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# On the performance of high power pulsed repeated laser irradiation for spatial structures propulsion

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## ABSTRACT

Changing debris orbits using High Power Pulsed Laser Interaction finds interest in the Low-Earth Orbit (LEO) due to space debris congestion. Laser facilities allowing both high energy and repetition rate of a short pulsed irradiation become available as provided by the high power HILASE beamline facility (Prague, CZ) with BIVOJ (100J, 10ns, 10Hz, 1030nm). In order to illustrate such an application, originally Crookes radiometer concept was adapted to quantify the efficiency of repeated laser shots in increasing rotating speed according to laser matter interaction. Various materials, from model to space applicative materials, allowed to estimate the material response with various irradiation characteristics (single shots vs. repeated shots). Matter behaviors (ablation, cratering, spallation, perforation) bracketed the laser conditions suitable in the perspective of laser propulsion with limited creation of extra debris or irradiated structures damages. Next is to strengthen the robustness of the simulation/experiment dialog to use simulation as a pre-design tool for laser space propulsion.

**Keywords:** High Power Pulsed Laser Interaction, HILASE BIVOJ laser, Space debris, propulsion, laser damage

## INTRODUCTION

The laser beam is a promising energy source for the development of future types of thrusters for space applications since the 1970s, thanks to the vaporization reaction of the material that exerts a thrust on the structure. This thrust can also be applied to orbiting objects to modify their trajectory. The program of the project deals with laser-matter interaction with space industry materials, seeking for most appropriate laser conditions offering possibilities for future systems which could be involved in space propulsion.

The Low-Earth Orbit (LEO) is congested with space debris due to the object launches frequency. Collisional cascades instability such as described by the Kessler syndrome is threatening. The main urgency is to mitigate future risks. The proposed solutions are changing debris orbits or reorbiting drifting space objects with laser irradiation [1]. Depending on the target material nature, studies on laser irradiation parameters are showing that shorter wavelength and pulse length could lead to a maximized momentum coupling coefficient ( $C_m$ ) to produce an optimum mechanical impulse coupling, opening the way to propulsion as soon as repeated irradiations could become possible. Using repetitive laser irradiations can lead to the production of extra debris, either induced by ablation or by spallation, with a risk of drilling the target. The debris ejection stemming from irradiation participate to the propulsive effect by reaction to their ejection backwards to the irradiating laser, unless spallation or drilling of the irradiated material occurs.

To address these points, we present some preliminary experiments performed with a high power pulsed laser facility with a high rate of repetition as offered by HILASE beamline facility (Prague, CZ) BIVOJ (100J, 10ns, 10Hz, 1030nm). An experimental set-up allows to evaluate comparatively the effect of a single irradiation and repeated ones on the integrity of a 1mm thick target of various materials of interest for space application (Aluminum, high molecular weight plastics such as polyoxymethylene (POM), hybrids (POM + Al)).

Another experimental set-up based on the Crookes mill concept was implemented in order to evaluate the propulsive effect of laser bursts on spinning objects under vacuum. For the demonstration, laser receivers were pure aluminum targets and a measurement of the velocity increase under a 4 laser shot burst is evidenced.

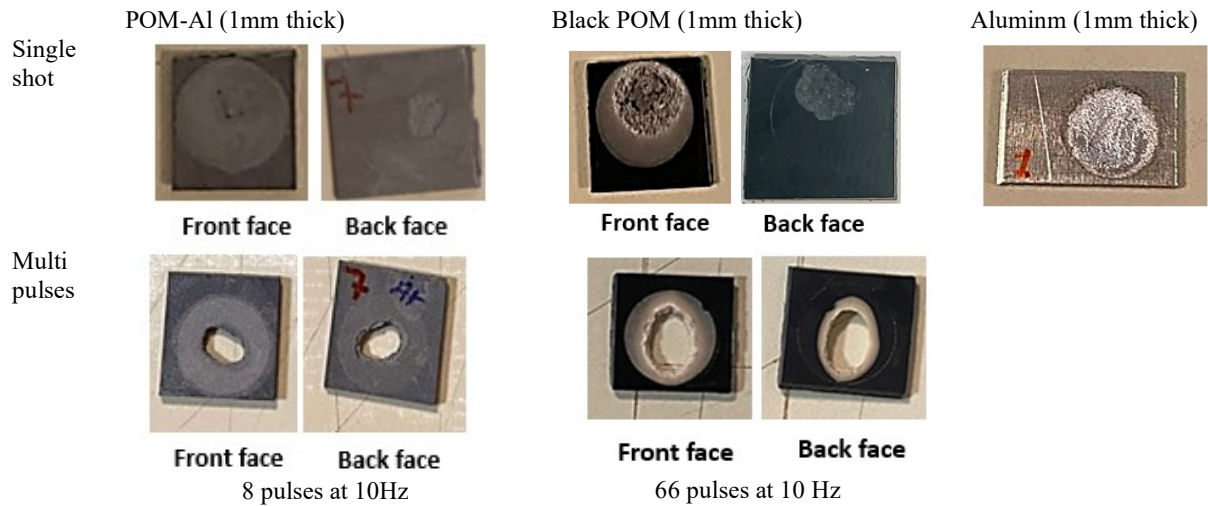


Figure 1: Observations of the front (BIVOJ side irradiation) and opposite face of 1mm thick targets of Al, POM-Al and black POM submitted to a single irradiation 80J-10ns\_ 76 GW/cm<sup>2</sup> or the same repeated irradiation

## EXPERIMENTAL SET-UP

BIVOJ laser facility [2] at HILASE Center is a single beam, cryogenically cooled, multi-slab laser system delivering over 1kW of average power in 80J, 10 ns pulses at 10Hz at 1030nm, representing the world's first kW average power, diode pumped solid state laser. The 22mmx22mm native square beam is then focused on the designated targets into a vacuum chamber on a spot of 3mmx3.5mm. Two modes of irradiation have been used: single shot or burst mode with a number of defined shots on the targets. Two experimental set-ups were implemented into the vacuum chamber: a fixed target holder to evaluate the material response in terms of damage to laser irradiation [3] and a rotating target holder based on the Crookes light mill concept [4] with limited friction to evaluate the propulsive effect of multiple irradiations on targets.

## DAMAGE ASSESSMENT

When irradiating a material with intensities above GW/cm<sup>2</sup>, the laser matter interaction results in a plasma formation and expansion/ejection in the vacuum chamber, resulting in a shock wave generation quickly followed by a release wave. This ejection acts as a rocket effect for propulsion all the more as many ejecta are produced. They need to be quantified, either directly or via the ablation crater left in order to address the overall integrity of the irradiated structure. The shock wave propagation initiated by the irradiation can also result in opposite damage to the loading via the spallation phenomenon which can also result in a detrimental thinning of the irradiated structure regarding its integrity. By piling shots in burst mode on the same location, these concomitant phenomena result in thinning the irradiated target up to its drilling which is the ultimate step prohibited for keeping some efficiency of the laser irradiation to boost a laser spotted structure. In order to determine the limits of irradiation ensuring an acceptable damage of the irradiated structure, a set of 1mm thick targets of pure aluminum (reference material) and high molecular weight plastics such as PolyOxyMethylene (POM), hybrids (POM-Al) were fixed on a target holder put into vacuum and irradiated at first by 1 shot at full energy of

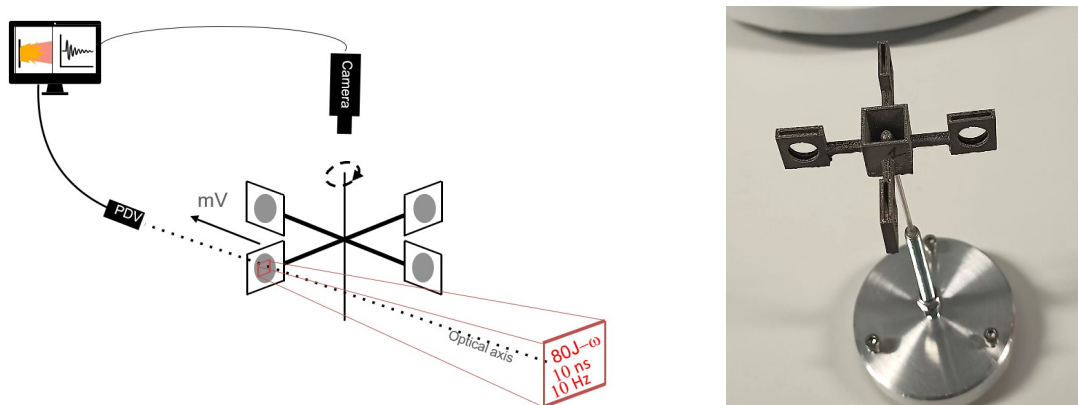


Figure 2: Experimental set-up based on Crookes light mill concept to evaluate spinning speed resulting of repeated laser matter irradiation. Each wing slot can be loaded with a selected material for laser matter interaction

recovered samples after irradiation (cf. Figure 1) evidences the plasma formation on the front face and consecutive cratering more pronounced for the POM-Al, less for Al and less POM. Watching at the opposite face to the loading, no damage was observed on Aluminum, a thin spall on POM-Al and on POM. Despite these observed damages, we could consider that the overall integrity of a space structure of these materials irradiated with these conditions could be acceptable.

The same experimental protocol was reproduced on new targets of the same materials, but using laser bursts on the same spot. The aluminum was irradiated by 12 shots at 10Hz and compared to a single shot, only an increased cratering could be observed. However, concerning the POM-Al, after a burst of 8 pulses, the repeated combined cratering by ablation and spallation resulted in a full drilling of the target, loosing all its integrity. The POM was illuminated by a burst of 66 shots in a sequence of 14+22+30shots.

## PROPULSIVE EFFECT

According to these raw preliminary results on materials integrity to repeated high power pulsed irradiation delivered by BIVOJ facility, Aluminum was retained for evaluating the propulsive effect of multiple irradiations. In order to demonstrate and evaluate the possible propulsive effect of laser bursts, an original target holder inspired on the concept of the Crookes light mill was designed using additive manufacturing (cf. Figure 2). On each wing, a slot is ready to host different kind of laser receiver materials. Placing this four targets receiver in vacuum on a vertical pin minimizing all friction forces, a first laser pointing is performed on a first target with a  $3 \times 3.5 \text{ mm}^2$  focusing position. Using a long focusing device (180cm), after the first shot activating rotation, the following shots are expected to interact with one of the four targets of the Crookes holder, with possible defocusing but within a limited difference on fluence. A high speed camera (2000fps) placed above the mill in the rotation axis imaged the plane of rotation. Opposite to the BIVOJ irradiated face, a Photonic Doppler Velocimetry interferometer measured the velocity of rotation of the mill under laser irradiation. This set-up could be tested successfully with one test (cf. Video 3); a burst of 4 shots at 80J were performed and can be seen on the clip Figure 3-a) at each lightening. Two of them were on the same receiver and each other on a different one. The important point is that even with superposition of shots on the same receiver, this one can still act as a plasma generator without drilling as checked before in order to benefit from the rocket effect. The velocity recorded by the PDV of the spinning of the light mill evidences clearly a four steps increase of the rotating velocity under each pulse (cf Figure 4). This measurement is correlated with image analysis from the camera on the top (cf. Video 3).

These preliminary tests demonstrated the ability of this twin experimental procedure to study the response of various materials under high power pulsed laser bursts. The ejected debris from cratering could be better characterized, so as the mapping of damage by spallation or drilling versus irradiation laser conditions for various space applicative materials could be addressed using this protocol. To that extent, experiments should be complemented acting on the many parameters driving space laser propulsion as laser parameters and materials constituents for spatial applications.



Video 3. “[Laser induced spinning](#)” of the simili Crookes mill target holder loaded with 1mm thick aluminum targets irradiated by a burst of 4 BIVOJ shots at 80J-10ns, 76GW/cm<sup>2</sup>: <http://dx.doi.org/doi.number.goes.here>

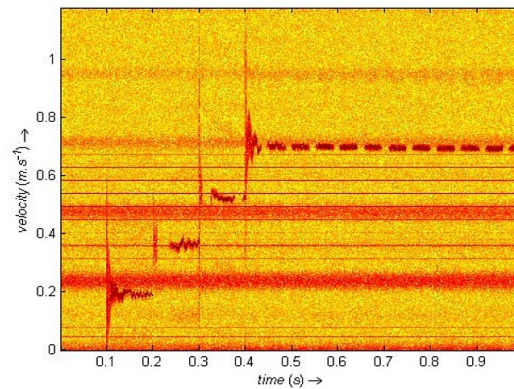


Figure 4. Photonic Doppler Velocity performed in the axis of laser irradiation opposite to the BIVOJ irradiation of the Crookes mill in configuration of video3 evidencing a step increase in velocity at each laser strike.

## CONCLUSION

Most of available data in the domain of laser driven space propulsion rely on the propulsion effect induced by single shots of high power pulsed laser sources. With the recent laser technologies development, new laser facilities allowing both high energy and repetition rate of a short pulsed irradiation become available as provided by the high power HILASE beamline facility (Prague, CZ) with BIVOJ (100J, 10ns, 10Hz, 1030nm). Experiments performed on targets of various materials from model materials to space applicative materials allow to estimate the material response with various irradiation characteristics (single shots vs. repeated shots). *Post mortem* observations on recovered samples evidence the different processes consecutive to laser matter interaction (ablation, cratering, spallation, perforation), evidencing the ability to bracket the necessary laser conditions most suitable in the perspective of laser propulsion with limited creation of extra debris or damaging of the irradiated structures. An original experimental set-up based on Crookes mill concept was adapted to quantify the efficiency of repeated laser shots in increasing rotating speed according to laser matter interaction. In addition, these experimental data are likely to provide a data base for the robustness of the dialog simulation/experiment to use simulation as a pre-design tool for laser space propulsion.

## ACKNOWLEDGEMENTS

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