Adjustable x-rays irradiation source based on Laser Induced Vacuum Discharge

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INTODUCTION

It is well known that high-current vacuum sparks (HVS), with plasma produced due to electrode erosion, are sources of characteristic x-rays emission [1-2]. However, this type of discharge requires a high amount of energy stored in capacitor banks input for discharge ignition. But the pinching process is spatially and temporally unstable. Accordingly, it is complicate to apply the high-current vacuum spark as a source of *X*-rays emission in practice.

The moderated laser-induced plasma vacuum discharge is introduced as a portable source of *X*-ray emission and ions within this paper. Plasma jet formed under irradiating of target by a laser pulse, can be a stable source of *X*-rays emission which spectral composition determined by laser irradiation parameters and geometry of the discharge circuit [3].

EXPERIMENTAL SET-UP AND RESULTS

The research was performed on a new facility called “Alligator” (fig.1). It consists of an interaction vacuum chamber (P = 10^{-5} torr), discharge system, 1.06 μm Nd-YAG laser with pulse energy $\varepsilon = 25$ mJ and duration of τ = 15 ns, operating at the Q-switching mode and diagnostic tools. To measure a temporal distribution of x-rays two identical p-i-n photodiodes were used. Diodes were placed inside of vacuum chamber at a distance l_{pd} = 18 mm from discharge perpendicular to the axis of the discharge. The input windows of diodes were covered by thin foils of 9 μm Al and 17 μm Mg to form a charge deduction spectral channel with energy interval of E_q = 1,3÷1,56 keV.

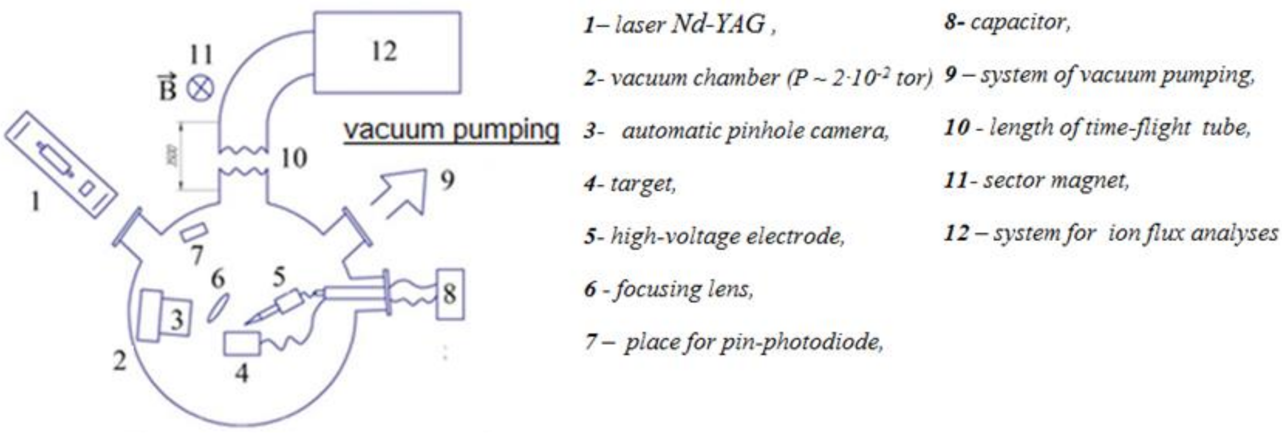


Fig.1 Schematic diagram of experimental facility “Alligator”

Discharge system consisted of electrodes, voltage source, storage capacitance C_1 = 0,22 μF (C_2= 0,011 μF), and low inductance currents conductor. To increase the intensity of x-rays emission the conical configuration was applied [4]. Conical cathode was chosen as a high-voltage electrode, and anode with a tip diameter of 250 μm was a target-electrode where laser beam was focused. Electrodes were arranged at an angle (α ~ 30º) from each other to create the opportunity for simultaneous study of *X*-rays emission and ion flux (fig.2).

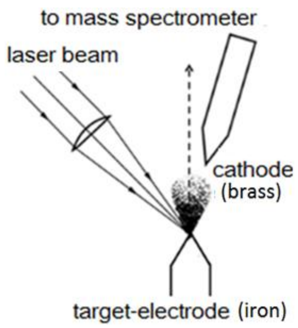
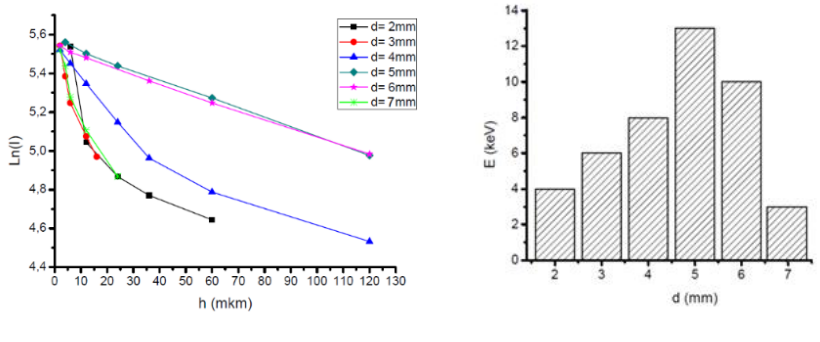


Fig.2. Principal experimental scheme.

In the first series of experiments the discharge current was sustained with a capacitor of C_1 = 0, 22 μF loaded up to −13 kV. The level of energy input into the discharge reached E_1 ~ 17 J and the magnitude of discharge current didn't exceed a value I_1 = 10 kA. The distance between electrodes was chosen as varied parameter, which affected spectral composition and magnitude of x-rays, created in plasma jet. The size of the electrode gap was changed from 2 mm to 7mm with step ~ 1 mm.

Analysis of the spectral composition of the x-rays was performed using a series of debilitating Al filters with the range of thickness h = 2÷120 μm. The set of Al filters and *X*-rays film was placed at a distance l_f = 6 cm from the radiation source inside protective shielding.

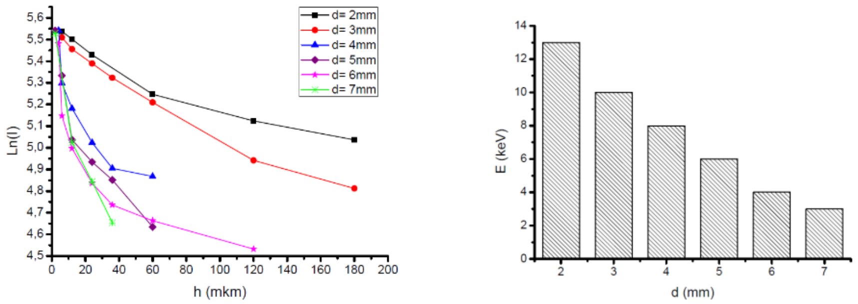


a) *b)*

Fig.3. a) X-ray attenuation curves for filters , b) Spectral composition of the X-ray source according to the distance between the electrodes.

Figure 3(a) demonstrated that the widest range of energies and the highest intensity of *X*-rays emission was observed at a size of electrode gap d = 5÷6 mm. Spectrum of *X*-rays was calculated by mathematical method of "effective energy" [5], (fig.3(b)).

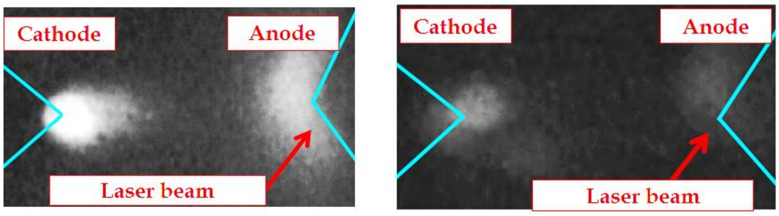
In the second series the discharge current was sustained with a capacitor of $C_2 = 0{,}011$ μF (fig.4). The level of energy input into the discharge was decreased to the value of $E_2 \sim 1$ J and the magnitude of discharge current reached $I_2 = 2$ kA. Other parameters were not changed. The most intense radiation was observed at an electrode gap of $d = 2{\div}3$ mm.



a) *b)*

Fig.4. a) X-ray attenuation curves for filters, b) Spectral composition of the X-ray source according to the distance between the electrodes.

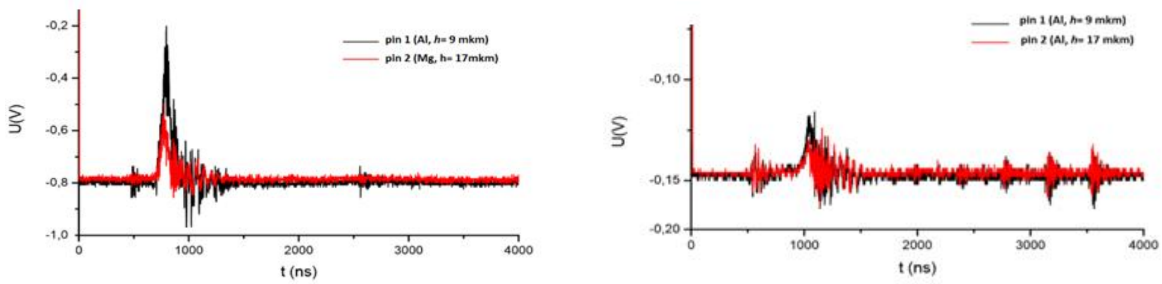
To obtain the spatial distribution of x-ray emission the automatic vacuum pinhole camera was applied. It located inside the vacuum vessel at the distant of 6 cm perpendicular to discharge axis. The aperture size was d_{ap} = *500* μm. It was covered by thin Al foils h =4÷12 μm thickness. The images of the discharge gap were detected on the x-ray film *Kodak* (fig.5). It should be noted that bright images of plasma was obtained only for the thin Al filter h = 4 mm.



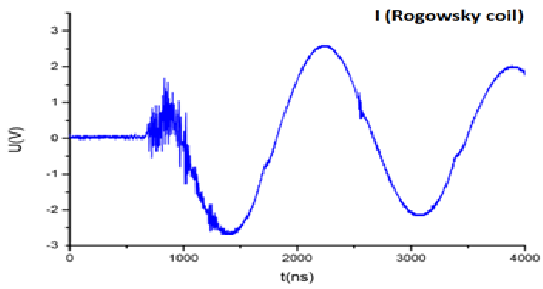
a) *b)*

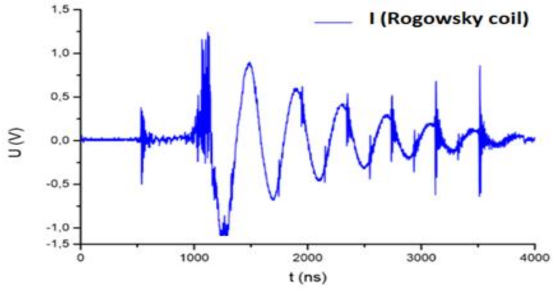
Fig.5. The pinhole images of the interelectrode gap, size d= 5mm, C_1= 0,22 μF, U= -13kV
a) Al filter h=4 μm, b) Al filter h=12μm

To control the temporal dependence of discharge current the Rogowsky coil was placed in the cathode circuit. The temporal characteristics of *X*-rays emission were measured by a system consisting of two pin-photodiodes that were covered by filters (fig.6).



a) *c)*





b) *d)*

Fig.6. The dynamics of the laser induced vacuum discharge

a) Pin-photodiodes signal, C_1= 0,22 µF, E_1 ~ 17J; b) Oscillogram of discharge current, C_1= 0,22 µF, E_1 ~ 17J; c) Pin-photodiodes signal, C_2= 0,011 µF, E_2 ~ 1J; d) Oscillogram of discharge current, C_2= 0,011 µF, E_2 ~ 1J.

It is shown that moment of emergency the discharge current oscillations correlated with a time when x-ray radiation has been emitted. The discharge current has damped oscillatory in the process of developing of plasma. It`s necessary to note that *X*-ray radiation was emitted in the initial stage of the discharge firing after t ~ 300 ns following laser initiation pulse. Duration of *X*-rays pulse was estimate t_{xr} ~ 100 ns and total energy of *X*-rays in pulse reached a value $D_1 \approx$ 0,4 mJ (for C_1= *0, 22 µF*, E_1 ~ *17 J*) and $D_2 \approx$ 2 µJ (for C_2= *0,011 µF*, E_2~ *1 J*) in full solid angle.

CONCLUSION

The new kind of adjustable source of x-ray emission based on laser induced moderate power vacuum discharge with a range of quantum energy hν = 1 ÷ 12 keV was created. The possibility to adjust the *X*-ray spectral composition by changing the geometry of the electrode system was demonstrated. In the case of using stored energy E_1 = 17 J the highest *X*-rays emission was observed when d = 5 mm and the spectral composition consisted essentially of hard component of radiation. The intensity decreased monotonically with grows of energy from 1 to 12 keV. In the case of E_2 = 1 J maximal intensity was obtained when d = 2÷3 mm.

LITERATURE

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