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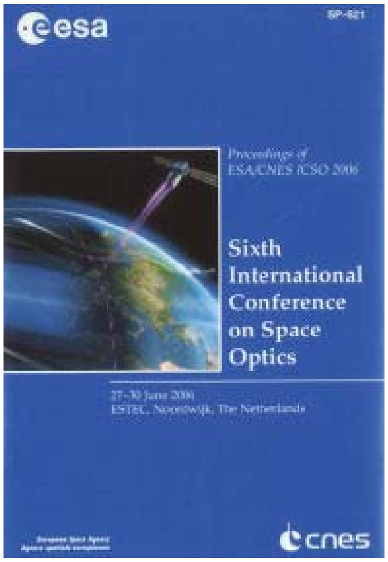

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LASER-INDUCED DAMAGE TESTING OF OPTICS FOR THE ALADIN LASER

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ABSTRACT

The European Space Agency is developing its first spaceborne LIDAR for global monitoring of wind velocities. ALADIN, to be launched on board ADM-Aeolus in 2008, is a pulsed Nd:YAG laser with about 120 mJ of pulse energy at 355 nm and a repetition rate of 100 Hz during bursts. Within the projected mission duration of three years, this gives a lifetime requirement of close to 5 billion pulses.

While laser-induced damage thresholds of optics in vacuum (possibly contaminated by small amounts of organic compounds) can differ from atmospheric conditions, their damage behaviour is generally poorly understood. The European Space Agency has therefore established a test campaign to measure the power handling of all the instrument optics with several European laboratories participating.

In the Optics and Opto-Electronics laboratory at ESTEC, a laser-induced damage threshold (LIDT) test facility has been set up with a 50 Hz Nd:YAG test laser. The pulse energy is 700 mJ at 1064 nm. This allows us to recreate the laser pulse conditions to which the ALADIN optics will be exposed. The flat-top beam profile of the test laser irradiates the optics with uniform fluences and relatively large spots (up to 1mm across) at damaging intensities.

Damage tests are performed with up to 1 million pulses per test spot according to the S-on-1 test ISO-11254 standard, requiring typically 10 days to test one sample. With such extended tests, we can predict the laser-induced damage threshold over the ALADIN lifetime with improved accuracy.

1 LIDT TEST CAMPAIGN AT ESTEC OF ALADIN'S OPTICAL COMPONENTS

As part of the test campaign, ESA has put together a Laser Risk-Reduction Group, which is attended by experts in the fields of laser-induced damage and materials analysis from several European countries. Together with ESA engineers, the group assesses the risks, gives advice on required qualification tests, and assesses the experimental results. Three major risks have been identified to have the potential to seriously impair laser operation in space through laser-induced damage.

The first is the intrinsic laser-induced damage threshold of the optical component as compared to the fluence to which they are exposed in the laser. Space qualification of the laser requires that every batch of unique component is tested with respect to their laser-induced damage threshold in vacuum. This is particularly significant since experiment shows that the damage threshold of coatings in vacuum can be lower than in air [2] and may hence deviate from manufacturer specifications.

A second risk is optical fatigue in the course of the mission. From literature very little is known of optical fatigue, but the issue was considered to be particularly important to Aladin because of the relatively long duration of the mission and due to the near impossibility of servicing the laser in orbit.

A third issue is the effect of contamination on the optics in vacuum. Literature suggests that the presence of air suppresses the formation of deposits on the irradiated optics. Since most high-power lasers operate in air, a special effort is required to investigate the effect of contamination under vacuum conditions.

It is expected that all the three above-mentioned types of risk could affect the ALADIN laser and that all must be properly managed. Even though the ALADIN laser is very compact, there are still more than 70 optical components in the laser box, which has diameters of about 30cm·50cm·60cm. Of these, more than twenty are unique combinations of substrate and coating, and the optics are subject to one or several of the laser wavelengths 1064nm, 532nm, or 355nm. The 39-month mission duration not only increases the risk of optical fatiguing, but also increases the chance of contamination build-up on the optics through the mission.

2 INTRINSIC LASER-INDUCED DAMAGE

The qualification of components with respect to their intrinsic damage threshold was conduced at DLR (German Aerospace Centre) in Stuttgart, Germany, under a contract with GA. In agreement with ESA,

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these tests were usually limited to 10,000 shots and never extended beyond 40,000 shots. In a very limited period of a few months DLR tested all the unique optics of the ALADIN laser. The tests themselves have all been described in [2], and will not be described in more detail here.

3 COATING AGING BEHAVIOUR

While DLR performed S-on-1 tests to 10,000 shots, ALADIN is expected to fire almost five billion pulses. Although it is possible to extrapolate S-on-1 test data [6], extrapolation over many orders of magnitude is by its nature inaccurate, especially since fatiguing effects may not be visible in experiments of short duration.

The optics and opto-electronics laboratory at ESTEC is equipped with a Continuum Powerlite II 9000 for laserinduced damage testing. The system has been optimised for beam quality and hence has a reduced output power (700mJ) as compared to the nominal system. An injection seeding laser is used to ensure operation in a single longitudinal mode. The system is flashlight pumped, with the flashlamps lasting approximately 60 million shots.

This is sufficient to allow for S-on-1 tests on optics with up to 1 million shots per site, while still retaining good statistics. For each optic, typically 100 sites would be tested per sample, with fluences optimised so that about twenty sites would normally survive the full 1 million pulses. In order to complete a test in a short time as possible, the laser system must operate day and night without the supervision of staff. Night operation required faultless damage detection since continued irradiation once damaged will exacerbate the damage and risk cross-contamination of sites. For safety reasons, the laser automatically shuts down and enters safe mode if the computer were to fail, if the interlock system is breached, or if the laser power were to drop.

The test setup is shown in Fig. 1. The output beam of the test is magnified by a factor of 1.5 by a telescope to reduce the risk of laser-induced damage to the optical components. An optical isolator (OFR 10-15-1064VHP) is used to ensure that back-reflection cannot re-enter the laser. A half-waveplate mounted on a computer-controlled stepper motor (NewFocus 8401M), in combination with a Brewster-angle thin-film polariser, adjusts the pulse energy of the impeding pulses. For optimal beam profile, an f=680mm objective is used to image the output of the laser amplifier rod onto the sample surface.

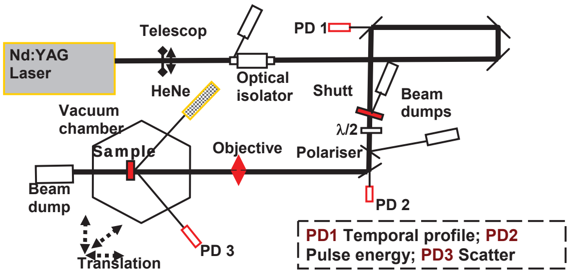

Fig. 1. The laser-induced damage threshold setup at ESTEC. The Nd:YAG output is imaged onto the sample using an objective of focal length f=680mm. The test chamber is pumped by an oil-free vacuum pump and typically reaches a pressure lower than 10-5mbar. It is mounted on a computer-controlled translation stage that moves the chamber and the sample with respect to the laser beam. The photodetectors PD1 and PD 2 are used to monitor the pulse temporal profile and the pulse energy, respectively. The HeNe laser and photo detector (PD3) combination is used as a scatter probe to detect any changes to the sample surface.

All damage threshold measurements are conducted according to the ISO 11254-2 standard for S-on-1 measurements [6]. The setup is fully automatic, with all parts of the setup controlled via a central computer by LabView software developed at Laser Zentrum Hannover (LZH).

The computer collects and records information on the pulse energy and the pulse to pulse stability of the laser, the Q-switch build-up time and the number of pulses. The temporal pulse profile is monitored on an oscilloscope for single-mode operation. Laser-induced damage is detected on-line either as an increase in scatter from a chopped HeNe signal irradiating the sample surface, or in terms of an increase in the pressure of the vacuum chamber.

Experience shows that the two detection methods complement one another, with either method generally detecting damage within a few pulses only. Once the test run has completed, the sample is investigated under a Nomarski microscope with available magnification of 200. The Nomarski investigation gives very good correlation with the on-line detection, with only very small damage (typically with diameters less than 10μm) on one or two sites per sample not being detected by the on-line detection methods.

We also image the sample plane onto a second CCD camera (Cohu 4810) placed behind the sample. This has the advantage that we can be sure that we are imaging the appropriate plane (the plane is detected by imaging any surface damage). Also, the damage process can be viewed in real time. However, it has the disadvantage that aberrations between the sample plane and the CCD camera may distort the image. This setup is described in Fig. 2. The distance between the image plane and the imaging lens is 594(5)mm, and from the lens to the camera is 802(5)mm. The focal length of the lens is 340mm. The magnification factor is then 1.35, with the image being larger than the object. With 13.5µm pixel size, we can derive the spot size of the laser directly from the image. The camera is also used to measure the cross-section and hence the fluence of the beam, which is derived by using the camera in combination with a Coherent joule meter.

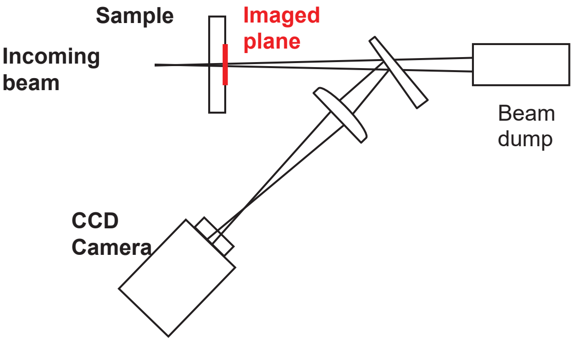

Fig. 2. Setup to image the laser beam at the sample plane. The wedge ensures that only a small fraction of the power is incident on the camera. Absorption filters (not shown) are used to attenuate the laser beam further to avoid CCD damage.

The test setup was used to characterise several anti-reflecting and partially reflecting coatings. A typical test result can be seen in Fig. 3. As was the case for almost all tested coatings, the damage threshold remains typically stable within measurement errors after the first 10 000 pulses until 1 000 000 pulses. We note that even when performing experiments with this many shots, the uncertainty to the extrapolation remains large, in particular since the mechanisms of aging are not well understood. We have plotted the function specified by the ISO standard [6]:

$$H_{thr}(N) = H_{thr,\infty} + \frac{H_{thr,1} - H_{thr,\infty}}{1 + \frac{1}{\Delta}\log_{10}(N)} \qquad (1)$$

where $H_{thr}(N)$ is the threshold for N shots, $H_{thr,1}$ and $H_{thr,\infty}$ are the damage threshold for one shot and an infinite number of shots, respectively, and Δ specifies the rate of aging.

For the purpose of comparison, we have also included the function proposed by Allenspacher et al. from DLR in [2]. At 5 billion pulses, the ISO-standard extrapolation gives an estimate of 3.7±0.7J/cm^2, while the DLR function extrapolates to 5.2±1.0J/cm^2, demonstrating the importance of the model used and the difficulty in performing an extrapolation.

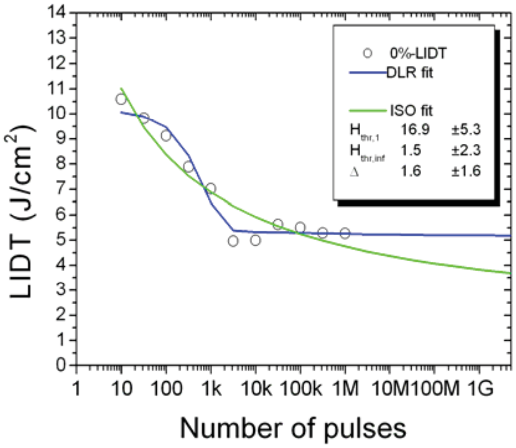

Fig. 3. Typical damage probability curve for a partial reflector. The solid line represents the fit suggested by the ISO standard 11254-2, the dotted line represents the function suggested in [2].

We would also like to mention that the ESTEC test laser and DLR's test laser, a Coherent Infinity have significantly shorter pulse lengths than ALADIN: τ=8ns and τ=3.5ns respectively as compared to τ=28ns for ALADIN. Scaling the test results to ALADIN is an important part of the qualification effort. For nanosecond pulses in dielectric materials, the damage mechanism is usually thermal and the laser-induced damage threshold scales with τk, with lower damage thresholds for short pulses. From models, k can be shown to be equal to 0.5 [4], but experiment shows that this factor is typically somewhat lower. It has been reported to lie between k=0.3 and k=0.4 in the nanosecond regime [5]. It is likely that the variation depends on the coating under test, with the distribution and properties of absorbers affecting the relationship [4]. By necessity a factor of k=0.35±0.05 for all the optics was used to scale the pulse duration. Currently, the test campaign to qualify the intrinsic damage threshold of the optics is nearing its end, with only a few components yet to be qualified.

4 CONCLUSION

A laser-induced damage setup has been produced at ESTEC with the capability of performing S-on-1 measurements in vacuum with as many as 1 million pulses at 50Hz.

5 ACKNOWLEDGEMENTS

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