UPGRADING OF THOMSON SCATTERING SYSTEM FOR MEASUREMENTS OF SPATIAL DYNAMICS OF PLASMA HEATING IN GOL-3

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Thomson scattering diagnostics has been updated to allow measurements at two instants of time for either of two spatial points in plasma during a single plasma discharge. Laser produces now two 15J laser pulses with variable (0.2 -100μs) delay between them. It was made possible by integration into previous laser system a second independent laser oscillator. Multichannel spectral measurements of scattered radiation can be accomplished at two spatial locations simultaneously, at z_1*=4m from the input of electron beam into plasma (old location) and at* z_2*=2m (new location). Three geometries of measurement are possible: a single radial point at each of plasma cross-sections at* z_1 *and* z_2 *or two radial points at either cross-sections at* z_1 *or* z_2*. Number of radial points is limited by number of available detector channels (15ch) now. We present first experimental results with 90° detection of scattered radiation with upgraded system.*

I. DIAGNOSTICS GOALS

In recent years, considerable progress has been achieved in studying of the beam-plasma system in the GOL-3 multimirror trap [1]. New interesting effects, such as fast ion heating, suppression of longitudinal electron heat transport, excitation of large-scale plasma density fluctuations, and the generation of neutron flux oscillations at μs-time scale were found [1, 2]. To describe these effects, various models have been proposed that require additional experimental verification. In papers [3, 4] the main attention was focused on measurements of plasma electron distribution function details with Thomson scattering (TS). In these experiments a single pulse laser was employed that makes possible observation of fast dynamics of the distribution function only on shot-by-shot basis. Typically in magnetic confinement plasma systems the temporal resolution in TS measurements is achieved by using either several repetition rate lasers combined into a single beamline [5] or with lasers operating in a burst mode [6]. A burst mode operating ensemble of separate Nd:YAG lasers can provide a μs-range time resolution [7]. The standard energy in a single laser pulse for such laser systems is 1-2J that is not sufficient for experiments on GOL-3. Here TS is required to measure non-Maxwellian plasma electron distribution function with electron tails extended up to heating electron beam energy ~1MeV and under condition of intense and fast varied plasma background light. The previous Nd-glass laser produced 20J single laser pulse in a system of master oscillator and two amplifiers [3] and enabled detection of plasma electrons with energy up to 20 keV [3]. New laser should extend this ability to several spatial locations in radial and/or axial directions and for at least two laser pulses during a single plasma shot. Generally, information on axial variation of plasma parameters is essential for mirror plasmas. TS can fit this requirement with the use of the LIDAR layout [8], or simply by forcing a probe laser beam to pass trough plasma several times each time at different axial location. In this work, setup of the new Thomson scattering diagnostics is described. First results from measurements of the electron distribution function in the GOL-3 multimirror trap are presented.

II. THOMSON SCATTERING DIAGNOSTICS

II.A. Laser setup.

The standard multi laser approach to temporally resolved TS [5] is too expensive with 10-30J lasers. Besides relative large single beam diameter (40mm) for such lasers makes combined laser beam cross-section too large to use it in TS. We employ two-module master generator that produces two coaxial laser pulses for upgraded laser system. Diagram of this generator is shown in Fig 1.

The modules are equipped with phosphate Nd-glass rods and optical Q-switches based on the Pockels cells. Each oscillator produces a single laser pulse (20-40ns, 10-30mJ, 2mm diameter (d), 1054nm). Then the beams are combined by mirrors and beam splitter (see Fig. 1). Time interval between two pulses can be varied from 0.1 to 100 μs. After passing preamplifier the 2mm diameter beam is directed to input of 5-pass telescopic phosphate glass amplifier and finally to silicate glass output amplifier. The total gain of two stages is order of 10^3 with the gain of the first stage near 200. The amplification of the first stage is strongly nonlinear with considerable gain saturation by the first pulse. As the gain for second laser pulse is several times lower it is compensated by respective increase of second laser pulse energy injected from master oscillator. In addition, variation of first amplifier gain mostly affects the first pulse amplitude while variation of second stage gain influences the output energy of both pulses evenly. Slight adjustment of gains of two amplifier during experimental campaign permits to keep the energy for two laser pulses equal. More detailed description of amplifiers is given in [3]. The parameters of the output laser beam in each pulse are as follows: *E=10*- 20 J, *t= 20-40* ns and *d* = 40 mm.

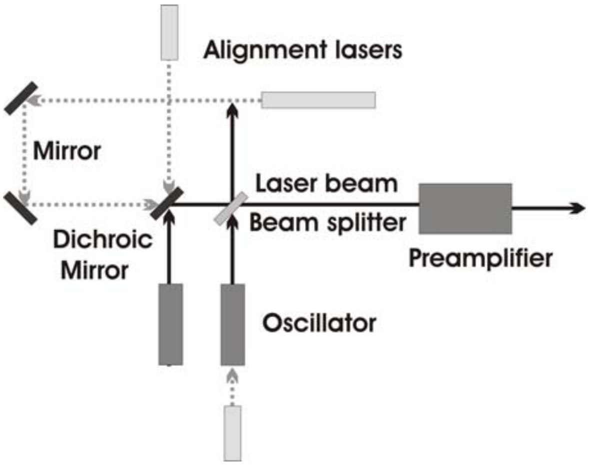

Fig.1. Two-pulse oscillator setup.

II.B. LAYOUT OF EXPERIMET.

A schematic of Thomson scattering diagnostics is shown in Fig. 2. The laser beam crosses the plasma normally to the magnetic field initially at about z=4m from the input of relativistic electron beam (REB) into plasma column. Then the laser beam is redirected by mirrors and crosses the plasma again at z=2m. The laser beam is focused near the plasma axis to the focal spot diameter a=0.2mm. Scattered at 90° light is collected by lens into inputs of 1mm-diameter 40m length IR silica fibers and directed to the control room. Each fiber transmits light scattered from (0.2 × 0.2 × 4 mm^3) volume. In the first experiments number of spatial locations was limited to 2 by the available detectors. Two radially separated (r_1=0mm and r_2=12mm) positions of scatter volumes at z=2m, newly accessible and closest to REB input plasma cross-section have been chosen. We use a grating polychromator with the same type silica fiber at the polychromator output. APD-amplifier modules based on Perkin Elmer C30659-1060-3A detectors are used to record scattering signals. The laser power and the photodetector sensitivity were monitored using a fiber delay line, through which a fraction of laser radiation was fed to a polychromator and uniformly illuminated all the recording channels.

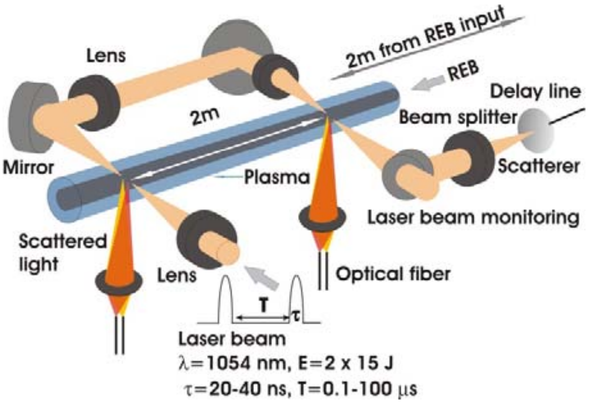

Fig. 2. Thomson scattering system**.**

III. FIRST EXPERIMETS RESULTS AND DISCUSSION

The experiments were performed with a plasma ($n_e=10^{14}$- $10^{15}cm^{-3}$) placed in a multimirror magnetic field (B_{min}= 3.5 T, B_{max}=4.8 T). Discharge plasma is heated with REB ($E\approx$1 MeV, $J\approx$30 kA, τ=11μs)

Figure 3 shows typical waveforms of the scattered signals. The first and third spikes correspond to the scattered signals, whereas the second and fourth spikes, to the calibration signal supplied via the fiber delay line.

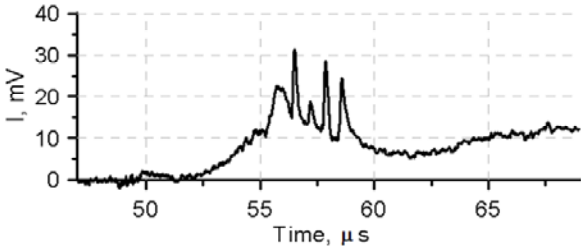

Fig. 3. Typical waveform of scattering signal.

Fig. 4 shows typical scattering spectrum at maximum of plasma electron energy content. This spectrum is equivalent to one-dimensional electron velocity distribution function. It can be seen that experimental points deviate significantly from the spectrum of light scattered by Maxwellian electrons, this deviation is typical for plasma heated with REB [1, 3]. A bi-temperature distribution can be fitted to experimental data. With additional assumption about isotropy of distribution function an averaged energy of plasma electron can be estimated as <E>= 2 keV an $<n>=3.5\cdot10^{14}cm^{-3}$.

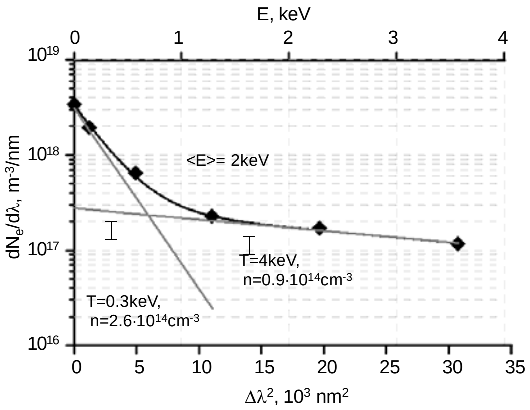

Fig.4. Bi-temperature scattered spectrum fitted to experimental data.

An example of plasma electron distribution function dynamics recorded with new TS system is shown in Fig. 5. Here the averaged energy of plasma electrons

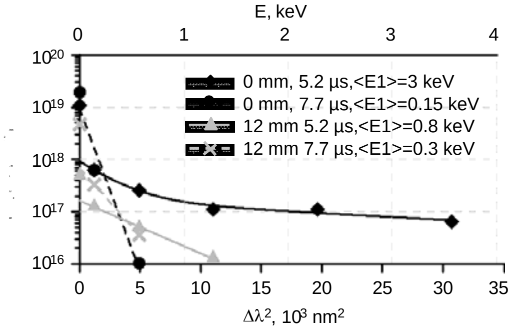

Fig. 5. Scattering spectra at two spatial locations for two time moments.

in the plasma core decrease almost one order within 2.5 μs, which is the time separation of two laser pulses. The density varies from $1.2\cdot10^{14}$ to $4\cdot10^{14}$ cm^{-3} Behavior of plasma parameter closer to the plasma edge shows the same tendency but with much smaller relative variation in averaged energy.

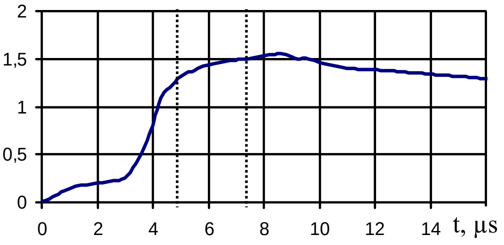

Fig. 6. Diamagnetic signal. Doted lines are laser scattering moments.

The energy content in plasma electron decreases during this time according to these data while the diamagnetic signal remains constant (see fig.6.). All these data match the ion fast heating scenario [9] but needs more comprehensive observations.

IV. CONCLUSIONS

The incoherent Thomson scattering system has been upgraded to allow more effective investigation of dynamics of electrons distribution function and heat transport in electron beam-plasma system.

First experimental data show cases of fast variation of electron distribution function which may correspond to fast heating ion scheme. To study details of this dynamics we will obtain more data and improve diagnostic. For this purpose we will increase number of spatial locations and number of detector channels. In order to investigate high energy electron tails we plan to use the small-angle TS scattering [3].

ACKNOWLEDGMENTS

This work was supported by Russian Ministry of Education and Science, Grants 2.1.1/3983, 2.1.1./3465, P2309, P276, 02.518.11.7113; Russian Academy of Science, Projects 30, 33; 34, 113; Russian Foundation for Basic Research, (RFBR) 08-01-00622a, 10-02-01317a, 10-08-00707a,.Grant of President Russian Federation MK-695.2009.2.

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