LASERS

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A 650-J XeCl laser

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***Abstract*. A 308-nm XeCl laser with an active volume of 200 L is described and the results of its tests are presented. The output energy of 660 J is obtained by pumping the Ar : Xe : HCl = 1520 : 40 : 2-Torr mixture. The FWHM laser pulse duration is ~ 350 ns. The nonuniformity of the laser-radiation density distribution over the cross section of the output beam in the near-field zone is within 10 %. An accelerator that forms a radially converging electron beam with an electron energy of up to 550 keV, a vacuum-diode current of up to 320 kA, a beam-current pulse duration of ~ 1 μs, and a beam current of up to 250 kA is used to pump the system. Two linear transformers with a 98-kJ energy stored in the primary storage serve as high-voltage sources. To reduce the effect of the self-magnetic field on the beam formation, the vacuum diode is divided into six diodes magnetically insulated from each other.**

Keywords: *XeCl laser, electron-beam pump.*

1. Introduction

High-power laser systems utilising exciplex lasers on haloids of noble gases are currently studied and developed [1 – 4]. These systems incorporate a master oscillator and several amplifiers. The final amplifier is typically a wide-aperture laser pumped by an electron beam. In the known wide-aperture electron-beam-pumped exciplex lasers [1 – 5], high pump powers were achieved due to the application of intermediate water storage lines that were charged from pulse generators. The use of an additional energy storage increases the size of the setup and complicates its design. Electron accelerators in which, due to the use of vacuum insulation, the inductances of the pump generator and the vacuum diode were significantly reduced, were developed at the Institute of High-Current Electronics (Siberian Branch, RAS) [6, 7]. This helped to design compact wide-aperture exciplex lasers [8 – 11] directly pumped from a Marx generator with a vacuum insulation. In these lasers, the active medium was pumped by four [8, 11] and six [9 – 11] radially converging beams.

This paper describes a wide-aperture XeCl laser with a radially converging electron beam. In this laser, the vacuum diode that consists of six magnetically insulated diodes is fed from two linear transformers connected in parallel. The current is distributed between the diodes using a collector in the form of a large-diameter cylinder and plates arranged inside the electron diode. The plates control the forward current from the cylinder to the cathodes and the reverse current.

2. Description of the setup

The external view of the laser with the accelerator is shown in Fig. 1. The voltage pulse at the diode is formed by two linear transformers connected in parallel. The secondary turn is vacuum-insulated. The transformers consist of ten stages, each of which is assembled of eight IK-100-0.17 (100 kV, 0.17 μF, 50 nH) capacitors and has an output power of ~ 12 GW. The voltage is fed to the diode through vacuum lines that simultaneously serve as the secondary turns of the transformers. The electron diode consists of the following main elements: vacuum chamber (*1*) with side flanges (*2*), collector (*3*), cathodes (*4*) with cathode holders (*5*), the plates for feeding the current to cathodes (*6*), magnetically insulating plates (*7–9*) of the reverse current, cell (*10*), and lodgements (*11*) for installing the cell. The vacuum chamber is 1310 mm in diameter and 2100 mm in length. Collector (*3*) is a 1200-mm-long cylinder 1140 mm in diameter. It is suspended coaxially with the vacuum chamber by two springs (*12*) that are placed in the upper part of the chamber.

The accelerator contains 18 cathodes. The cathodes with cathode holders (*5*) are installed on cathode plates (*6*) so that the sectioned cathode of each magnetically insulated cathode consists of three parts. Dividing the cathodes in magnetically insulated diodes reduces the current flowing over the cell surface in the axial direction, thus contributing to a decrease in the beam loss at the ribs of the supporting grating. The magnetic insulation is achieved as a result of using the collector, cathode plates (*6*), and reverse-current plates (*7–9*). The inductance of the electron diode is ~ 40 nH, which is comparable to the inductance of the vacuum insulators of the forming lines in the accelerators assembled according to the conventional scheme.

The profile of the cathodes was selected in compliance

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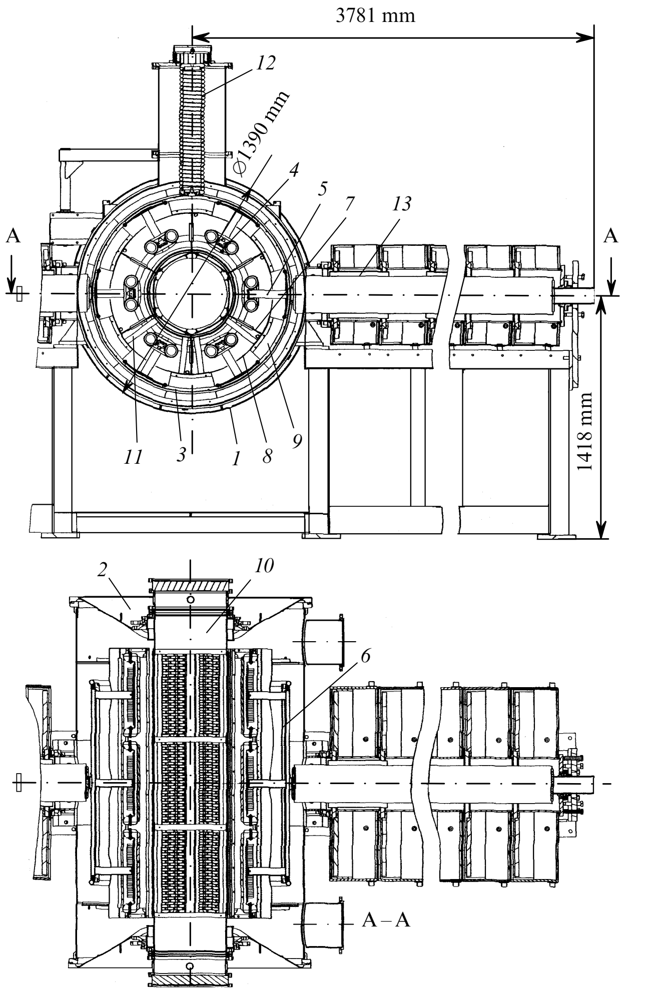

Figure 1. Scheme of a laser pumped by a radially converging electron beam using two linear transformers connected in parallel: (*1*) vacuum chamber; (*2*) side flanges; (*3*) collector; (*4*) cathodes; (*5*) cathode holders; (*6*) plates for feeding the current to the cathodes; (*7, 8, 9*) magnetically insulating reverse-current plates; (*10*) cell; (*11*) lodgements; (*12*) springs; and (*13*) high-voltage turn of the transformer.

with the results of two-dimensional numerical calculations of the beam parameters using a specially developed program. The emitting surface of the cathodes was manufactured from carbotextime (a graphite-fibre material) with a resistivity of $\sim (5-50)\times 10^{-2}$ Ω m and was coated with velvet. The width of the cathode emitting surface was 120 mm, and its total area was 0.95 m^2. The interelectrode gap between the emitting surface and the supporting structure of the exit window was 60 mm.

The supporting structure contained 18 windows. The geometrical transparency of the extraction system was $\sim$ 75 %. The beam was injected into the gas through a titanium foil 40 μm thick. The cell had a 410-mm diameter and a 200-L volume. The maximum gas pressure was 3.5 atm. The vacuum system was evacuated by two AVDM-250 pumps with nitrogen traps at an evacuation rate of 870 L s^{-1}. The residual pressure in the diode was $(3-4)\times 10^{-5}$ Torr.

The laser resonator was composed of a flat aluminium-coated mirror and a plane–parallel KU-quartz plate 420 mm in diameter. The working mixture (Ar, Xe, and HCl) was prepared directly in the laser chamber.

The output energy was measured using an OPHIR calorimeter with an L30A-EX measuring head and TPI-2M calorimeters with a size of the working region of 6 × 6 cm, which were assembled in a single unit consisting of 36 calorimeters. The radiation-energy distribution over the cross section of the output laser beam was determined from its print on the AGFACOLOR photographic paper. For a laser-energy density ranging from 70 to 550 mJ cm^{-2}, the paper blackening was almost linear. The laser-pulse profile was recorded using a FEK-22 vacuum photodiode. The energy deposited in the active medium was determined from the pressure jump in the laser volume measured with a 6 MDX-3B pressure gauge. However, the energy loss due to the generation of shock waves in the beam-injection region was neglected in these measurements.

3. Experimental results

The accelerator operation is described in Ref. [12]. Figure 2 shows oscillograms of the voltage measured across the vacuum diode from the side of each of the two parallel linear transformers and the corresponding currents in the diode, an oscillogram of the photodiode current, and the total energy transferred to the diode. We see that, at a charging voltage of 85 kV, the voltage across the vacuum diode is $\sim$ 550 kV, the total current is 320 kA (the sum of two currents (*3*) and (*4*) shown in Fig. 2), and the energy transferred from the transformers to the diode is 86 kJ. For a charging voltage of 80 kV, the voltage across the vacuum diode is $\sim$ 500 kV, the total current is 280 kA, and the energy transferred to the diode is 75 kJ. The energy deposited in the gas increases, as the pressure rises to 2.5 atm, and then remains virtually constant for pressures 3.5 atm. The maximum energy deposited in the gas by the electron beam is $\sim$ 19 kJ. The efficiency of the energy transfer from the primary storage to the gas is $\sim$ 19 %, which is close to the efficiency obtained in conventional accelerators.

The high reliability and stability of the accelerator should be mentioned. The amplitude instability of voltage and current pulses at a constant charging voltage is a few

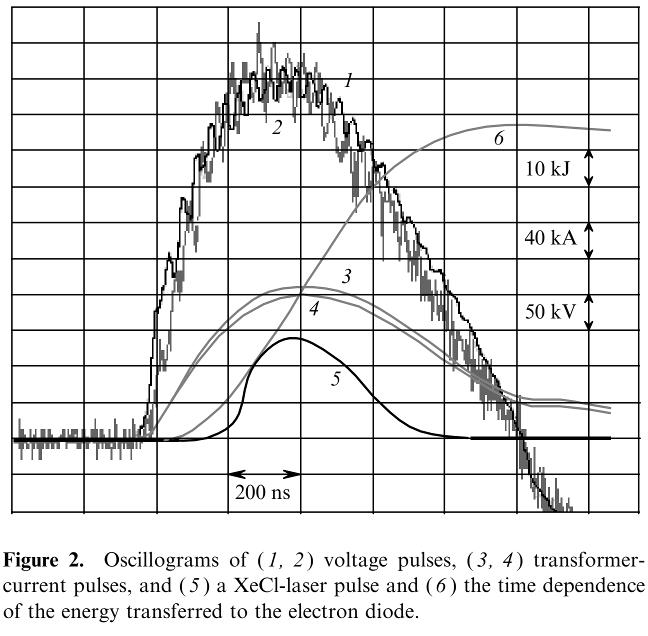

Figure 2. Oscillograms of (*1, 2*) voltage pulses, (*3, 4*) transformer-current pulses, and (*5*) a XeCl-laser pulse and (*6*) the time dependence of the energy transferred to the electron diode.

percent, and the pulse profiles are reproduced well. No case of a beam-caused damage of the exit-window foil was observed in our studies. The pulse FWHM duration was $\sim$ 350 ns.

Figure 3 shows the laser pulse energy as a function of the pulse number for measurements on a freshly prepared mixture with a composition of Ar : Xe : HCl = 1520 : 40 : 2 Torr. The output pulse energy was as high as 660 J and slowly decreased from pulse to pulse due to the escape of HCl molecules from the volume to the walls of the laser chamber and the appearance of impurities and dust knocked out from the foil and laser-chamber walls by the electron beam. When the charging voltage decreased to 80 kV, the output energy decreased by > 30 % and the uniformity of the laser-power density distribution over the cross section of the output laser beam deteriorated. Increasing the mixture pressure to 2.5 atm at a charging voltage of 85 kV also resulted in a nonuniform distribution of the output-energy density over the laser-beam cross section. In this case, the output-energy density near the foil exceeded that at the axis of the laser chamber by $\sim$ 35 %. Under the optimal conditions (at a charging voltage of 85 kV and a pressure of the Ar – Xe – HCl mixture of $\sim$ 2 atm), the energy-density distribution over the laser-beam cross section was quite uniform (Fig. 4), and its deviations from the mean value were 10 %. The radial steps in Fig. 4 appeared upon joining separate parts of the beam print. Since the laser print was large, a sheet of the photographic paper was divided into four parts during scanning.

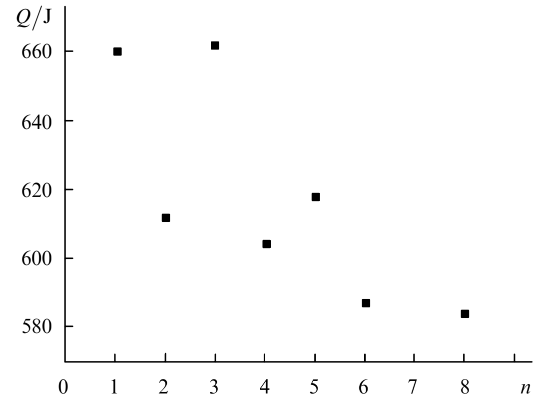

Figure 3. Laser radiation energy Q as a function of the pulse number n for a mixture composition of Ar : Xe : HCl = 1520 : 40 : 2 Torr at a charging voltage of 85 kV.

Note that the fraction of IR laser radiation generated on Xe atomic transitions at a specific pump power of $\sim$ 200 kW cm^{-3} under the optimal conditions for the given XeCl laser is 1 % of the 308-nm radiation power. The known effect of an increase in the IR radiation energy emitted on Xe atomic transitions in the Ar – Xe – HCl mixture with a decrease in the pump power is observed at a specific energy deposition of 100 kW cm^{-3} [13, 14]. Even in an Ar – Xe mixture, when only IR lasing was obtained in a wide-aperture laser with a 600-L active volume, the output energy on Xe atomic transitions at a specific pump power of $\sim$ 100 kW cm^{-3} was within 10 J and the lasing efficiency was 0.05 % [10].

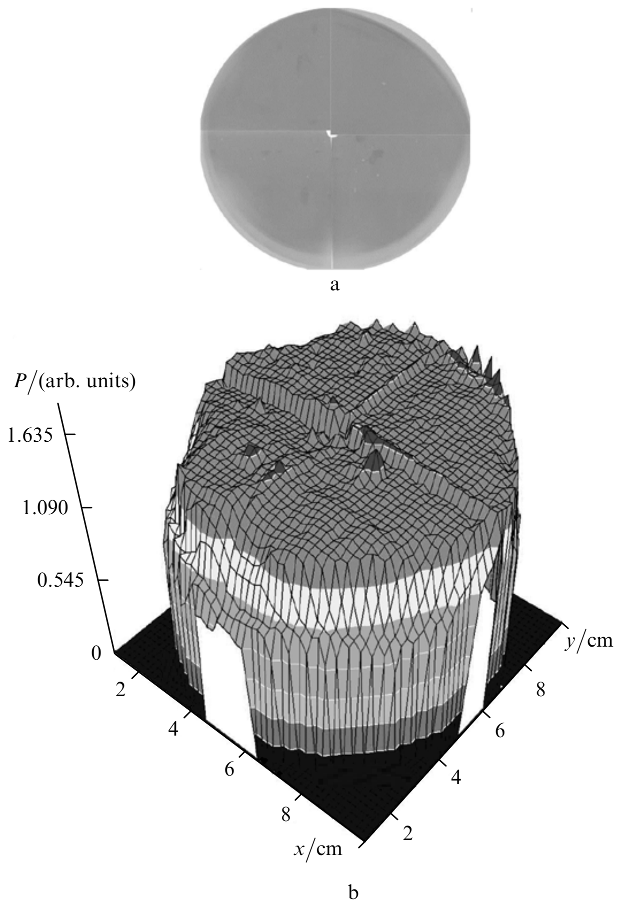

Figure 4. (a) Photographic-paper blackening distributuion (without development) per pulse and (b) the distribution of the reconstructed energy density P of laser radiation over the cross section of the output laser beam for a mixture composition of Ar : Xe : HCl = 1520 : 40 : 2 Torr at a charging voltage of 85 kV and a laser-beam diameter of 41 cm.

4. Conclusions

A wide-aperture laser with an output energy of 650 J has been developed. An electron accelerator with a pulse generator based on linear transformers is used for the first time to pump this type of lasers. At a voltage across the diode of $\sim$ 550 kV and a total diode current of 320 kA, a radially converging electron beam with a current of up to 250 kA, a cross section of $\sim$ 1.5 m^2, and a pulse duration of $\sim$ 1 μs is obtained. This beam is injected into a gas-filled cell with a volume of 200 L and a pressure of up to 3.5 atm. Compared to conventional electron accelerators with fast storage units in the form of forming lines, the accelerator developed is a simpler and more reliable and compact device. Its efficiency is close to the energy efficiency of conventional accelerators. It can be used to pump various dense-gas lasers.

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