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Improvement of Thomson Scattering System Using SBS Phase Conjugation Mirrors in JT-60U

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1. INTRODUCTION

Thomson scattering diagnostics is one of the standard diagnostics for electron temperature and density measurement in magnetic fusion devices. Since the Thomson scattering light is very weak, an increasing of scattered light improves the measurement accuracy. Increasing the incident laser energy is the most effective way in order to increase the scattered light without degrading the measurement accuracy. Possible methods to increase the laser energy and scattered light are as follows: (1) Bundle the beams from more than one laser device into a single path. (2) Make an incident laser beam go back and forth in the plasma to double a scattered energy. (3) Improve the existing laser to get higher energy output.

Since these improvements need generally a large amount of R&D cost, a long-term research period and a larger laser system, then, more development of new optical technology is required. This paper focuses on items (2) and (3). A high performance phase conjugation mirror by stimulated Brillouin scattering (SBS-PCM) using a liquid fluorocarbon was introduced into the existing YAG laser Thomson scattering system at JT-60U. For the item (2), a double path Thomson scattering method with SBS-PCM was newly proposed. For the item (3), improvement of the output energy of YAG laser system using the SBS-PCM was achieved.

2. HIGH PERFORMANCE PHASE CONJUGATION MIRROR

A phase conjugation mirror by stimulated Brillouin scattering (SBS-PCM) [1-3] generates a reflecting wave whose shape of spatial wave front is the same as that of incident wave front and its direction of propagation is perfectly reverse. The SBS-PCM compensates a wave front distortion that occurs when a laser beam propagates through optically non-uniform medium due to thermally induced aberration in high power amplifying rods of solid-state lasers. An SBS cell for SBS-PCM including a liquid SBS medium is a stainless steel pipe (length=300mm, bore=30mm) with AR-coated windows at both ends. A liquid fluorocarbon (the trade name is 3M Fluorinert, FC-75) filtered by a membrane filter (0.025 μm) is used as an SBS medium [4]. To operate the SBS cell as a reflective SBS-PCM, the incident laser beam was focused with a plano-convex lens (f=150mm or 200mm). Figure 1 shows the reflectivity of SBS-PCM, that has a high reflectivity of 95% at high laser energy input of 1.8J with a repetition rate of 50Hz (average power is 90W).

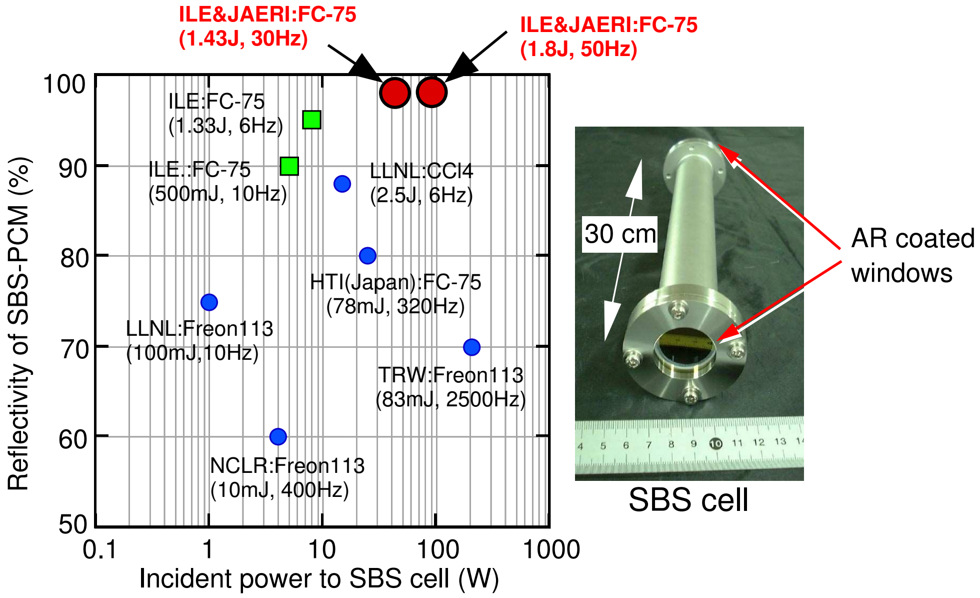

Fig.1. Reflectivity of SBS-PCM and the outside of SBS cell

3. DOUBLE PATH THOMSON SCATTERING METHOD BY USING SBS-PCM

For the application of SBS-PCM, we newly propose a double path Thomson scattering method with SBS-PCM as shown in Fig.2. In this new optical design, a laser beam passing through the plasma is reflected by the SBS-PCM in place of a beam dumper, and a reflected beam returned back through exactly the same path as the incident one by the phase conjugation effect, and passed through the plasma again. If a conventional mirror is used for this purpose, very severe beam alignment is frequently required to reduce a stray light. However, it is completely unnecessary for such alignment in the case of SBS-PCM. After an initial simple positioning, the SBS-PCM is alignment-free. By this new method, we obtain two times larger scattered light with an alignment-free operation in contrast with a conventional single path design. A Faraday isolator easily removed the laser beam returning back to the laser system. The input power to SBS cell was about 100W (2J, 50Hz). Note that double path amplifiers with SBS-PCM that is mentioned later is not installed in the laser system to get high reflectivity of SBS-PCM. From the preliminary results using the double path scattering, the scattered light became 1.6 times larger and relative error reduced to 2/3 of that for single path scattering as shown in Fig.2. The amount of scattered light by a returned laser beam is affected by followings: a laser quality (quality of single longitudinal mode structure), small depolarization due to propagation with standard mirrors and transmission loss. If the laser quality and depolarization could be improved, the amount of double path scattered light would be increased to about 2 times. On the other hand, the double path scattering also increased the amount of stray light to 1.6 times of that for single path. Since the stray light in JT-60U has been always kept at a low level compared with scattered light, the increased stray light has not influenced the measurement of scattered spectra.

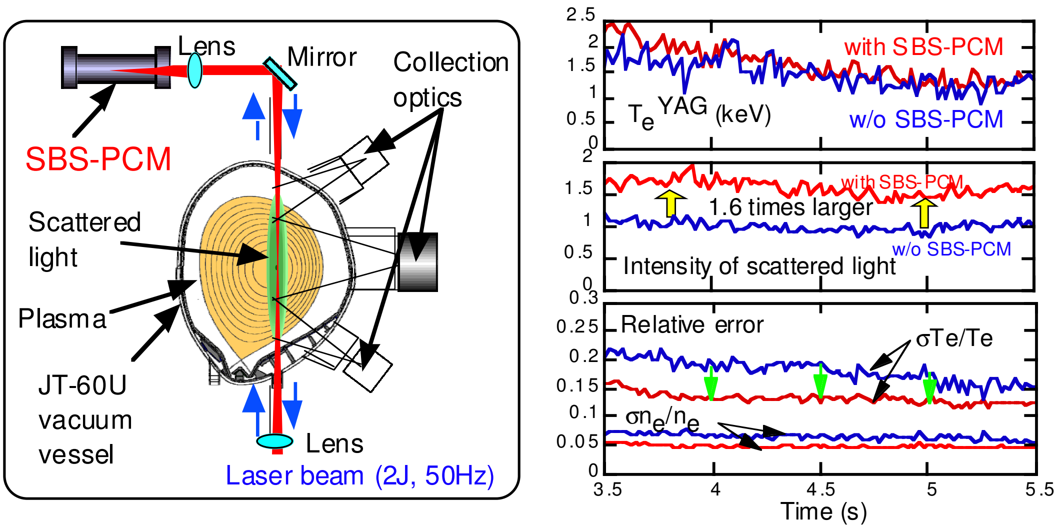

Fig.2. Schematic of double path Thomson scattering measurement and its first result

4. INCREASE OF LASER OUTPUT POWER BY USING SBS-PCM

The SBS-PCMs were installed in each of the multi-stage YAG amplifiers in order to change the amplification arrangement from a single to double path amplification. Schematic of double path amplification is shown in Fig.3. The laser source was a linearly-polarized, single-frequency, TEM_{00} Nd:YAG Q-switched laser. The output was amplified to 30mJ in a quasi-Gaussian pulse shape, and its FWHM was about 30ns at a repetition rate of 30-50Hz. The input beam passed through a polarizer, and entered amplifiers. The one-pass amplified output beam passed through a Faraday rotator, and was focused into a 150 mm point inside a 300-mm long SBS cell by a lens of 200-mm focal length. The 90-degree rotator was inserted between amplifiers to compensate the depolarization induced in the laser rod. Although a reflected beam by the SBS-PCM returned through the same path, the polarization of the beam was rotated 90-degree against the incident one by the Faraday rotator. Consequently, since the polarization of output beam was rotated 90-degree, the doubly amplified beam was extracted by the polarizer. The double path amplification using SBS-PCM increased the laser energy by 40% in contrast with that of single path at 30Hz operation. We must draw attention to a time evolution of pulse waveform. In the case of input pulse, the energy rises to its peak for 30ns. In the case of output pulse after double path amplification, the pulse has a sharp increase for ~2ns. The reason for the sharp increase is that a rising edge of reflected pulse is made steep gradient due to a SBS process and it is emphasized due to a process with threshold power in YAG amplifiers. Furthermore, when the pulse with sharp rise was reflected by the SBS-PCM, the SBS-PCM did not work fully. The remained issue is a multistage double path amplification using SBS-PCM.

The phase conjugation of the optically nonlinear SBS process compensated perfectly a thermal effect of power amplifiers, and an average power increased from 1.5 J in 30-Hz repetition (average power was 45W) to 4J at 50-Hz drive (average power was 200W) as a result of the implementation of SBS-PCM. The beam quality was also recovered without a wave front aberration with a transfer-limited divergence and a good flattop pattern in a near field.

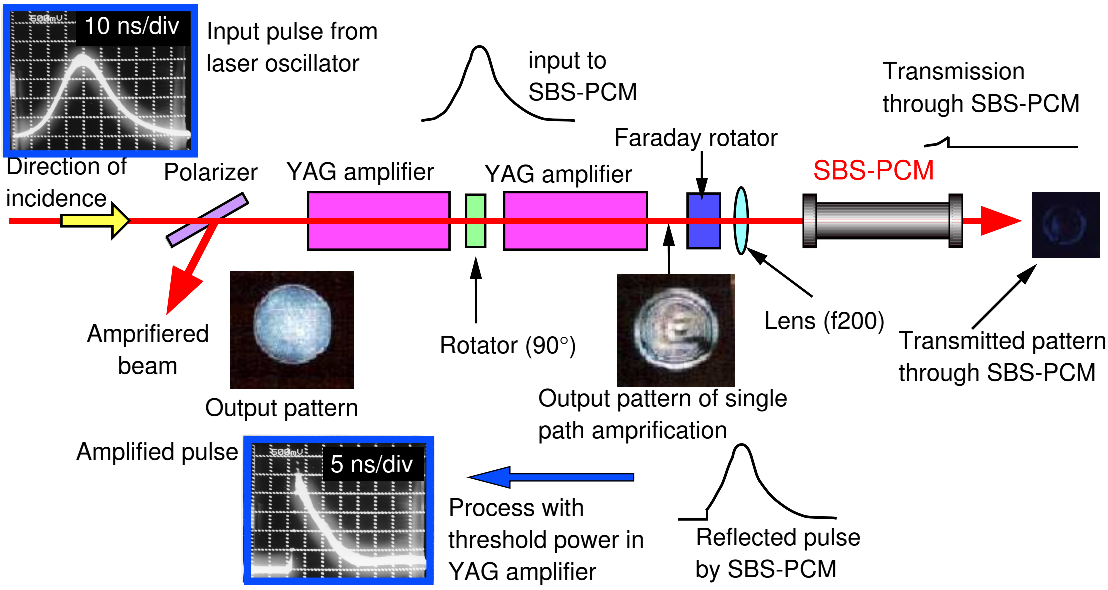

Fig.3. Schematic of double path amprification with SBS-PCM

5. CONCLUSION

A double path Thomson scattering method with SBS-PCM demonstrated for the first time and the scattered light increased 1.6 times larger than the conventional measurement. It is possible to extend this idea to a multi-path scattering scheme in which laser beam goes back and forth in the plasma many times. Also, an improvement of the output beam power/quality of multi-stage YAG laser system by using the SBS-PCM was achieved. Consequently, average power was increased up to 4.4 times in contrast with conventional system. Both approaches promise us precision Thomson scattering diagnostics with higher accuracy in JT-60U.

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