# THE GENERATION OF HIGH-POWER CHARGE PARTICLE MICRO BEAMS AND ITS INTERACTION WITH CONDENSED MATTER

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**Abstract**

As it was observed in experiment [1], during enfluence picosecond laser beam on the Al-target in air a generation and acceleration of high-power micro electron and ion beams take place. The original theoretical model for describing of generation and particle acceleration of such micro beams in result of micro channeling effect are represented. It had been established, that the extreme states of matter with compression in Gbar pressure range can be produced by such micro beams.

**Introduction**

As at first was established in [1] during interaction of high- intensity picosecond laser beam with aluminum target in air an effect of micro-channeling with the generation of an intense electron beam ( with the particle density of about $6 \times 10^{20}$. $cm^{-3}$ ) and following extracting and acceleration (up to few MeV) of an intense (with maximum current density $j_0$= 4 $10^8$ $A/cm^2$ ) ion beam appears. For explanation of this phenomena we took into account the possibilities of electron beam focusing and acceleration by pondermotive force of ultra short laser pulse [2]. In contrast to [3] we propose, that the mechanism of ion acceleration is connected with three phenomena, which take place simultaneously :

- the microchanneling of directed energy flows (electron, laser and ion beams);
- the collective acceleration of heavy ions by the wave of space charge of electron beam, which initially generated by laser beam;
- the ion acceleration by magnetic field of electron beam (due to Fermi acceleration), which at initial stage has a tubular form, so the during magnetic field compression the ions can have an additional acceleration like as in plasma layer system [4] or in plasma focus system [5,6].

Perhaps the mechanism of charged particle beams in our case is also due to an azimutal instability of tubular current carrying plasma [7].

Note that such micro beams of heavy ions may be used for generation of a short pulse of neutron flux and for initiation of controlled thermonuclear fusion in micro volume of gold target with D-T mixture [8]. This paper is a continuation of mentioned above work and deals with an experimental and theoretical investigation of high-power ion beams generation and its interaction with condensed matter (gold targets). The computer simulation of micro ion beams (with pulse duration $\tau$=100 ps, current density 400 MA/cm2, diameter of beam 5 $\mu$m) interaction with a condensed matter was produced by using mathematical model [9,10], in result of which it is predicted that the extreme states of matter with compression in Gbar pressure range accur.

**The generation and acceleration of micro beams**

In result of analysis of different possible mechanism of charged particle acceleration [2-7] we conclude that none of them has a single operation in our case. Probably some of them combination takes place. Especially greate interest for our opinion has theoretical model [7], because of namely the tubular plasma jet generation takes place (see Fig.1) at initial stage as it was established in experiments with a good repetitions. Unfortunately, in [7] a simplest case of dynamic particle acceleration in tubular uncompressive plasma jet with fixed boundary was considered and hence we can not directly use this model.

We think that the observed acceleration of intense charged particle beams may be explained by the following scheme: 1) selffocusing laser beam and production channel of hot air with small diameter (about of 10 μm) for transportation of electrons, which are extracted from Al-plate; 2) the generation, acceleration (by pondermotive force of laser wave) and transportation a high intense electron beam in such channel; 3) the collective (by space charge of electrons) and Fermi like acceleration of Al-ions.

The measurement of magnetic field by using Faraday effect shows that the induction of mangetic field may reach the values up to 7.6 MG, and tension of electric field - $10^8$ V/cm. So due to this fields the AL-ions (with mean charge Z=4) can accelerates up to 8 MeV.

At the later stage the electron current can return back (see Fig.2, at which two electron flows moving in opposite directions are shown). In this experiments the laser probe pulse was with $\lambda$=532 nm. For our estimation the ion acceleration take place during approximately 100 ps. So let us consider the dynamics namely ion micro beams with matter. For this purpose we produce the next computer simulation.

**The interaction of heavy ion micro beams with matter**

We used the mathematical model, which is based on the system of two-dimensional hydrodynamic equations (in r-z -geometry) and is complemented by wide-range equations of state (analogous as in [10]), corresponding correlations for the calculation of beam energy loss in the matter (with taking into account the dependence of stopping power on the temperature). The hydrodynamic equations were integrated on a rectangular region by the big particles method [11] of the first degree of approximation on time and space. The energy loss by radiation and energy input due to thermonuclear reaction (in a corresponding cases of D-T targets) were taken into account . Equations of energy and number of particles (D,T, $^3$He ,$^4$He , protons and neutrons) balance of thermonuclear reactions were solved with taking into account the present-day information about cross-section and rate coefficients of the resonance thermonuclear reactions [12]. In our calculations we varied parameters ($E_0$, $j_0$ ,$\tau$) of heavy ion beam (Al-ions, at $1.6 10^{12}$-$3 10^{16}$ W/cm$^2$) and targets as well as material of target and percentage of D:T. But now we consider mainly the case when the maximum current density of ion beam was equal 4 $10^5$ A/cm$^2$ (such current density may be easy obtained in experiment ).In these examples ion beams are uniform cylindrical beams with the parabolic pulse time form: $j(t)=j_0\,(t/\tau)[1-(t/\tau)]$ for $t<\tau$, and $j(t)=0$ for $t>\tau=100$ ps . The total energy $E_t$ of such beam is $j_0E_0\tau\pi d_s^2/24$ and equals 0.00002 J . Note, that the energy of laser pulse was about of 0.06 J. So in this a case may be realized if only 0.03 % of laser beam energy is transferred to ion beam.. Some spatial distribution of the main matter parameters for the time t=1 ns are represented on Fig.3. These are not record parameters. At the end of pulse influence at time t=0.1 ns the maximum value of pressure in the target reaches 8 Mbar, specific internal energy -23 kJ/g.

Note, that, as it was obtained in our computer simulation the possibility of extreme state generation with pressure of about few Gbar in Au-target by heavy (Al-) ion beam with more higher intensity may be achieved. For example in case when the current density of micro ion beam was 400 MA/cm2 and energy of Al-ions was 8 MeV the corresponding maximum values were 0.77 Gbar and 23.7 MJ/g . In a case when j = 4 GA/cm2 the maximum pressures increased up to 3.3 Gbar and specific internal energy was about of 128 MJ/g. As it was shown in [8] at such ion beam parameters (when its total energy equals 0.001-0.01 J) the initiation of thermonuclear reaction is possible in D-T mixture, which is arranged between two thin gold plates.

**Conclusions**

It had been shown, that during short pulse laser discharge the complex mechanism of heavy ion acceleration can take place in result of which the ions can accelerate up to 4-8 MeV on the distance of 100 μm. In principal one can continue ion acceleration to more higher energies by using the second and so on laser beams.


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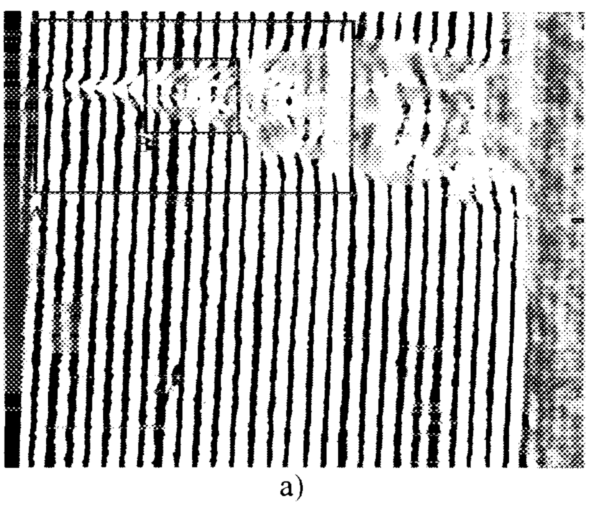
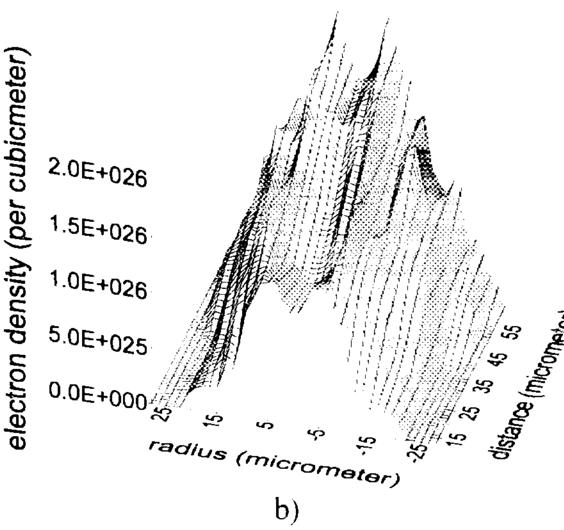
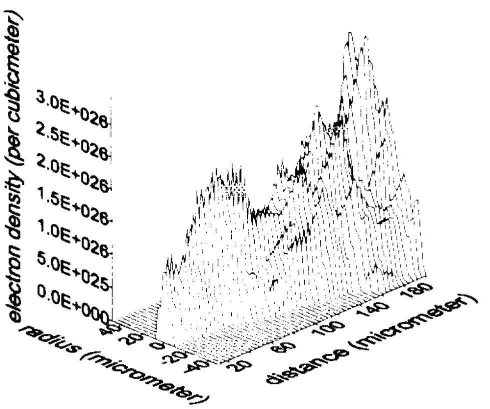


a)

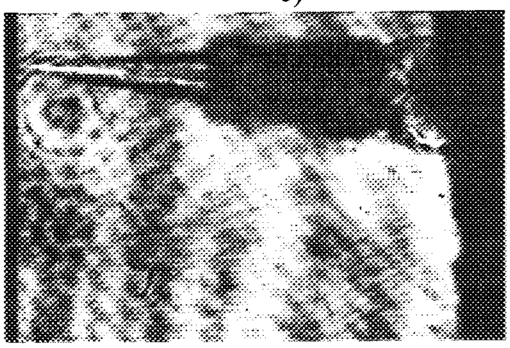



b)

Fig. 1

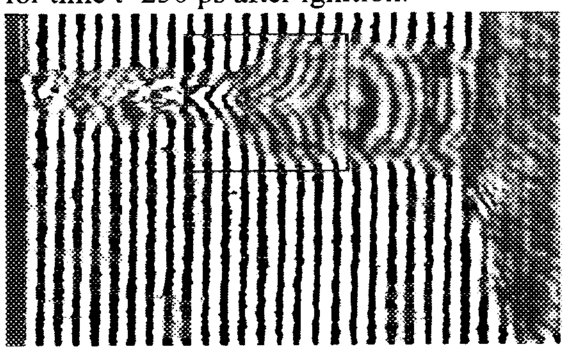



c)

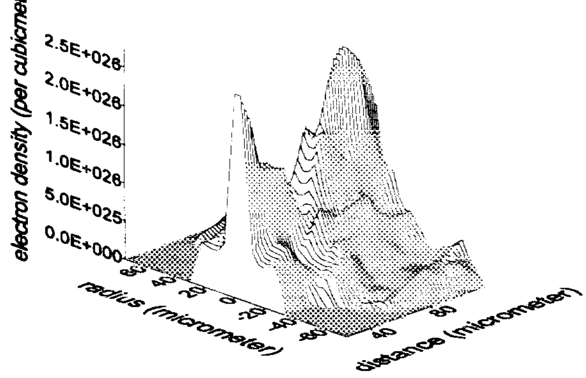


d)

Fig.1 The interferogram (b), electron density distribution (b,c) and Absorbtion image (d), for time t=250 ps after ignition.

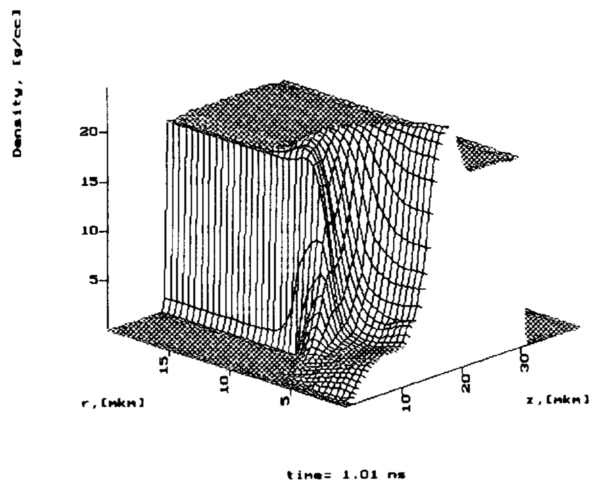


a)

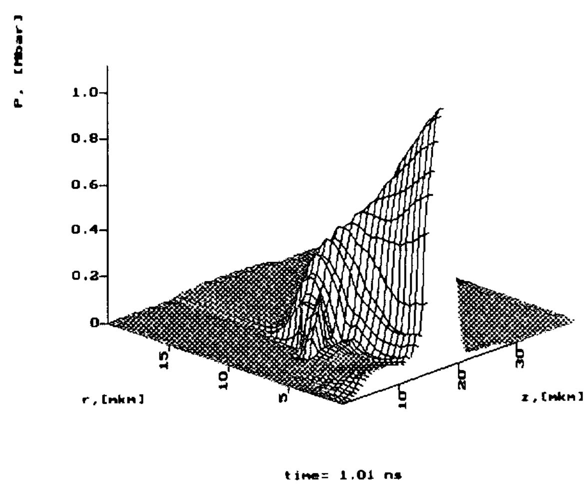



b)

Fig.2. The interferogram (a) and electron density distribution (b) for delay time t=1.16 ns after ignition.




a)




b)

Fig.3: The distributions of density -(a) and pressure (c) of matter at t =1.0 ns.