Aspects of laser optics qualification for space applications

W. Riede, H. Schroeder, P. Mahnke, P. Allenspacher
German Aerospace Center (DLR), Institute of Technical Physics, Stuttgart, Germany

D. Wernham
European Space Agency (ESA / ESTEC), Noordwijk, The Netherlands

Accessing space with high-power laser systems is not a straightforward task as the space environment entails various risks [1] for optical surfaces and even bulk materials. High-power laser systems can respond very sensitively on absorption increase on its manifold of optical surfaces or in the bulk of transmissive optics, on misalignment of the optical axis, or coating delamination or destruction. These deleterious effects can be conveyed by a simultaneous action of outgassing contaminants and (UV) laser radiation leading to absorbing deposits on optical surfaces, by high energy solar or cosmic radiation generating color centers in the bulk of materials, by vibration-sensitive mounting of optics leading to misalignment during launch, by high-fluence exposure exceeding vacuum laser damage thresholds (coating destruction) or mismatch of thermal expansion coefficients (coating delamination), to mention just the most important risks. Extensive tests are currently supported by ESA / ESTEC at various labs in Europe to find ways to dispose of or mitigate the risks mentioned above.

The DLR laser optics qualification laboratory has specialized on vacuum laser damage testing of optical coatings [2,3], on contamination effects, efficient long term phase matching stability of nonlinear crystals. In addition, various external tests on vibration testing, thermal vacuum testing, and high energy radiation testing of optical components were arranged and coordinated. The results of these tests will be presented in this article.

Several upcoming ESA space laser missions like ADM-Aeolus, EarthCARE, or BEPI Colombo necessitate the profound laser damage testing of the involved laser optics as they will be exposed to relatively high fluence levels (up to 20 J/cm^2) at various wavelengths (1064 nm, 532 nm, 355 nm) and are required to have a lifetime of several years equating to several billions of laser shots emitted overall.
Consequently, all critical optics must be tested rigorously to eliminate weaknesses in the laser-optical chain. At the DLR lab were tested all exposed laser optics of the ALADIN laser system, which is the laser source used during the upcoming ADM Aeolus mission (launch planned 2011). These tests are done according to the International Standard ISO 11254-2.0 – 2001 [5], in which multipulse laser damage tests are defined. The main result was that dense optical coatings have to be used, as the porous e-beam coatings tend to degrade massively under vacuum exposure (so called “air-vacuum effect” in optical coatings). The Fig. 1 below shows the mobile high-vacuum chamber, developed for laser-induced damage threshold (LIDT) assessment under vacuum conditions.

Another important task is to optimize the frequency conversion efficiency during long term operation of second or third harmonic generation (SHG/THG) crystals, as these are necessary to access the desired wavelength range, e.g. for LIDAR applications. A high conversion efficiency is of uttermost importance as large distances have to be bridged from low earth orbit during earth or cloud observations. As candidate crystals, borates (LBO, BBO and BiBO) and phosphates (KTP, KTA) are considered, under various combinations, with the goal to reach > 30% energy conversion efficiency from 1.06 µm (fundamental wavelength of the Nd:YAG laser) to 355 nm. This was proven yet for the LBO THG system, further tests are currently performed. In Fig. 2 is depicted the ultra-high vacuum chamber designed for these tests.

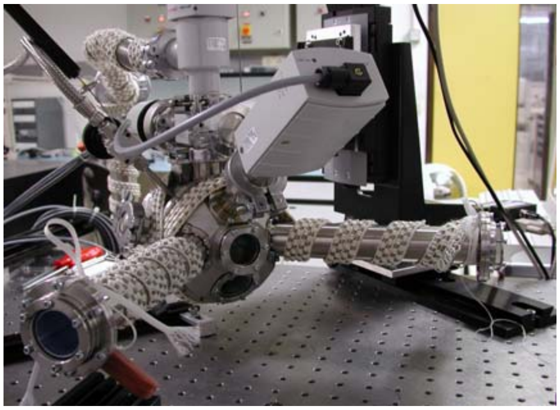

Figure 1: Mobile high-vacuum chamber used for laser-induced damage threshold assessment under vacuum conditions.

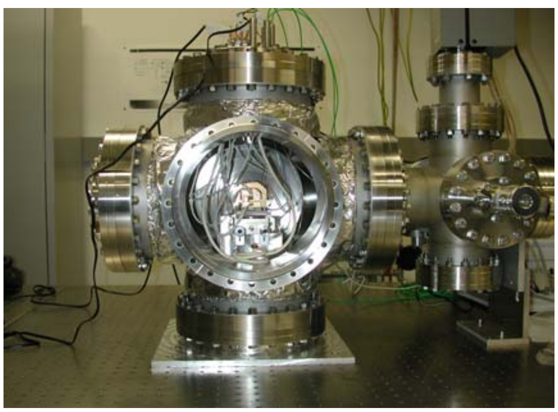

Figure 2: Ultra-high vacuum chamber designed for long-term frequency conversion tests of nonlinear crystals.

In the past, several space-based laser missions have suffered from anomalous performance loss or even failure after short operation times. This degradation is due to selective contamination of laser-exposed optical surfaces fed by outgassing constituents. These volatile components are omnipresent in vacuum vessels. Various organic and inorganic species were tested at the DLR and ESA / ESTEC facilities for their criticality on deposit built-up. Deposits tend to built up favorably when operating in the UV at 355 nm. Thicknesses range on the order of several tens of nanometers, which can be sufficient to induce a noticeable absorption.

Finally, active optical components like Q-switch crystals or frequency converter crystals can also suffer from bulk absorption induced by high-energy radiation (so called gray tracking) and dehydration. To identify for these effects, crystals were exposed to proton (10 MeV) and gamma radiation at the corresponding test sites at Paul-Scherrer Institute in Switzerland (proton source) and gamma radiation (Co-60 source at ESA/ESTEC). The result was striking, as the borates in general did not show a degradation or only a minor degradation, whereas the phosphates and arsenates displayed noticeable performance loss. An example is shown in Fig. 3, where several transmission spectra of KTP (used as SHG crystal) are plotted after receiving an orbit-representative dose of gamma radiation (100 krad, in various steps). An absorption loss due to color center formation in the visible is observed. After heating the crystal for one hour at 150 °C, an almost complete recovery of the transmission can be found.

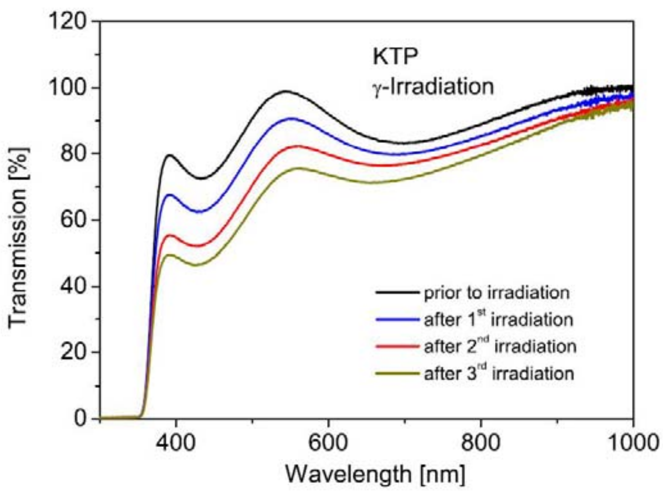

Fig. 3 Transmission spectrum of KTP (10 mm X 10 mm X 6 mm) after various dose steps (10, 30, 60 krad) applied with a Co-60 source. A continuous degradation is observed.

Further work will be directed to long term efficiency tests run over a period of two weeks under ultra-high vacuum conditions. In addition contamination tests and LIDT testing will be continued. Further details can be found in an upcoming presentation [6]. Additional proton radiation tests (100 / 250 MeV) are planned in the near future for passive and active optics, used in space lasers.

References:

1. Lien, Y, Wernham, D., Riede, W., Allenspacher, P. „Risk mitigation in spaceborne lasers“ ,Photonics Europe, Strasbourg, France, 2006.
2. P. Allenspacher, W. Riede, D. Wernham; “Laser qualification testing of space optics”, Laser-induced damage in optical materials 2006, SPIE Vol. 6403; 0T, 2007.
3. P. Allenspacher, W. Riede, D. Wernham; “Vacuum laser damage test bench”, Laser-induced damage in optical materials 2005, SPIE Vol. 5991,28, 2005.
4. H. Schroeder, S. Borgmann, W. Riede, D. Wernham, “Investigation of laser induced deposit formation under space conditions”, International Conference on

Space Optics, Toulouse 2008.
5. International Standard ISO 11254-2.0 - 2001, „Determination of laser-induced damage threshold of optical surfaces- Part 2: S-on-1 test“, 2001.
6. W. Riede, P. Allenspacher, H. Schroeder, P. Mahnke, D. Wernham, „Aspects of laser optics qualification for space applications”; Invited talk at the Boulder Damage Symposium 2009.