Studies of laser-induced plasma in argon using emission spectroscopy and laser Thomson scattering: thermodynamic equilibrium and plasma heating by the probe laser beam

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Scattering of electromagnetic waves by free electron of a plasma, named the Thomson scattering is a powerful and largely used method to measure important plasma parameter – the electron temperature T_e and density n_e. Thomson scattering has played an important role in the studies of nuclear fusion plasmas where it is still the most reliable method for measurements of the electron temperature. However, using high power probe laser beam to generate a scattered signal by free electrons can lead to plasma heating via inverse Bremsstrahlung and thus can modify the plasma parameters. In this work, we have studied the effect of the probe beam laser energy on T_e and n_e in argon plasma and the existence of the local thermodynamic equilibrium (LTE).

1. Experimental setup

The plasma was created with frequency doubled Nd:YAG laser, at 532 nm pulses of 4.5 ns duration and a repetition rate of 10 Hz, by focussing the laser beam in a chamber filled with 1 bar argon. For the Thomson scattering (TS), another Nd:YAG laser at 532 nm, named "the probe laser", with similar duration as the plasma generating one and energy from 1 mJ to 15 mJ, was used. The probe laser beam is directed perpendicularly to the plasma generating one and the emission from laser induced plasma and the scattered light were observed at 90° and imaged onto an entrance slit of a spectrograph (Acton SP-2750i).

The radiation scattered from free charges is mainly due to electrons because their mass is much lower than the mass of ions resulting in their much higher acceleration in an electric field of the laser and consequently large dipole radiation. Applied to laser-induced plasma, TS allows to directly determine parameters of the plasma electrons e.g. T_e and n_e without any assumption about plasma thermodynamic equilibrium.

2. LTE in the argon plasma

Laser-induced plasma (LIP) is usually described statistically assuming the local thermodynamic equilibrium (LTE). At this approach, velocities of plasma components, populations of their energy levels and chemical composition of plasma are described by the Maxwellian velocity distribution function, the Boltzmann distribution function and the Saha-Eggert equation, respectively. Each of these functions is dependent on the distinctive temperature: kinetic, excitation and ionic - which are equal under LTE conditions. Unfortunately, it is very common that the LTE plasma is assumed *a priori*, without any experimental verification. Even if such validation takes place, usually only optical emission methods are applied.

The main goal of this work was to investigate the equilibrium state of laser-induced plasma in argon at different stages of its evolution using optical emission spectroscopy (OES) and laser Thomson scattering (LTS) technique[1]. Spatially resolved electron temperature and electron density were directly derived from TS spectra while excitation temperature was calculated from the spectra of argon atoms and ions employing the Boltzmann plot method.

Our preliminary results show huge discrepancy between intensity ratios of ionic to atomic argon lines computed with measured electron density and temperature and assuming plasma in LTE, and those directly obtained from emission spectra. It implies either incorrect data processing or some principal problems with thermodynamic state in such kind of plasma.

3. TS for the electron parameters measurements

Using high power probe laser beam to generate a scattered signal by free electrons can lead to plasma heating via inverse Bremsstrahlung and modify the plasma parameters Our first results show that in general the electron density seems not to be disturbed or modified by the probe laser. It is not the case for the electron temperature: Te could be considerably increased by the probe laser beam.

[1] K. Dzierżęga, A. Mendys, B. Pokrzywka, *What can we learn about laser-induced plasmas from Thomson scattering experiments*, Spectrochim. Acta Part B 98 (2014), 76