X-ray Source for Gas Laser Preionization

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Abstract- Results of an experimental research of x-ray source of radiation for laser mix preionization in wide aperture gas lasers are presented. The pulse of x-ray radiation is formed in the vacuum diode of the inverted type at bombarding accelerated electrons of Ta foil. It is shown, that using metal-dielectric cathode allows receive the x-ray radiation with non-uniformity of distribution of intensity within the limits of 10 % at energy of quantums up to 55 keV and an exposition doze of radiation up to 160 mR.

1. Introduction

Using of x-ray radiation for laser mix preionization in wide aperture gas lasers allows provide a high uniformity of initial electron concentration necessary for excitation of the large volumes of gas at a high pressure. So in works [1-4] it has been shown that in excimer lasers the best results on generation efficiency and radiation uniformity are reached at use of x-ray radiation. Use of soft x-ray radiation with quantums energy of ~30-50 keV has allowed to receive the laser radiation pulses with energy of tens joules [5,6].

Formation of x-ray radiation in a source, as a rule, occurs in the vacuum diode at bombardment by accelerated electrons of a target with a big nuclear number. It is known, that deceleration radiation thus has a continuous spectrum with a maximum of energy distribution of quantums near to half of accelerating voltage [7]. For effective ionization of gas the x-ray radiation should meet the certain requirements which are imposed on a power spectrum of radiation, its intensity and uniformity of distribution on an output from the vacuum diode. In the works [8,9] it has been shown, that optimum for the laser the working range of accelerating voltage of the vacuum diode is within the limits of 30-50 kV. Restriction from above is connected by that at energy of quantums of x-ray radiation more than 35 keV there is a reduction of the absorbed doze of radiation in active volume of the laser due to reduction of mass factor of x-ray radiation attenuation in gas. Restriction from below at a voltage on the diode less than 25 kV is caused by significant growth of x-ray radiation losses in foil, closing a window for a radiation output from the vacuum diode into gas.

For formation of high-intensity x-ray radiation in the vacuum diode it is usually used cold explosive emission the cathode. The main problem at work of such cathode is bad stability of explosive emission and, as consequence, non-uniform electron distribution on the cathode surface for the account concerning a low accelerating voltage in the diode [10]. In work [11] the design and results of researches of a soft x-ray radiation source with the size of output window of 5x100 cm, developed by us are described earlier. In this source the vacuum diode of the inverted type was used, the cathode has been executed from strip of Ta foil. Research of work of such source has shown, that at size of supply capacity of 5 nF and more in the vacuum diode instability which limits of a x-ray radiation doze develops. Besides the distribution of radiation on cross section of output window was insufficiently homogeneous.

The purpose of the given work was carrying out of researches and creation of an experimental model of x-ray source with the raised intensity and uniformity of output radiation.

2. The equipment and measurement technique

Researches were carried out on x-ray source with the sizes of output window 5x100 and 4x80 cm. The basic electric circuit of a source is submitted on Fig. 1. A pulse supplied of the vacuum diode was carried out at switching by a spark gap (1) storage capacities C, charged up to 60 kV, or from Marx three-stage generator with peak capacity of C=15 nF and own inductance ~ 1 μH. Charge voltage of Marx generator is changed from 20 up to 30 kV. The storage capacity C is changed from 3.3 nF up to 25 nF. In all cases the

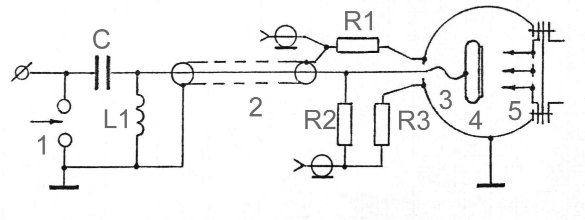

Fig. 1. Electric circuit of x-ray source. L = 10 μH, R1 = 0,02 Ohm, R2= 10 kOhm, R3 = 50 Ohm.

pulse of a high voltage of positive polarity is transmitted on the diode with the help of KVI-120 cable (2) which length is changed from 2.5 m up to 13.5 m. Inside of the diode the high voltage was brought to the anode (4) with the help of several conductors (3) having the identical length. During experiments the different types of the cathode (5) were investigated. 25 microns located in chessboard order served in one case the cathode as a strip from a Ta foil thickness, in the second case the cathode represented a strip foil-clad glass fiber plastic with thickness of 0.5 mm, in the third - a line of the copper wires pasted on a strip glass fiber plastic. The backlash between the anode and the cathode was changed from 14 up to 23 mm. For going out of x-ray radiation from the diode the window closed Ti - a foil thickness 50 microns behind the cathode settled down. The pulse of a current in the diode was registered with the help of R1 shunt, a voltage on the diode - of R2 and R3 divider.

The pulses of a current and a voltage were registered by oscillograph of TDS-3014. Measurements of an exposition doze of x-ray radiation behind a foil and its distributions on output window of the diode were made with the help of KDT-02M and KID-1 dosimeters, specially modified by us for measurement of soft x-ray radiation. Except for it the radiation intensity distribution was registered by RF-3 film.

3. Results and discussion

The basic attention in our researches has been paid attention to search of conditions of uniform density formation of an electronic beam in the vacuum diode as it first of all sets the parameters of x-ray radiation. In turn it is known, that the density uniformity of an electron beam is defined both properties of the cathode, and parameters of the power supply system of the vacuum diode.

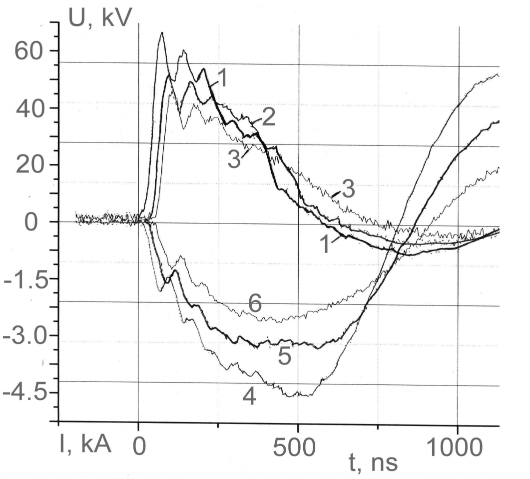

Fig.2. Oscillograms of the input voltage (1,2,3) and diode current (4,5,6) pulses of X-ray source. Anode-cathode gap d=19 mm, cathode is thin Ta-foil, L=1.6 m, Marx generator, charging voltage U_0=30 kV (1,4), 25 kV (2,5), 20 kV (3,6).

First our experiments were carried out with use of the cathode executed from a Ta foil. Thus a supply of the diode was carried out by a pulse generated at switching of the different storage capacity. Researches have shown that parameters of the diode in a strong measure depend on length of the cable connecting the capacity and the diode. With a short cable length of 3.5 m the pulse of a voltage is shorter, than a current in the diode, and falls down essentially faster, than with a long cable (13.5 m). This fact and presence of return polarity of a current, denote the development of instability in the diode during the first half-cycle of a current pulse, and, hence, about shorting of x-ray radiation pulse. With a long cable the voltage pulse duration practically coincides with the current pulse duration. In this case we registered higher doze of x-ray radiation.

The maximum of a voltage in both cases exceeds a supply voltage of 60 kV. It has been caused by charging of constructive interelectrode capacity of the diode. The peak of diode voltage denotes the presence of big delay between beginning of the diode work and the moment of a feed pulse arrival. The peak voltage facilitates the beginnings of explosive emission with a spike cathode and formation of cathode plasma [12]. In this connection the greater voltage on the diode with a long cable allows faster and, hence, more homogeneously to form the cathode plasma and to develop the higher amplitude of a current in the diode for the same time. In our opinion it has allowed to realize the stable work of the vacuum diode with a long cable. It is probable, that in these conditions the electron beam with enough uniform density is formed and exists during all duration of a voltage pulse on the diode.

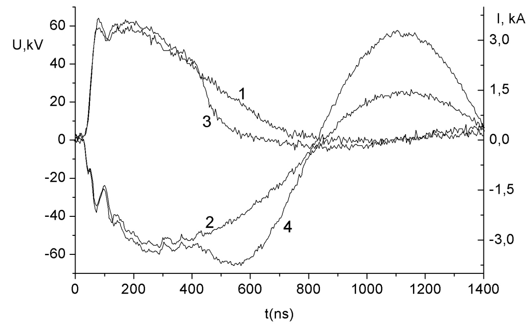

Fig.3. Oscillograms of the input voltage (1,3) and diode current (2,4) pulses of X-ray source. Anode-cathode gap d=23 mm, cathode is copper foil on dielectric substrate, L=1.6 m, Marx generator, U_0=28 kV (1,2), 30 kV (3,4).

For increase in an exposition doze of x-ray radiation the supply capacity and an accelerating voltage had been increased. Thus for convenience of work with a high voltage a Marx generator was used instead of storage capacity. Charging voltage of Marx was changed from 20 up to 30 kV. Researches were carried out on the same diode with the Ta cathode and with various length of a supplying cable. In this case the length of a supplying cable any more did not play the important role in work of the diode. Therefore further in all cases we used supplying cable in length of 2.5 m. The oscillograms of a voltage on an input into the diode and a current of the diode for this case are shown in Fig.2. From these oscillograms it is visible that in all cases in the diode the instability is developed and it results to current in the diode with the oscillatory mode. The best situation was observed at charging voltage of 20 kV when the electron beam existed practically during all pulse duration of a voltage and instability developed only in its end.

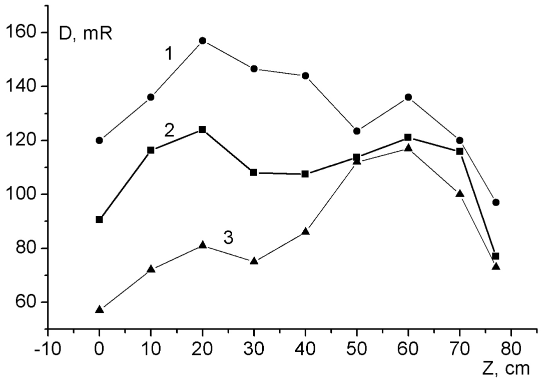

Fig.4. Distribution of dose over the X-ray source length (80 cm). 1- cathode is copper wire on dielectric substrate, Anode-cathode gap d=19 mm, U_0=30 kV. 2 - cathode is copper foil on dielectric substrate, d=18 mm, U_0=25 kV. 3- cathode is thin Ta-foil, d=18 mm, U_0=25 kV

Presence of an instability in the diode with the Ta cathode shows to the insufficient uniformity of plasma distribution on the cathode. For improvement of its uniformity the metal point cathode has been replaced on the metal-dielectric cathode (foil-clad glass fiber plastic) as it is known that the metal-dielectric cathode allows facilitate the plasma formation [13]. The work of such diode was investigated at various distances between the anode and the cathode and as at various amplitudes of a voltage pulse. Change of the anode - cathode distance from 17 up to 23 mm has shown that optimum value is close to size of 19 mm. Thus the diode steadily works at charging voltage of Marx generator up to 28 kV. Oscillograms of the voltage pulses and a current for this case are resulted in Fig.3. The amplitude of the diode current thus reached of 3.5 kA at pulse duration of 700 ns, the accelerating voltage in a maximum of a current was 50-55 kV. Comparing these oscillograms with the oscillograms received at use of the metal cathode, it is necessary to note smaller amplitude of a voltage pulse and the big speed of increase of a current at the same values charging voltage. So the time of achievement of the maximal value of a current has decreased from 350 ns up to 220 ns. All this shows that the metal-dielectric cathode starts to work effectively at smaller voltage on the diode in comparison with metal and the plasma emerges on its surface faster. Due to the greater speed of the plasma formation it distributes more uniform on the cathode surface. As result the more steady work of the diode and the best uniformity of a current density of an electron beam in the vacuum diode are realized. The exposition doze of x-ray radiation in air for all operating modes of the given diode with the size of output window of 5x100 cm was 80-100 mR at enough good uniformity of intensity distribution of radiation. More detailed research of x-ray radiation parameters for various cathodes was carried out on a source with the size of output window of 4x80 cm. The distance between the anode and the cathode of the vacuum diode in these experiments was 18 mm, Marx charging voltage - 25-30 kV. Distribution of x-ray radiation doze on length of the central part of a output window is resulted on Fig.4. Value of each point was averaged from 8 operations of a source. From figure it is visible that with the metal-dielectric cathode the doze distribution uniformity is much better. The quantitative estimation of non-uniformity without taking into account extreme points gives 37% and 10% for the cathode executed from a Ta foil and strip foil-clad glass fiber plastic accordingly.

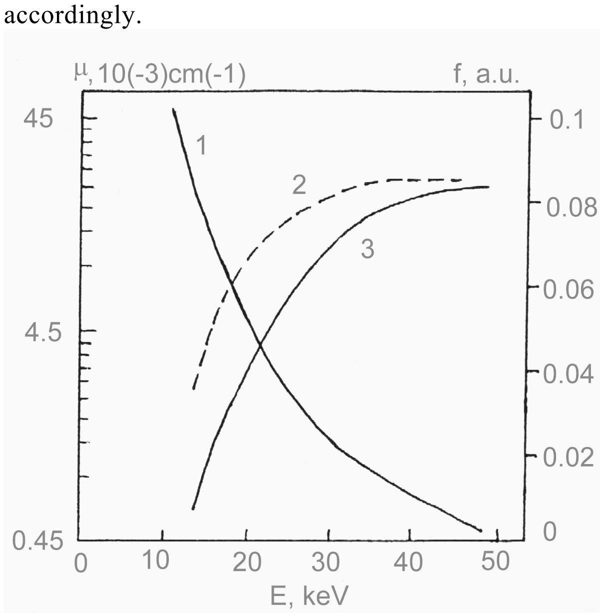

Fig.5. Calculated behavior of the linear x-ray absorption factor (1), output part of x-ray energy from source (2, 3) for different photons energy. Ti-50 μm (2), Ti-130 μm (3)

We had been carried out the calculations of a share of the x-ray radiation leaving the vacuum diode through 50 microns and 130 microns of a Ti-foil, and linear attenuation coefficient of x-ray radiation in Ne-Xe-HC1 gas mixes depending on energy of x-ray quantums. The energy of x-ray quantums of 10-50 keV corresponds to experimental values of an accelerating voltage on the diode. The transmission a output window for our diode was 0,09. It was defined by a solid angle of a useful part of generated x-ray radiation and losses of radiation on a dividing lattice. The gas mix of Ne:Xe:HC1=2000:2,5:1 at pressure 4 atm was used, the basic absorption of x-ray radiation in such mix occurs on Xe and Ne atoms.

Results of calculations are shown on Fig.5. From figure follows, that attenuation coefficient of x-ray radiation essentially depends on thickness of output foil, the transmission which comes nearer to 100% at energy of quantums more than 50 keV. The low-energy component of x-ray radiation with quantums energy of 15-25 keV gives the essential contribution to ionization of a gas mix in active volume of the laser however they have the significant losses at passage through Ti foil.

The estimation of the energy conversion of electrons accelerated into braking x-ray radiation, the attenuation of x-ray radiation stream at passage through a Ti foil and degree interaction of x-ray radiation with a gas mix of Ne:Xe:HC1=1000:10:1 has shown that electron concentration in a mix under action of a pulse of x-ray radiation should make $(5\text{-}10)\times10^{8}$ cm^{-3}.

4. Conclusion

As a result of experimental researches the breadboard of a tape source of soft x-ray radiation with the vacuum diode of the inverted type and the cold explosive emission cathode was created. Marx generator with peak capacity of 15 nF is used for a supply of the vacuum diode of a source. The source generates the x-ray radiation with pulse duration of 700 ns and an exposition doze up to 160 mR. Due to using the metal-dielectric cathode the non-uniformity of intensity distribution of x-ray radiation under the aperture of a output window of the vacuum diode makes ~10 %.

Intensive and homogeneous x-ray radiation of a source can provide in a gas mix of excimer laser the initial electron concentration sufficient for effective work. The source has been successfully tested for gas mix preionization of wide aperture (9x6 cm) XeCl laser with 10 J radiation energy and pulse duration of radiation at a level of FWHM of 300 ns [14].

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