Determination of electron parameters in nascent aluminum laser-induced plasma by means of Thomson scattering

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In the purpose of determining the electron density and temperature of a laser-induced plasma, a Thomson scattering experiment is performed. A 5 ns laser pulse at 532 nm is focused on an aluminum target. The resulting plasma is probed using a 5 ns laser pulse at 355 nm with an angle of 90° with respect to the pump laser direction. The Thomson scattering results are compared with the ones obtained by the study of the continuum radiation or spectral lines with known Stark parameters. The first results show that the electron temperature and density reach 15000 K and 10^{25} m^{-3} respectively, at time t = 20 ns after the maximum of the pump laser pulse.

Large intentions are dedicated to the laser-surface interaction since the development of short laser technology. Many research works have shown that the predominant parameters are the laser fluence F and the pulse time τ. The plasma results from the absorption of the laser light by the ejected matter. This so-formed plasma radiates lines which lead through emission spectroscopy analysis to the identification of the material elemental composition: the derived diagnostic method is called LIBS (Laser Induced Breakdown Spectroscopy). This analysis is based on the Local Thermodynamic Equilibrium (LTE) assumption. During the last years, different calibration free procedures have been elaborated [1] which illustrates the improvement of the LIBS technique. However, the Local Thermodynamic Equilibrium (LTE) seems to be systematically assumed in the purpose of deriving the elementary composition of the sample [2]. This hypothesis is still largely discussed [3] and conditions to obtain LTE have to be clearly understood to estimate its validity.

The situation studied here concerns an interesting case of irreversible evolution and illustration of the second law of thermodynamics. The initial conditions at the moment of the laser pulse – sample interaction correspond indeed to a strong non-equilibrium between matter and radiation. The subsequent evolution leads the system from this initial situation until the final equilibrium according an irreversible evolution driven by radiative and collisional elementary processes. At each time of this evolution, the system presents a departure from equilibrium decreasing with time. The whole duration of the transient state until the final equilibrium depends strongly on the initial conditions.

In this context, these initial conditions have to be perfectly identified. One of the main objectives of the work developed in our lab is to study thoroughly the early phase of the plasma, in other words the few nanoseconds corresponding to the laser pulse, when the light interacts with the sample. The aim of the study is the experimental characterization of the plasma just during and after its formation.

Thomson scattering (TS) is a powerful and well known technique suitable for measuring the electron temperature T_e and density n_e when these parameters are sufficiently high. The estimate of these parameters has been obtained using other methods mainly based on emission spectroscopy. The continuum, ascribed to thermal Bremsstrahlung and radiative recombination, has a spectral radiance compatible with strong values of n_e and T_e. TS was therefore chosen to confirm the values thus obtained.

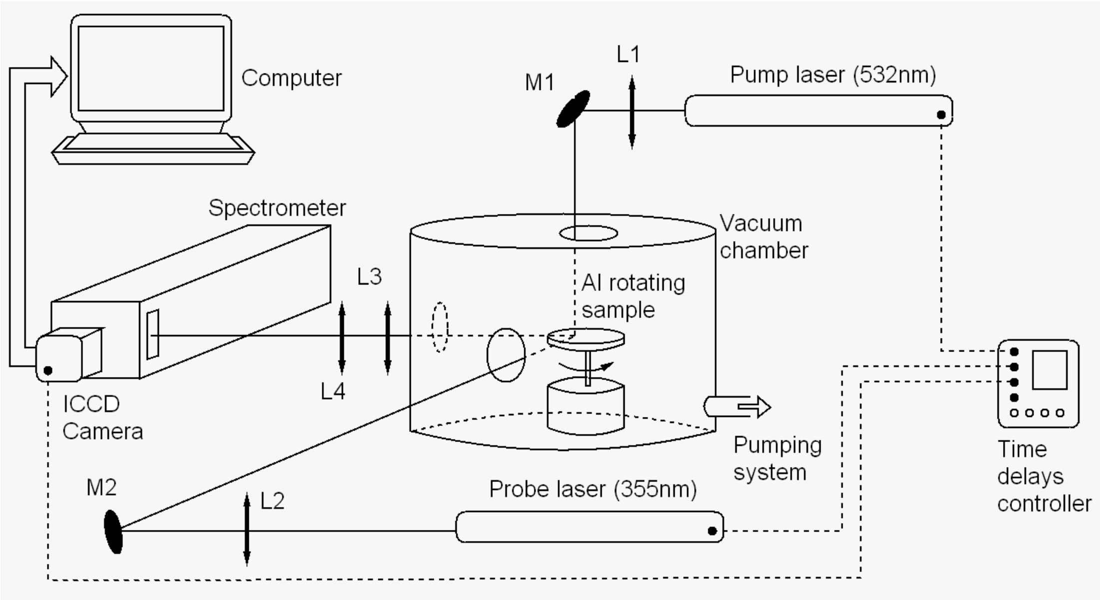

Fig.1. Thomson Scattering setup for LIBS experiments performed in vacuum.

Figure 1 illustrates the experimental device. A 5 ns Nd:YAG laser source (λ = 532 nm) is used to form the plasma (pump pulse) on an aluminum sample. The sample rotates on its axis to provide similar conditions for interaction between the pump pulse and the sample at any moment. The angle between the laser light direction and the aluminum surface is 90°. Experiments are performed at low pressure (1 Pa) obtained by pumping the gas inside the chamber where the sample is located, and the fluence is limited (under 8 J cm^{-2}) to avoid the formation of shock waves and explosion phase. As a result, the aluminum sample is heated by the laser pulse, melts and evaporates: the vapor thus formed is then ionized. The TS cross section is weak: as a result, a second nanosecond Nd:YAG source is used as probe laser. The wavelength is not the same as that of the pump laser (λ = 355 nm) in order to identify unambiguously the TS signals. In addition, these signals are collected at 90° to maximize their intensity. By controlling the delay time between the pump and the probe laser pulses, the time evolution of electron temperature and density can be followed during the plasma lifetime [4].

The scattered light is collected by a lens set and its analysis is carried out using an Acton SP750i spectrometer equipped with a 1800 gr mm^{-1} grating and an iCCD camera PI-MAX.

The Thomson scattering diagnostic quickly described above is used to validate the measurements performed using others methods previously mentioned and lead to the temporal evolution of the electron density and temperature during the creation phase.

During the conference, the Thomson scattering experiment will be detailed. The results will be presented. In addition, they will be compared to those obtained from analysis of the continuum and the lines with known Stark parameters.

References

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