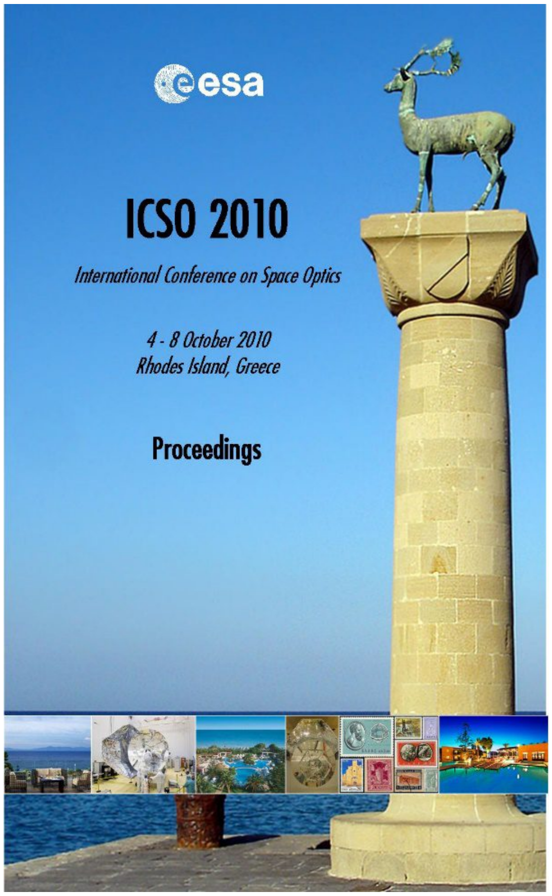
International Conference on Space Optics—ICSO 2010

Rhodes Island, Greece

4–8 October 2010

Edited by Errico Armandillo, Bruno Cugny,
and Nikos Karafolas



Highly-reliable laser diodes and modules for spaceborne applications

E. Deichsel

International Conference on Space Optics — ICSO 2010, edited by Errico Armandillo, Bruno Cugny,
Nikos Karafolas, Proc. of SPIE Vol. 10565, 105650O · © 2010 ESA and CNES
CCC code: 0277-786X/17/$18 · doi: 10.1117/12.2309258

HIGHLY-RELIABLE LASER DIODES AND MODULES FOR SPACEBORNE APPLICATIONS

E. Deichsel
JENOPTIK Laser GmbH, Göschwitzer Straße 29, 07749 Jena, Germany

ABSTRACT

Laser applications become more and more interesting in contemporary missions such as earth observations or optical communication in space.

One of these applications is light detection and ranging (LIDAR), which comprises huge scientific potential in future missions. The Nd:YAG solid-state laser of such a LIDAR system is optically pumped using 808nm emitting pump sources based on semiconductor laser-diodes in quasi-continuous wave (qcw) operation. Therefore reliable and efficient laser diodes with increased output powers are an important requirement for a spaceborne LIDAR-system. In the past, many tests were performed regarding the performance and life-time of such laser-diodes. There were also studies for spaceborne applications, but a test with long operation times at high powers and statistical relevance is pending.

Other applications, such as science packages (e.g. Raman-spectroscopy) on planetary rovers require also reliable high-power light sources. Typically fiber-coupled laser diode modules are used for such applications. Besides high reliability and life-time, designs compatible to the harsh environmental conditions must be taken in account. Mechanical loads, such as shock or strong vibration are expected due to take-off or landing procedures. Many temperature cycles with high change rates and differences must be taken in account due to sun-shadow effects in planetary orbits. Cosmic radiation has strong impact on optical components and must also be taken in account. Last, a hermetic sealing must be considered, since vacuum can have disadvantageous effects on optoelectronics components.

INTRODUCTION

In an extensive qualification program, laser-bars and packages were investigated. Theoretical investigations lead to a selection tool, which allows optimum laser bar conditioning for the customized applications. Such laser bars were tested intensively on electro-optical characteristics, but also on life-time. Life-time tests at up to triple output power and strongly accelerated conditions such as higher duty cycles or increased temperatures have proven the reliability of the laser bars.

Based on the requirements of an upcoming mission, a new laser package was developed, specially designed for highest demands in spaceborne applications. Critical issues from past investigations and mission were taken in account and a fully new concept was introduced. A laser stack, based only on thermal expansion matched materials, hard soldering and improved mechanical design rules lead to a fully space compatible device.

The new laser stack is passively cooled and is designed for highest reliability, longest life time and robustness against environmental loads. Additionally, the design is compatible to any customized interface or packages and can be adapted in an easy manner to the needs of future applications. Each laser bar type can be used, meeting requirements on wavelength, optical output power, operation current, efficiency and polarization. Thermal expansion matched materials allow storage and operation of the laser stack in a large temperature window, even with fast temperature changes. Additionally it is designed to be light weight and robust against mechanical vibration and shocks. These features make the design interesting for applications in harsh conditions such as aerospace, automobile or defense. The increased bar-to-bar pitch of 1.7mm (compared to g-stack) allows a mechanical and thermal decoupling of the individual laser bars, leading to reduced stress, lower operation temperatures and promises longer lifetime. Additionally, the increased pitch provides also an increased heat exchange area and therefore a much better thermal connection, enabling much higher operation power at higher duty cycles at increased life time expectations. This is one of the major advantages compared to the classic g-stack. Another advantage of the increased pitch is an improved fast-axis collimation (FAC). Since FAC lenses with large focal length can be used, the design is less sensitive to misalignment of the lenses, smile of the laser bars and provides much better optical properties. This again makes the design much more interesting for precise operation or harsh conditions.

Such stacks with 8 laser bars were fabricated approx. 40 times. Electro-optical tests up to 140A and >1100W peak output power were performed in quasi-continuous-wave (qcw) operation. A full burn-in sequence was performed together with a detailed visual inspection. After this environmental testing was performed, including mechanical loads, thermal cycles and radiation tests. The following investigations did not show any degradation or disadvantages.

In a 1.5years lasting life-time test, 12 laser stacks were operated under nominal and accelerated conditions. Daily electro-optical measurements were performed, frequent monitoring of all relevant parameters were logged and the fully computer controlled set-up did not require to handle the stacks during this test. As a result from this test, no changes or degradation of electro-optical parameters were observed.

A detailed inspection after the life-time test did not identify any issues. Even harder environmental loads and stronger temperature cycles did not harm the stacks. Destructive tests, such as catastrophic-optical damage (COD) tests or constructional analysis emphasized the reliability of the device.

Based on reliable laser diodes, conceptual studies have been performed. Space-compatible fiber-coupled modules were investigated in detail. Here the focus was on reliable optical concepts, stable and light-weight materials and a compact design. Besides the above mentioned environmental requirements, a hermetic sealing was investigated. Here a leak tightness of several years is required. Additionally all organic materials, such as glue for optics, were carefully selected and tested for stability and out-gassing.

LASER BAR SELECTION

Since qcw operation produces more than one order of magnitude less heat compared to cw operation, heat removal is not the main driving factor of the laser bar design. In fact, more attention can be taken on optimization of output power, efficiency and driving current.

Figure 1 shows the calculated efficiencies for an 808nm laser bar in dependency of resonator length and filling factor at 100W output powers. In these calculations COMD was not taken in account and the mirror reflectivity was kept constant. To achieve high efficient operation at 100W output power, a laser bar with resonator length of approx. 1.5mm and 50% filling factor is the best choice. With increasing output power the highest efficiency is obtained for longer resonators and higher filling factors.

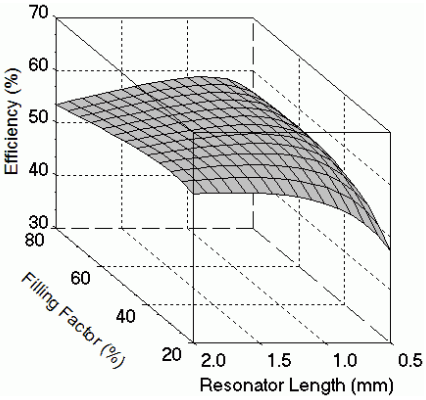


Figure 1: Calculated efficiencies for 808nm laser bars in dependency of resonator length and filling factor at 100W output power.

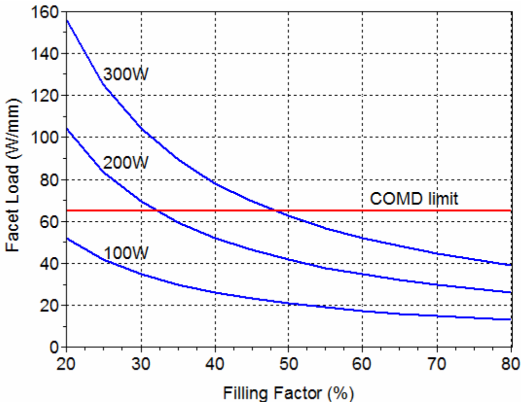


Figure 2: Calculated facet loads for different output powers and lower boundary of COMD limit.

Additionally the facet load must be taken in account, since a reliable operation close to COMD limit is not possible. For this type of laser bars a limit of approx 65…80W/mm emitting area was achieved. Figure 2 shows the dependency of facet load on filling factor and output power. Additionally the lower boundary of COMD limit is shown. For low filling factors (<30%) reliable operation is only possible for powers <<200W. Bars with 50% filling factors are limited to <300W and bars with 75% must be used for applications with output powers at or slightly above 300W.

STACK DESIGN

The new laser stack is passively cooled and is designed for highest reliability, longest life time and robustness against environmental loads. Additionally, the design is compatible to any customized interface or packages and can be adapted in an easy manner to the needs of future applications. Each laser bar type can be used, meeting requirements on wavelength, optical output power, operation current, efficiency and polarization.

Thermal expansion matched materials allow storage and operation of the laser stack in a large temperature window, even with fast temperature changes. Additionally it is designed to be light weight and robust against mechanical vibration and shocks. These features make the design interesting for applications in harsh conditions such as aerospace, automobile or defense.

The increased bar-to-bar pitch of 1.7mm (compared to g-stack) allows a mechanical and thermal decoupling of the individual laser bars, leading to reduced stress, lower operation temperatures and promises longer lifetime. Additionally, the increased pitch provides also an increased heat exchange area and therefore a much better thermal connection, enabling much higher operation power at higher duty cycles at increased life time expectations. This is one of the major advantages compared to the classic g-stack. Another advantage of the increased pitch is an improved fast-axis collimation (FAC). Since FAC lenses with large focal length can be used, the design is less sensitive to misalignment of the lenses, smile of the laser bars and provides much better optical properties. This again makes the design much more interesting for precise operation or harsh conditions.

Figure 3 shows a schematic drawing of the laser stack. The laser bars are sandwiched between copper tungsten (CuW) heat spreaders, which are arranged vertically on an electrically insulating base plate in such a way, that there are air gaps between the sandwiches providing the thermal and mechanical decoupling of the bars. For this type of stack only hard solder is used during fabrication.

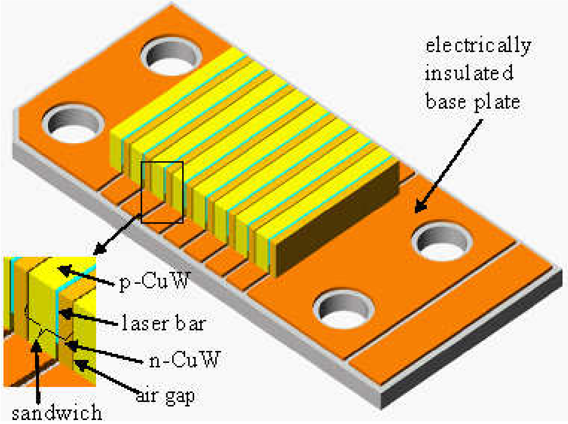


Figure 3: Schematic drawing of the passively cooled laser stack. The small figure shows a magnified section of a sandwich with laser bar and p- / n- CuW heat spreader and air gap.

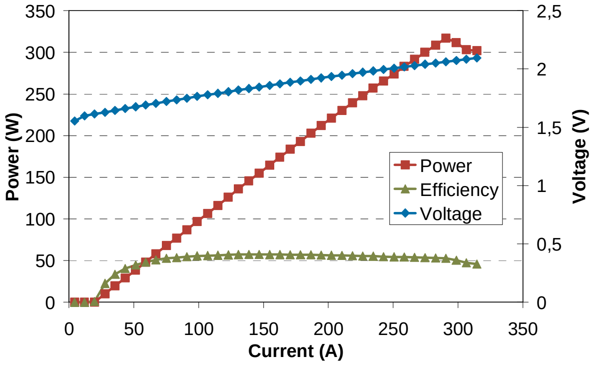


Figure 4: LIV characteristics of a 50% filling factor laser bar (808nm, 1.5mm resonator length) in qcw operation (200µs pulse width, 2% duty cycle) at 25°C.

LASER BAR PERFORMANCE

Figure 4 shows a typical LIV characteristic of a laser bar with 50% filling factor in qcw operation (200µs pulses, 2%d.c.). At 290A a maximum output power of 317W is reached before catastrophically optical mirror damage (COMD) occurred. The overall-efficiency is in a wide range more than 50% with a maximum of 57%.

Life time tests on such bars at 200A with 200µs pulses and 10% duty cycle (Figure 5) showed stable operation at approx 220W output power up to 8.1 GShots (corresponding to 4500h) where 2 bars failed and 9.9GShots (5500h) where the other 2 bars failed. During the test no degradation was observed and the lasers failed due to catastrophic optical mirror damage (COMD). This leads to the assumption that the COMD level decreases with time.

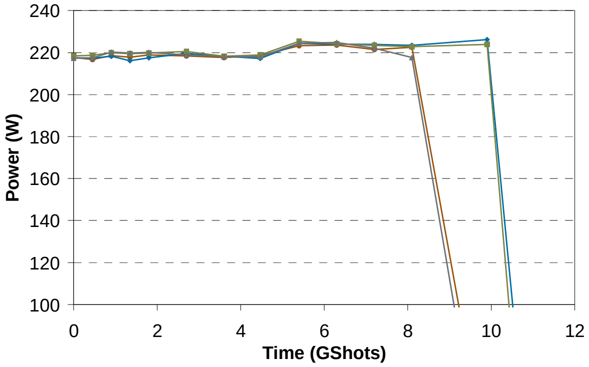


Figure 5: Life time test of 4 laser bars (808nm, 1.5mm resonator length, 50% filling factor) at 200A qcw (200µs pulse width, 10% duty cycle) at 25°C.

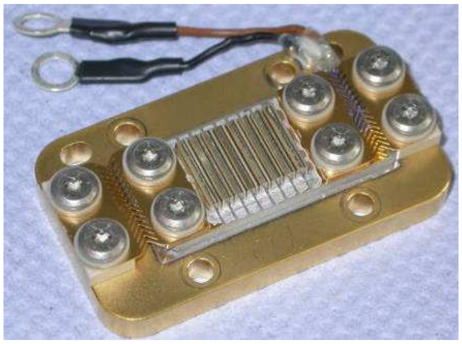


Figure 6: Laser stack mounted on test-interface with electrical contacts and temperature sensor.

LASER STACK PERFORMANCE

After fabrication all stacks went through the manufacturer's standard inspection program consisting of visual inspection, electro-optical characterization and burn-in. After this, each laser stack used for the life-time tests went through environmental stress screening. Here temperature cycles and mechanical loads were applied as they appear in spaceborne applications. Even radiation tests with gamma-rays and protons were performed. The characteristics before and after the tests showed no degradation due to the loads. A typical LIV characteristic of such qcw stacks is shown in Figure 7. Additionally spectra, polarization, near- and far-fields were measured and documented.

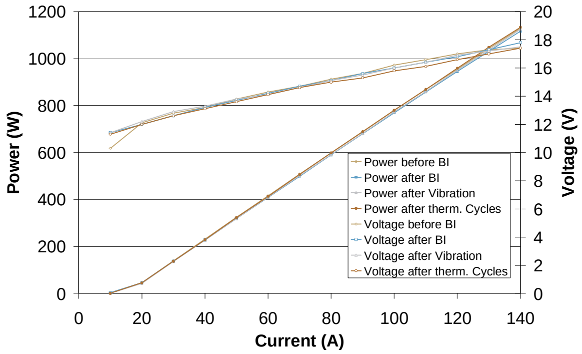


Figure 7: LIV characteristic of an 808nm qcw laser stack with 8 bars at 24°C and 200µs pulses with 2% duty cycle.

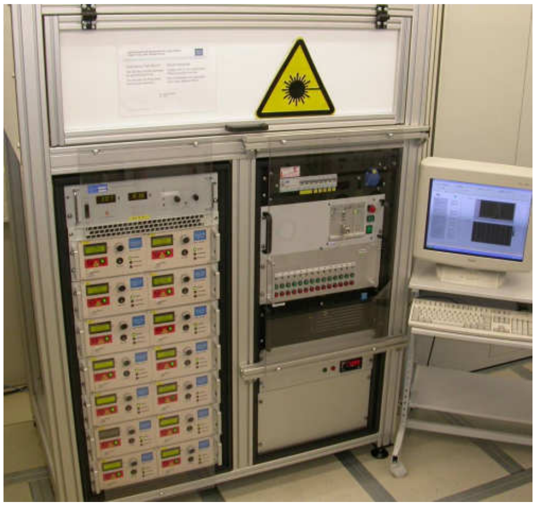


Figure 8: Fully computer controlled test set-up for the 1.5years lasting lifetime test.

LIFE TIME TEST ON STACK LEVEL

For the 1.5 years lasting life time test a customized test bench was built (Figure 8). Daily measurements of power, spectra and near-field were performed together with frequent monitoring of voltage, stack temperature, cooling water and pulse shape.

One main focus of the investigation is a comprehensive life time test at nominal and accelerated conditions. 6 stacks are operated with qcw currents of approx. 100A with 200µs pulses and 100Hz repetition rate (2% duty cycle) leading to output power of approx. 750W. Stable operation was achieved more than 5GShots without any degradation (Figure 9).

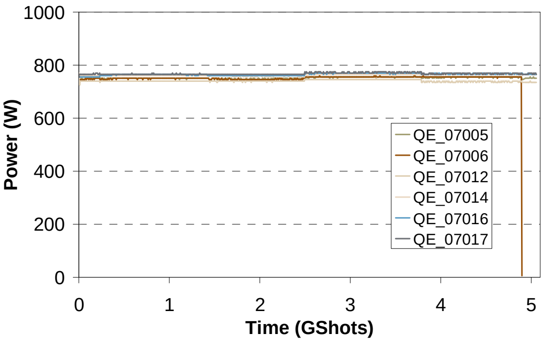


Figure 9: Life-time test of 6 qcw stacks operated at nominal conditions (200µs pulses, 2%d.c.).

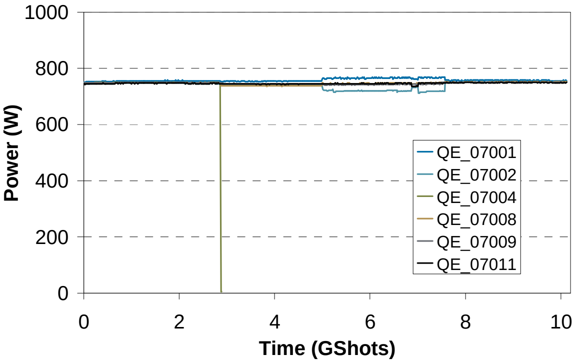


Figure 10: Life-time test of 6 qcw stacks operated at accelerated conditions (200µs pulses, 4%d.c.).

6 other stacks are operated under accelerated conditions (100A, 200µs pulses, 200Hz repetition rate, 4%d.c.). Here more than 10GShots were achieved without degradation (Figure 10). Due to a problem with the current sources two stacks failed during these tests. A detailed final characterization and inspection of all laser stacks after the tests did not show any disadvantages. From this point of view all tests were passed successfully.

From the 6 stacks which have been tested for 14.000h under accelerated conditions, 2 stacks were randomly selected and the life-time tests was continued at even stronger acceleration. The new operation conditions are 100A, 200µs, 10%d.c. at 24°C. Figure 11 shows this continued test. Due to the increased duty cycle, the power drops slightly, and for another 8500h no degradation is observed. In total more than 22.000h test time and 25GShots were achieved without degradation and the test is still running.

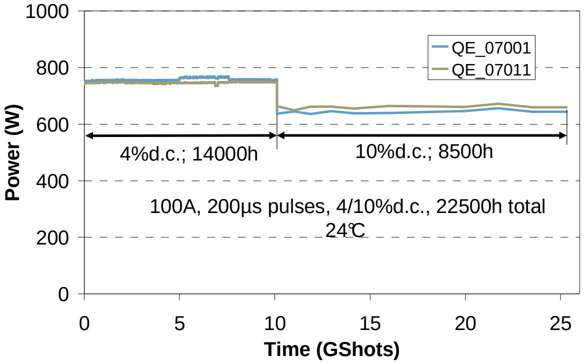


Figure 11: Continuation of life-time test under accelerated conditions (100A, 200µs, 10%d.c.).

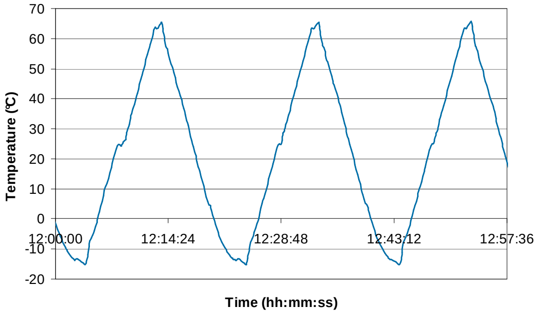


Figure 12: Temperature cycling of selected stacks with temperature change rates of up to ±10K/min – more than 400 cycles were performed.

ADDITIONAL TESTING

After the lifetime tests further tests including destructive analysis were performed. Environmental testing with maximum mechanical loads and more than 400 temperature cycles from -15 to 65°C with ±10K/min (Figure 12) did not influence the performance of the stacks. COD tests on several devices showed a small degradation of COD level by approx. 20%. This indicates that there are still reserves in life-time of several years if a linear decrease is assumed. A final destructive test (e.g. cross-sectional analysis, construction analysis) showed also no issues.

SPACEBORNE LASER MODULES

Based on the laser stacks presented above detailed investigations for space compatible pump modules have been performed. An important issue is of course the redundancy of the module. In the optical concept in Figure 13 two types of redundancy were chosen. First a dual module redundancy is selected, where each element is duplicated and in case of failure it can be switched to the other element. Both branches can be operated individually and have the same performance. However it is not foreseen to use both branches in parallel. The second redundancy is included in each branch, where the raw laser power is distributed on 3 stacks. This allows in case of a failing stack to increase the power of the remaining stacks leading to unchanged output performance. Figure 14 shows the implementation of this concept in a mechanical design. Here only light wheight and space compatible materials have been selected, with a adapted cooling interface for the laser stacks.

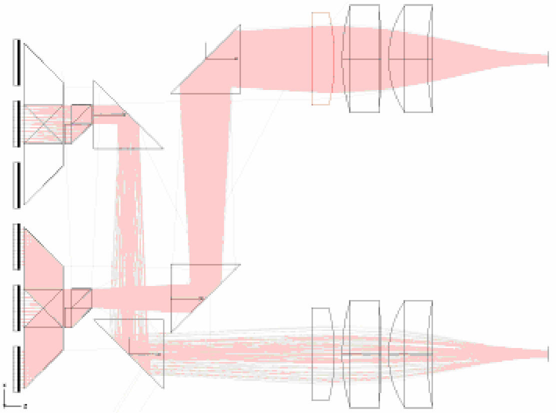


Figure 13: Optical concept for a fiber coupled spaceborne qcw pump source.

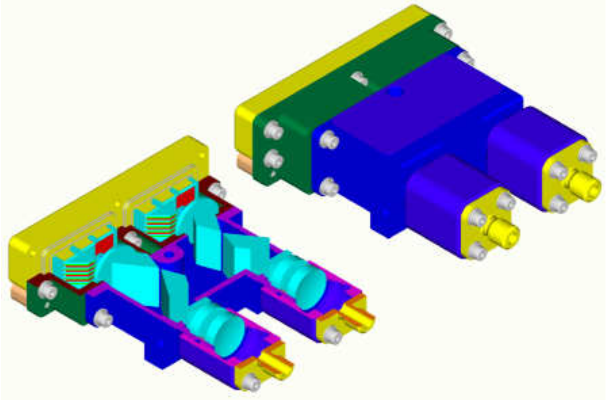


Figure 14: Detailed mechanical design of a spaceborne qcw pump module.

CONCLUSION

In conclusion a comprehensive investigation for spaceborne pump diode laser stacks was presented. A systematic selection of laser bars with proven lifetime at high powers together with a consequent laser stack design for highest spaceborne demands lead to a new diode laser stack generation, able for reliable operation under harsh environmental conditions. Reliable operation of the laser stacks was demonstrated within a 1.5years lifetime test at nominal and accelerated conditions, after a full environmental test program was applied. Final investigations did not identify any critical issues. On two stacks more than 20.000h stable operation under accelerated conditions with more than 25GShots was shown. Based on this reliable spaceborne laser modules were investigated in detail.

ACKNOWLEDGMENT

This work was partly supported and financed by the European Space Agency under contract No. 19819/06/NL/FF and performed in collaboration with Jena-Optronik GmbH.