X-RAY SPECTROSCOPY DIAGNOSTICS OF DENSE FEMTOSECOND LASER PLASMA

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The current level of laser technology, i.e. the ability to generate ultrashort (a few tens of femtoseconds) pulses with a total energy of a few tens or even hundreds of joules (e. g. the recently commissioned ELI-NP facility in Romania), characterized by a laser temporal contrast value of $>10^{10}$, makes it possible to heat matter to temperatures of several hundred eV or even a few keV, while maintaining a high (up to sub-solid state values) density for at least a few picoseconds. Such plasma forms within the focal spot as well as on its periphery or deep inside the target under the influence of hot electrons accelerated in the interaction region (warm dense matter).

In connection with the study of dense, short-lived plasmas, it is necessary to emphasize an object that has only recently become experimentally accessible and in which processes that were not important in the previously studied plasmas can play a major role. This is a laser plasma that exposed to strong short-wave radiation from an external source. The intensity of this external radiation can exceed the intensity of the radiation generated in the plasma itself by orders of magnitude, which should increase the probabilities of the corresponding photoexcitation and photoionization processes to such an extent that they begin to play a crucial role in plasma kinetics. Examples of such objects are laser plasmas formed by indirect X-ray heating within hohlraum targets or laser plasma exposed to radiation from powerful X-ray free-electron lasers (XFELs) [1]. It should be emphasized that XFELs already able to generate pulses with intensities 10^{18}–10^{22} W/cm^2 [2]. In this case absorption of external radiation occurs mainly through the photoionization of electrons from the lower shells of atoms, which leads to the formation of exotic, highly unbalanced states of matter: atoms or ions with empty inner and filled outer electron shells, the so-called “hollow” atoms/ions.

The properties of dense femtosecond plasma such as short lifetime, ultra-high density, non-equilibrium energy distribution functions of electrons and ions, excitation of strong oscillating electric fields require the development and modification of traditional plasma diagnostic techniques, in particular X-ray spectroscopy.

The report gives an overview of the methods of X-ray spectroscopy for dense femtosecond laser plasma diagnostics developed in the Laboratory for the Diagnostics of Matter in Extreme Conditions of the Joint Institute for High Temperatures of the Russian Academy of Sciences. These methods take into account not only the extreme values of the parameters of the dense femtosecond plasma itself, but also a number of other effects, including excitation of hollow ion states, the effect of external photopumping on ion kinetics, excitation of plasma satellites, generation of hot electrons, energy transfer to the depth of solid targets, and non-stationarity of the generated plasma.

References

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