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A six-beam high-power KrF excimer laser system with energy of 100 J/23 ns

YUSHENG SHAN, NAIYAN WANG, JINGLONG MA, WEIYI MA, DAWEI YANG, KUN GONG,
XIUZHANG TANG, XIAOJUN WANG, XINGDONG JANG, AND YEZHENG TAO
China Institute of Atomic Energy, P.O. Box 275(7), Beijing 102413, China

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Abstract

A six-beam multiplexing master-oscillator-power-amplifier (MOPA) high power KrF excimer laser system has been built at CIAE for fundamental research on laser–plasma interaction. The MOPA system consists of front-end, two-stage KrF amplifiers (preamplifier and main amplifier) pumped by two-side electron beams, an optical angular multiplexing system, a synchronization trigger system, and a controlling-data acquisition system and some diagnostic systems. The total energy of the six-beam output from main amplifier on the target is 100 J/23 ns, the divergence of one beam is 0.2 mrad, the focal spot diameter is 220 μm, and the focal intensity on the target is 10^{13} W/cm^2.

Keywords: KrF laser

1. Introduction

In inertial confinement fusion (ICF) research, a KrF laser is considered to be a promising candidate for the reactor driver due to its short wavelength, wide bandwidth, high efficiency, scalability, and advantages of UV laser in laser–plasma coupling (Sethian *et al.*, 1994; Okuda *et al.*, 1999; Shaw *et al.*, 1999). This paper describes some performance of the 100-J level multistage KrF laser system "Heaven-I." This high-power KrF excimer laser system has been completed at China Institute of Atomic Energy (CIAE) (Wang *et al.*, 1998). The laser will be used for fundamental research on the ICF driver and laser–plasma interaction in this year. This multiplexing MOPA system includes a front end with a spatial filter, two-stage KrF amplifiers pumped by electron beams, an optical angular multiplexing system, the laser trigger switches and a synchronization trigger system, a controlling-data acquisition system, and some electron and laser beam diagnostic system. The 100-J/23-ns laser output on the target has been obtained in this multiplexing MOPA system. The recent progress and some results of this multiplexing MOPA system are described in this paper.

2. MAIN AMPLIFIER AND PREAMPLIFIER

The scheme diagram of the six-beam multiplexing MOPA system—"Heaven-I"—is shown in Figure 1, whose main modules are the main amplifier and the preamplifier pumped by two opposing electron beams. The main design parameters of the main amplifier and the preamplifier are given in Table 1. The layout of the main amplifier and the preamplifier is shown in Figure 2.

The two-side electron pumped KrF main amplifier consists of an oil-immersed Marx generator, a pulse-forming line of 2.5 ohm which has a laser trigger switch. The forming line is divided into two 5-ohm transmission lines, then each is divided again into two 10-ohm distribution lines connecting the four vacuum feedthrough into the diode tank. Four segment diodes (Ma *et al.*, 1996) are installed inside the tank. Each diode has an impedance of 10 ohm. Each cathode covering velvet has a rectangle planar face with the dimension of 45 × 17 cm^2, electrode separation is 3.7 cm. When the V_{Marx} is 1.2 Mv, each diode has a voltage of 600 kV and current of 60 kA. The four waveforms are very similar. The laser cavity with the diameter of 270 mm has a gain length for double pass of 1.9 m. The ratio of gas mix components in the cell is $Ar/Kr/F_2 = 89.6/10/0.4$, with a gas pressure of 0.2 MPa. The KrF laser output energy is 400 J/200 ns which is operated in a parallel plane resonator

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Address correspondence and reprint requests to: Shan Yusheng, China Institute of Atomic Energy, P.O. Box 275-7, Beijing 102413, P.R. China. E-mail: shanys@iris.ciae.ac.cn

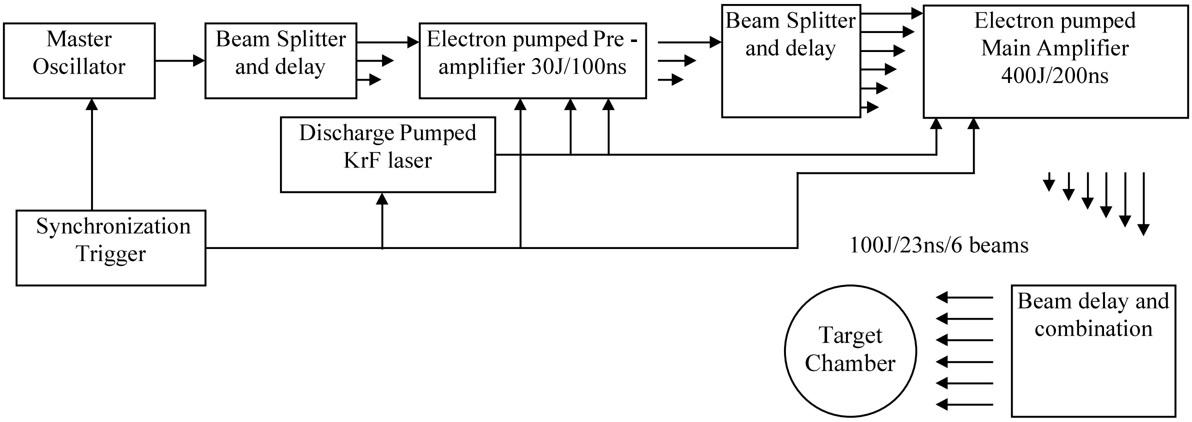

Fig. 1. The scheme diagram of the six-beam multiplexing MOPA KrF laser system.

with output mirror reflectivity of 25% or unstable resonator with M = 5. The four e-beams are injected into the laser cell through an anode and pressure foils (Al foil and Ti foil, respectively) and support structure. Total e-beam energy deposited into gas and averaged pumping rate are measured to be 7 kJ and 0.6 MW/cm^3 (Gao *et al.*, 1997), respectively. The intrinsic efficiency and wall plug efficiency are 6% and 2%, respectively. A new array calorimeter detector (Feng, G. *et al.*, 1998) with a tantalum foil as the absorber has been developed and used to measure the spatial profile of the laser beam in the near field. At conditions mentioned above, the spatial profile of the resonator is shown in Figure 3.

Table 1. *The main parameters of main amplifier and preamplifier*

	Preamplifier	Main amplifier
Marx generator		
Capacitance	14.3 nF	35 nF
Voltage	980 kV	1400 kV
Stored energy	6.87 kJ	34 kJ
Pulse forming-line		
Number of lines	2	1
Capacitance	14.3 nF	34 nF
Voltage	910 kV	1300 kV
Stored energy	5.69 kJ	31 kJ
Impedance	7 ohm	2.5 ohm
Pulse duration	100 ns	200 ns
Diode		
Number of diodes	2	4
Voltage	400 kV	600 kV
Impedance	7 ohm	10 ohm
Anode current	57.1 kA	60 kA
Cathode area	40 × 10 cm^2	45 × 17 cm^2
Current density	143 A/cm^2	78 A/cm^2
Total diode energy	4.6 kJ	24 kJ
Laser cell		
Pumping way	Two-side	Two-side
Diameter of laser cell	120 mm	270 mm
Gas pressure	0.2 MPa	0.25 MPa
Gas content	Ar:Kr:F$_2$ 89.6%:10%:0.4%	Ar:Kr:F$_2$ 89.6%:10%:0.4%
Power pumping rate	0.99 MW/cm^2	1.04 MW/cm^2
Energy deposit in gas	0.45 kJ	8 kJ
Output energy(PP cavity)	30 J	400 J

The one-dimensional kinetic simulation of the KrF laser pumped by an electron beam was also performed with the above parallel plane resonator parameters (Feng, Q. *et al.*, 1998); the main results are illustrated in Figures 4 and 5. The small signal gain coefficient of $g_0 = 5\%$ and the saturated absorption coefficient $\alpha = 0.45\%$ are obtained, the pumping rate is around 0.6 MW/cm^3, the saturation intensity is about 1.5 MW/cm^2, the maximum output intensity I_{output} of 3.3 MW/cm^2 and calculated output energy 390 J and calculated intrinsic efficiency of 5% were obtained. These results agree well with the experiment results.

The two-side electron beam pumped KrF laser preamplifier consists of one Marx generator, two 7-ohm pulse-forming lines which each has a laser triggering switch, two vacuum diodes, and a laser cavity with a diameter of 120 mm, and the gain length of the cavity for double pass equals 1 m. When the V_{Marx} is 840 kV, each diode has a voltage of 400 kV and a current of 60 kA. The KrF laser output energy is 40 J/100 ns, which is operated in a parallel plane resonator; the gas mix condition is the same as with the main amplifier.

Experiments of amplifying the seed light injected from the front end were performed. First the one beam from the multiplexer with a pulse width of 23 ns is amplified by a double-pass in the preamplifier. When the injected energy of one beam changes from 2 mJ, 20 mJ up to 200 mJ, the outputenergy of each pulse is 1.5 J, 4 J, and up to 7 J, respectively. The net small signal gain of 8%/cm is obtained from these results and it is reduced to 5.5%/cm at large input energy.

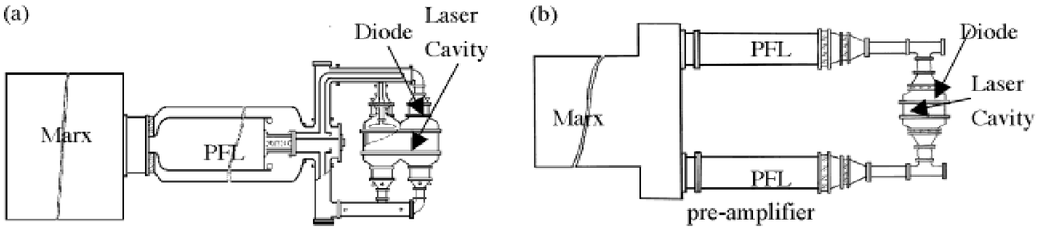

Fig. 2. The layout of (a) the main amplifier and (b) the preamplifier.

3. THE FRONT END AND MULTIPLEXER

The front end is an inject-locked discharge KrF laser LPX-150 (Lambda Physiks) with a spatial filter, which has an output energy of 400 mJ/23 ns. The laser beam is divided into three beams and delayed each other by the splitters, and which is amplified by the double-pass preamplifier sequentially. Then each beam is divided into two beams and delayed each other by splitters again, the six beams are amplified by the double-pass main amplifier sequentially, then using a demultiplexer to make six beams arrive at the target simultaneously. This multiplexer has been completed and used in experiments. We have also developed an optical coating of HfO_2/SiO_2, high reflector $Al_2O_3/SiO_2/MgF_2$, $Al_2O_3/MgF_2/SiO_2$ antireflection coating (Gao *et al.*, 1997). They have been used on the multiplexing MOPA system successfully.

4. SYNCHRONIZATION TRIGGER SYSTEM AND LASER TRIGGER SWITCH

A block diagram of the triggering system is shown in Figure 6. The synchronization trigger system includes a DG535 delay generator and two HV pulsers, each of which includes a three-stage pulse amplification, and the final stage output voltage is 150 kV with leading edge 10 ns which is used to trigger the Marx generators of the preamplifier and main amplifier. The other discharge pumped KrF laser is used to trigger pulse-forming line switches for the main amplifier and preamplifier. The jitter of delay time of the KrF laser trigger switches is ±3 ns and total jitter of the MOPA system is less than 10 ns.

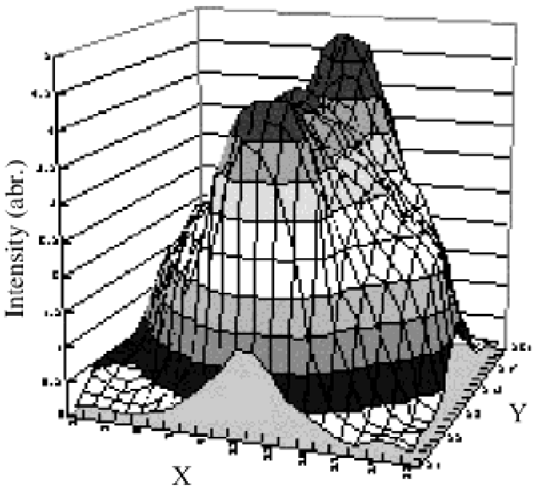

Fig. 3. The spatial profile and contour of the laser beam produced from the Heaven-I main amplifier.

5. FOCUS OPTICS AND VACUUM TARGET CHAMBER

The focus optics is a compound system consisting of six concave mirrors ($\phi 90$, $f = 13{,}000$ mm) and six convex

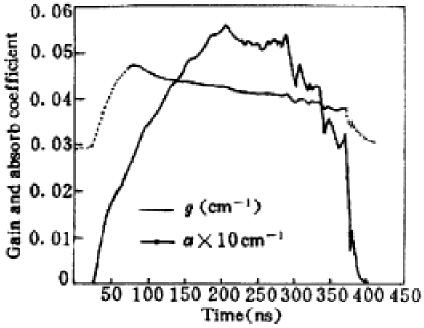

Fig. 4. Gain and absorption coefficient versus time.

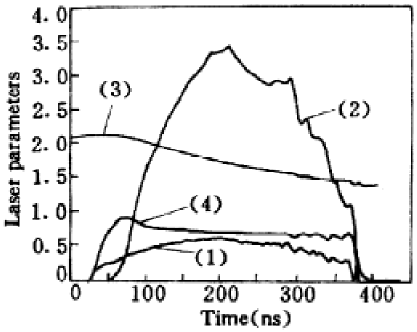

Fig. 5. Laser parameters: (1) pumping rate (MW/cm^2), (2) laser output power (MW/cm^2), (3) saturation flux (MW/cm^2), (4) side light (× 10 kW/cm^2).

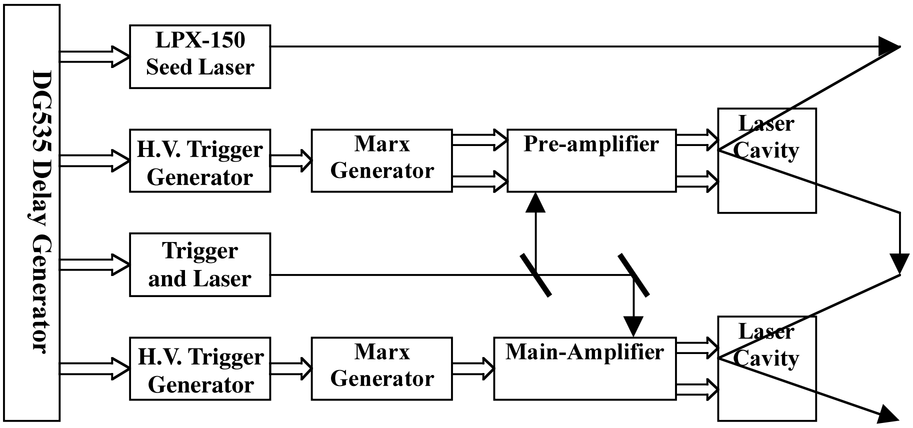

Fig. 6. The block diagram of the synchronization trigger system.

lenses (ϕ40, $f = 693$ mm). The concave mirror array reflects and focuses the laser beams first, then the convex lens array focuses the six beams to the same position on the target. The diameter of the target chamber is 1.5 m; the vacuum is 10^{-5} Torr. The target can move in three directions and can be rotated in two directions; the movement can be controlled from outside of the chamber, which is used to optimize the focus condition.

6. EXPERIMENTAL RESULTS OF SIX-BEAM-PULSE AMPLIFICATION

The three laser pulse beams are expanded using the concave lens array of the multiplexer and injected into the preamplifier and amplified by double-pass, then the output beam is divided into six beams and expanded again and injected into the main amplifier and amplified by double-pass. The experiment results show that when the injected total energy of three-beam pulses into the preamplifier is 170 mJ, the output from the main amplifier is 100 J with six beams, which is shown in Figure 7.

To optimize the laser beam quality, the spatial intensity distribution of the laser beam at several positions has been measured by UV CCD; the results at the front end and after the two amplifiers are illustrated in Figure 8. We found that the beams were uniformed slightly by amplifiers; the reason is the gain saturation in the amplifiers. The divergence angle of each laser beam at far field was measured utilizing a $f/80$ lens; the focal spot was measured by a UV CCD. The laser beam has a divergence of 0.2 mrad.

The total energy of the six beams was measured by a calorimeter with diameter of ϕ100 mm. The calorimeter was placed after the focus mirrors array. The total energy of the six beams is 109 J; the stability of the laser energy is below 10%. The simultaneity of the six beams was monitored by a photodiode equipped with a digital oscilloscope. The focal spot of the six beams on the target was monitored by a CCD and measured by an X-ray pinhole camera. The X-ray camera has a pinhole with a diameter of 25 μm and a

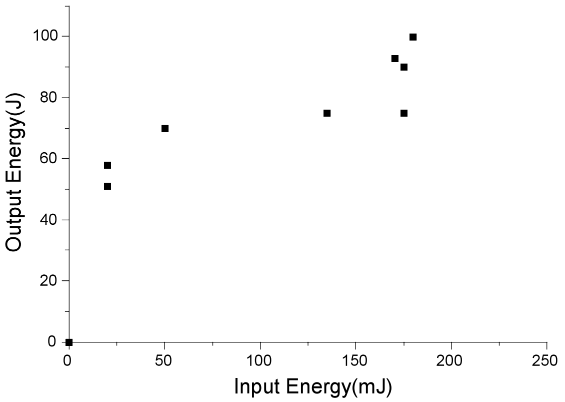

Fig. 7. The experiment results of the six-beam-pulse train amplification.

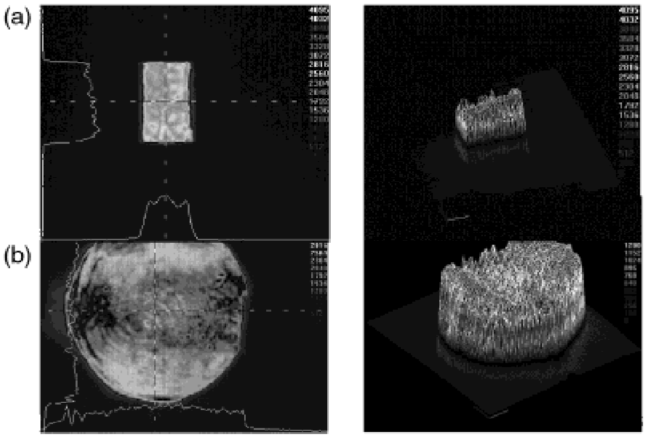

Fig. 8. The intensity spatial distribution of the laser beam at the front end (a) and after two-stage amplifiers (b).

magnification of 8, and uses a 10-μm Al film to prevent the X-ray with energy below 500 eV. The diameter measured by an X-ray pinhole camera is 220 μm. The laser pulse is measured by the photodiode; the FWHM is 23 ns. So the intensity on the target can reach up to 10^{13} W/cm^2.

In conclusion, a six-beam 100-J/23-ns high-power KrF excimer laser has been developed at CIAE. The two two-side-electron-pumped KrF amplifiers were developed; the main amplifier with a diameter of ϕ270 mm can produce a 400-J/200-ns 248-nm laser pulse in the free running mode. The pulse-power systems work very stably; the stability of the electron beam energy is below 5%. The total energy of six beams on the target is 109 J/23 ns, the diameter of the focal spot of the six beams is 220 μm measured by an X-ray pinhole camera, and the intensity reaches up to 10^{13} W/cm^2. Now we are researching the equation of state for some materials.

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