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# Validation of a time-of-flight mass spectrometer using an ionic liquid ion source

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ABSTRACT

A low-cost time-of-flight mass spectrometer has been developed to characterize the plasma plume resulting from pulsed laser ablation. In this paper, an ionic liquid ion source using EMI-$BF_4$ is used to experimentally validate the spectrometer, as well as a model of the spectrometer. The mass spectrometer is shown to experimentally measure the energy-per-charge distribution of the ion source, and match with literature. In addition, a relation between alignment error and measurement error predicted by theory is confirmed, further validating the model. Now that it has been validated, the spectrometer can confidently be used to determine the two-dimensional distribution of speed and energy-per-charge of a pulsed laser ablation plasma, or other pulsed plasma sources.



## 1. Introduction

A sub-nanosecond pulsed laser fired at a target material generates an ablation plasma plume of ions, ion clusters, and nanoparticles [1,2]. This paper introduces the design of a time-of-flight mass spectrometer (TOF-MS) to use for characterizing the plasma plume generated by laser ablation, developed by the authors at the University of Maryland College Park Space Power and Propulsion Laboratory (SPPL). Multiple configurations and designs for TOF-MS systems are discussed in literature [3–7]. The mass spectrometer in this paper is designed to measure charged particles with energies up to 30 keV, so particles ranging from ions to clusters and nanoparticles can be detected. The energy range of this design, combined with the ease of fabrication, makes this spectrometer design very useful. This paper focuses on simulations and validation experiments conducted in order to properly process the raw output of the TOF-MS. The validation experiments are conducted using an ionic liquid ion source. This ion source generates large ions of a known mass and energy, so the TOF-MS measurements can be compared to the expected values.

Research is currently being conducted at SPPL using a Xenon and Argon ion source to analyze the effect of particle bombardment on spacecraft material [8], such as solar panels, as would be exposed in the space environment. A laser ablation plasma source extends this capability by increasing the sizes of energetic particles that can be generated. Before being used to conduct satellite impingement tests, the plasma plume must first be well characterized.

In addition, laser ablation can be used to generate thrust for space propulsion [9,10]. This is particularly well suited for deorbiting orbital debris [10–12], or deflecting asteroids from a collision with Earth [13–15], since the objects to be moved can be used as the propellant. Characterization of the plasma plume's mass, energy, and velocity distributions with the TOF-MS can be used to calculate the propulsion parameters associated with ablation.

## 2. Hardware overview

### 2.1. Laser ablation facility

Fig. 1 shows a schematic diagram of the laser ablation facility. The laser is a Q-Switched Nd-Y2SO4 (Photonics Industries model SN-1064-40). It emits pulses of 0.7 ns (FWHM) duration at a wavelength of 1064 nm. The laser is operated at 40 kHz, with a maximum pulse energy of 827 μJ. Inside an optics enclosure, the laser is expanded by a beam expander, and then focused to a point in the vacuum chamber. The chamber's nominal operating pressure during TOF-MS testing ranges from 0.5 to 2 mPa. The target material to be ablated is mounted on XYZ translational stages to allow it to be moved and maintain a fresh ablation spot. The ablation plume has a cosine dependence with the center of the plume normal to the target surface [16], and is oriented to go towards the TOF-MS.

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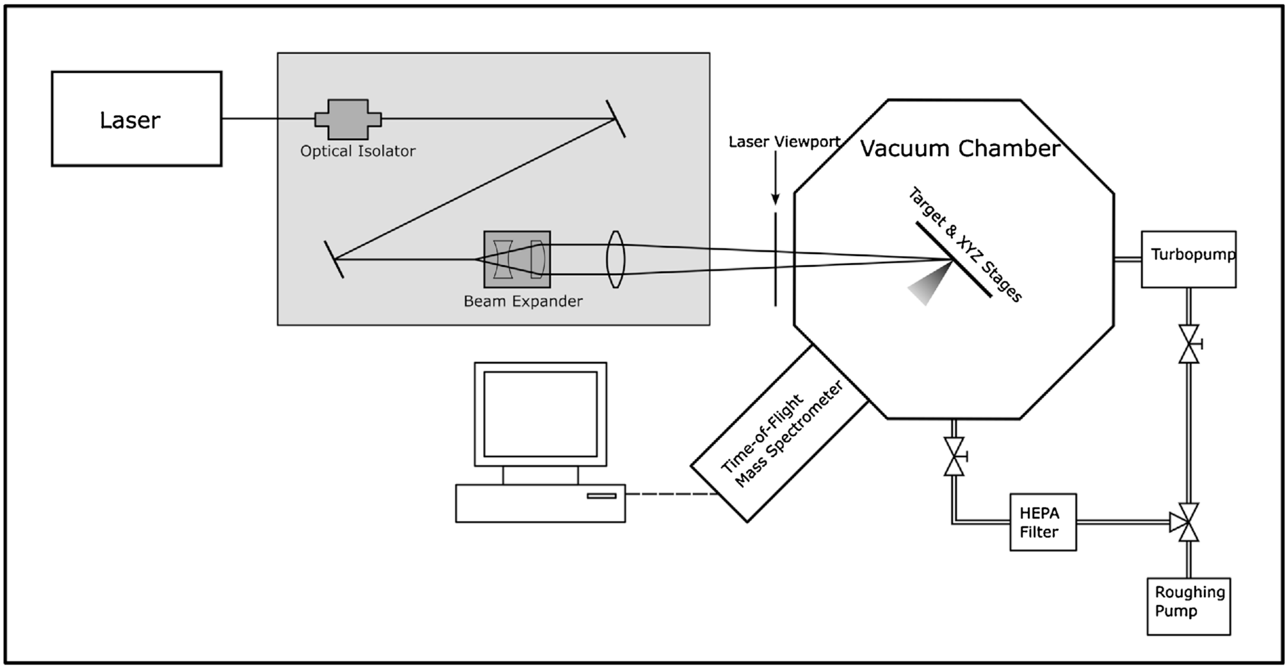


**Fig. 1.** Schematic of hardware.

### 2.2. *Time-of-flight mass spectrometer*

Fig. 2 shows a schematic diagram of the TOF-MS. The spectrometry measurement begins with a single laser pulse, which generates a plasma ablation plume and marks the start of the TOF. After traversing through a field-free region, the particles reach the energy gates, which filter particles by their energy-to-charge ratio $\tilde{E}$ by setting the center plates to a voltage $V$. Throughout this paper, the $\sim$ accent is used to denote variables that are per-charge.

A particle of the correct $\tilde{E}$ is then accelerated and collides with the back wall of the detector, releasing secondary particles. The number of secondary particles released is a function of the kinetic energy of the primary ablation particle. The secondary particles are accelerated to the scintillator, which generates light when it is hit with the particles. This signal is amplified by the photomultiplier, which is in turn measured by the oscilloscope. The time between the ablation pulse occurring and the photomultiplier signal corresponds to the time of flight of a particle. Although a microchannel plate is typically used as a detector, a photomultiplier was used instead because it can operate in lower vacuum, and be stored at atmospheric pressure. In addition, the scintillator bias can be varied to attract either secondary ions or electrons, while maintaining the photomultiplier anode at ground.

Since the distance between the ablation spot and detector is known, the particle velocity $v$ can be calculated using the TOF measurement. The particle's $\tilde{E}$ is known from the energy gates. Finally, the particle's kinetic energy is determined from the number of secondary particles emitted. From $E = \frac{1}{2}mv^2$, the mass and charge of the particle are determined. Analysis relating primary particle kinetic energy with the number of secondary particles emitted is left for future work.

### 2.3. *Ionic liquid ion source*

Before characterizing a plasma plume of unknown distribution, the spectrometer is validated using well-characterized ions. This was done using an ionic liquid ion source developed at the MIT Space Propulsion Laboratory [17,18], which was borrowed for these experiments. The referenced papers include details of the design and fabrication of this device. A diagram of the ion source is shown in Fig. 3.

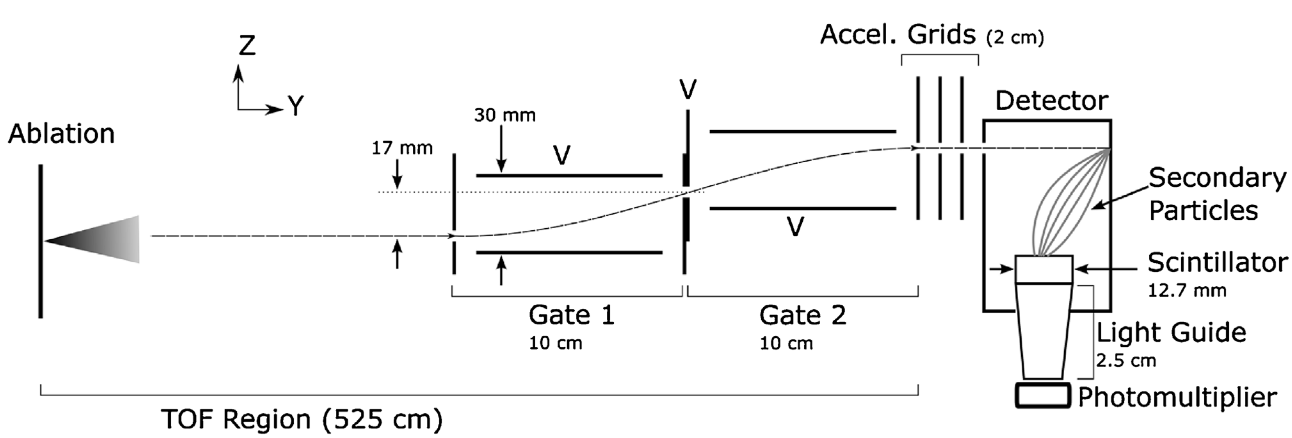


**Fig. 2.** Schematic of Time-of-Flight Mass Spectrometer.