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Measurement of temperature evolution for the laser ion source plasma

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Abstract

Temporal evolution of X-ray spectra of lead plasma produced by a CO_2 laser pulse with energy of 100 J and a duration of 15 ns has been measured using a six-channel X-ray polychromator. The polychromator registered the radiation intensity in the range from 180 to 1850 eV. Plasma temperature was determined by comparison of measured results with radiation spectra obtained by numerical simulation. The values of electron temperature are in good agreement with results of hydro simulations.

Keywords: Radiation; X-ray polychromator

Beams of multicharged ions are widely used for experimental studies, for example, in nuclear physics and fusion research (Baranov *et al.*, 1996; Fournier *et al.*, 2000), as well as for material studies and processing (Pleshivtsev & Bazhin, 1998). Such beams can be efficiently extracted from a laser-produced plasma. Plasma ion composition is a function of its temperature, density, and lifetime. Time evolution of these parameters affects, in turn, characteristics of an extracted ion beam. This article is aimed at investigation of temperature dynamics in lead plasma, created by a pulse of CO_2-laser TIR with pulse duration 15 ns and total energy 100 J (Makarov *et al.*, 2001). This type of diagnostic is also of interest for ICF studies.

The scheme of experiments is shown in Figure 1. The peak power density provided by the laser beam on the lead target surface was $P \simeq 3 \cdot 10^{13}\ \mathrm{W \cdot cm^{-2}}$. The radiation characteristics for generated plasma were measured with temporal resolution using an X-ray polychromator (Akhsakhalyan *et al.*, 1992) designed according to the scheme Θ–2Θ. Multilayer X-ray mirrors were used as dispersive elements. The channel registration energy E_{ch} is varied, changing the mirror inclination angle Θ. The device has six channels, which can be matched to energy $E_{ch} = 180$–1850 eV.

E_{ch} for "hard" channels were chosen from condition $E_{ch} > 1$ keV to avoid to the maximum possible extent the influence of spectral lines. This threshold energy was obtained in model simulations using the GIDRA code (Roerich & Stepanov, 1994). The simulation was performed for one-dimensional geometry, lead target, and radiation parameters that are typical for the TIR installation. A simplified—"scaled hydrogenic"—atomic model was used for calculation of level energies and elementary processes that determine the level populations. Ideally, E_{ch} for all polychromator chan-

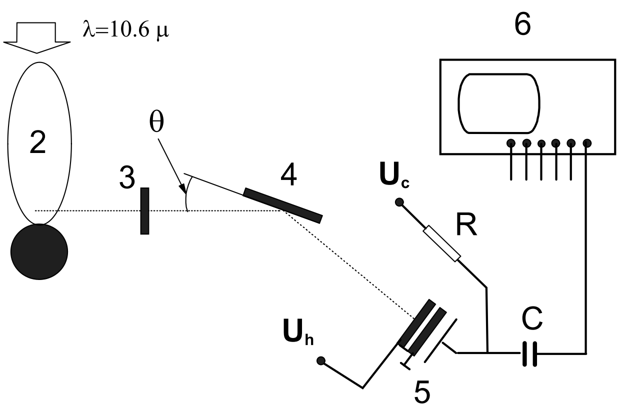

Fig. 1. Polychromator measurements scheme: 1—target, 2—plasma jet, 3—X-ray filter, 4—multilayer mirror, 5—micro-channel plate with collector, 6—oscilloscope.

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Table 1. *Polychromator registration channels characteristics*

	Number	Channel energy (eV)	Reflection index of the mirror	Registration zone width (eV)	Filter and its thickness (μm)
Soft channels		183	0.375	11.3	Ag, 0.3
		525	0.106	9.2	Cu, 0.3
Hard channels	1	1080	0.324	19.5	Be, 25
	2	1250	0.356	21.3	Be, 30
	3	1486	0.447	25.3	Be, 30
	4	1865	0.224	29.3	Be, 30

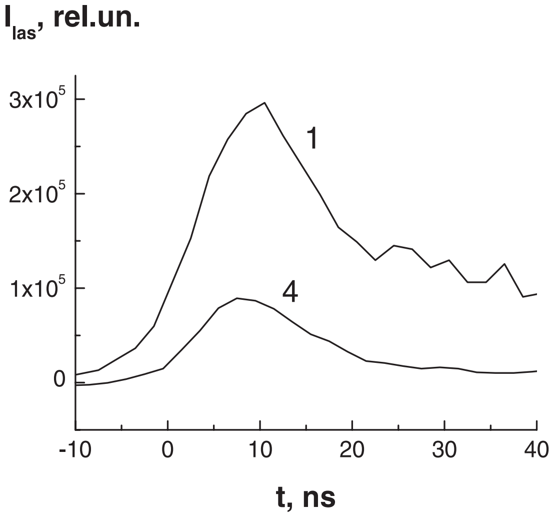

Fig. 2. Temporal shape of signals from channels 1080 eV (1) and 1865 eV (4) in the case of a smooth laser pulse.

nels must correspond to the continuum "tail" of the X-ray spectrum. But, practically, the registration energy is restricted by a value of $E_{ch} \simeq 1850$ eV. In the energy region $E_{ch} > 1000$ eV four channels were used in the device. Two other "soft" channels, tuned at energies $E_{ch} = 183$ eV and $E_{ch} = 525$ eV, allowed us to compare the temporal dependence of X-ray radiation in soft and hard regions of the spectrum. The parameters for all registration channels are gathered in Table 1.

Preliminary experiments have shown that the major part of plasma radiation losses fall in the photon energy range 100–500 eV. The source of continuum radiation in the region above 1 keV is the high-temperature plasma corona with relatively low density. Low spectral density of the plasma corona radiation in this spectral interval did not allow us to use semiconductor diodes as radiation detectors. We used microchannel plate detectors (MCP) of the chevron type (Akhsakhalyan *et al.*, 1992). An important advantage of these detectors is their insensitivity to the CO_2 laser radiation. For preliminary radiation selection a Be foil of 25–30 μm thickness has been used. For absolute calibration of MCP detectors we used K_α line of Al ($E = 1486$ eV) excited by pulsed electron beam (Bobashev *et al.*, 1988), as well as the laser plasma radiation itself, registered by channel No. 3 (Table 1). The required sensitivity of MCP was reached for chevron assembly voltage in the range of 1250–1400 V. In the laser source experiments this allowed us to register signals up to 800 mV with a duration of less than 25 ns, still keeping the detectors in the linear region. The particular polychromator design was similar to the device described in Attelan-Langlet *et al.* (1998). The device allowed us to make measurements at distances above 50 cm and had a simple scheme of alignment to the radiation source using a built-in laser sight. The accuracy of setting up the inclination angle of a multilayer mirror was about $4'$, which is pretty sufficient for present applications.

The technique of electron temperature reconstruction is based on the use of simulated values of X-ray radiation intensity ratios for photon energies corresponding to E_{ch}. The use of intensity ratio allows us to avoid the absolute calibration of the numerical model. The X-ray intensity ratios in the continuum region ($\hbar\omega > 1$ keV) are practically independent of the electron density. While calculating the plasma radiation spectrum, the relative populations of the lead ground states Pb^{18+}–Pb^{32+} were fixed according to results of measurement of energy and charge ion spectra at 3 m distance from the target (Makarov *et al.*, 1994; Baranov *et al.*, 1996). .

Two laser system regimes with smooth and modulated pulses were investigated. The modulated (spiked) profile of the laser pulse was obtained by corresponding adjustment of the master oscillator. In Figures 2 and 3, characteristic signal shapes for channels 1080 eV (1) and 1865 eV (4) are shown in the case of smooth and modulated laser pulses, respectively. In the case of the modulated pulse, the X-ray peak duration is notably lower than for the smooth pulse.

The temporal profile of the temperature obtained from the hard channels 4 and 1 signal ratio (see Table 1) for the

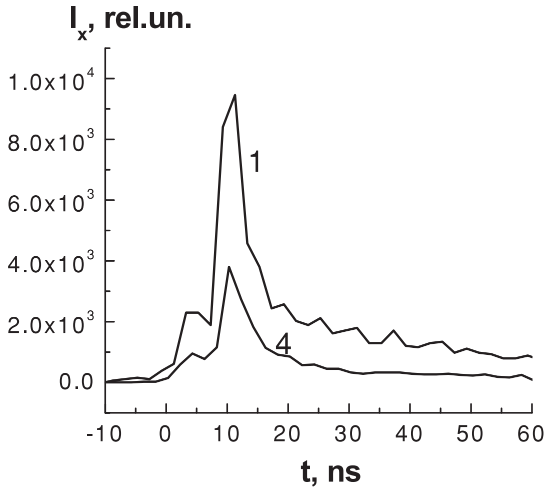

Fig. 3. Temporal shape of signals from channels 1080 eV (1) and 1865 eV (4) in the case of a modulated laser pulse.

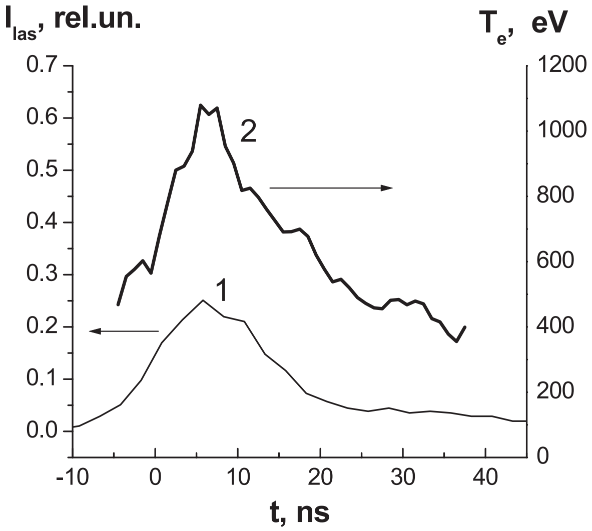

Fig. 4. Time dependencies for the laser radiation intensity (1) and for the electron temperature (2) for a smooth laser pulse.

smooth pulse is shown in Figure 4 together with laser pulse shape. The temporal evolution of the electron temperature is smooth enough in this case. The peak value of the temperature, 800–1000 eV, is in good correspondence with simulation data (Makarov *et al.*, 1994; Baranov *et al.*, 1996). The situation becomes different if the laser pulse intensity has a characteristic spiked temporal shape. The results are presented in Figure 5. It is easy to see that in this case the temporal dependence of the temperature has a sharply expressed spiked structure and the peaks of the electron temperature and the laser radiation are time correlated.

The described techniques combining measurements using multichannel X-ray polychromator followed by results processing using numerical simulation data allows us to determine temporal evolution of the temperature of lead plasma created by CO_2 laser radiation for moderate radiation power density. For further development of the technique it is proposed to extend the range of X-ray photons energy registration above 2000 eV and to improve the kinetics model to get more reliable numerical spectra.

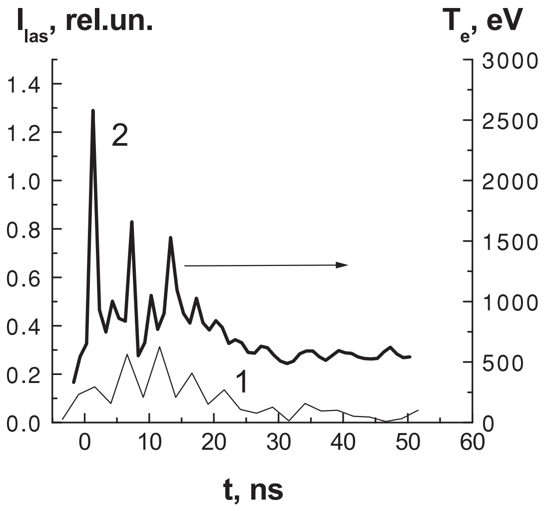

Fig. 5. Time dependencies for the laser radiation intensity (1) and for the electron temperature (2) for a modulated laser pulse.

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