

Goddard Technology Efforts to Improve Space Borne Laser Reliability

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I. Introduction

In an effort to reduce the risk, perceived and actual, of employing instruments containing space borne lasers NASA initiated the Laser Risk Reduction Program (LRRP) in 2001. This program managed jointly by NASA Langley and NASA Goddard and employing lasers researchers from government, university and industrial labs is nearing the conclusion of its planned 5 year duration. This paper will describe some of the efforts and results obtained by the Goddard half of the program.

Goddard has been a pioneer in laser instrumentation based upon the diode pumped neodymium-yag laser flying systems such as the Mars Orbiter Laser Altimeter (MOLA), the Geoscience Laser Altimeter System (GLAS), and the Mercury Laser Altimeter (MLA). For this reason the efforts at Goddard centered on understanding the features that would lead to improved reliability and performance for lasers of this type and for measurement systems employing this type of laser. An evaluation of the most prominent Earth Science measurement needs on the horizon that would probably require the use of a laser was used to further define the scope of the program. These measurements included altimetry, aerosol studies, wind measurements and lidar measurements of a number of trace atmospheric constituents—most prominently ozone and carbon dioxide.

Analysis of areas that had caused failures of laser measurement systems in the past or that generated difficulties in the development of lasers for space further guided the effort to select a number of technologies for investigation and development. Roughly speaking this divided into three broad areas—lifetime studies and phenomenology for pump laser diodes, wavelength conversion techniques, and design/fabrication procedures for Nd:YAG lasers. The third category was further subdivided into a number of subtopics including contamination effects, mechanical stability,

wavelength control, thermal engineering, and laser architectures.

Finally a knowledge capture effort was begun to make sure that hard won knowledge developed by previous laser programs was not lost and to develop a method by which results obtained by the Laser Risk Reduction Program could best be disseminated to the working laser/lidar community.

It is impossible to begin to describe all the discoveries and results obtained by such a large and diverse program. The remainder of this manuscript will be devoted to providing a snapshot of the current status of a number of these programs with a view toward informing about the progress made to date and inciting the community to continue the development of these technologies

II Laser Pump Diodes

At the time that the LRRP began the biggest single factor threatening the reliability of diode pumped lasers in space was the performance of the diodes themselves. Spectra Diode Labs (SDL), the principal manufacturer of pump diodes had decided to stop the production of pump diodes to move into other business opportunities. NASA had spent considerable time and resources on lifetime tests for the SDL diodes since these were the ones used in the GLAS lasers scheduled for launch in early 2003. A number of companies including Coherent and CEO had announced their intent to supply these diodes but of course nothing was known about their lifetime or any other operating characteristics.

Under the direction of Mark Stephen Goddard has assembled a state of the art diode testing facility that includes capabilities for photomicrography, thermal imaging as well as long duration test stands. Figure 1. shows some of the imaging spectrometer set up in the facility and Figure 2 shows the vacuum diode test stand.

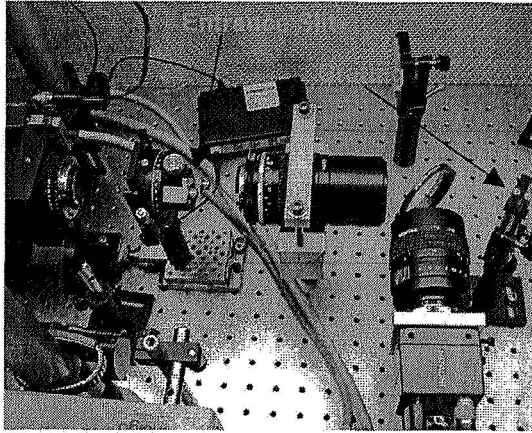


Figure 1. The imaging spectrometer setup

The team has developed a protocol for characterizing diodes that is used before lifetime testing is begun and then is repeated at intervals throughout the testing period. This characterization includes microscopic inspection of the emitting facets, thermal imagery, spatial and temporally resolved spectra, time resolved power, polarization, as well as current pulse width, efficiency, voltage and threshold current. Although a few failures have occurred on the whole the diodes appear to have reasonably good reliability. However, our test sample is too small for form statistically significant conclusions to date

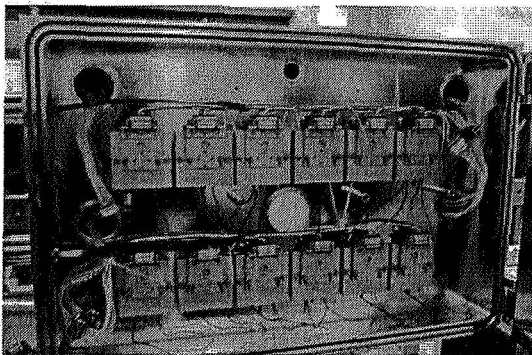


Figure 2. The vacuum life test chamber

Figure 3 shows a photomicrograph of a failed diode. The failure mechanism here is indium creep that has caused a short circuit of the diode bar. Figure 4 shows a summary of the lifetime test conducted so far. This work is ongoing and diodes proposed for use in the LOLA mission to the moon are under test right now

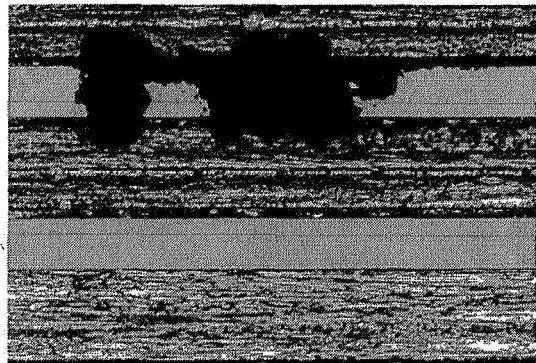


Figure 3. Indium has shorted out the bar

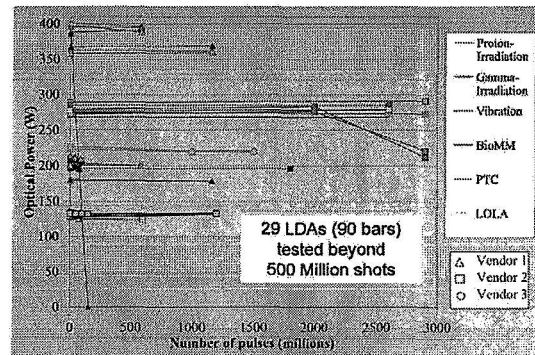


Figure 4. Lifetime test results to date.

III. Laser Architecture.

The goal of the laser architecture task has been to develop a scalable sequence of laser oscillators and possibly amplifiers that would be suitable for attacking the design problems posed by any of the list of measurements considered in the formulation stage of the program. This is a broad range of requirements with altimetry systems requiring relatively low pulse energies and loose requirements on wavelength control while chemical profiling and wind measurements require very high peak powers and stringent wavelength controls. It was also recognized that the very process of building one or more prototype lasers with an eye toward space qualification would uncover a set of design and procedural problems whose solutions would be of great value to the LRRP.

Two approaches were initiated. The first was a design for a high power stand alone oscillator with peak pulse energy on the order of 100 mJ. This laser would have potential application in an aerosol lidar or for an altimetry system with the ability to resolve tree canopy heights. The second approach was to design a master

oscillator power amplifier (MOPA) system based upon the designs employed in the GLAS lasers and in MLA. The target goal for this system was 100 Watts of average power roughly achieved by 1 Joule pulses and 100 Hz repetition rate. A system of this size appears to be within scaling distance of the lasers required for space borne wind lidar or tropospheric ozone profiling. The oscillator has been assembled in a number of versions. The design is called HOMER. HOMER features two laser heads oriented at right angles to one another. This design reduces amplified spontaneous emission (ASE) and reduces the effects of thermal lensing on beam shape. Each laser head employs 4 6-bar 100 Watt pump diode arrays derated to 77 W. The laser cavity is an unstable resonator design with a gradient reflectivity mirror output coupler.

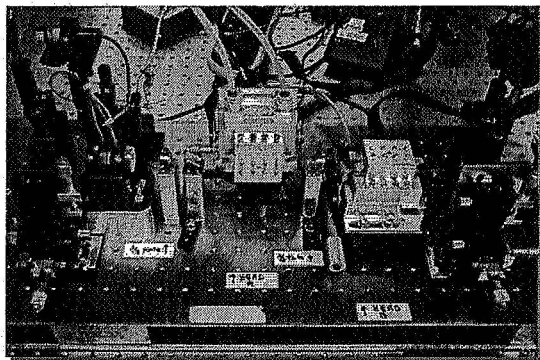


Figure 5. Breadboard of the HOMER oscillator.

The HOMER design is capable of 100 mJ pulses at 100 Hz. It has an optical efficiency of 21.6%. Work continues on this system to develop; an injection seeded version. A lifetime test is underway as well and the system has accumulated over a billion shots.

The MOPA effort encompasses both oscillator and amplifier design work. The oscillator is called the heritage laser because its design is based upon the 2 flight systems—GLAS and MLA. A version of the oscillator in a package suitable for space qualification was completed in February and plans are to begin a 3 billion shot vacuum lifetime test in April. The heritage oscillator employs a crossed porro cavity with a Cr:YAG passive q-switch. The Nd:YAG slab is pumped by 2 derated G2 diode stacks and will continue to lase even if one of the stacks fails. The design has a very stable TEM00 mode structure and favors a single longitudinal mode as well. The excellent beam quality persists over a wide range of temperatures and repetition rates offering the possibility that the laser output

power could be adjusted simply by varying the diode drive current.

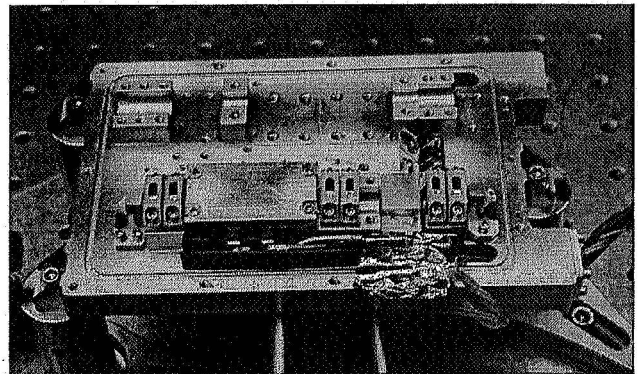


Figure 6. The heritage oscillator.

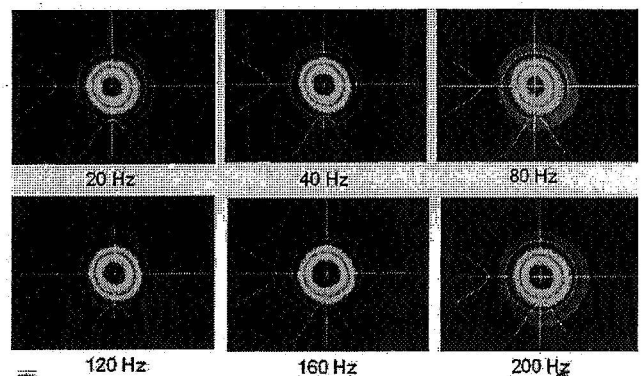


Figure 7. Heritage beam quality versus rep rate.

The laser for the Lunar Orbiter Laser Altimeter (LOLA) presently under construction at Goddard is very similar in design to the heritage laser.

IV. Wavelength Conversion

Clearly there are many potential Earth Science measurement requirements that can not be met by a laser operating at 1.06 microns. In order to address these needs a number of studies were undertaken to improve the reliability of non-linear optical methods used for wavelength conversion. Some of the studies involved measurement of lifetime characteristics for non-linear materials as well as effects of radiation. Another effort focused on the use of an optical parametric amplifier (OPA) to convert 1 micron light to 1.57 microns which can be used to measure atmospheric CO₂. For this task a contract was issued to ITT in Albuquerque, NM to fabricate an integrated package containing a high repetition rate 1 micron laser with an OPA locked to a CO₂ line in the 1.57 micron region.

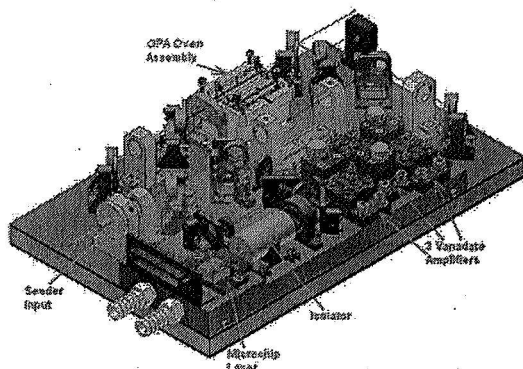


Figure 8. Layout of the integrated laser/OPA

This work is ongoing but preliminary results have demonstrated a 10 kHz system with 38% conversion efficiency to the CO₂ wavelength and 3 Watts average output power. In addition a hollow fiber filled with CO₂ has been employed as a reference cell and the output has been locked to a line in the cell.

Another task contracted to ITT is the development of OPO to convert 1 micron light to the 320 nm region for measurement of tropospheric ozone from space. Again an integrated package including a high rep rate laser is under development with the ability to generate two UV wavelengths so that a differential absorption lidar (DIAL) can be implemented using a single source for the laser light.

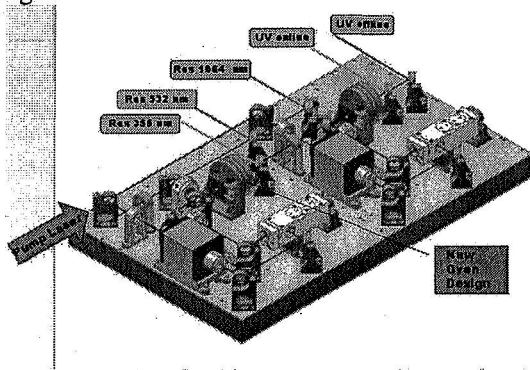


Figure 9. Layout of the integrated ozone OPO

V. Other studies

As mentioned earlier a number of additional studies have been undertaken over the past five years. An investigation of the risk for optical contamination in a system arising from commonly used solvents and adhesives has led to a number of recommendations for assembly procedures as well as material choices. A small

effort to develop improved detectors in the near IR region has been supported with an aim toward enabling photon counting in the near IR.

A small investigation of the use of fiber lasers has been supported as well. Fiber lasers have already been flown in space for military communication applications and their basic design promises excellent mechanical stability and resistance to contamination. On the other hand their peak power to date is only a few hundred Watts versus megaWatts for open cavity lasers so their suitability for space borne lidars is problematic.

VI. Conclusions

This has been an overview of the efforts to improve the performance and reliability of lasers for use in space borne instrumentation conducted by Goddard Space Flight Center under the Laser Risk Reduction Program. There can be little doubt that the LRRP has made significant contributions to the probability of success for missions already under way such as MLA and CALIPSO as well as missions to be such as LOLA, BioMM and wind lidar.

Although much has been accomplished much remains to be done. I hope the international lidar community represented at this 23rd International Laser Radar Conference will join me in supporting the continuation of such technology efforts in the future,

VII. Acknowledgements

The support of the Earth Science Technology Office and the Office of Exploration at NASA Headquarters is gratefully acknowledges.