Journal of Physics: Conference Series

PAPER • **OPEN ACCESS**

Ion energy distribution from colliding laser plasmas

To cite this article: C B Doherty *et al* 2019 *J. Phys.: Conf. Ser.* **1289** 012033

IOP Conf. Series: Journal of Physics: Conf. Series **1289** (2019) 012033 doi:10.1088/1742-6596/1289/1/012033

Ion energy distribution from colliding laser plasmas

C B Doherty[1], M Kelly[2], T Donnelly[3], J G Lunney[4] and J T Costello[1]

[1] School of Physical Sciences and the National Centre for Plasma Science and Technology (NCPST), Dublin City University, Glasnevin, Dublin 9, Ireland

[2] School of Mathematics and Physical Sciences, University of Hull, Hull, UK HU67RX

[3] University College Dublin, Belfield Dublin 4, Ireland

[4] Trinity College Dublin, College Green, Dublin 2, Ireland

columb.doherty33@mail.dcu.ie

Abstract. We report the development of an electrostatic sector analyser (ESA) combined with a time-of-flight (TOF) spectrometer along with some preliminary results from its use in measuring the energies of ions emitted from colliding laser produced plasmas.

1. Introduction

To date, most experiments on the measurement of ion emission from laser-produced colliding plasmas have been carried out with simple Faraday Cups (FC) [1]–[2]. FC detectors only permit the measurement of the time evolution of the plasma current and are not capable of discriminating between charge states. Here we measure ion energies for selected charge states by combining a time of flight (TOF) mass spectrometer with an electrostatic sector analyser (ESA) [3]. When two plasma plumes collide there are two extremes of behaviour, namely they may interpenetrate or they can decelerate rapidly to form a hard and well defined stagnation layer. Whether or not the plasmas will interpenetrate or stagnate depends upon the collisionality parameter ζ [4]:

$$\zeta = D/\lambda_{ii} \quad (1)$$

$$\lambda_{ii}(1 \to 2) = \frac{m_2^i v_{12}^4}{4\pi q^4 z^4 n_i \ln \Lambda_{1\to 2}} \quad (2)$$

Where D is seed plasma separation, λ_{ii} is ion-ion mean free path (mfp), m_i is ion mass, v_{12} is relative collision velocity, q is electron charge, z is average ionization state of the plasma, n_i is the average ion density of the plasma and $ln\Lambda_{1\to 2}$ is the Coulomb logarithm (revealing whether small- or large-angle collisions are more predominant within the plasma) [5]. In summary rapidly moving and/or dilute plasmas will tend to interpenetrate while slow moving and/or dense plasma plumes will tend to stagnate at the collision plane. By altering one or several of the variables shown in equation 2 we can exercise a degree of control over the outcome. We report here initial results from measurements made with an ESA-TOF on ion emission from both a single laser plasma plume and a pair of colliding laser plasmas. The detector exhibits sufficient resolution to resolve the isotopes of the copper which have a ratio of 3:1 (^{63}Cu:^{65}Cu) for the targets used.

2. Experimental system

To generate the plasma we used a Q-switched Surelite Continuum SLIII-10 Nd:YAG laser (73 mJ, 6 ns) focussed to a 0.5mm spot size. The output beam was split into two parts for the colliding plasma experiments using a bi-prism, with the two resultant beams focused onto the target 2 mm apart using a lens of focal length 30 cm. The target used was a Cu block with V-shaped wedges cut into the face measuring 30°, 60° and 90°. The two plasmas were created on opposite walls of each wedge, allowing them to expand into one another. The ESA itself was designed and constructed in-house for laser plasma analysis and the internal schematic of which can be seen in Figure 1.

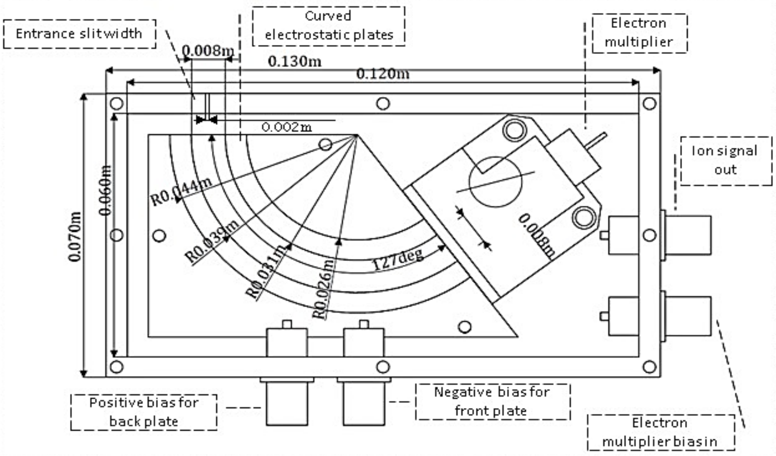

Figure 1. Schematic of the ESA design

The detector is composed primarily of narrow entrance and exit slits for the collimation of ion beams, a pair of curved electrically biased plates for the bending and kinetic energy separation of the ion beam and a final electron multiplier for amplification of the ion signal to be displayed on an oscilloscope. When a positively charged ion enters the electric field with some kinetic energy, it is subject to an electrical force repelling it from the positively biased back plate [6]. The effect of this force as a function of the particle's kinetic energy is described by the following equations:

$$q = \frac{1}{2}\frac{md^2}{t^2\Delta V}\left(\frac{r_1}{r_2} - \frac{r_2}{r_1}\right) \tag{3}$$

$$\Rightarrow E_p = \frac{q\Delta V}{\left(\frac{r_1}{r_2} - \frac{r_2}{r_1}\right)} \tag{4}$$

where q represents the ion charge, m is the ion mass, d is the distance from plasma formation to the ESA, t is the ion flight time, E_p stands for pass energy and is the kinetic energy that a particle must possess in order to pass through the inter-plate bias of magnitude ΔV, measured in volts and $r1$ and $r2$ represent the inner and outer radii of the curved plates which help to determine the distance of the path the ions will take through the ESA. Building on the result from equation 4 one can extract a method for the calculation of the time of flight that an ion should have given a certain charge, mass, energy and plate voltage:

$$t = \sqrt{\frac{m \times d^2}{2 \times E_P}} \tag{5}$$

where t is the time of flight (generally on the scale of tens of microseconds), m is the mass of the ion to be examined (in kg) and d is the distance from the target to the detector [7]. Using these equations and comparing a sample from the experimental values for the ToF of ions we can determine which elements are present in the target and arriving at the detector.

3. Results and Discussion

Figures 2 and 3 show some sample plots with a 75 V ESA plate bias, structurally typical of most of the plasma signals observed. Figure 2 shows ToF signals for the three plume types (single plume-full laser pulse energy, single plume-half pulse energy and a pair of colliding plasmas) formed on a flat target while Figure 3 shows the ion signals from the various shaped target on which colliding plasmas were formed. Superimposed on these figures are the calculated ToF values for the Cu, C and H isotopes. The fitted isotope ToF values informs us which charge states and isotopes are present in the plasma plumes and how the charge state distribution varies with kinetic energy, laser fluence and target geometry.

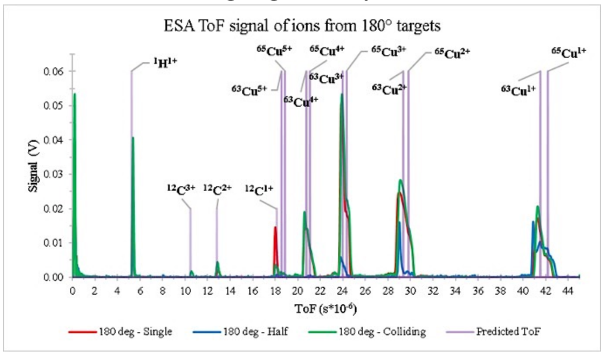

Figure 2. Ion ToF signals for different plume types on a flat target.

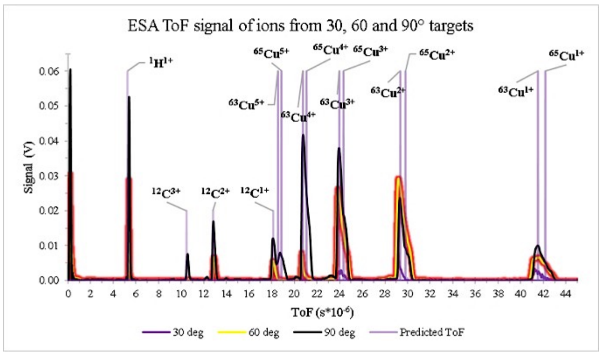

Figure 3. Ion ToF signals from colliding plasmas formed on 30°, 60° and 90° wedge targets.

The plots display first the fast photo signal followed by H, C and Cu ions, in order of mass. The signals shown are an average of 25 shots each and were smoothed using a Savitzky-Golay filter and then normalised for comparison. This averaging of minutely different signals and the presence of two isotopes in the Cu signal explains the broader peaks seen there relative to the C signals.

4. Conclusions

We have developed a tuneable ESA-ToF mass spectrometer device capable of well resolved charged particle analysis over a large range of kinetic energies, which works well in the low pressure conditions necessary for the generation and propagation of colliding laser plasma stagnation layers. From the sample set of results shown in figures 2 and 3 one can exercise a degree of control over the ionization balance within the plasma. Future work will examine this aspect further by examining the ion signal with respect to changing target geometry over a range of kinetic energies.

References

[1] Hough P 2010 “Laser, Optical and Electrical Diagnostics of Colliding Laser-Produced Plasmas,” PhD Thesis, Dublin City University (2010).
[2] Doggett B 2006 “Characterisation of Laser Produced Plasmas,” PhD thesis, University of Dublin Trinity College
[3] O’Connor A 2009 “Ion Spectroscopy of Laser Produced Plasmas with Potential for Extreme Ultraviolet Sources,” PhD Thesis, University College Dublin
[4] Rambo PW and Denavit J 1994 *Phys. Plasmas* **1**, 4050
[5] Chenais-Popovics C *et al*. 1997 *Phys. Plasmas* **4**, 190
[6] Purcell EM 1938 *Phys. Rev*. **54**, 818
[7] Morris O *et al*. 2007 *J. Phys. Conf. Ser*. **58**, 391