The Electro-Discharge Implosion

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Abstract – The explosional transfer of electromagnetic energy flux directed in the deep of metallic target (cathode) is numerically investigated. This energy flux is initiated by electroexplosion of micro hot spot or tip on the metallic surface. The perspectives of such physical phenomena applications in miniature thermonuclear systems as well as for creation of pulse sources of X-ray radiation and neutron flux are discussed too.

1. Introduction

It is known a few implosional schemes with using different high energy densities flows [1–3]. Here we consider a new possibility of high energy density concentration due to micro electrical explosion directed in internal region of metallic target (copper cathode) on the surface of which takes place the immediately heated (for example, by femtosecond laser beam) hot spot. It is demonstrated that matter transition into extreme states in micro volume of such electro-discharge system occurs under comparatively low applied voltage ($U \sim 240$ V, in case of laser-induced plasma) or in system with micro tip (with height $h \sim 20$ μm, and for a small interelectrode gap distance $L \sim 60$ μm, at which applied pulse of extremely high voltages with voltage growth $G = \mathrm{d}U/\mathrm{d}t \leq 1$ MV/ns). It is shown that in this microsystems an electron and ion temperatures reaches up to 0.5–1 keV, the total pressures increases to 10's–100's Mbar, the inductance of magnetic fields $B \sim 1$–30 MG in the thin layers ($L \leq 20$–100 μm) on the cathode surface. The same radiative 2 D MHD computer code had been used as well as in [4, 5].

2. Mathematical Model

The numerical simulation are performed by using the mathematical model which is based on system of the 2-D axisymmetrical magnitohydrodynamic (MHD), radiative and heat transfer equations. The system of MHD equations was completed by a wide-range two-temperature equation of state which includes effects of an electron degeneration. Thermal and electrical conductivity's were calculated by using semi empirical relationships for real matter (copper in a wide range of densities and temperatures), with taken into account effects of magnetic fields influences as well as properties of strongly coupled plasmas. The discrete model is implemented on the base of implicit full conservative finite-difference scheme corresponding the difference system of MHD equation and used the technique of adaptive grid. The algorithm for solution the system of finite-difference equations derived a few groups of equations depending on physical processes. There are motion, energy, electro-magnetic field groups. Every group of equations is solved by means of Newton-like iteration procedure. The energy balance calculation was carried out for the convergence control during the solving of the discrete MHD equations. The non-equidistant difference moving grid and two-temperatures approximation had been used.

3. Electroexplosion of Cathode Hot Spot

Let us propose that on the surface of copper cathode there exist a hot spot (produced instantaneously, for example, by intense fs-laser pulse). Its initial electron and ion temperatures (at $t = 0$)

$$T_e = T_i = T_0 \exp\{-[r/r_0]^2 - [(z - z_0)/z_0]^2\}, \quad (1)$$

where $T_0 = 20$ eV, $r_0 = 20$ μm, $z_0 = 6$ μm. The dimensions of calculated area are: $0 \leq r \leq 200$ μm, $L = 100$ μm, $0 \leq z \leq 200$ μm. The length of vacuum gap equals to 100 μm and applied voltage $U_0 = \text{const} = 240$ V. The voltages at time t are defined by equation

$$U(t) = U_0 - RI - L_c\, \mathrm{d}I/dt, \quad (2)$$

where $I = \int j\mathrm{d}S$ – total current (j – current density), $R = 0.03$ Ohm – active resistance of external circuit, and $L_c = 1$ nH – its inductance. The results of computer calculations for this case are represented in Figs. 1–5.

4. Electroexplosion of Cathode Micro Tip

Another means of electro-discharge implosion can be associated with the high voltage breakdown. Namely, if in small interelectrode gap (with $L = 60$ μm) we have micro tip with height $h = 20$ (see, e.g., Fig. 6) at which electric voltage U_0 increases with time as $U_0(t) = G\ t$, where $G = \text{const} = 1$ MV/ns (in this case $L_c = 1$ nH, $R = 3$ Ohm, but in ideal it is better to have $L_c \to 0$ and $R \to 0$, the case of shorting) we can have an unique possibility to obtain at moment of time $t = 210$ ps (when $U \sim 100$ kV, see, e.g., Figs 7–9) the physical conditions (high temperatures $T_e \approx T_i \approx 1$ keV, high pressures P~ 80 Mbar, and magnetic fields inductance $B \sim 2$ MG) in the region of high density DT-mixture ($\rho \approx 0.2$ g/cc with ambient copper compressed by internal shockwave anvil $\rho \approx 22$ g/cc). It is obvious we will have in this conditions the initiation of thermonuclear reaction and neutron generation. In present computer simulation the maximum of neutron flux riches $7 \cdot 10^9$ neutrons/s·cm^2 at the time $t \approx 200$ ps, but this only the first moments of time. What will we have after 210 ps? There are two possibility: the increasing of neutron flux due to micro thermonuclear explosion, or continue of neutron flux decreasing up to zero owing to plasma expansion and cooling considered systems. It will be interesting to verify such "simple" scheme in experiments. But, if in a case of "hot spot" everything is clear with the considered electrodischarge implosion accompanied by matter transition into extreme states, in a case of a cathode micro tip it is not clear what is a better way to initiate an electric pulse with such large value of G in practice. This computer simulation has been performed (7 years ago) before computer simulation of super high power thermonuclear detonation and explosion in neutron stars [5], which takes place in Nature. May be the considered here physics will be also useful for basic research and practical applications.

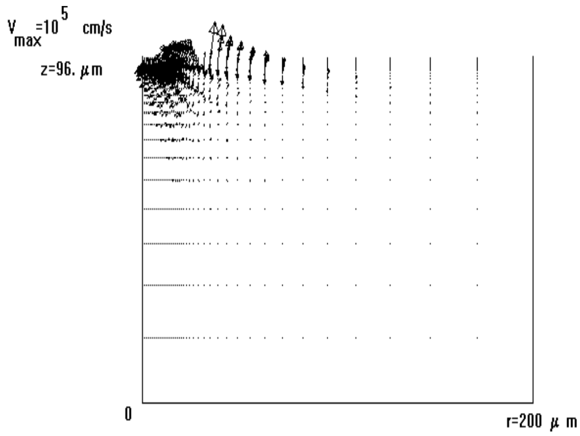


Fig. 1. The field of velocities at t = 11.85 ps

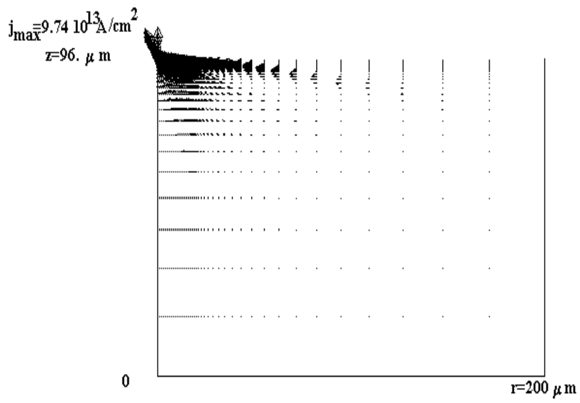


Fig. 2. The current density at t = 11.85 ps

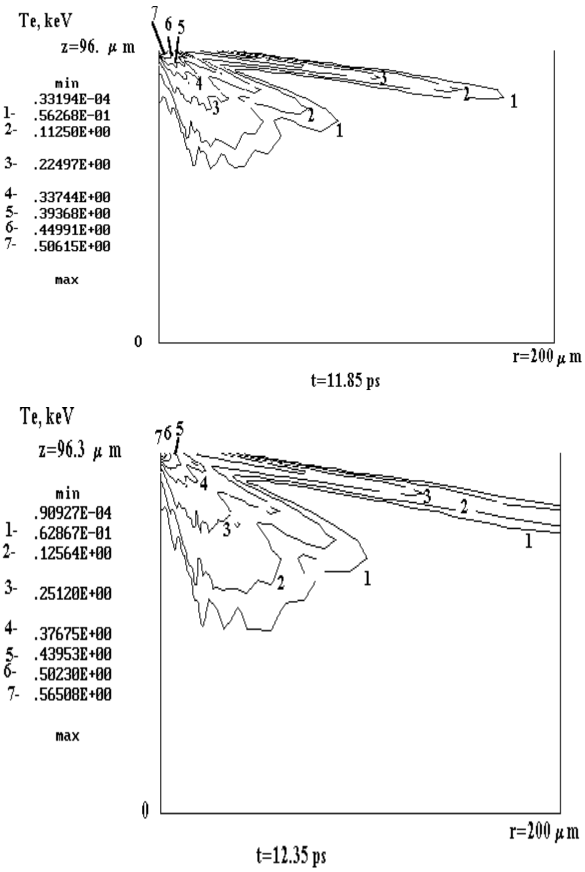


Fig. 3. The spatial distribution of electron temperatures for different times (11.85 and 12.35 ps)

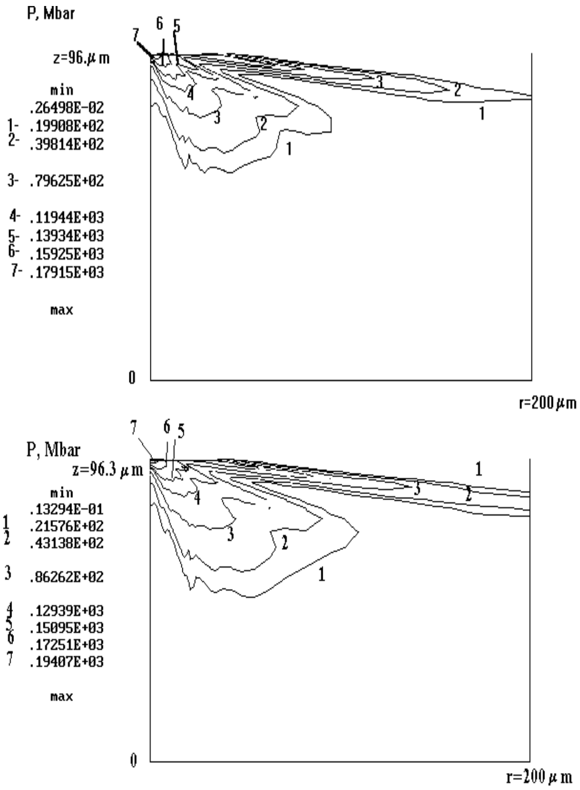
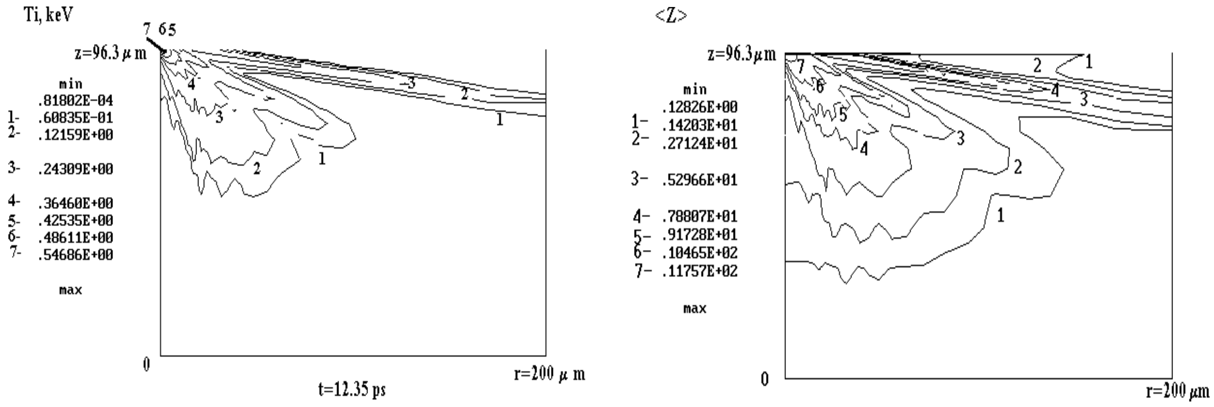


Fig. 4. The spatial distributions of total presser in matter at t = 11.85, 12.35 ps



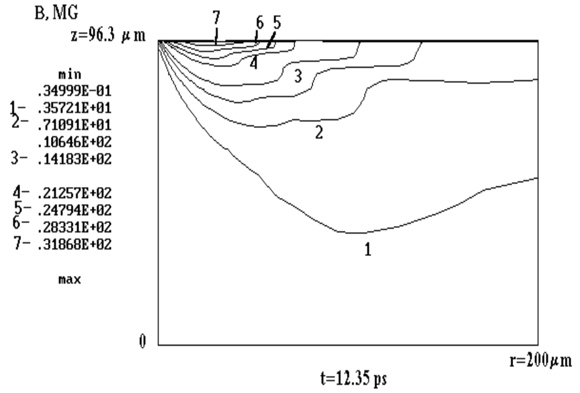
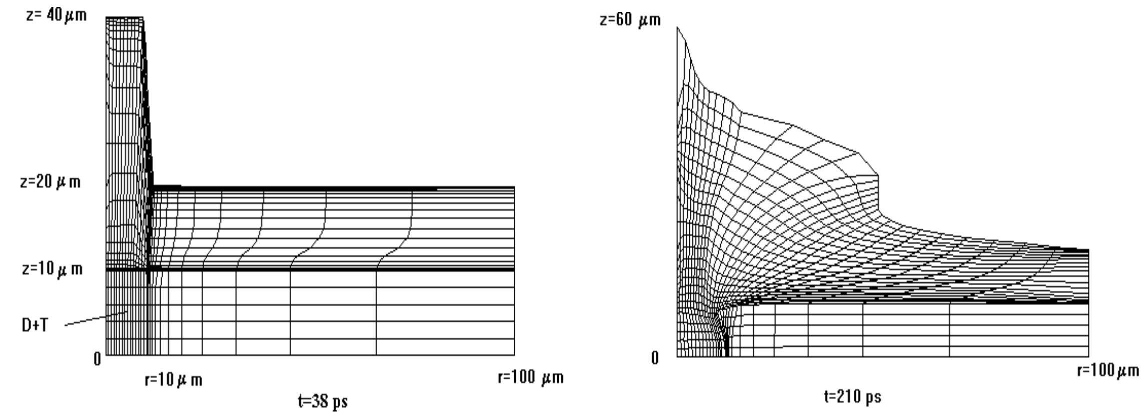


Fig. 5. The spatial distribution of ion temperature, ratio of ionization $<Z>$, and inductance of magnetic field B at t = 12.35 ps



a b

Fig. 6. The calculational grid for t = 38 ps (a) and t = 210 ps (b)

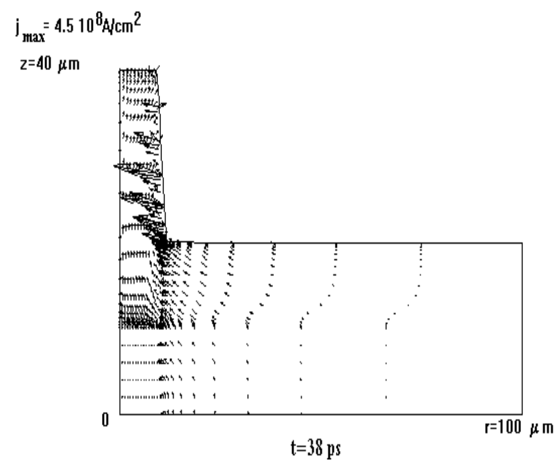


Fig. 7. The current density at t = 38 ps

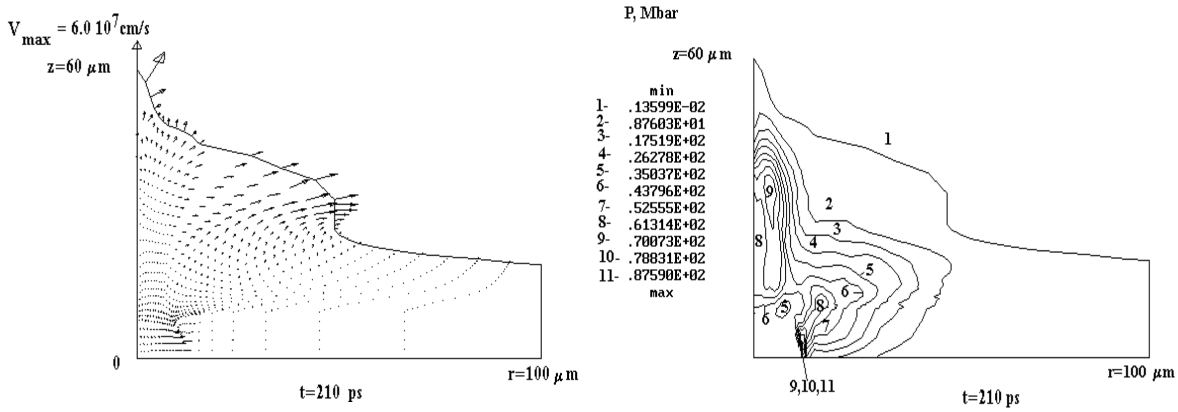


Fig. 8. The field of velocities and pressures at $t = 210$ ps

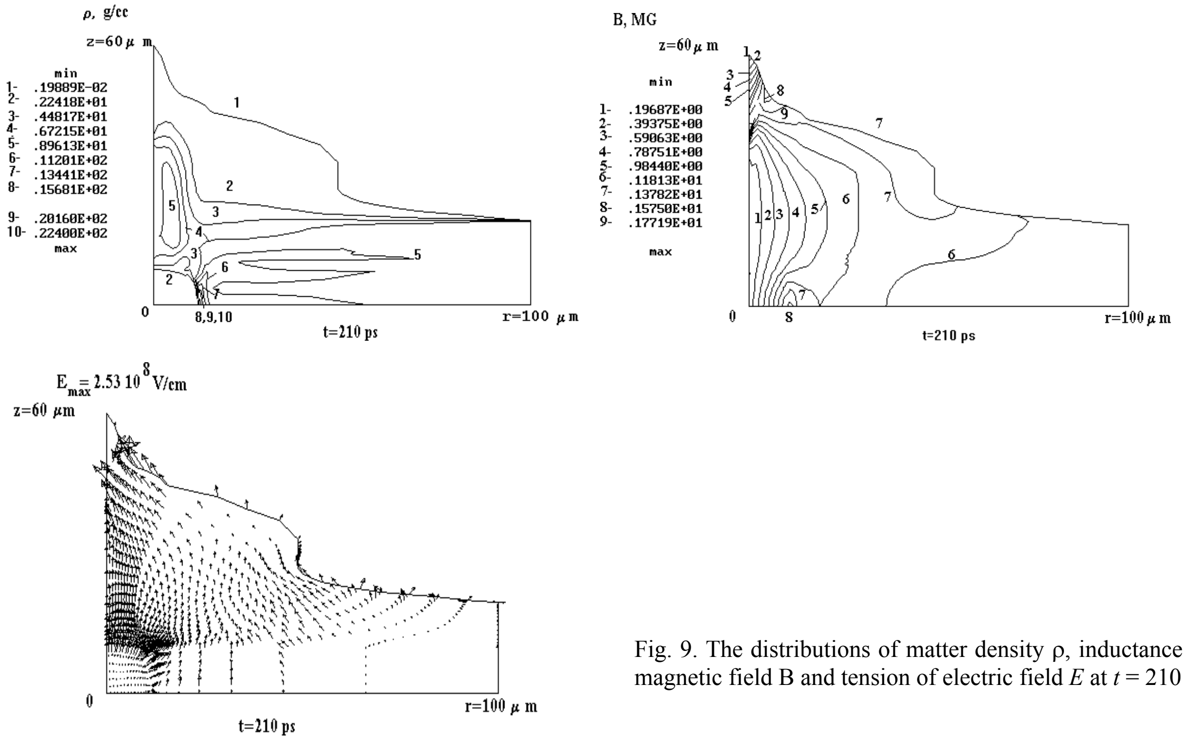


Fig. 9. The distributions of matter density ρ, inductance of magnetic field B and tension of electric field E at $t = 210$ ps

References

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