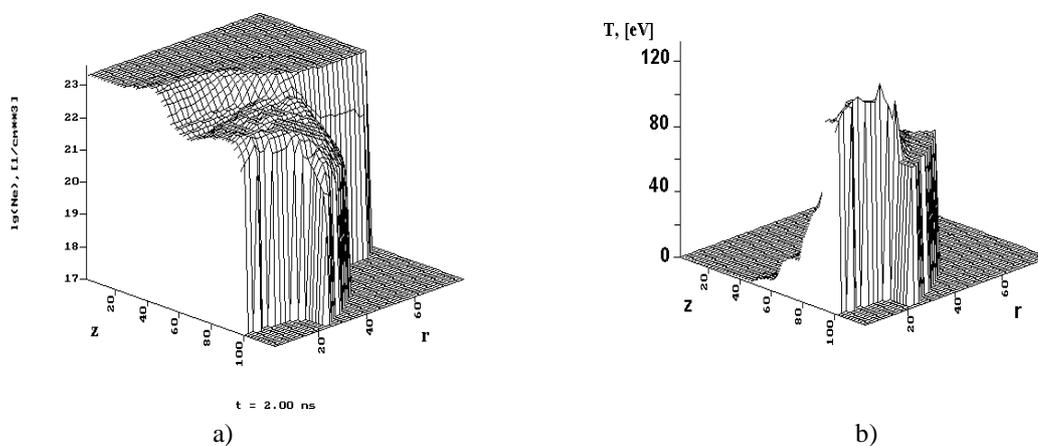

Fig. 1: The spatial distribution of plasma density (a) and temperature (b) at t = 2.0 ns. Cathode is located at 0≤**z**≤70 μm, anode (not shown)- at **z** ≥120μm.

a)   b)

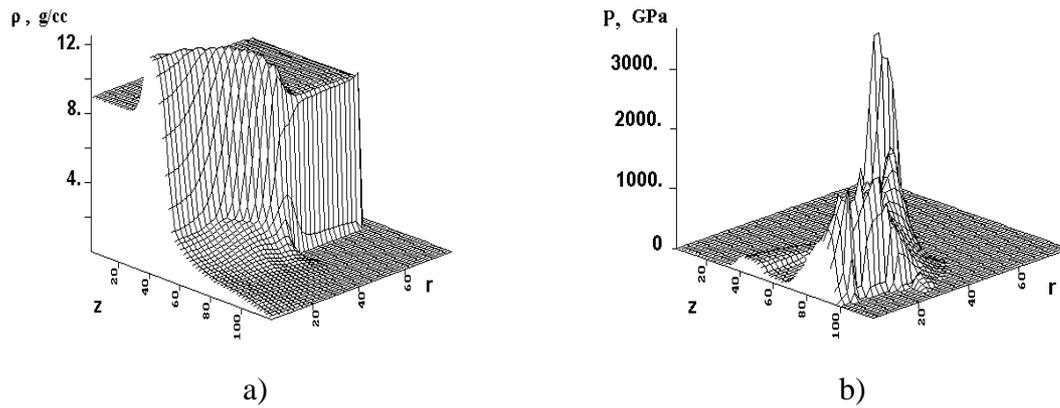**Fig. 2:** The spatial distribution of mass density (a) and pressure (b) of matter at t = 2.0 ns.
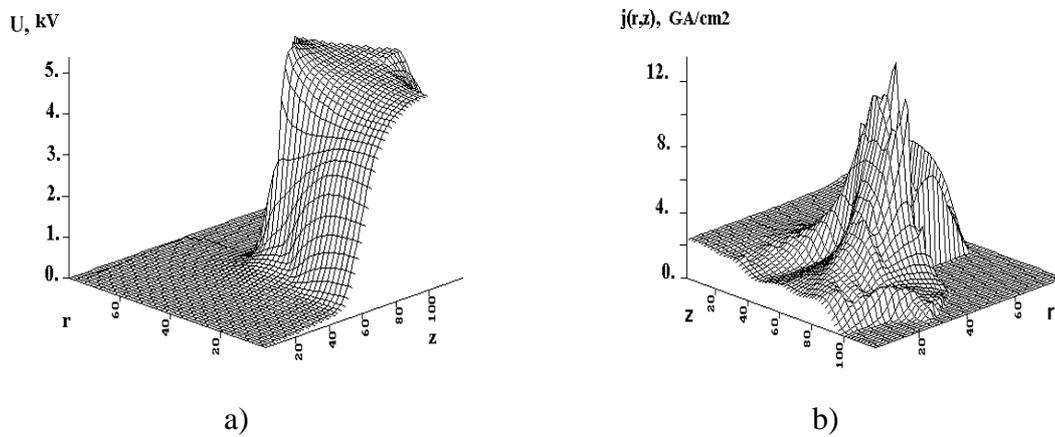

a)   b)

Fig. 3: Spatial distribution of electric potential in plasma torch a) & current density b) at t=2. ns.

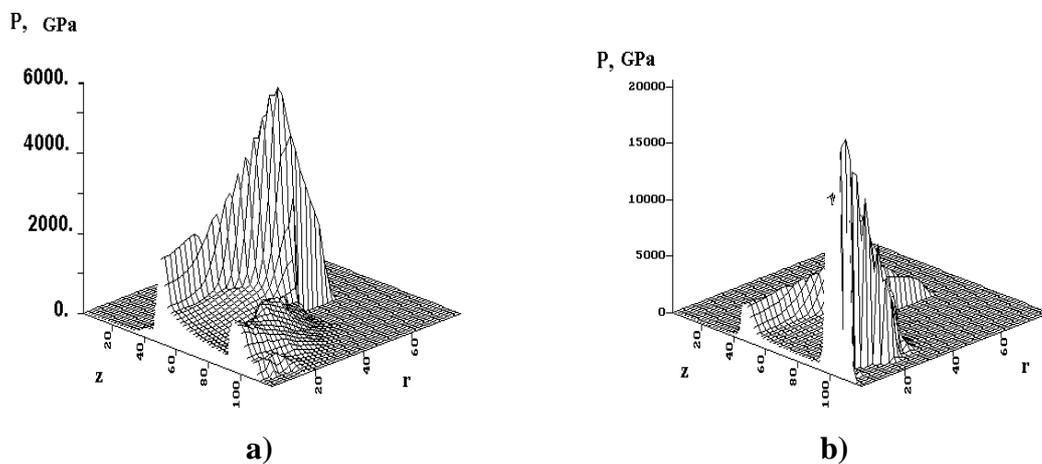**a)**   **b)**

Fig. 4: The spatial distribution of pressure at t = 2.05 ns -(a) and 2.075 ns - (b).

In comparison with the considered above situation, in a case of computer simulation with taken into account a Child-Langmuir's current limitation, it has been shown that analogous processes take place (see, for example, Fig. 5), but only with some time delay at the arc stage (when such limitation losses its sense). Fig. 5 shows the plasma temperature at the different times. As it is seen from these figures, the ring-like wave of heating propagates with high velocity (up to 100-200 km/s). This wave transforms from one micro ring to two ones (or to a few hot micro points at other times). So we have very complicated nonlinear

phenomena - „contact collapse" (just as radiative collapse), when a micro- plasma focus formation takes place (see additional results and discussions in [14,15]).
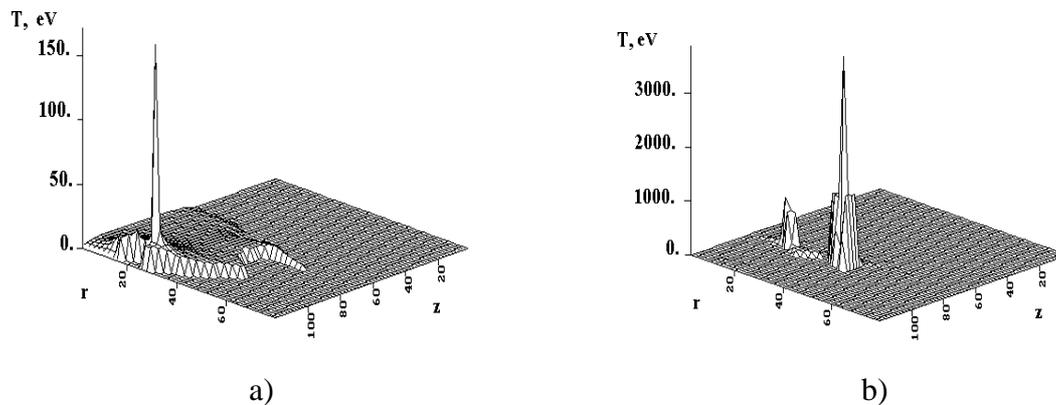

a)   b)

Fig. 5: The spatial distribution of the temperatures at t= 2.925 ns -a), t=3.025 ns - b).

Acknowledgement

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