ONE MICRON LASER TECHNOLOGY ADVANCEMENTS AT GSFC

William S. Heaps

NASA Goddard Space Flight Center

ABSTRACT

In recent years, lasers have proven themselves to be invaluable to a variety of remote sensing applications. LIDAR techniques have been used to measure atmospheric aerosols and a variety of trace species, profile winds, and develop high resolution topographical maps. Often it would be of great advantage to make these measurements from an orbiting satellite. Unfortunately, the space environment is a challenging one for the high power lasers that would enable many LIDAR missions. Optical mounts must maintain precision alignment during and after launch. Outgassing materials in the vacuum of space lead to contamination of laser optics. Electronic components and optical materials must survive the space environment, including a vacuum atmosphere, thermal cycling, and radiation exposure. Laser designs must be lightweight, compact, and energy efficient. Many LIDAR applications require frequency conversion systems that have never been designed or tested for use in space. For the last seven or eight years the National Aeronautical and Space Administration (NASA) has undertaken a program specifically directed at addressing the durability and long term reliability issues that face spaceborne lasers (The Laser Risk Reduction Program-LRRP).

Index Terms—Lasers, Space Technology, Remote Sensing, Reliability

1. INTRODUCTION

When the LRRP was first being proposed, a survey of desired space based LIDAR missions was conducted. It was determined that there were six categories of measurements of high priority to earth science: coherent wind detection, noncoherent wind detection, coherent detection of river/ocean surface currents, altimetry/bathymetry, and range resolved measurements of ozone and carbon dioxide using the differential absorption technique. It was decided that all six of these measurements could be enabled by the development of two primary laser systems operating at 1.0 micron and 2.0 micron. These would then be combined with a limited number of frequency conversion methods.

The effort was shared between NASA Goddard Space Flight Center in Greenbelt, Maryland, and NASA Langley Research Center in Hampton, Virginia with Goddard concentrating on 1 micron lasers and Langley on 2 micron.

The fundamental goal is to develop knowledge about building space qualified lasers. To achieve this, we designed, and built testbed lasers which were then be subjected to rigorous environmental testing required for space qualification. Although future LIDAR missions may not use the exact architectures produced under this program, we have developed the baseline knowledge of how to design and build successful spaceborne laser systems. For both laser systems under development it was decided to target 1.0 Joule/pulse output energy. Some of the desired measurements require substantially less energy per pulse, but may require high repetition rates. Rather than spread resources too thin it was decided to focus on the high energy per pulse system, which was regarded as the more challenging problem to solve them, and some of our more significant achievements over the course of the LRRP. This paper is an overview of these issues plus more facing spaceborne lasers, the goals that Goddard has been pursuing to address these problems.

2. THE GODDARD PLAN

The first figure shows a roadmap of the Goddard program spanning the years 2002-2006. The plan initially involved the first four areas on the chart. As the program developed the next two investigations were added as we developed a better picture of the technologies that would likely be required for future missions. The knowledge capture effort was initiated when we recognized that a wealth of laser lore was already available from the documentation produced by previous laser instrument programs such as MOLA and ICESAT. This figure shows the status of the program in late 2005. “Slashed” items were underway. “XXXed” items were completed.

A number of issues were already known to be major factors in the reliability of space based lasers. Many of these issues center around reliability of materials or manufactured products. Others are related to processes and handling during the build, test, and integration of instruments. One of the most important reliability efforts was the evaluation of high power laser diode arrays used as the laser
pump source. Since the 1.0 and 2.0 micron lasers each require different pump wavelengths and are designed to operate under substantially different conditions, both GSFC and LaRC set up diode test and evaluation facilities.

Diodes from various vendors have been put through an exhaustive series of inspections and checkout procedures, some of which are high magnification photos, thermal imaging of the diode arrays while operating, optical output power versus current measurements, and spectral profiling. Once the diodes had been fully characterized they were placed in a long term life test which subjects the diodes to operational conditions similar to existing space flight programs. At designated intervals the diodes were removed from the life test, re-characterized, and returned to the life test. As failures develop, the characterization tests are reviewed to determine whether early data could have predicted the failure. The goal was to develop a battery of screening tests that will enable NASA to hand pick laser diode arrays from those provided by a vendor. We also worked closely with the vendors to address failure modes and refine manufacturing processes.

Both the laser diodes and the nonlinear optical materials have been subjected to radiation tests that included beta (cobalt 60) proton exposure. Diodes have proven to be robust. Most non-linear materials suffer darkening which may be reversible.

Fig. 2 This illustrates results for a life test on some G4 diode arrays. Diodes at top are power cycled off 2 minutes out of 20. Diodes at bottom have run continuously. Decreases in lower figure represent bar failures.
Contamination is another of the leading concerns related to space flight lasers. This is because the resulting damage is so catastrophic and widespread. Many contamination related failures have been suffered during ground testing of flight lasers. This is obviously a costly way to determine what materials are to be considered contaminants. Under the LRRP we have conducted a number of tests in which a high energy laser is fired at a test window inside a vacuum chamber. A compound under test is released into the test chamber and allowed to deposit on the test window. The window is monitored for optical damage as a function of contaminant level, laser energy fluence, and number of laser shots. The goal was to develop a database of laser induced damage thresholds for as many relevant compounds as possible. This database will be used as a resource in developing approved materials lists for future flight laser programs. It will also be used to determine minimum cleanliness levels.

2.1 Space LIDAR enabling hardware

Although the laser itself is considered the primary risk associated with space based LIDAR technology, there are other components of a LIDAR system that clearly need to be made ready for space. Among these are improved detectors, receiver systems and frequency conversion systems.

For most LIDAR applications, an improvement in the optical efficiency of the detector results in a corresponding reduction in the output power required by the laser itself. This has added system level benefits by reducing electrical power, thermal load, size, and weight. Both LaRC and GSFC worked with industrial and academic partners to develop avalanche photodiode detectors that have high sensitivity and low noise levels. LaRC with partners to develop InGaSb detectors for use in the 2.0 – 2.5 micron range while GSFC with partners to improve the technology of InGaAs detectors for use in the 1.0-2.0 micron range.

Ozone profiling will require the development of space qualified frequency conversion technology that can convert 1.0 micron light to 308 nm and 320 nm. The high average power that will be required to penetrate the atmosphere presents a challenging problem for such a system. Two approaches were pursued. LaRC has partnered with Sandia National Laboratory to pursue an optical parametric oscillator (OPO) system capable of 200 mJ pulses at 10 Hz. GSFC has partnered with ITT Advanced Engineering and Science Division (ITT AES) to develop an OPO system capable of 10 mJ pulses at 1.0 kHz. GSFC has also been working with ITT AES to develop an optical parametric amplifier system to convert 1.0 micron light to 1.55 microns for use in CO2 profiling. The system is designed to produce an average power of ~ 2.0 W at a pulse repetition rate of 10 kHz and have a spectral line width of 70 MHz HWHM [5].

2.2 Knowledge management

It is important to understand that the primary deliverable of the LRRP is knowledge. Even in the hardware oriented tasks the goal is to better understand how to design and build space qualified systems. Thus, it is critical to disseminate the knowledge developed under the LRRP within NASA, to other government agencies with space borne laser programs, and to our industrial and academic partners. The LRRP is developing a comprehensive electronic database of space borne laser related knowledge. A web based interface has been designed at GSFC so that users can easily search for relevant information. Sadly this asset is no longer supported.
3. CONCLUSIONS

The program at each center was based upon three main goals: (1) Laser Architecture, and implementation, (2) Pump diode testing and evaluation and (3) Wavelength conversion techniques. The program at each center was targeted for 5 years at 5M$ per year.

The actual funding profile never matched this plan. Changes in accounting procedures within NASA reduced the funds available to the program. The total funds received at Goddard from 2002 through 2007 (duration of the LRRP at Goddard) amounted to 26.9M$ based upon the current estimates for the value of an full time equivalent. Despite this shortfall which amounted to almost 50% because of labor costs that were not included in the original proposal the program has generated many significant results.

The laser diode testing task has generated a larger program (the diode array working group-DAWG), involving GSFC, LaRC, and a number of diode manufacturing companies (Northrup Grumman, Coherent) that meet independently several times a year to discuss issues of diode performance and reliability. The contamination study has generated a number of studies presented at the annual Laser Damage Symposium. The laser development test has been represented at the International Laser Radar Conference and at the Wind Lidar Working Group. The oscillator architecture task received a national award for laser diagnostic software developed under the LRRP.

The diode test program continues to evaluate the pump diodes used for the Mercury Laser Altimeter (MLA) which recently established a range record for bidirectional laser communication. The diode test program qualified the diodes used in the Lunar Orbiting Laser Altimeter (LOLA) that was assembled by Goddard in less than 36 months leveraging heavily on technology developments supported by LRRP.

missions that NASA ought to conduct in the upcoming years. Seven of the fifteen missions involved spaceborne lasers including measurements of vegetation canopy height, wind, ice sheet thickness, carbon dioxide, plus cloud and aerosol properties. Technologies developed during the LRRP are already being employed in the development work for the lasers envisaged for all of these missions. The LRRP has proved to be an exceedingly valuable technology effort for NASA Earth Science as well as Space Science and will continue to be for years to come.

Fig. 4. This is a relief map of the Goddard crater on the moon. This map was generated using altitude data taken by the LOLA instrument.

The Decadal Survey of Earth Science at NASA issued by the National Research Council in early 2007 identified 15 missions that NASA ought to conduct in the upcoming years. Seven of the fifteen missions involved spaceborne lasers including measurements of vegetation canopy height, wind, ice sheet thickness, carbon dioxide, plus cloud and aerosol properties. Technologies developed during the LRRP are already being employed in the development work for the lasers envisaged for all of these missions. The LRRP has proved to be an exceedingly valuable technology effort for NASA Earth Science as well as Space Science and will continue to be for years to come.

Fig. 5. This OPO developed under the LRRP converts 1.0 micron light to 1.55 microns suitable for CO2 measurement.