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

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Introduction

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 complicated 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 e = 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 lpd = 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 Еq = 1,3÷1,56 keV.

Fig.1 Schematic diagram of experimental facility “Alligator”
Discharge system consisted of electrodes, voltage source, storage capacitance \( C_1 = 0.22 \, \mu\text{F} \) (\( C_2 = 0.011 \, \mu\text{F} \)), 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 \( \mu\text{m} \) was a target-electrode where laser beam was focused. Electrodes were arranged at an angle (\( \alpha \sim 30^\circ \)) from each other to create the opportunity for simultaneous study of X-rays emission and ion flux (fig.2).

In the first series of experiments the discharge current was sustained with a capacitor of \( C_1 = 0,22 \, \mu\text{F} \) loaded up to \(-13\) kV. The level of energy input into the discharge reached \( E_1 \sim 17\) 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 7 mm with step \( \sim 1\) mm.

Analysis of the spectral composition of the x-rays was performed using a series of debilitating Al filters with the range of thickness \( h = 2\div120 \, \mu\text{m} \). 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.

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 \( d = 5\div6\) 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 \( C_2 = 0.011 \, \mu F \) (fig.4). The level of energy input into the discharge was decreased to the value of \( E_2 \approx 1 \, J \) 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 \( d = 2\pm3 \, mm \).

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

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 \( d_{ap} = 500 \, \mu m \). It was covered by thin Al foils \( h = 4\pm12 \, \mu m \) 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 \( h = 4 \, mm \).

![Fig.5. The pinhole images of the interelectrode gap, size \( d= 5mm, C_1= 0.22 \, \mu F, U= -13kV \) a) Al filter \( h=4 \, \mu m \), b) Al filter \( h=12 \, \mu m \)](image)

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

a) Pin-photodiodes signal, $C_1 = 0.22 \mu F$, $E_1 \sim 17 J$; b) Oscillogram of discharge current, $C_1 = 0.22 \mu F$, $E_1 \sim 17 J$; c) Pin-photodiodes signal, $C_2 = 0.011 \mu F$, $E_2 \sim 1 J$; d) Oscillogram of discharge current, $C_2 = 0.011 \mu F$, $E_2 \sim 1 J$.

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 $t \sim 300$ ns following laser initiation pulse. Duration of X-rays pulse was estimate $t_{xr} \sim 100$ ns and total energy of X-rays in pulse reached a value $D_1 \approx 0.4$ mJ (for $C_1 = 0$, $22 \mu F$, $E_1 \sim 17 J$) and $D_2 \approx 2 \mu J$ (for $C_2 = 0.011 \mu F$, $E_2 \sim 1 J$) 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 $h\nu = 1 \div 12$ 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 $d = 2\div3$ mm.

LITERATURE


