Electrical and magnetic spectrometry of ions emitted from laser-generated plasma at 10^{10} W/cm^2 intensity

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Abstract

Plasmas were generated by 3 ns pulsed laser at 1064 nm wavelength using intensities of about 10^{10} W/cm^2 irradiating solid targets with different composition. The ion emission was investigated with time-of-flight measurements giving information of the ion velocity, charge state generation and ion energy distribution. Measurements use an electrostatic ion energy analyzer and a coil to generate a magnetic field suitable to deflect ions towards a Faraday cup and/or a secondary electron multiplier.

Ion acceleration of the order of hundred eV per charge state, plasma temperature of the order of tens eV, charge states up to about 4+ and Boltzmann energy distributions were obtained in carbon, aluminum and copper targets.

The presented results represent useful plasma characterization methods for many applications such as the new generation of laser ion sources, proton ion sources, pulsed laser deposition techniques and post ion acceleration systems.

Introduction

Plasma generated by laser at low intensity regime ($10^8 \div 10^{12}$ W/cm^2) can be studied by magnetic or electric deflector coupled to an Ion Collector, or to a Secondary Electron Multiplier to enhance the resolution. In this way, it is possible to characterize the plasma source properties such us plasma's potential and temperature, ion's velocity and energy distributions, ion's charge state and others.

A magnetic spectrometer is a device that use the Lorentz Force, $\mathbf{F} = q\mathbf{v} \times \mathbf{B}$ where q is the ion charge, $\mathbf{v}$ is the ion velocity and $\mathbf{B}$ is the magnetic field, to deflect charged particles along the focal plane, based on their velocity and charge state. Instead, an electric spectrometer use the electrical force acting on a beam of charged particles, $\mathbf{F} = q\mathbf{E}$, where $\mathbf{E}$ is the electric field, to separate them according to their energy and charge state.

The devices presented in this paper are very useful for low energy plasmas ($1 \div 10$ keV); but when the energy increases other devices must be used for its characterization, such as Thomson Parabola Spectrometer, complex mass spectrometer, and others [1].

Experimental Setup

A Nd:YAG laser with 1064 nm fundamental wavelength, 3 ns pulse duration, and 200 mJ maximum pulse energy was employed to irradiate solid targets in vacuum (10^{-6} mbar). The targets used consist of thick sheets, of 2×2 cm planar dimensions, made of polyethylene ($-CH_2-$), aluminium and copper. They are attached on a target holder that can be rotated 45° counterclockwise, to study the produced plasma by a magnetic deflector (Magnetic Spectrometer Chamber, MSC), or 45° in a clockwise direction, to analyze the produced plasma by an electric deflector (Ion Energy Analyzer, IEA) [2], as well as shown in Figure 1.

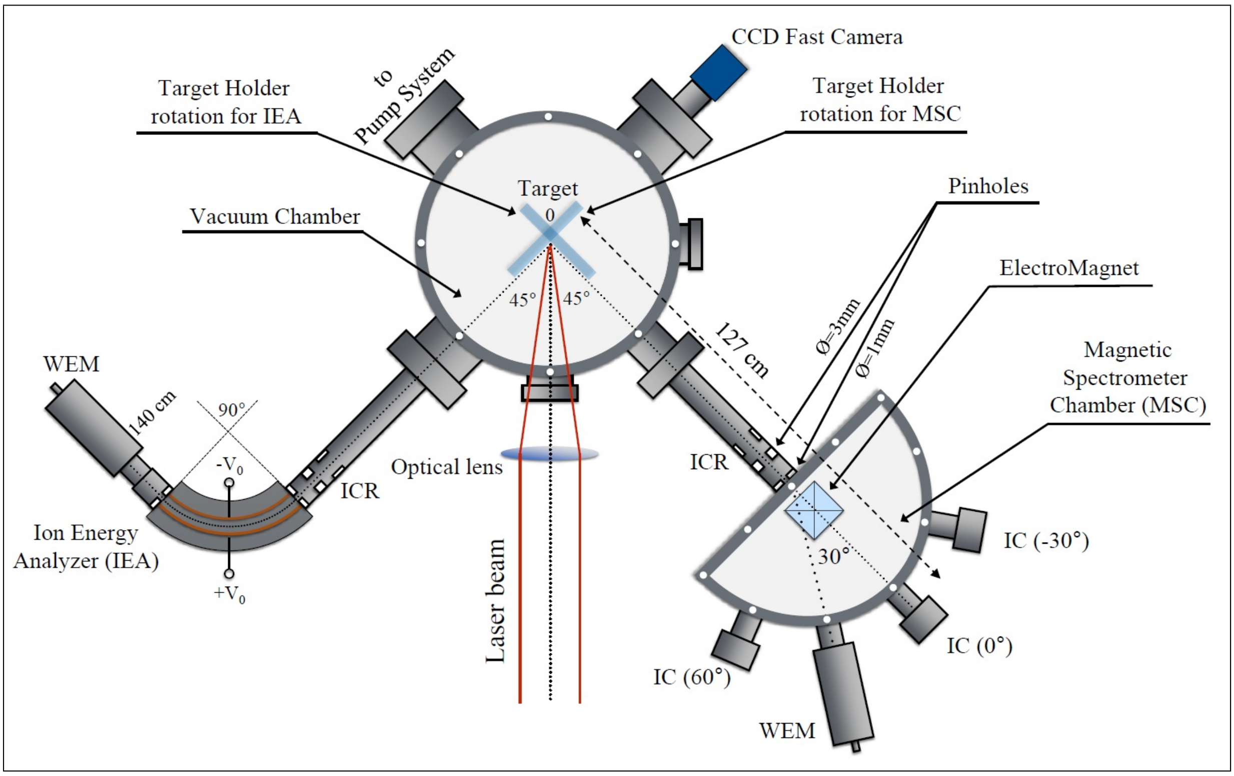

Figure 1: *Scheme of experimental setup with vacuum chamber, magnetic deflector (MSC) and electric deflector (IEA).*

The MSC consists in a system of two pinholes and immediately after these there is an electromagnet consisting of a “C”-shaped ferromagnetic core and a copper coil; it generates a suitable magnetic field, through a bias supply. Finally, there are some detectors placed at fixed angles; in particular, for this experiment will be presented the spectra obtained with a Windowless Electron Multiplier (WEM) placed at an angle of 30°, varying the magnetic field.

On the other side, the IEA is constituted by two input pinholes, two semicylindrical electrodes polarized exactly at the same way but having opposite sign, an output pinhole, and finally the WEM to increase the resolution of the apparatus.

Results and Discussion

Figure 2 shows a WEM spectrum, obtained by irradiating copper target, acquired by IEA (on the left) and by the MSC [3] (on the right).

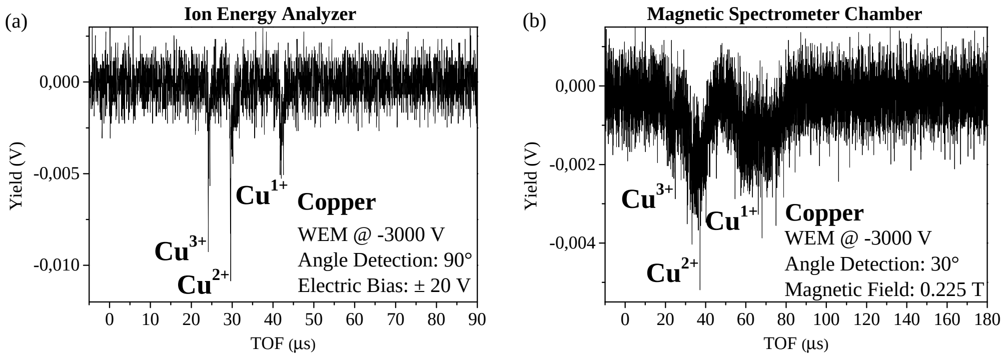

Figure 2: *WEM spectrum acquired by IEA with ± 20 V for deflection plate (a), and by MSC with a magnetic field of 0.225 Tesla (b).*

When we varying the electrical potential in the case of the IEA, and the magnetic field in the case of the MSC, a series of spectra are obtained such as those shown in Figure 2. Evaluating the area of these peaks vs. the energy or the velocity of the ions, we obtain points that can be fit with Coulomb-Boltzmann Distributions (CBS) in energy or velocity [4], as shown in Figure 3.

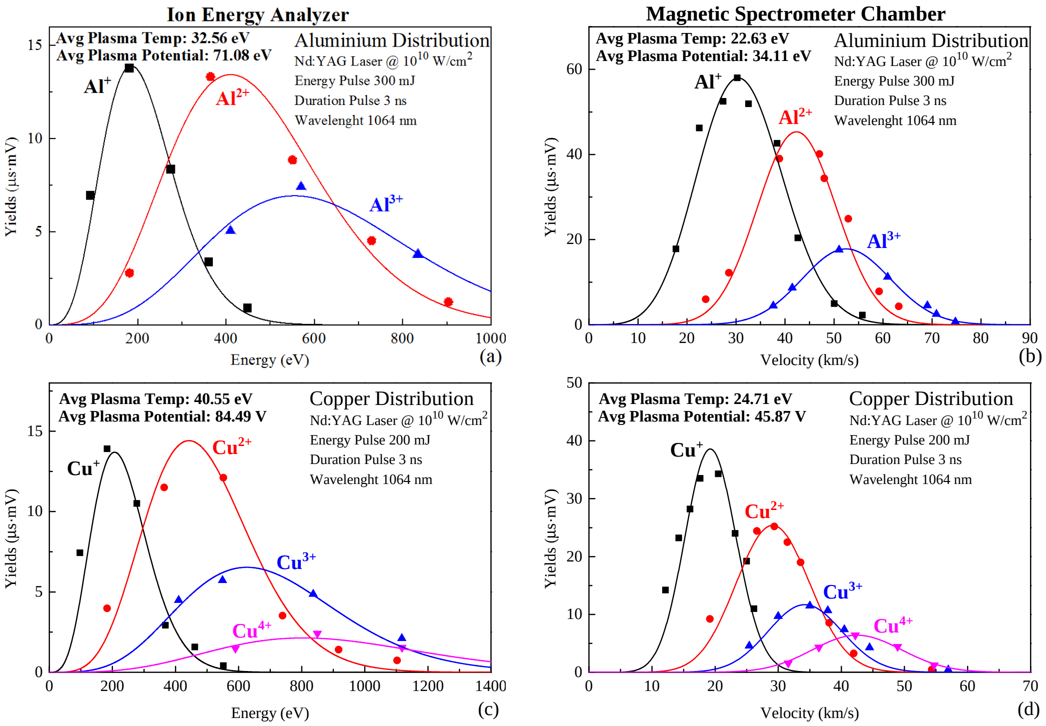

Figure 3: *WEM spectrum acquired by IEA with ± 20 V for deflection plate (a), and by MSC with a magnetic field of 0.225 Tesla (b).*

The values obtained from the fit are almost comparable, within the limits of experimental errors (changes in the focal point, accuracy of the spectrometer, etc.). There is also an excellent agreement between the theoretical prediction, obtained by simulation with COMSOL Multiphysics software [5], and the experimental data, as illustrated in Figure 4.

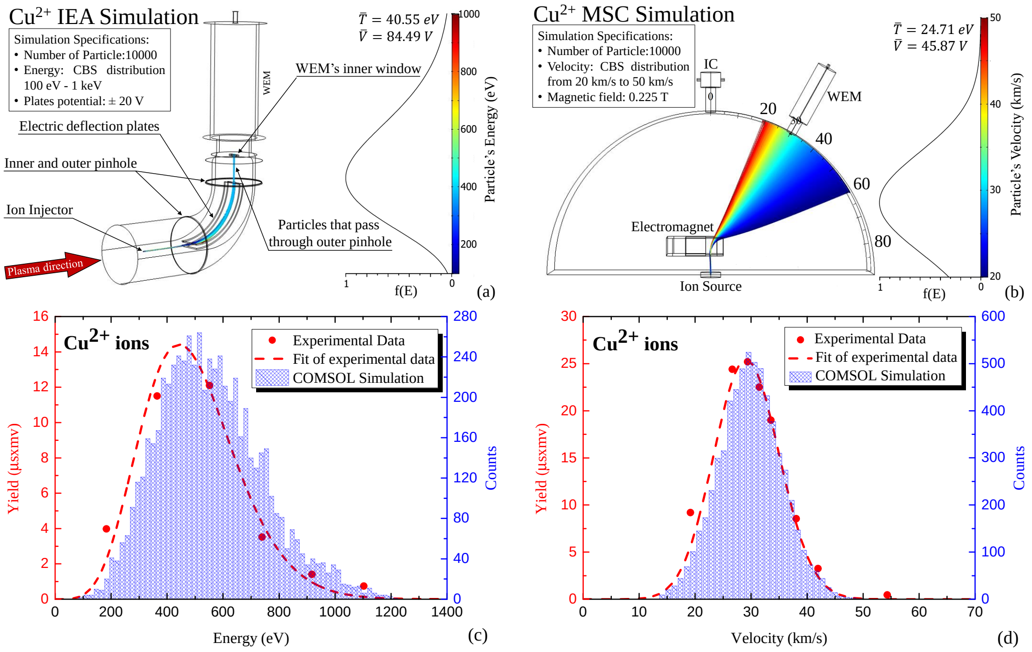

Figure 4: *COMSOL simulation for* Cu^{2+} *in IEA (a) and MSC (b) and its respective comparison with experimental data (c) and (d).*

Conclusions

In this paper we presented the comparison between an already well-known electric spectrometer and a prototype of a new magnetic spectrometer. The values obtained are in good agreement with each other. The WEM spectra obtained in the two cases seem to be more accurate for the IEA, but the data analysis showed a better agreement of the points obtained with the fit and with the numerical simulation in the case of the MSC. The strength of this device lies in its ease of construction and assembly, which has allowed us to create a uniform magnetic field up to 0.35 T. Work is progress to try to increase the deflection magnetic field, use a more sensitive WEM, and insert multiple detectors at more deflection angles.

References

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