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Recent progress in development of Nd:YAG laser for ITER edge Thomson scattering diagnostics

T. Hatae, T. Hayashi, S. Kajita[1)], H. Yoshida[2)], H. Fujita[2)], M. Nakatsuka[2)], J.-H. Lee[3)], K. Yahagi[4)], K. Shinobu[4)], T. Ono, Y. Kusama

Fusion Research and Development Directorate, Japan Atomic Energy Agency, 801-1 Mukoyama, Naka, Ibaraki 311-0193, Japan, [1)] Nagoya university, [2] Osaka university, [3)]National Fusion Research Institute, [4)]NEC Engineering, Ltd.

We are developing a high-energy (5J) and high repetition-rate (100Hz) laser system for ITER. Optical design of the laser system has been conducted. The design is based on the design of Nd:YAG laser for Thomson scattering system for JT-60U. A prototype laser amplifier has been designed, and developed experimentally. Two laser rods and four flash lamps are installed in the prototype laser amplifier. From initial tests of the prototype laser amplifier, it has been confirm that the net laser energy of ~1.3J is extracted from one laser rod.

Keywords: ITER, Thomson scattering, YAG laser, stimulated Brillouin scattering, phase conjugate mirror, laser oscillator, laser amplifier

1. Inroduction

An edge Thomson scattering system for ITER is a diagnostic system which measures electron temperature (T_e) and density (n_e) at a peripheral region of the plasma [1]. The edge Thomson scattering system is required to measure T_e and n_e over a relatively narrow spatial area (r/a>0.9) but with a high spatial resolution (5 mm at the midplane). The requirements are summarized in Table 1. A high-energy (5J) and high-repetition-rate (100Hz) Q-switched Nd:YAG laser system is necessary for this system. We are developing a high-energy and high repetition-rate laser system for ITER based on the laser design in JT-60U[2-5]. In this article we report recent progress in development of Nd:YAG laser for the edge Thomson scattering system in ITER.

Table 1. Requirement for ITER edge Thomson scattering system

Parameter	Area*	Range	Resolution		Accuracy
			temporal	spatial	
T_e	r/a > 0.9	0.05 – 10 keV	10 ms (100Hz)	5 mm	10%
n_e		5×10^{18}– 3×10^{20} m^{-3}			5%

*Measurement area of 0.85<r/a<1.07 has been considered recently.

2. Target performance of the Nd:YAG laser and technical issues

A laser system having energy of 5J, repetition rate of 100Hz, and pulse width of 10 ns is necessary in order to realize the ITER measurement requirement. Nd:YAG laser is possible to realize the performance. The Q-switched laser which simultaneously has energy of 5J and the repetition rate of 100Hz is categorized as a high average power laser. It generally requires advanced technology in order to make the high-average-power laser. The 5-J, 100-Hz Q-switched laser has not been made until now. The technical issues of development the high-average-power laser are as follows.

(1) Limitation of the output energy by thermal lensing effect which are caused by the temperature gradients across the active area of the laser rod.

(2) Decreasing of the beam quality by deplolarization which are caused by thermally induced birefringence.

(3) Decreasing of the output energy by parasitic oscillation which originates from multistage and high gain amplifiers.

The stimulated-Brillouin-scattering phase conjugate mirror (SBS-PCM) is an important tool for improving the performance of high-average-power laser systems [6]. It is possible that the SBS-PCM compensates the thermally induced wavefront distortion such as the thermal lensing effect, and improves the depolarization caused by thermally induced birefringence. Furthermore, the parasitic oscillation due to the amplitude spontaneous emission (ASE) is suppressed by threshold of the stimulated Brillouin scattering. In the Nd:YAG laser system for Thomson scattering in JT-60U, SBS-PCMs has been utilized, and successfully achieved energy of 7.46J and repetition rate of 50Hz[2-5]. The ITER laser system is designed based on design of the JT-60U laser system.

author's e-mail: hatae.takaki@jaea.go.jp

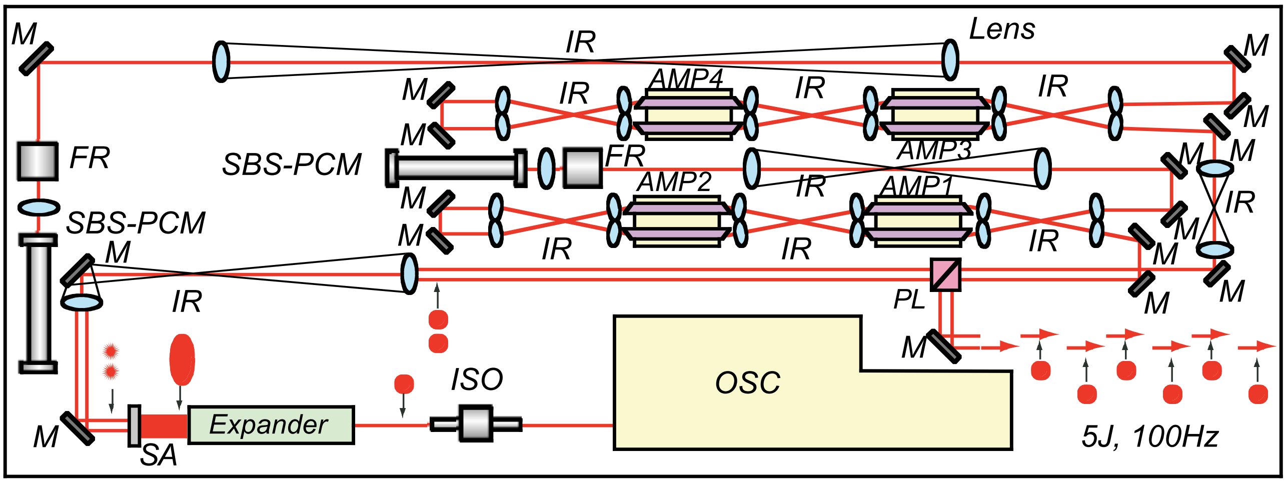

Fig.1 Optical layout of Nd:YAG laser for edge Thomson scattering system in ITER

3. Design of Nd:YAG laser for edge Thomson scattering system in ITER

In the optical configuration of the laser system, MOPA configuration is adopted. The oscillator produces single-longitudinal-mode (SLM) laser pulse (Energy =20mJ, repetition rate=100Hz, pulse width=30ns) [1,7]. The laser beam from the oscillator is shaped from a circular pattern to elliptic pattern using a beam expander composed of cylindrical lenses. The elliptic pattern is divided into two beams, and converted to top-hat profiles employing a dual serrated aperture (SA) and a successive spatial filter. Relay imaging optics (IR) are installed to maintain the top-hat profile. Each beam is amplified by an amplifier stage utilizing an SBS-PCM. There are two high-power amplifiers in the amplifier stage, and four laser rods are used in the laser system. Double-pass amplified beams by the SBS-PCM are extracted by a polarizer (PL). To reduce the thermal effect, each amplifier stage is fired at 50Hz, and dual beams are amplified alternately by dual amplifier stages. Finally, 100-Hz, 5-J beam is obtained. The optical layout is shown in Fig.1. Note that the dual beams are automatically aligned by the phase conjugate effect, and shapes and positional relation of dual input beam before dual amplifier stages and final output beams are always identical at the polarizer.

Output energy is roughly estimated from the performance of JT-60 amplifier. Net extract energy which is defined difference between the output energy and the input energy of a rod was measured using JT-60 amplifier (14mm of Nd:YAG rod diameter, 90 mm in length). Since the maximum extract energy is 1.86 J, total extract energy using four rods is expected 7.44J. If effective amplification is carried out, the output energy over 5J is expected in the case of ITER laser system.

4. Design of prototype laser amplifier

For the compact optical layout, two Nd:YAG laser rods (14mm in diameter, 100mm in length, 5.35° of wedge angle, concentration of Nd is 1.1 atomic%) and four xenon flash lamps are installed in a prototype amplifier. Each laser rod is pumped by two flash lamps, the electric energy of ~100J is supplied to two flash lamps at 50Hz of repetition rate. The average electric power of 10kW is supplied per one amplifier. The efficiency of Nd:YAG laser is ~2%, generally. Most of the electric power is changed to the heat in the amplifier. Therefore, ~10kW of heat removal is required for the amplifier, effective cooling techniques are necessary. Fig.2 shows a schematic of the prototype amplifier. Bolosilicate-glass flow tubes are installed to effectively cool for laser rods and flash lamps. Gap between the laser rod (flash lamp) and the flow tube is 1mm. The reflector is gold-plated mirror, and is cooled by cooling water.

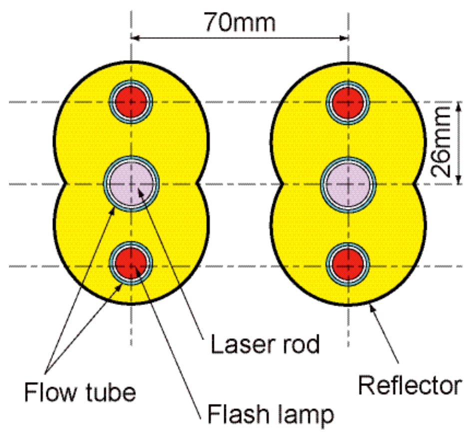

Fig.2 Schematic of prototype amplifier (cross section)

5. Initial tests for prototype amplifier

The small signal gain (SSG) of new amplifier has been measured using the ITER SLM oscillator. The SSG and the extracted energy measurement are shown in Fig.3. Though the SSG monotonously increases in the low charged energy region, the SSG is saturated around 65J as shown in Fig.3(a). The SSG of ITER amplifier is lower than that of JT-60 at the full pump (100J of charge energy). The maximum extracted energy is ~1.3J at the full pump as shown in Fig.3(b). JT-60 laser system is used to measure the extract energy of ITER amplifier.

Since intensity of the flash lamp emission increases with increasing of the charged energy, it seems that the laser rod is pumped normally. Further more, significant ASE is not observed. Influence of repetition rate and flow rate of cooling water upon SSG is examined. The SSG decreases with increasing of the repetition rate. This means the SSG decreases when the heat load increases. Even if the flow rate of cooling water for one laser rod is changed from 2.6 to 4.1L/min at 20°C, the SSG is not drastically improved. We think that the rod center is not cooled sufficiently.

As for the laser crystal, the gain profile shifts to the long wavelength side when the temperature of the crystal rises as shown in Fig.4 [8]. From the characteristics, we think that the laser beam of the oscillator can not be sufficiently amplified due to the mismatch of gain profile and wavelength of oscillator. Since it is difficult to lower the temperature of the rod center, the gain profile control is also difficult. To amplify in the best gain, we consider that matching the wavelength of oscillator with gain profile of the amplifier is effective. We will measure their spectra to verify this hypothesis.

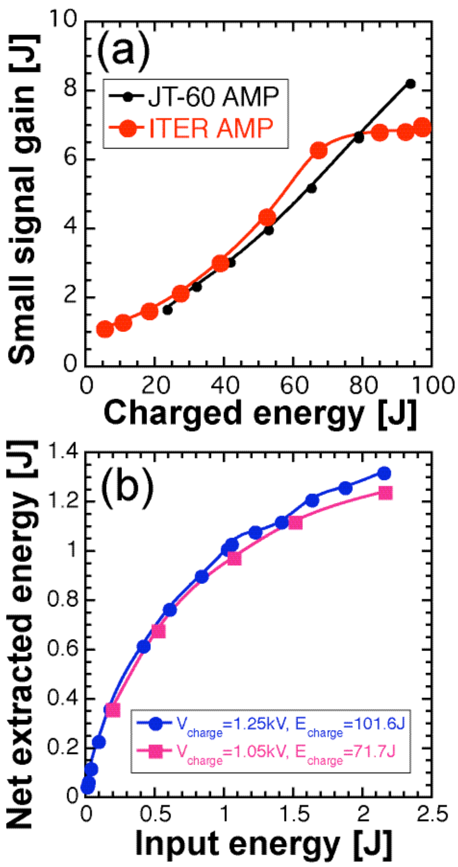

Fig.3 (a) Small signal gain versus charged energy for flash lamps (repetition rate 50Hz). (b) Net extracted energy versus input energy to ITER amplifier.

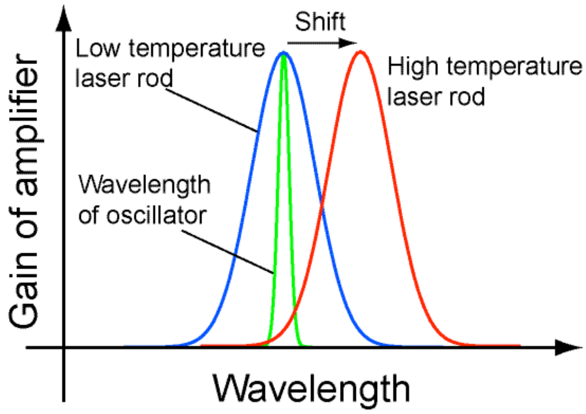

Fig.4 Gain profile shift of laser amplifier with changing the rod temperature

6. Conclusion

A Nd:YAG laser for ITER edge Thomson scattering system is developing. The target performance is 5J, 100Hz. Design of the laser is based on that of laser system for Thomson scattering in JT-60U. New laser system will utilize stimulated-Brillouin-scattering phase conjugate mirrors to solve issues for high average power lasers. To get high reflectivity of the phase conjugate mirror, a laser oscillator with the single longitudinal mode has been developed. A prototype laser amplifier has been produced experimentally. From the initial tests, it found that the small signal gain was saturated around the maximum pumping. We are investigating the causes. As one possibility, we consider the mismatch of amplifier's gain profile and wavelength of oscillator causes saturation of small signal gain. We will measure their spectra to verify this hypothesis. Producing improved four amplifiers, and the assembling of the new laser system will be started in 2009.

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