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Recent ICF Experiments on S-300 Pulsed Power Machine

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Fast high-current Z-pinches are considered as a possible way of electric energy transforming into an X-ray pulse for the inertial confinement fusion. Such experiments are performed on S-300 facility.

1. Multi-wire arrays

At the S-300 facility (t~100 ns, I~3MA, Z~0.15 Ohm) a study of multi-wire arrays implosion aimed at the powerful X-ray source creation was pursued. These arrays were made of aluminium and tungsten wires and their combinations. The main question under investigation was instabilities arisen on different steps of the implosion and their effect on the final compressed state. There are three laser shadow images in Fig.1 that correspond to three instances of tungsten array dynamics. In the first image, a periphery plasma perturbation is observed with typical period of 0.3-0.4 mm. In the next two pictures made at 110 ns and 120 ns from the beginning, fast large scale plasma structure rebuilding is seen. It is more evidence of the prolonged plasma generation from the solid wires. In a set of experiments at the initial stage of implosion transparent strips arise inside the liner shadow. They could be treated as "filamentation" effect in the plasma of neighbour conductors, carrying tens of kilo-amperes (Fig.2). Nevertheless, these instabilities allow tungsten array to implose to the final size of 0.2-0.5 mm with the same scale of longitudinal nonuniformity. It is demonstrated in the pinhole picture Fig.3, realized in hν~1 keV radiation. Quite different situation is observed in the case of Al-wire array implosion in the middle picture of Fig.3,

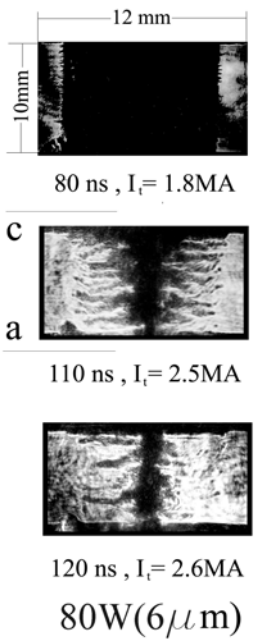

Fig.1

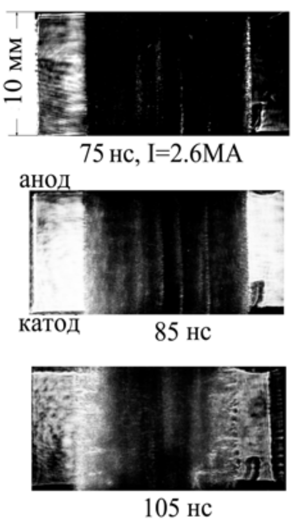

Fig.2

where typical eventual size is 2-3 mm in diameter. In the right-hand image, there is a final stage of 12 mm array assembled in alternate order of the equal quantity tungsten and aluminium wires. This wire-array design did not give an improvement in the implosion dynamics of the liner, but essentially reduced K-shell emission of Al (see Fig.4).

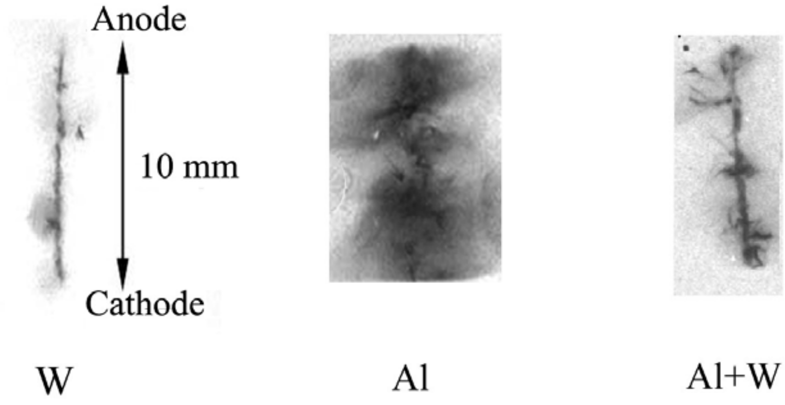

Fig.3

In the nested W-array (diameter of 4 mm) inside of 12 mm Al array, X-ray spectra of aluminium were observed. They seem like those of the single aluminium array of R = 12 mm. This fact is presented in Fig.4. When inner tungsten-array is placed at diameter of 6 mm, aluminium K-shell spectra vanish. It is correlated with the electric current run on the periphery of the plasma; so, aluminium did not acquire sufficient kinetic energy to reach required for K-spectrum temperature before current switching to the still immobile tungsten array. Thus, substance and design variation of the wire-arrays may be used to control the spectrum of X-ray pulse. In more details these experiments are presented in the poster [i].

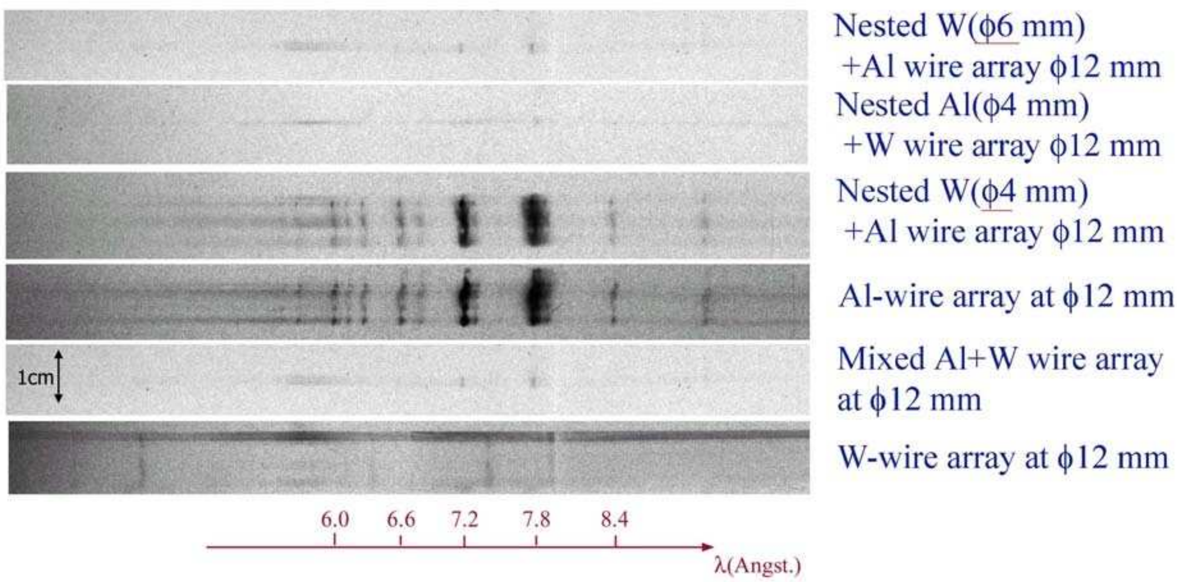

Fig.4

2. MINIATURE LOAD

An increase of radiation flux density to the "Hohlraum"- target could be achieved by the decrease of the radiating wall area in the cavity where this target is placed. The experiments with such miniature load of 2 mm in diameter were performed at S-300 facility by sharpening the pulse to a few nanoseconds scale [ii]. It was made by an output unit represented in Fig.5- that is a plasma flow switch device. In the experiments, the current-carrying plasma bridge was created as a result of electric breakdown and successive ionization of the aluminized mylar film which was placed in the annular gap of the feeding line. A load would be switched to the energy supplying line while the current-carrying plasma layer crossing a gap between two edges of the inner cylinders. This process is indicated by the dashed lines in Fig.5.

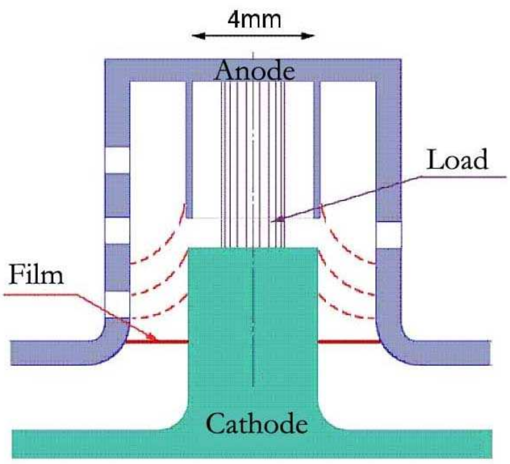

Fig.5

Special shunt measurements show that the main part of the whole current is switched to the load with the rise-time Δt ~ 2-10 ns. Current flow in the load lasts 7-20 ns, and it is affected by the gap between the edges of the cylinders. This optimal gap width was 1.6-1.8 mm. In a few shots current pulses of magnitude 2.5 MA on the load arose with time of 2.5 ns, as it is shown in the upper part of Fig.6. But the most stable current reconnection was performed in the experiments with two membranes situated in consecutive order in 1-2 mm. In this case only one third of the whole current is delivered to the load for the time essentially overcoming the switching rate (Fig.6 lower part). Numerical simulations of the plasma bridge dynamics demonstrated its very high sensitivity to the initial conditions. As an example, with the variation of the initial plasma temperature within the range of 7 to 5 eV, the radial velocity became greater then the axial one to the 40-th ns, and some plasma vortex formed near the cathode. We believe such a plasma behavior to be transformed too soon from the hydrodynamic flow into the

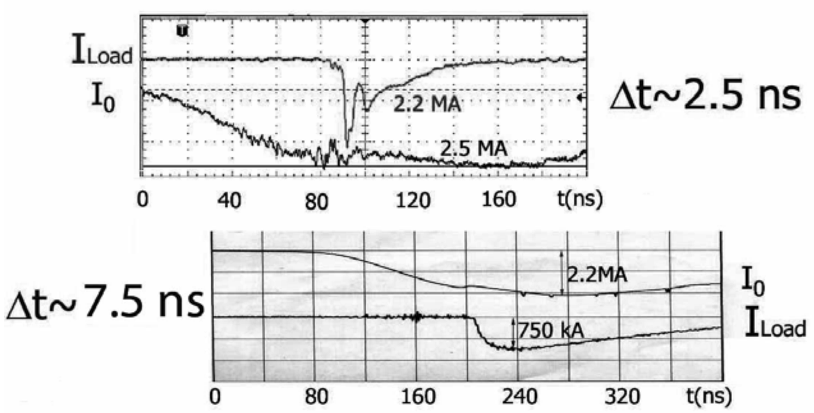

Fig.6

space charge regime corresponding to the eventual phase of the plasma erosion switching.

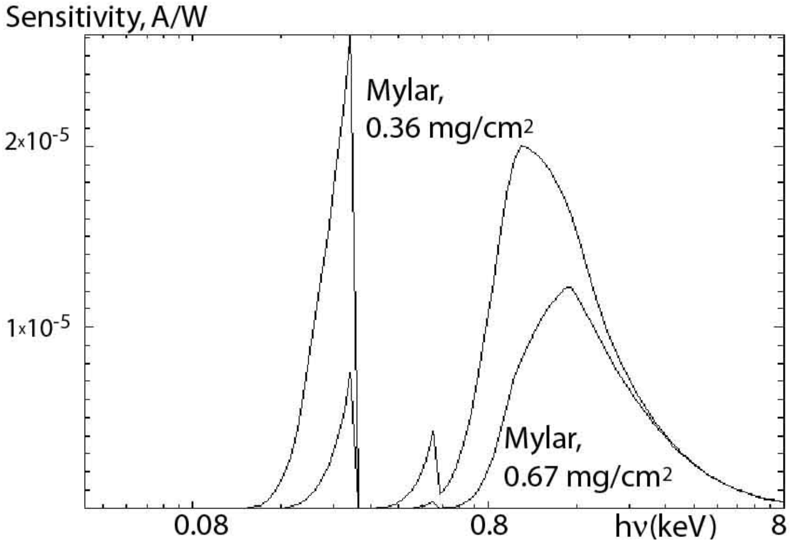

Fig.7

As a load in this set of experiments, 8- or 16-wires arrays were used at the radius of 1 mm inside the metallic tube with the diameter of 4 mm (see Fig.5). The length of the load was 10 mm. Except of the electric current measurements, X-ray radiation from the inner wall of the cavity in the region of hν > 80 eV was recorded. This measurement was performed by two X-ray diodes equipped with mylar filters of 0.36 mg/cm^2 and 0.67 mg/cm^2. The sensitivity of these detectors is imaged in Fig.7. The direction of observation was chosen so that the first-hand radiation from the wire-array was avoided as it is shown in the view from above of the load unit (Fig.8). In assumption of the blackbody radiation character passing through a hole, we got the wall temperature evaluation as 40-50 eV. An estimation of the effect of the backward electric current on the heating of the wall gives minimal surface temperature of ~30 eV and maximal one just equal to ~ 50 eV. It is done taking into consideration self-consistence of magnetic field and heating wave penetration into the wall at the pulse filling of the cavity by the magnetic field. Such a heating could serve as a good help in “Hohlraum” scheme of inertial confinement fusion.

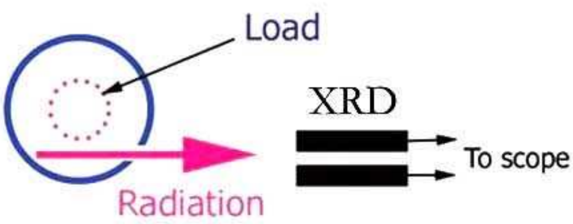

Fig.8

[i] Yu.G. Kalinin, A.S. Kingsep, Li Zhenghong, et al. See this conference, P2.037.

[ii] Yu.L. Bakshaev, A.V. Bartov, P.I. Blinov, et al. Plasma Physics reports V.30, N.4, p.318