Construction of the 1 kJ Nd:Glass laser facility at KAERI

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Abstract. We report on the design and present status of a 1 kJ Nd:Glass laser facility for basic research on quantum engineering at KAERI (Korea Atomic Energy Research Institute). By applying a newly designed spatial filter with a serrated aperture, we improved the diffracted Gaussian spatial profile of an oscillator into a flat-top one. The laser system consists of 4 beam lines, each with the energies of more than 200 J at the nano-second regime. We measured the gain and spatial profiles of each amplification stage. A spectral shaping by a two-stage OPCPA (Optical Parametric Chirped Amplifier) for a pico-second front end was studied to compensate for gain narrowing in multi-stage amplifier chains.

1. Introduction
One of the purposes of high energy lasers, such as NIF, LMJ, Gekko XII and SG-III, is to investigate the principles of a high energy density plasma science [1-5]. The high energy density plasma produced by high energy lasers has received vast attention due to its fundamental physics and variety of applications; laboratory astrophysics, the acceleration of a high energy electrons and protons, equation of state, and fast ignition for inertial fusion energy. The photo-radiation sources from the laser interaction with matter have also opened up a new science field in quantum engineering.

The Korea Atomic Energy Research Institute (KAERI) is developing a 1 kJ Nd:Glass laser facility for basic research on quantum engineering. The 1 kJ Nd:Glass KAERI laser facility (KLF) is based on the laser components of Gekko IV [6] which was transferred from the Institute of Laser Engineering (ILE) Osaka University Japan in January 2005. The KLF system will deliver 4 beam lines with a clear aperture of 100 mm and each beam will be more than 200 J at the nano-second regime. For a wide application of the system, we designed the laser to be operated in hybrid type; 1 kilo-joule from 4 beam lines at the nano-second regime and 50 TW one beam line at the pico-second regime. Combination of nano-second high energy beams with a pico-second high power beam is expected to open up a new physics field for high energy density plasma science.

This paper will present the current status of KLF. The system design and engineering facilities were completed in March 2006. All laser components were installed on an optical bench. We measured the gain and spatial profiles of each amplifying stage. KLF is expected to demonstrate its first laser-plasma experiment through 4 beams by early 2008.
2. Engineering facilities and optical layout

Re-structuring of the laser building was finished in March 2006. The building presents 500 m² of floor space on the ground level, reserved for the laser system and the spherical target chamber. The rooms on the ground level are equipped with class 2,000 clean rooms. For the cleaning of an optical component and laser cavity assembly, a class 100 clean room, of about 30 m², is also situated on the first floor of the building. The measured temperature and the humidity accuracy of the laser room have been less than 0.5°C and 3%. The foundation is a 30 cm thick layer of concrete, which is separated from the building to avoid a vibration at the site. A steel frame serves to hold the optical components to provide a stable beam transport to the implosion chamber room. The measured frame vibration amplitude was less than 5 μm. Control room is located on the second floor of the building.

In parallel to the building re-modelling, preparations for a laser installation were made. A schematic of the 4 beam KAERI laser facility is illustrated in Fig. 1. The test of the pulsed power system for the main amplifier was performed with a set-up of the capacitor bank and switching mode power supplies (SMPS). RG217/U coaxial cables are used to connect the capacitor bank to the flash-lamps. We tested the integrity of the flash lamps and pulse forming network without a Nd:Glass gain medium to avoid a thermal shock. Wireless current and voltage sensors were prepared to monitor the status of each flash lamp.

New electronic modules based on a micro-processor, 16F74 Micro-chip, were developed to control the SMPS, the ignitron switches and the monitoring of the flash-lamp discharge. These new modules allow for a remote computer control of the power supply units, ignitron switches, and a monitoring of the current of the lamp, gas/water flow, temperature and humidity. The control signals between the computer and micro-processor are delivered by an optical fiber to avoid electrical noise from the discharge.

3. Spatial beam profiles and gains

High spatial frequency component or diffraction ripples of the relay planes in a high energy pulsed laser system can cause damage to optical components. Based on the equations in ref. [7], we made a serrated aperture and spatial filter. The aperture outer diameter is 10 mm. The serrations have a height of 1.2 mm, period of 0.2 mm, and a V-shaped taper. The beam transmitted through the serrated aperture propagates through a 1.4 magnifying vacuum spatial filter. The input lens has a focal length of 0.5 m. The pinhole diameter of the spatial filter was 0.43 mm. Figure 2 shows the experimental results of the spatial profile. We improved the diffracted Gaussian spatial profile of the oscillator into a flat-top one.
Figure 2. Spatial beam profile (a) before a serrated aperture, (b) after a vacuum spatial filter and (c) photograph of the V-shaped serrated aperture (Tip is approximately 25 $\mu$m round).

Near field patterns of the rod amplifiers are shown in Fig. 3. The gain of each rod amplifier was measured between 2 and 9 depending on the charging voltage. The energy of the 80 mm rod amplifier was 110 J with a beam diameter of 67 mm. The energy variation of the 80 mm rod amplifier was less than 5% during the experiment.

Figure 4 shows near field pattern and far field pattern of the 110 mm disk amplifier. The energy of the 110 mm rod amplifier was 220 J in 8 nsec with a beam diameter of 98 mm. The maximum gain of the disk amplifier was 2.3. The oscillator wavelength (Quanta-ray Pro-230, Spectra Physics) is 1064 $\mu$m, which is far from Nd:Glass (Hoya LHG-8, LHG80) wavelength of 1054 $\mu$m. So, a matching between the oscillator wavelength and the amplifier wavelength could improve the energy of the system.
4. OPCPA for short pulse front-end

Advantages of OPCPA include a broad gain bandwidth, high gain in a short optical path, and reduced amplified spontaneous emission. In this paper, we studied spectral shaping by a two-stage OPCPA to compensate for the gain narrowing in multi-stage Nd:Glass amplifiers. Gain narrowing is one of the limitations in preserving the bandwidth of oscillator during amplification of short pulse in multi-stage Nd:Glass laser. To predict the spectral profile of the OPCPA, we introduce a gain-distortion parameter:

\[
D = \log_{10} G \times \left( \frac{\Delta s}{\Delta s_0} \right) \times \exp \left( -a \frac{\Delta \lambda_c}{\Delta \lambda_0} \right) \tag{1}
\]

where \( G \) is the total gain of a signal, and it is defined by

\[
G = \frac{\int g(\lambda, \theta, \alpha) s(\lambda) d\lambda}{\int s(\lambda) d\lambda} \tag{2}
\]

\( s(\lambda) \) is a signal as a function of a wavelength \( \lambda \), and \( g(\lambda, \theta, \alpha) \) is a calculated gain profile as a function of a wavelength \( \lambda \) and of a configuration \((\theta, \alpha)\). From formula (1), \( \Delta \lambda_c/\Delta \lambda_0 \) is a bandwidth factor, which is defined by a ratio of the spectral bandwidth between \( \Delta \lambda_c \) (of an original signal) and \( \Delta \lambda \) (of an amplified signal).

By controlling the incident angle of two BBO crystals, we obtained a spectrum that is reduced in the centre as shown in Fig. 5. The amplified spectrum of spectrally-shaped incident pulse can compensate for gain narrowing of the amplifiers and it can also reduce the pulse duration after a compressor.

![Figure 5. The calculated gain of the two-stage OPCPA as a function of a wavelength.](image)

5. Conclusion

We have constructed a 1 kJ Nd:Glass laser facility, which will demonstrate its first laser produced plasma in a few months. We measured the gain and spatial profiles of each amplifying stage. The energy of a disk amplifier was 220 J in 8 nsec. We introduced a gain-distortion parameter to calculate the spectrum and gain of a two-stage OPCPA.

A short pulse front-end will be installed within a year to broaden application of the system.

6. References

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