KrF Laser Development for High Repetition Rate and High Peak-Power Driver

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Abstract: Krypton fluoride (KrF) laser is an efficient ultra-violet (UV) gas laser and can be scaled up to reactor scale direct-drive IFE driver. At the AIST, a prototype rep-rated electron-beam (e-beam) pumped KrF laser/amplifier is being developed to establish technology for rep-rated durable driver, and near term goals, >20 J /pulse at 1 Hz, 10^4 shot life time, are being reached. To investigate the feasibility of fast igniter scheme with UV laser pulses, the Super-ASHURA (12 beams, 3 kJ) KrF laser has been modified and a focused intensity of 3 x 10^{18} W/cm^2 has been obtained in the preliminary test operation. Target shooting experiments with focused intensity > 10^{19} W/cm^2 are scheduled in near future.

1. Introduction

Krypton fluoride (KrF) laser is an efficient ultra-violet gas laser which has various advantages for inertial fusion driver. Its short wavelength (248 nm) gives good target coupling (high classical absorption, high ablation pressure, etc.), its broad bandwidth (1 nm) enables smooth irradiation by means of wavelength dispersion and/or induced incoherence, and the gas laser medium allows rapid cooling for high repetition-rate (rep-rate) operation. At the AIST, a prototype rep-rated electron-beam (e-beam) pumped KrF laser/amplifier is being developed to establish technology for rep-rated durable driver for inertial fusion energy (IFE). The broad band width of KrF laser also allows amplification of short intense pulse which is required to examine the feasibility of fast igniter scheme. A part of the Super-ASHURA (12 beams, 3 kJ) KrF laser system [1] is being modified for short- intense pulse generation and shooting experiments.

2. High Repetition Rate Amplifier Development

The prototype rep-rated KrF laser amplifier, of which first-stage goal is repetitive laser-pulse extraction (> 20 J / 80 ns) at a repetition rate of 1 Hz, pursues durability of high voltage power supply and e-beam diode.

For the power supply, a high-voltage generator based on short-life spark-gap switch has been changed to a long-life solid state system, a combination of step-up transformer and high voltage magnetic switch both of which employ iron-based amorphous metal cores. This pulsed power system produces 300 kV / 40kA, 80 ns e-beams at a repetition rate of 1 Hz.[2].

For the e-beam diode, a water-cooled hibachi structure is used to support anode- and pressure sustaining foils. Heat deposited in the foils is removed by conduction to the hibachi rims and heat radiation from the foils themselves. We employ cobalt-based alloy (HAVAR) for the pressure foil (15 micrometer thick), which has a high tensile strength at high temperatures (1410 MPa at 800 K) and excellent resistance to fluorine.[3] Various types of cathode, nanoscale silicon needles, graphite nanofibers, or corona-discharge emitters with molibdenum or tantalum mesh, are being tested for optimization of faster current rise and longer life time.

Figure 1 shows the laser head of the prototype amplifier. Through the foils, e-beams is injected into the laser cell from one side. Approximately 10^3 consecutive shots [4] and 10^4 total shots of e-beam have been obtained at a rep-rate of 1 Hz without a failure.

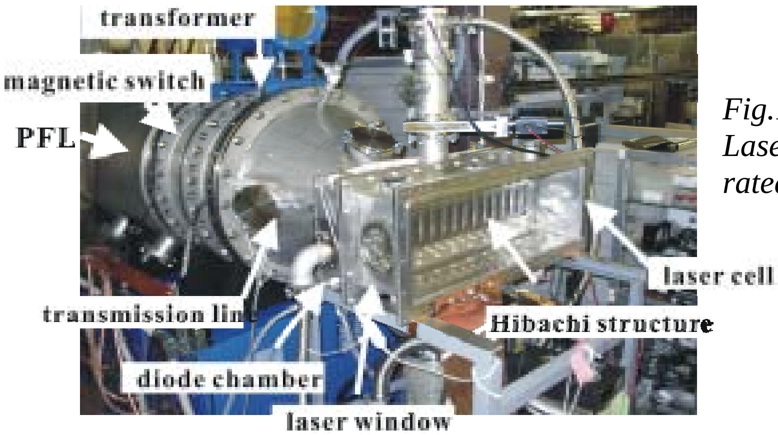


Fig.1
Laser head of the rep-rated prototype amplifier

The temporal waveform of the gas pressure in the laser cell is shown in Fig. 2. The pulse train of pressure jumps demonstrates continuous pulsed-energy deposition into atmospheric buffer gas (Ar) in the laser cell at a repetition rate of 1 Hz. In 20 seconds, temperature of the gas comes to a steady state where conduction through the walls of the laser cell balances with average e-beam input power. (There was no gas circulation and cooling in this case.)

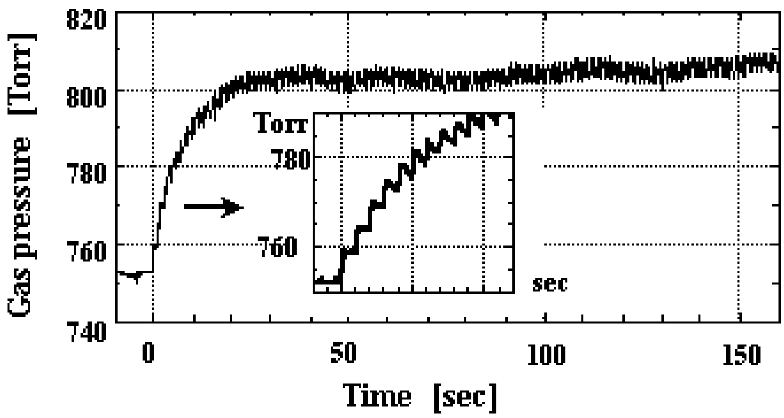


Fig.2
Temporal waveform of the pressure of the laser cell

As shown in Fig. 3, temporally averaged temperature of the e-beam injection (pressure sustaining) foil (at the highest point) has been measured to be 550 K at an averaged e-beam deposited power of 0.11 W/cm^2 . This temperature can be extrapolated to be 650 K at designed deposited power density of 0.2 W/cm^2 . These results show that this foil-cooling design can be extended to even higher deposition power (higher current density or repetition rate). Maximum electron beam energy deposited into laser gas is 250 J / pulse and it coressponds to an extractable laser energy of >20 J / pulse. More energy deposition can be expected by adjusting impedance of the e-beam diode and the pulsed power supply.

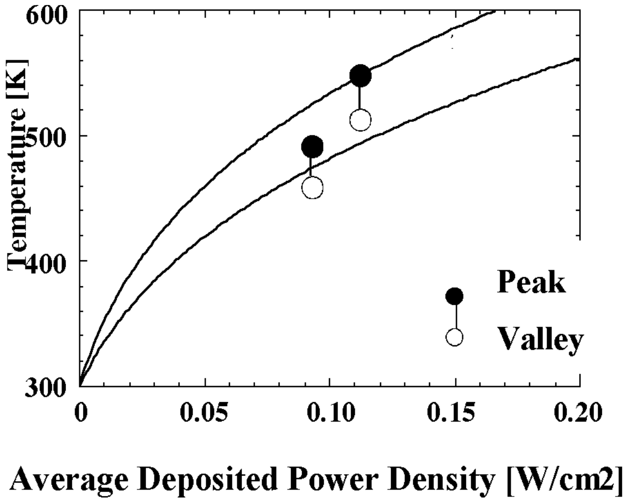


Fig.3
Measured and calculated foil temperatures
Peak-Valley variation coresspponts to temperature change during shot intervals (1 second).
Curves coressponds to various possible emissivity of foils

3. High Intensity Pulse Generation and Focusing

In the fast igniter scheme of IFE, ultraviolet laser light has some advantages because it can penetrate into higher density region without aid of another guiding laser pulse and the energy of generated hot electrons is lower (about 1 MeV) and suitable for heating of compressed core. Experimental results with KrF laser up to 10^{18} W/cm^2 have been reported [5] , but even higher power density and energy is required to examine the feasibility of UV fast ignition scheme.

We have also performed some preliminary experiments in the power density region of 10^{17} - 10^{18} W/cm^2 [6] with a few pico second terra watt pulses produced by using a beam line of Super-ASHURA KrF laser. The planer target experiments with preformed long scale length plasma showed that the energy of the short pulse was deposited fairly close to the original target surface. To achieve higher focused power density, > 10^{19} W/cm^2, a part of the laser system is has been modified.

A new short pulse front-end (Ti-S laser based), vacuum beam tubes which cover all optical paths, all reflective optics and thinner laser amplifier windows (quartz, aperture 30cm, tickness 1cm) have been installed. Figure 4 shows the new layout of the middle stage of the Super-ASHURA. The output pulse (3J / 1ps) from the 30 cm amplifier (Amp-3) obtained by direct amplification of a seed pulse is focused to a diffraction limited spot size by F=3.7 off-axis paraboloid focusing mirror.

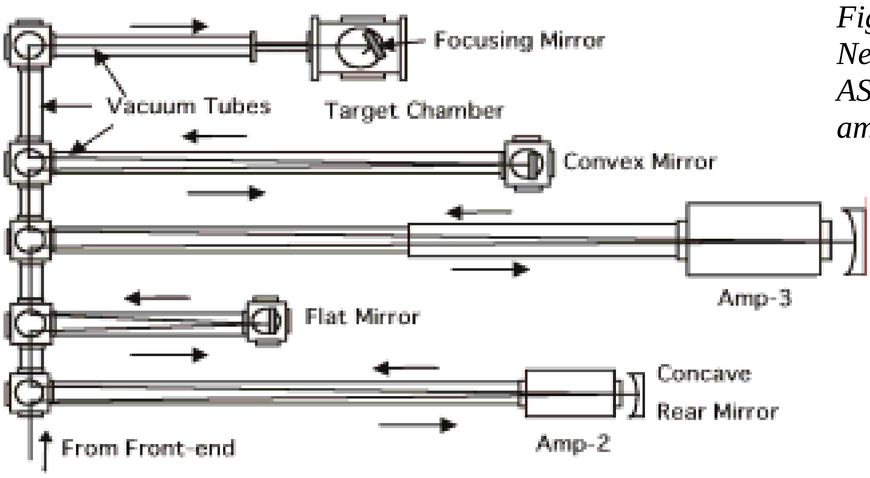
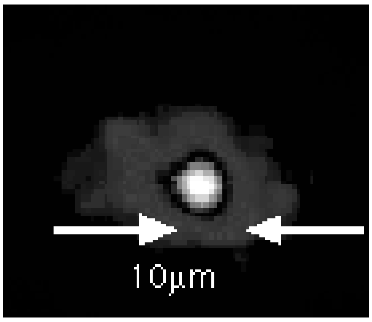


Fig.4
New layout of the Super - ASHURA for short pulse amplification

So far, a single short pulse energy of 2.5 J has been obtained with a pulse duration of < 1 ps and a focal spot size of < 10 micrometer. Intensity distribution on the focal plane is shown in Fig.5. Focused intensity and intensity contrast ratio to the background (amplified spontaneous emission) are estimated to be 3 x 10^{18} W/cm^2 and 10^7 respectively. The spot size is currently 6 times difraction limitted size and is being reduced to 3 times, that enables focused intensity of > 10^{19} W/cm^2. Even higher focused intensity is achievable by shortening the seed pulse width and replacing the laser window material to CaF_2.

Fig.5
Intensity distribution on focal plane.
Space between arrows is 10 micrometer



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