Long-lasting laser-driven proton source

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Abstract. Laser-driven ion accelerators are a promising alternative to conventional accelerators currently in use. Following the laser-plasma interaction, the target is destroyed, making it necessary to replenish it, a task particularly challenging in the case of state-of-the-art laser systems operating at multi-hertz repetition rates. Here, we will introduce some of the different target systems currently being developed for continuous operation at such rates. In particular, a target system based on a tape-drive that is currently being developed at the Laser Laboratory for Acceleration and Applications (L2A2, USC) will be presented, which addresses the need of a target system capable of operating continuously for thousands of shots at several hertz. Preliminary measurements show tape stabilities below 10 μm of standard deviation.

1 Introduction

The lower shielding requirements, compactness and reduced operational costs of laser-driven ion accelerators make them an interesting alternative to conventional accelerators, opening the possibility of increasing the number of facilities capable of offering ion beams. Characteristics such as ultra-short ion bunches, broad spectrum, simultaneous electron acceleration or gamma production, make these accelerators suitable for, among others, replicating outer space conditions, electron-driven fast ignition (FI) scheme in inertial confinement fusion (ICF), FLASH therapy for cancer treatment, or radioisotope and neutron production in combination with a secondary target [1].

To produce such ion bunches, an ultra-short, high-energy laser pulse is focused down to a few-micron focal spot onto a thin solid target, reaching intensities above 10^{18} W cm^{-2}. Under these conditions, ions are accelerated via the Target Normal Sheath Acceleration (TNSA) mechanism. In this regime, the pedestal and the prepulses typically preceding the main pulse create a plasma on the front side of the target. Subsequently, when the main pulse reaches the target, the ponderomotive force accelerates the electrons in the plasma. Those electrons travel through the target before escaping from the rear side along the direction normal to the surface. As a result, a quasi-static charge-separation sheath, with fields up to TV/m, is established, capable of accelerating protons and ions from the rear surface along the target normal direction [1].

Following the interaction with the laser, the target is damaged, making it necessary to replace it. In the past, lasers were typically operated in a single-shot mode, which meant that target replacement could be done individually. However, with the emergence of high repetition rate (HRR) lasers, it has become necessary to investigate alternative target designs compatible with these new systems. In the present paper, we will outline some of the recent developments on target systems for ion acceleration, particularly focusing on the tape-drive system designed at the Laser Laboratory for Acceleration and Applications (L2A2, Universidade de Santiago de Compostela).

2 High repetition rate targets

The acceleration of ions using ultra-intense lasers requires the use of overdense targets [1]. Such densities can be achieved through several alternatives such as solid targets, liquid jets or high density gas targets. Of these, solid targets are arguably the most commonly employed solution, given the simplicity of the setup. However, compared to the other options, the use of solid foils is also the most complicated in terms of replenishing after the irradiation. Several solutions to address this issue have been proposed, such as the use of pre-characterised wheel systems [2]. It consists of a wheel that can hold up to a few thousand targets and is attached to a three motor system that can precisely position the targets at focal plane. The alignment positions of each target are pre-characterised and then programmed to automatically replenish the target after the laser interaction. Such systems have been successfully used to accelerate ions at rates up to the hertz level. Nevertheless, their use at higher repetition rates is limited due to the velocity of movement required to reach the necessary separation among shots.

To further extend the number of shots, alternatives such as liquid targets have been explored [3]. They consist of one or two colliding jets, forming a thin sheet where the laser impinges. However, improvements are being developed as their operation is limited due to loss of vacuum caused by imperfections in liquid extraction, before they can be reliably used in the context of HRR PW lasers. Following the same principle, high pressure gas jets with overcritical densities can be used [4]. Originally, this kind

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of systems were used with CO_2 (λ = 10.6 µm) lasers exploiting their lower critical density ($n_c \approx 9.8 \times 10^{18}$ cm^{-3}), enabling the study of novel radiation-pressure-based ion acceleration mechanisms. The development of gas jets reaching even higher densities, over the critical density of the Ti:Sapphire systems (λ = 800 nm, $n_c \approx 1.7{\times}10^{21}$ cm^{-3}) is an active field of research.

Despite the potential of these target systems, another possibility with relatively easy implementation is a tape-drive system [5]. In this system, the target is a tape that is continuously refreshed, and once it is placed at the desired plane, it is mechanically ensured to keep the position stable. In the following section, the tape-drive system developed at the L2A2 will be presented.

3 Tape-drive design and characteristics

The tape-drive system developed (Fig. 1) has two spools that can allocate tens of metres of few-micron thick tape, allowing for thousands of consecutive shots, and several rods to guide the tape though and place it on the shooting position. Those spools are both attached to rotary motors, giving the possibility of moving the tape forward and backwards, which, for tapes sufficiently wide, would significantly increase the shots available. For this reason, to change the shooting position, the main body is mounted over two motorised stages that can be remotely controlled and automatised. Moreover, these stages are used to precisely place the tape at the focal plane. Furthermore, the angle of incidence of the laser can also be precisely controlled using the micrometric screws (see *Angle screws* in Fig. 1a). Additionally, transverse probing of the interaction is enabled by a side window on the body of the tape-drive.

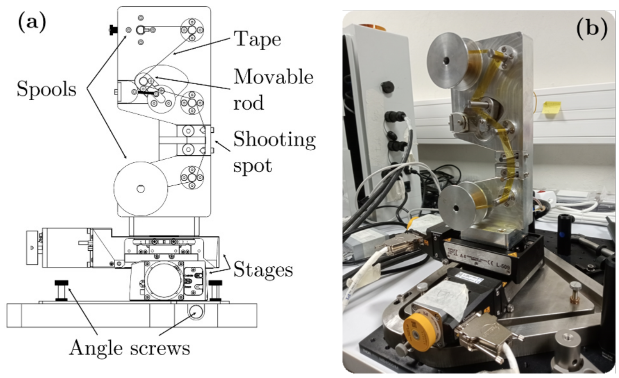

Figure 1: (a) Schematic and (b) picture of the tape-drive developed at L2A2.

Following the initial alignment of the system, the tape must remain stable on the focal plane as the target is replaced. In our case, this is achieved by using a closed-loop system which uses feedback from one of the rods. Such rod is movable and attached to a spring to ensure it stays in contact with the tape and give a certain margin to prevent tape breakage in case of excess tension. The position of the rod depends on the tension applied to the tape and is monitored with an angular encoder. The angle read by this encoder is used in the closed-loop to change the rotating speed of the motors and maintain the optimum tension in the tape to keep it stable at shooting spot.

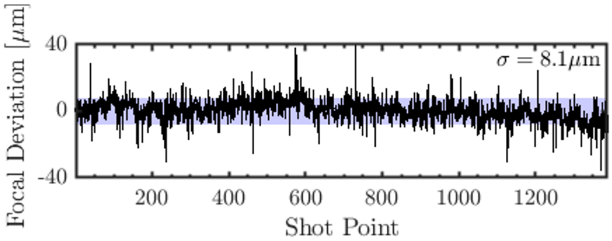

Figure 2: Stability of the tape position over almost 1400 consecutive shots. The standard deviation is σ = 8.1 µm.

Preliminary stability measurements were done using a Kapton tape of 13 µm. The tape surface position was measured using an optical position sensor (optoNCDT 1320). The results show a standard deviation of 8.1 µm (Fig. 2), a displacement below the Rayleigh length of the focusing optics typically employed to accelerate ions using lasers.

4 Conclusions and future prospects

We have developed a tape-drive target for laser-driven ion acceleration that can be used continuously for several thousands of shots. It has shown good stability using a 13 µm Kapton tape. We expect to use aluminium tapes in the near future and further improve the stability, specially peak to peak, improving the closed-loop algorithm and the tape winding.

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