LASER INDUCED DAMAGE THRESHOLD TESTING: APPLICATIONS AND RESULTS

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Laser Induced Damage Threshold (LIDT)is an established method used to estimate the maximum affordable energy or power that a particular optical component may handle without detrimental damage. Although the damage threshold testing procedure is standardised and commonly used for testing optics, the use of its principles for other applications, like laser processing window determination, is relatively scarce. The newly emerging kW-class ultrashort laser systems in combination with advances in their utilisation brings challenges in durability, efficiency and reliability of devices and processes, where proper testing provides the right answers.

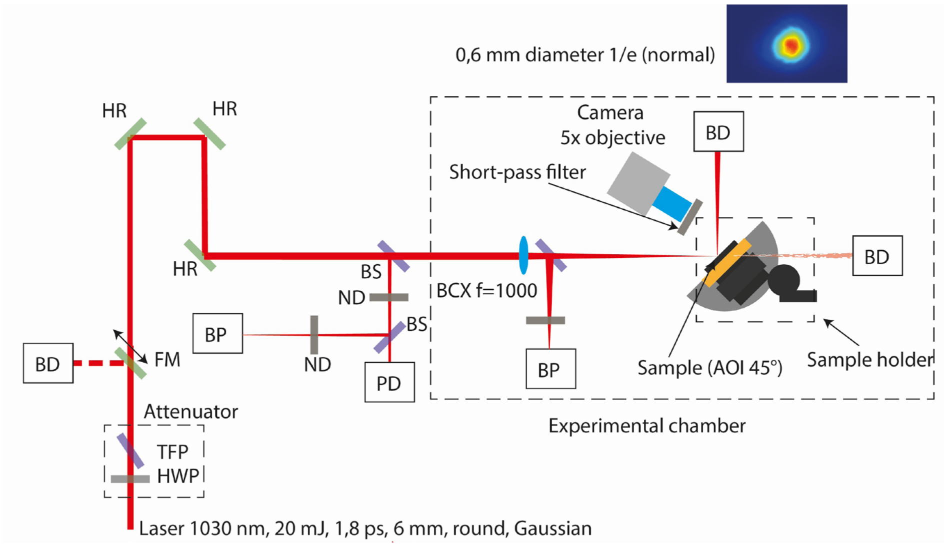

Figure 1: LIDT station layout designed at HiLASE (for Perla laser). HWP - half wave plate, TFP – thin film polariser, FM – flip mirror, BD – beam dump, HR – highly reflective mirror, BS – beam sampler, ND – neutral density filter, PD – photodiode, BP – beamprofiler.

Laser Induced Damage Threshold testing is a well-known method, recognised by the International Standards Organisation (ISO) in a series of ISO 21254 standards [1]. These standards were developed in order to ensure reliability and portability of results among different testing facilities. Although testing schemes initially reflected the need of laser optics manufacturers, rapid development of high power laser sources and their applications stimulated interest from other fields, such as machine integrators and (micro)machining [2].

LIDT testing capabilities at HiLASE

The LIDT laboratory benefits from advanced laser development at HiLASE, which gives access to the state-of-the-art diode-pumped solid-state systems which offer incomparable energies for experiments. Two systems are mostly used for tests: Bivoj (10 ns, 1030/515/343 nm @10 Hz, flat-top square beam) and Perla (1.7 ps, 1030/515/343 nm @1 kHz, round Gaussian beam) [3].

With both lasers providing very high pulse energies, it is possible to measure LIDT using a larger beam size, which greatly increases the measurement accuracy. The testing station, as shown in Figure 1, is situated in a clean laboratory with controlled humidity, temperature and dust particle concentration, with a measured cleanliness of ISO class 6. The sample mount and damage detection setup is placed in an experimental chamber with the option of a vacuum (10^{-3} mBar) or non-corrosive atmosphere (up to 2 Bar). A remote-controlled micrometer 2-axis translation stage is used for sample mounting. Online damage detection is realised by an online camera with high magnification that continuously monitors the exposed site. A laser scanning microscope is used for the examination of the sample before and after the testing procedure [4].

Development of new optical coatings

A further development of silver mirrors is possible with the deposition of functional dielectric coatings, in order to enhance the mirror reflectivity in a narrow spectral range around 1030 nm. To develop and assess the laser performance of such designs, respective prototypes were tested on LIDT according to ISO 21254 recommendations. At least 100 sites on each sample were exposed to a ~500 µm diameter laser beam at the plane of incidence with ten different energies.

Online camera-based damage detection was used to observe sites during the exposure and damage events were noted. Collected data were used to extrapolate damage thresholds of respective samples and results are plotted in Figure 2.

Although the standard design demonstrated fairly good LIDT, minor changes in design, such as an intermediate layer or different coating material, may offer up to 30% improvement in performance. Further tuning of the technology with feedback from damage testing may lead to even better results, as more than five times higher LIDT of mirror enhanced with dielectric multilayer compared to the commonly used mirror design [5].

Laser processing window assessment

The dependence of ablated material volume on energy is is a key parameter for efficient laser use in various kinds of laser cutting, drilling or other means of material removal. Thus, laser damage threshold testing procedures are ideal to measure such dependency, allowing proper setup of processing conditions and optimalisation of the whole process.

A good example of such application is protective coatings removal, which is used in the industry to increase the wear and oxidation resistance of tools. If the tool needs to be sharpened, repaired, or the protective layer needs to be restored, the current layer has to be removed. Standard removal methods are based on chemical etching which is energy-demanding and brings a significant environmental burden. The replacement with efficient laser ablation could shorten the removal process time, decrease environmental impact and reduce overall costs. Particularly in the case of CrAlSiN layer removal, LIDT testing plays a key role in the determination of two main laser parameters – fluence and number of pulses. Also, the quality of the ablation crater is observed, because it is desirable not to harm the base material.

The graph in Figure 3 clearly shows the trade-off between process energy, volume of ablated material and speed of the coating removal. As a price-per-pulse is given for any laser system,

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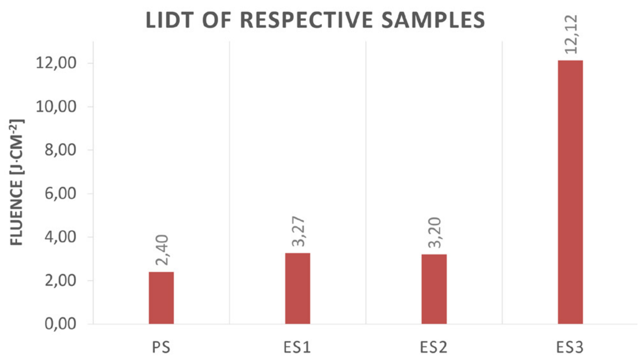

Figure 2: Damage thresholds of tested samples. PS: silver mirror protected with standard SiO_2 layer; ES1: silver mirror protected with standard SiO_2 layer, enhanced with Al_2O_3 intermediate layer; ES2: silver mirror protected with Al_2O_3 layer; ES3: silver mirror protected with dielectric multilayer improving the reflectance at 1030 nm and enhanced with Al_2O_3 intermediate layer.

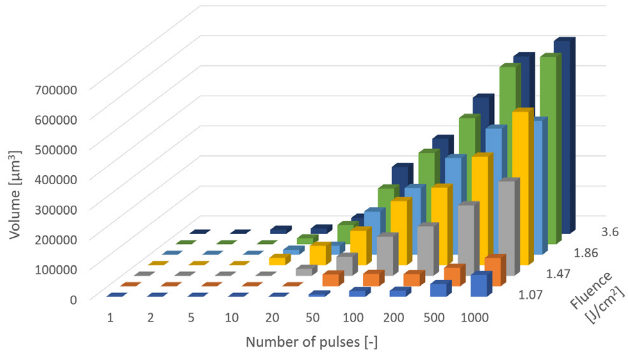

Figure 3: Measured dependence of ablated coating volume on fluence and number of pulses at fixed spot size.

such information is a must when looking for cost-effective lasers to be used in such processes at an industrial scale.

Laser components certification

The emergence and growth of new high-power laser applications keeps pushing the laser industry to its limits both in terms of the achievable laser power and offered laser parameters. This popularity drives forward development in laser optics and components. In particular, when a new material or manufacturing technology emerges, it is essential to validate such a part for laser induced damage performance to determine the scope of its usability. One such example are calomel crystals (mercury chloride). Although well-known and used in other fields, only recently has it been possible to produce the crystals in large batches with sufficient quality to be used in laser optics [6]. LIDT tests are even more important here, as the calomel crystal is composed of two very toxic elements which are released after laser induced ablation.

Results from the testing showed strong correlation of LIDT on the angle between the testing beam and the optical axis of the crystal, with the LIDT being five times larger for the 001 configuration over the 110 configuration. Damage morphology varied from colour centres over small cracks and surface blisters to full craters (see Figure 4). Although further testing and exploration of this crystalline form is still required, related damage threshold and consequently a window of safe usage was clearly defined by LIDT tests.

Integration of new technologies

A typical example of the integration of technologies is where LIDT testing plays a key role in the use of optical fibres as a transmitting medium for high energy laser pulses. Optical fibres offer a stable and safe environment for laser pulse propagation, minimising risks from optics misalignment, beam pointing stability and hazards for operational staff. However, optical fibres are not designed primarily for transmission of high-power laser pulses and the capabilities of standard fibres are quite limited [7]. Recent tests of real large-core optical fibres and their comparison with bulk preforms demonstrated an order of magnitude difference in damage threshold [8]. Observed damage, occurring mostly on the fibre surface, led to the conclusion that more development in technology and in fibre cable manufacturing has to be conducted in order that this technology is suitable for high energies. Proper on-site diagnostics allowing the continuous monitoring of exposed fibre is as important as the precise measurement of the laser beam. Iterative steps to improve fibre front-surface properties, based on feedback given by LIDT testing of respective samples, led to fibre solutions offering transmission of ns laser pulses with a peak power as high as 100 MW.

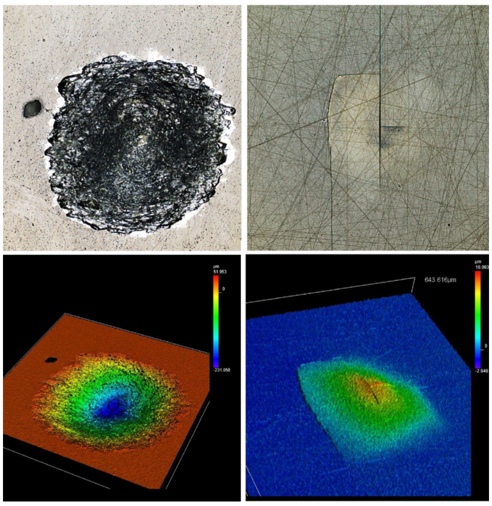

Figure 4. Details of the craters ablated on HgCl crystals with 1,8 ps pulses at 1030 nm. Crystals were prepared in plane 110 (left, damaged at 1 J/cm²) and 001 (right, damaged at 5 J/cm²)

Summary

The growing market for high-power laser devices as well as the evolution of related applications comes together with the need for precise testing and measurement tools. Since lasers are an integral part of modern technologies, which can be found in almost any industrial field, their reliability, traceability and a systematic assessment of their related components, is key when looking at their suitability for a particular application. Although standardised LIDT tests are not the only way to approach such a concern, we have demonstrated several case studies, where our results were essential for successful deployment of assessed technologies and components.

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