High Rep-Rate KrF Laser Development and Intense Pulse Interaction Experiments for IFE*

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Abstract. A high repetition-rate e-beam pumped Krypton fluoride (KrF) laser has been developed as a prototype of future IFE driver. A combination of power supply with high voltage magnetic switches and e-beam diode cooled by water and self heat-radiation is generating e-beam at 0.5 Hz. Laser oscillation at 1 Hz with output energy over 20 J is expected in near future. Intense short pulse (> 10 J, ~3 ps) has been generated by using a SBS (stimulated Brillouin scattering) short pulse generator and one of the Super-ASHURA's beam line. Interaction experiments with a power density ~ 10^{18} W/cm^2 were performed with long scale-length plasma produced by 20 ns pulse. X-ray images show that the short pulse reached to the point close to the original target surface.

1. Introduction

Krypton fluoride (KrF) laser is an efficient ultraviolet 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.), and its broad bandwidth (1 nm) enables smooth irradiation by means of wavelength dispersion and/or induced incoherence. Also, the gas laser medium allows rapid cooling for high repetition-rate (rep-rate) operation. To establish technology of rep-rated efficient driver is one of the most important issues of inertial fusion energy (IFE). At the Electrotechnical Laboratory (ETL), development of a prototype rep-rated electron-beam (e-beam) pumped KrF laser (amplifier) has been started in parallel with short- intense pulse shooting experiments with the Super-ASHURA (12 beams, 3 kJ) KrF laser system.

2. Rep-rated KrF Laser Development

In the prototype rep-rated amplifier, two key issues for the rep-rate operation, high voltage switch and e-beam diode, are being pursued. The power supply of the prototype amplifier is shown in Fig.1. It consists of low voltage switch (thyratron array), step-up transformer and passive magnetic-switch pulse compression circuit instead of Marx bank and spark gap switches which have been used in high energy single shot lasers.

The initial stored energy is switched out by the thyratron array (8 thyratrons in parallel) at 30 kV and stepped up by the x10 pulsed transformer (Tr1) to charge the intermediate storage capacitor in 1.3 microseconds. Then, energy is transferred to the pulse forming line (PFL) through the magnetic switch 1 in 0.3 microseconds. The PFL is switched by the magnetic switch 2 and the output is transferred to the e-beam diode through x2 transformer, Tr2. The low voltage switch can be replaced by an array of semiconductor switches which have life time much longer thyratron.

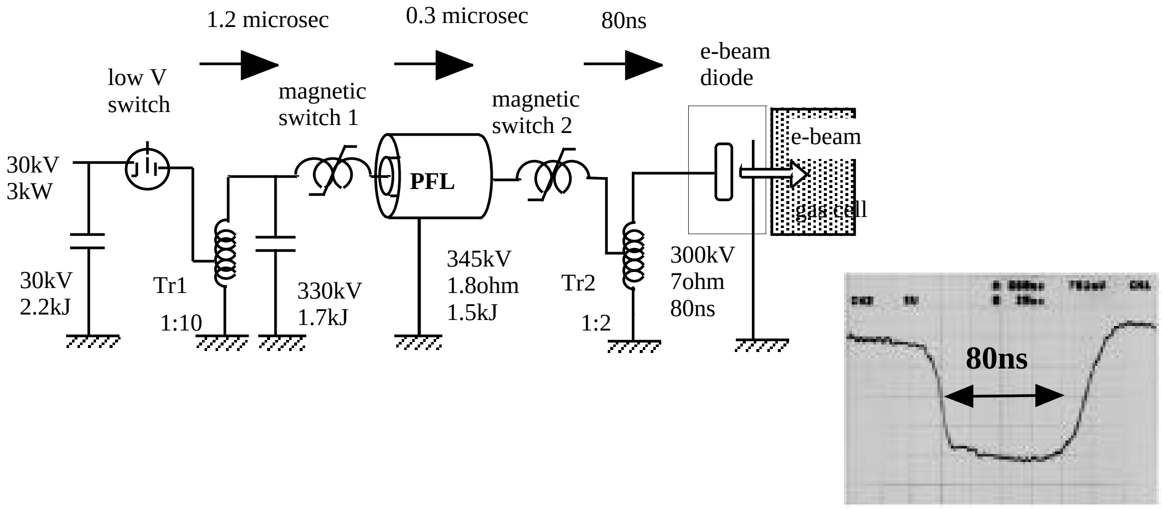

Fig. 1. Left: Power supply circuit of the prototype rep-rated KrF laser amplifier
Right: Output voltage waveform from the power supply.

Magnetic switches can be operated at high rep-rate and have no deterioration compared with spark gap switches which suffer from electrode erosion and need replace after a few thousand shots. The power supply system is producing 300 kV / 80 ns (1 kJ) pulses at 1 Hz [1]. Output voltage waveform for a dummy load is also shown in Fig.1. Timing jitter is within 5 nanoseconds.

Electron beam diode for rep-rated operation requires robust structure and cooling capability. Figure 2 shows structure of the e-beam diode. Although various materials and structures are being tested for electron emitting cathode, glass fiber wool, which shows fast current rise and marginal robustness, is being used in initial stage experiments. For the cooling of e-beam transmitting foils of the diode, heat removal through water cooled foil supporting structure

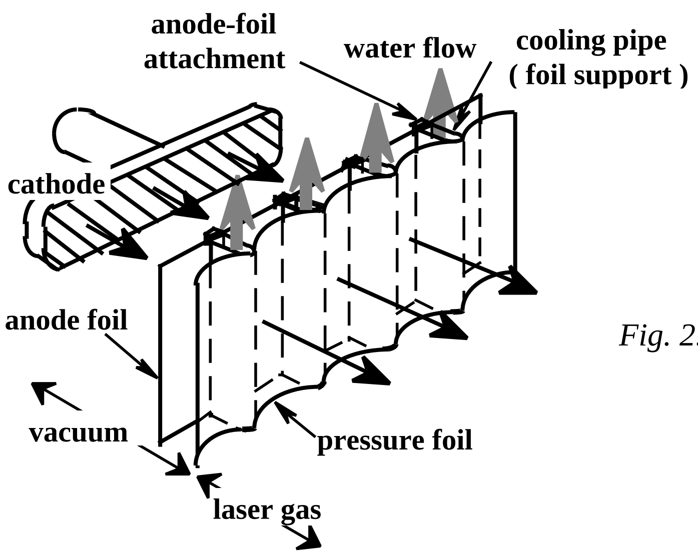

Fig. 2. Structure of high rep-rated e-beam diode

(hibachi) and self heat radiation from the foils are used. For effective heat radiation, foil temperature is set to 800 K and HARVAR alloy has been chosen as a foil material which has enough tensile strength at the high temperature and also has fluorine resistance.

During the initial stage of the e-beam generation test, repetition rate was limited to 0.5 Hz by the out gas from the cathode and foils. So far, 3000 shots were fired at 0.5 Hz without a failure. In this condition, e-beam energy of 500 J is estimated to have transmitted to laser gas chamber. Improvements in diode vacuum and cathode design are being performed in parallel with preparation of laser amplification.

3. Intense Laser Pulse Generation

In the fast igniter scheme of IFE, ultraviolet laser light has advantageous because it can penetrate into higher density region without aid of another guiding laser pulse and energy range of the generated high energy electron is estimated to be adequate for heating of the compressed core. To investigate the interaction of intense ultraviolet laser pulse and preformed long scale-length plasma, high energy short pulses have been generated by the Super-ASHURA KrF laser system [2].

In ultraviolet wavelength region, CPA (chirped pulse amplification) scheme is not very advantageous because damage threshold and reflectivity of the final optical grating pair are considerably low for ultraviolet light. In the Super-ASHURA, although various schemes for pulse compression have been examined, a combination of short pulse direct amplification and pulse shortening by saturated amplification is being used.

The short seed pulse is generated by backward stimulated Brillouin scattering (SBS) of the master oscillator output. Two stage SBS using SF_6 gas and Fluorinate liquid generates 90 ps short pulse stably from 20 ns line narrowed master oscillator pulse [3]. This scheme can suppress the level of prepulse extremely low ($< 10^{-5}$) and keeps the beam divergence to near diffraction limited. This SBS scheme has also been applied successfully to broad-band KrF oscillator output which is used to achieve smoothed intensity profile on target [4].

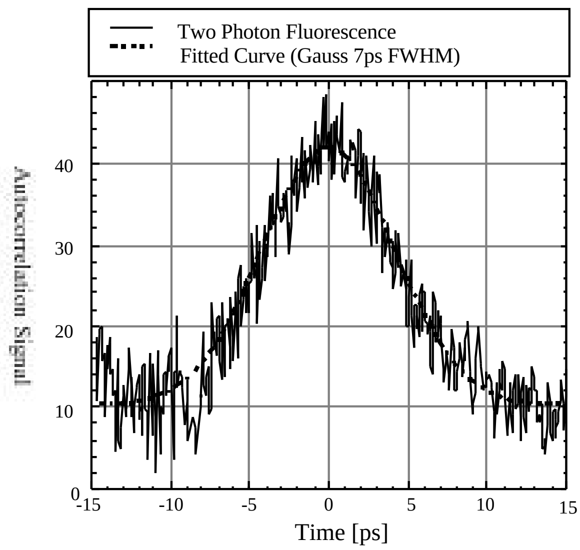

Fig.3 Duration of the short pulse measured by two photon fluorescence (at 30 cm amplifier output).

The short pulse is amplified through a chain of amplifiers of the Super-ASHURA. In the strongly saturated amplification, the pulse width is compressed down to a few picosecond due to gain depletion at the pulse tail. Figure 3 shows pulse duration after 30 cm e-beam pumped amplifier. At this point, pulse duration has been compressed to 7 ps. From the main amplifier (60 cm aperture), peak power of 3 - 4 TW (10 -15 J / 2-3 ps) can be obtained per pulse. The pulse can be focus to a spot size of 20 micrometer by F = 8 focusing lens and the peak power density is estimated to be 10^{18} W/cm^2.

4. Target Experiment

Arrangement of the short pulse interaction experiments is shown in Fig.4. One beam line of the Super-ASHURA is used to produce a long scale-length plasma by spatially smoothed long pulse (100 J / 20 ns, 10^{13} W/cm^2). A short pulse amplified through another beam line is focused on to the preformed plasma. Peak power and focused power density of the short pulse is estimated to be 3.5 TW and 10^{18} W/cm^2 respectively.

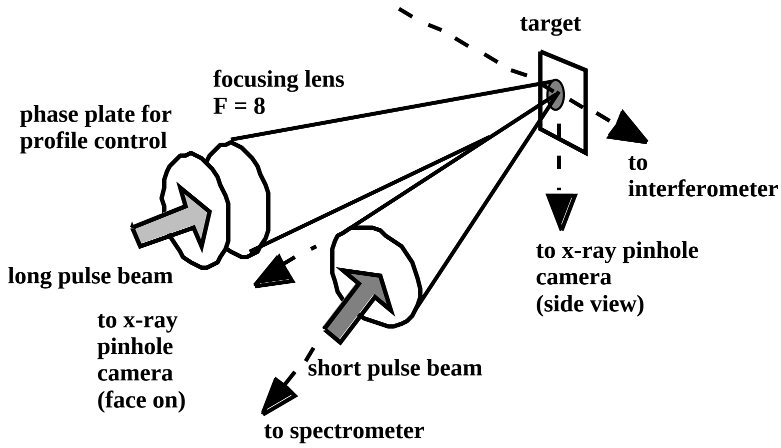

Fig. 4. Arrangement for intense beam interaction experiments.

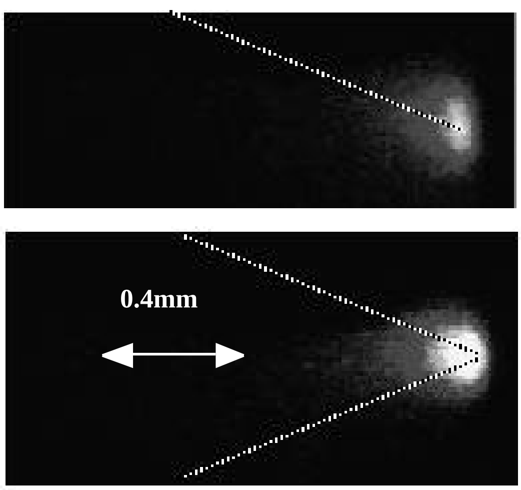

Fig. 5. Side view x-ray images of plasma produced by
Top: long pulse only at ~ 1keV,
Bottom: overlapped long and short pulses at ~ 3 keV.
Both were imaged through 0.05mm pinhole.
Lines show directions of incident pulses

Figure 5 shows side view x-ray pinhole images for long pulse only irradiation at photon energy of 1 keV (top) and long and short pulse irradiation at photon energy of 3 keV (bottom) respectively. In this case, short pulse was injected 10 ns after the rise of the long pulse. Intensity profiles show that the short pulse reached to the point close to the original target surface. High energy electron and rear side x-ray image measurements are being prepared.

5. Conclusion

A high repetition-rate e-beam pumped KrF laser has been developed as a prototype of future IFE driver, and e-beam is being injected into the laser gas chamber. Laser oscillation at 1 Hz with output energy over 20 J is expected in near future.
Intense short pulse (> 10 J, ~3 ps) has been generated by using a Super-ASHURA's beam line, and interaction experiments with a power density ~ 10^{18} W/cm^2 were performed with long scale-length plasma produced by 20 ns pulse. X-ray images show that the short pulse reached to the point close to the original target surface.

References

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