Laser-optics qualification for space applications

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Suitable optical components must be developed to ensure reliable, efficient, and autonomous operation of space laser systems.

Operation of high-power laser systems in space is not straightforward as this environment poses various risks\(^1\) to optical surfaces and even to bulk materials. Such systems may respond very sensitively to absorption increases of their multiple optical surfaces or in the bulk of transmissive optics, misalignment of the optical axis, or coating delamination or destruction. These effects can be caused, for instance, by simultaneous action of outgassing contaminants and (UV) laser irradiation (leading to deposits on optical surfaces), high-energy solar or cosmic radiation (which generate color centers in bulk materials), vibration-sensitive mounting of optics (leading to misalignment during launch), high-fluence exposure exceeding vacuum laser-damage thresholds (coating destruction), or mismatch of thermal-expansion coefficients (coating delamination). Extensive tests are currently supported by the European Space Agency’s European Space Research and Technology Centre (ESA/ESTEC) at various laboratories in Europe to facilitate canceling or mitigating these risks.

The German Aerospace Center’s (DLR) laser-optics qualification laboratory specializes in vacuum laser-damage testing of optical coatings,\(^2,3\) contamination effects,\(^4\) and efficient long-term phase-matching stability of nonlinear crystals. In addition, various external approaches to vibration, thermal-vacuum, and high-energy radiation testing of optical components have been arranged and coordinated.

Several forthcoming ESA space-laser missions—for instance, ADM (Atmospheric Dynamics Mission)-Aeolus, EarthCARE, and BepiColombo—require extensive laser-damage testing of their optics as they will be exposed to relatively high fluence levels (up to 20\(\text{J/cm}^2\)) at various wavelengths (1064, 532, and 355nm, respectively) and are designed to have lifetimes of several years, corresponding to a total of several billion emitted laser pulses. Consequently, all critical optics must be tested rigorously to eliminate weaknesses in the laser-optical chain.

At the DLR laboratory, we tested all exposed laser optics of the ALADIN (Atmospheric Laser Doppler Instrument) system on board the ADM-Aeolus mission (launch planned for 2011). These tests are done according to the ISO 11254-2.0 international standard,\(^5\) which defines multipulse laser-damage tests. The main result was that dense optical coatings must be used because the alternative, porous e-beam coatings tend to degrade significantly under vacuum exposure (referred to as the ‘air-vacuum effect’ of optical coatings). Figure 1 shows the mobile high-vacuum chamber developed for laser-induced damage-threshold (LIDT) assessment under vacuum conditions.

It is also important to optimize the frequency-conversion efficiency during long-term operation of second- or third-harmonic-generation (SHG/THG) crystals. These are necessary to access the desired wavelength range, e.g., for lidar (light detection and ranging) applications. A high conversion efficiency is of the utmost importance because long distances have to be bridged from low-earth orbit during earth or cloud observations.

Figure 1. Mobile high-vacuum chamber used for laser-induced damage-threshold assessment in vacuum.
Borates (for instance LBO: lithium triborate) and phosphates (e.g., KTP: potassium titanyl phosphate) have been considered for this purpose, in various combinations, with as goal to reach >30% energy-conversion efficiency from 1.06\mu m (fundamental wavelength of the neodymium-doped yttrium aluminum garnet laser) to 355nm. This has so far been proved for the LBO THG system. Further tests are currently being performed. In Figure 2 we show the ultrahigh-vacuum chamber designed for these tests.

In the past, several space-based laser missions have suffered from anomalous performance loss or even failure after short operational periods. This resulted from selective contaminate of laser-exposed optical surfaces caused by outgassing constituents. These volatile components are omnipresent in vacuum vessels. We tested various organic and inorganic species at DLR and ESA/ESTEC facilities for their criticality to deposit buildup, which tends to accumulate preferably when operating at 355nm. Thicknesses are on the order of several tens of nanometers, which can be sufficient to induce noticeable absorption.

Finally, active optical components like Q (‘quality’)−switched or frequency-converter crystals can also suffer from bulk absorption induced by high-energy radiation (called ‘gray tracking’) and dehydration. To identify these effects, we exposed crystals to proton (10MeV) and \gamma (^{60}Co source) radiation at the Paul Scherrer Institute (Switzerland) and ESA/ESTEC, respectively. Strikingly, the borates in general did not show any or only minor degradation, while the phosphates and arsenates displayed noticeable performance loss. An example is included in Figure 3, where several transmission spectra of KTP (used as SHG crystal) are shown after receiving an orbit-representative dose of \gamma radiation (100krad, in various steps). Absorption loss caused by color-center formation is observed at visible wavelengths. After heating the crystal for one hour at 150°C, almost complete recovery of the transmission was achieved.

Further work will focus on long-term efficiency tests over a period of two weeks under ultrahigh-vacuum conditions. In addition, contamination and LIDT testing will continue. Additional proton-radiation tests (at 100 and 250MeV) are planned in the near future for passive and active optics, both of which are used in space-laser applications.

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**Figure 2.** Ultrahigh-vacuum chamber designed for long-term frequency-conversion tests of nonlinear crystals.

**Figure 3.** Transmission spectrum of KTP (10 x 10 x 6mm$^3$) after various dose steps (10, 30, 60krad) applied using a $^{60}$Co source. Continuous degradation is observed.

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References


