*31st EPS Conference on Plasma Phys. London, 28 June - 2 July 2004 ECA Vol.**28G**, P-5.001 (2004)*

# Physics of a point-like x-ray sources based on micro-plasma focus systems

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The results of experimental and theoretical investigation of a new type of pulsed point-like sources of the X-ray radiation based on micro-plasma focus system in laser-induced discharges at applied voltages $U_0 \leq 1.7$ kV are considered.

## Introduction

This is a continuation of our experimental and theoretical investigations [1-3] of a new type of pulsed point-like sources of soft and hard X-ray radiation, which are based on a dense micro-plasma focus systems created in laser-induced discharges. Here we consider concrete case of discharge induced by picosecond laser beam under applied voltage $U_0$= 1.7 kV (note, that as a theory predicts [3] an analogous physical effects can take place under low applied voltages down to $U_0$= 12 V). An unique experimental device RFR-4 [4] had been used in our work for X-ray diagnostics with high spatial (~ 2 μm) and temporal (30 ps) resolutions and in computer simulation a mathematical model, detailed described in [5]. A mathematical model of vacuum breakdown induced by picosecond laser beam (with the same parameters as in experiments [1,2]) in the presence of electric fields is based on the 2-D (in r-z geometry) electro-hydrodynamic and heat transfer equations, with taken into account an electron emissive processes and radiation transfer, including self-consistent calculation of the electric field and current distributions. The system of hydrodynamic equations was solved by using method of “big particles” , completed by equations of state in a wide range and semi-empirical relationships for thermal and electric conductivity calculations (including states of strongly coupled plasmas).

Computer simulations have been carried out for the following conditions: applied voltage $U_0$=1.7 kV, an inter-electrode gap distance Dg=50 μm, the initial temperature of hot spot in cathode $T_0$= 20 eV, in all other parts of copper electrodes the initial temperature equals to the room temperature under low inductance L≈ 0, for two cases of active resistance of external circuit **a**): $R_c$ = 0.03 Ω and **b**) $R_c$ = 50 Ω. We also consider cases: **c**): $R_c$ = 0.03 Ω and **d**): $R_c$ = 50 Ω for $T_0$= 10 eV. In this report a normal dynamics of cathode torches as well as ultra-fast nonlinear processes connected with the micro plasma focus formation will be considered. Here we can shortly consider some peculiarities only. The evolution of main matter parameters for all cases are presented in Fig.1-4. In the cases (**a**, **c**) of low resistance (at mode of the shorting) the initial energy input is shorter then in cases (**b**, **d**) of 50 Ω. It is connected with the more high current densities in case **a** in comparison with the case **b** (and in case **c** then in **d**). The one of the interesting peculiarity is the formation of micro plasma focus near the (grid-like) anode in laser induced discharge due to nonlinear phenomenon - a contact collapse [6] when an increasing of current density, specific internal energy, mean ion charge and etc. take place (see, e.g., Fig.1). The another ultrafast non-linear phenomenon in laser-induced discharge is the "shooting solitons" generation [7] which also is accompanied by matter transition into extreme states with a high temperatures, pressures, a multiple ionisation and etc. (see, Fig.2-4, for case "**b**"). It is interesting to note that only in case "**b**" we have a spark stage of vacuum discharge with such high pressures (up to 40 Mbar but for very small time $\tau \approx 10$ ps). Our computer simulation shows that the lifetimes of hot spots are very short ($\tau \approx$ 10-50 ps), but the pulse duration of X-ray radiation can be greater owing to the definite time of radiation process and due to the fact, that one pulse of X-ray radiation can be produced from a few point-like hot spots. Usually, the electric potentials in all cases (**a**- **d**) have a typical values of 1-100 V, but owing to plasma disruption (for example, due to decreasing conductivity in strongly coupled plasmas [6-7]) the electric potentials can growth up to hundred kV(see Fig. 4). This process must be accompanying by a hard X-ray radiation. The analogous situation occurs for all considered cases, but also for a short times. We have only high voltage bursts on the comparatively small potential distribution. For case "d" we also have a multiple charged ions creation in micro volume of hot plasma for a short period. This process must be accompanying by a line hard X-ray radiation generation. At later time for this case we have not peaks in spatial distributions of electrical potential and temperature. But on the arc stage of such discharges the mentioned above ultrafast non-linear phenomena can take place again. So, the matter transition into extreme states and the short pulse X-ray radiation occurs in non-periodic mode on the background of "usual" dynamics of vacuum sparks or arcs.

An experimental investigations confirm a theoretical results. Figure 5 shows temporal evolution of x-ray radiation in spectral range of 200eV -10 keV for laser-induced spark discharge with a gap distance of 50 μm and applied voltage of 1.7 kV.

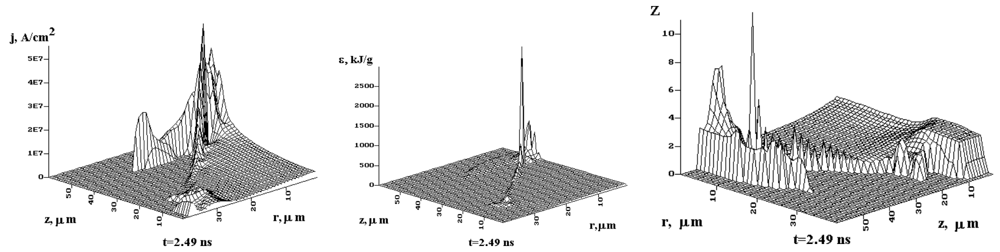



Fig.1.The amplitude of current density **j**(r,z) , specific internal energy ε, and mean ion charge Z at t = 2.49 ns (case **c)**.

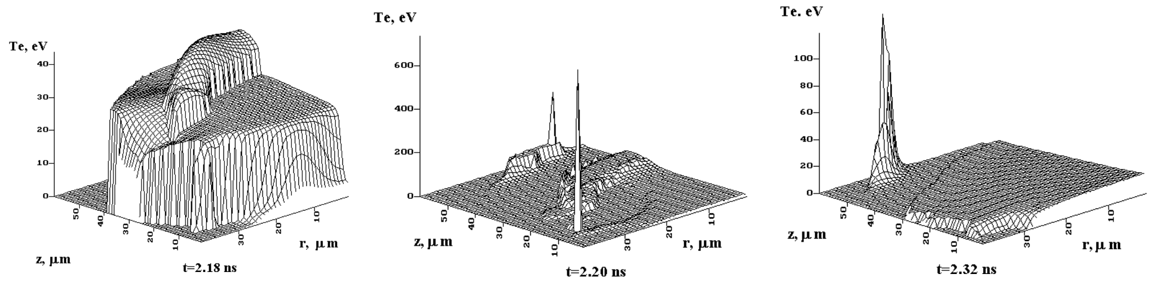



Fig.2. The electron temperature in plasma for different times, case **b**.

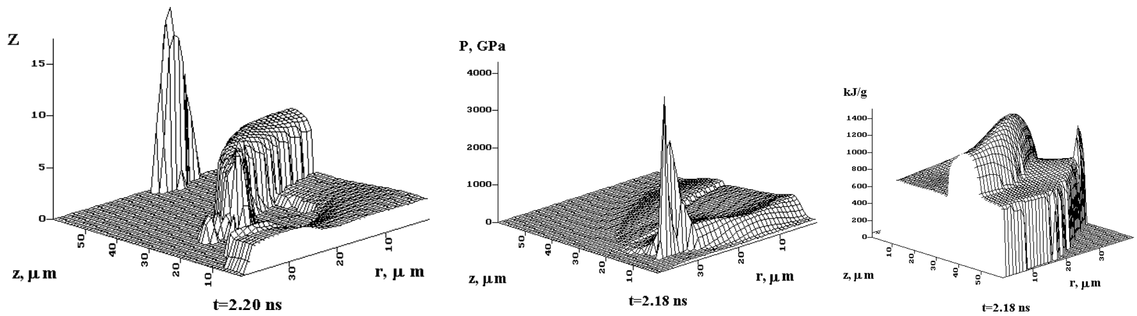



Fig.3. The spatial distribution of mean ion charge Z at t = 2.20 ns , pressure P and specific internal energy ε at t = 2.18 ns.

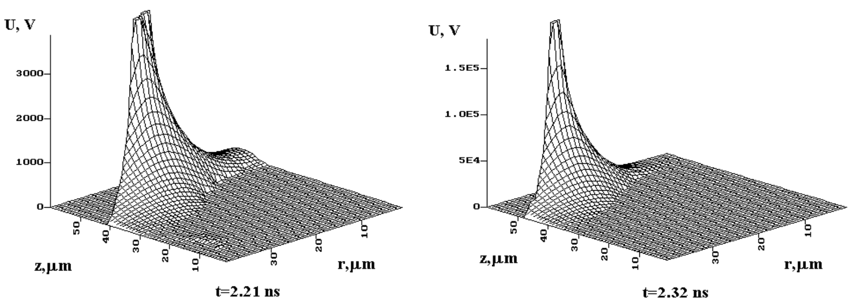
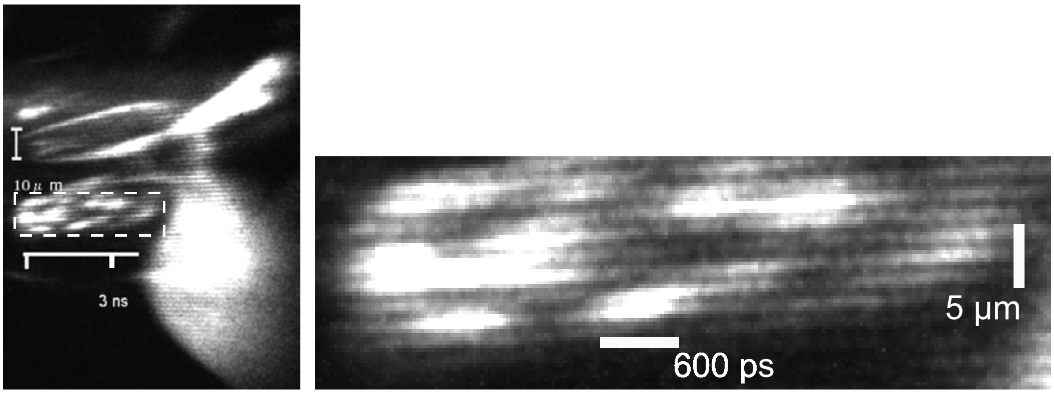



Fig.4. The electric potentials U(r,z) for different times, case **b**.

**Summary**

The most interesting results of present investigation are: a creation of an extreme states of matter - increasing of pressures up to 40 Mbar and specific internal energy up to $\varepsilon \approx 2.5$ MJ/g during a short times of $\tau \leq$ 10-30 ps in laser- induced discharge under applied voltage of




a): b).

Fig. 5 A streak picture of x-ray emission of laser-induced vacuum discharge with a voltage of U = 1.7 kV. Delay time t = + 9.63 ns. Arc current I = 34 A. b) - Magnified detail from the streak picture marked by a broken line

U = 1.7 kV in case of "**b**". With an initial temperature of hot spot of 20 eV and an active resistance of 50 Ω in all four considered cases it is possible to generate a soft X-ray radiation owing to shooting solitons generations and overheating instability, as well as a hard X-ray radiation due to initiation of a peaks of electrical potentials in plasma torch. It is established a possibility of line X-ray radiation generation from a multple charged ions created in considered micro plasma focus system at different conditions (for all **a,b,c,d** –cases). At a lower applied voltages (for example, under $U_0 \sim 12$ V) the described above ultrafast nonlinear phenomena take place in a mode of the shorting only.

The work was supported by INTAS project (Nr. 03-56-172).

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