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Compact, passively Q-switched Nd:YAG laser for the MESSENGER mission to the planet Mercury

Danny J. Krebs[1], Anne-Marie Novo-Gradac[1], Steven X. Li[1], Steven J. Lindauer[2], Robert S. Afzal[3], Antony Yu[4]

NASA Goddard Space Flight Center, Greenbelt, MD, USA

ABSTRACT

A compact, passively Q-switched Nd:YAG laser has been developed for the Mercury Laser Altimeter (MLA) instrument which is an instrument on the MESSENGER mission to the planet Mercury. The laser achieves 5.4 percent efficiency with a near diffraction limited beam. It has passed all space flight environmental tests at system, instrument, and satellite integration. The laser design draws on a heritage of previous laser altimetry missions, specifically ISESAT and Mars Global Surveyor; but incorporates thermal management features unique to the requirements of an orbit of the planet Mercury.

[1] NASA Goddard Space Flight Center, Greenbelt MD 20771.

[2] Northrop Grumman Laser Division, 2787 S. Orange Glossom Trail, Apopka, FL 32703.

[3] Spectra Systems Corporation, 321 S. Main Street, Providence, RI 02903.

[4] Northrop Grumman Electronic Systems Division, PO Box 17319, Baltimore, MD 21203.

1. INTRODUCTION

The MESSENGER mission to the planet Mercury requires a laser altimeter capable of performing range measurements to the surface of the planet over highly variable distances and with a constantly changing thermal environment.[1] Specifically, the satellite will execute an orbit with an apogee of 200-500 km and a perigee of more than 15,193 km; with an orbital period of 12 hours. For the altimeter instrument, science observations are taken during the 0.5 hours of closest approach to the planet. During the close approach, the satellite is heating, and it is not possible to fully isolate the laser subsystem from the rest of the satellite. In terms of laser performance, it is necessary to achieve more than 18 mJ of output energy in a near-diffraction-limited beam with 4-8 nano-second pulses while the laser bench temperature is executing a thermal ramp from 15C to 25C.

2. DESCRIPTION OF THE LASER

To satisfy the requirements above, we chose an oscillator/amplifier architecture with passive Q-switching (see Figure 1). This approach is similar to one previously taken by the GLAS[2] laser instrument, previously developed by NASA for the ICESAT mission. The primary difference between this laser and the lasers in the GLAS instrument is that only one amplifier slab is used in this laser whereas the GLAS lasers have two amplifier heads. The oscillator/amplifier approach has several advantages for this application: (1) the bleached loss of the passive Q-switch only affects the efficiency of the oscillator section, thereby enabling a reasonable overall efficiency with a passive Q-switch, (2) the small mode diameter (~ 0.1 cm) of the oscillator permits a compact and stable laser resonator with reasonable alignment tolerance, and (3) the ratio of internal to external optical fluence is lessened relative to oscillator only systems.

The oscillator section comprises a crossed-porro optical resonator[3,4] with polarization output coupling, a Brewster-angle Nd:Cr:YAG slab pumped by a single, a two-bar stack of GaInAsP laser diode bars (Coherent G-2), an air gap polarizer (Synoptics), and passive Q-switch (Cr^{4+}, 0.46 optical density, Scientific Materials Inc.), zero-order quartz waveplates for polarization control, and fused silica steering wedges for optical alignment. A thermo-electric cooler is employed between the pump array and the laser bench, in order to keep the oscillator pump array at its design temperature and output wavelength. The nominal oscillator mode diameter is 1.0 mm and its output energy is 3.0 mJ in a 5 nano-second pulse. The cavity Q was adjusted by rotating the angle of the quarter wave plate to produce the Q-switched laser pulses after 0.15 msec of pumping.

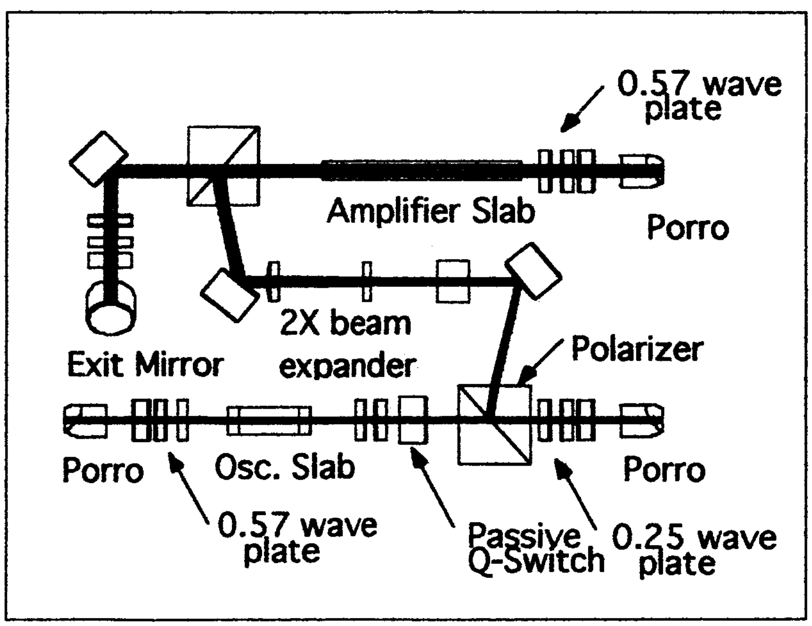

Figure 1. Optical layout of the MLA laser.

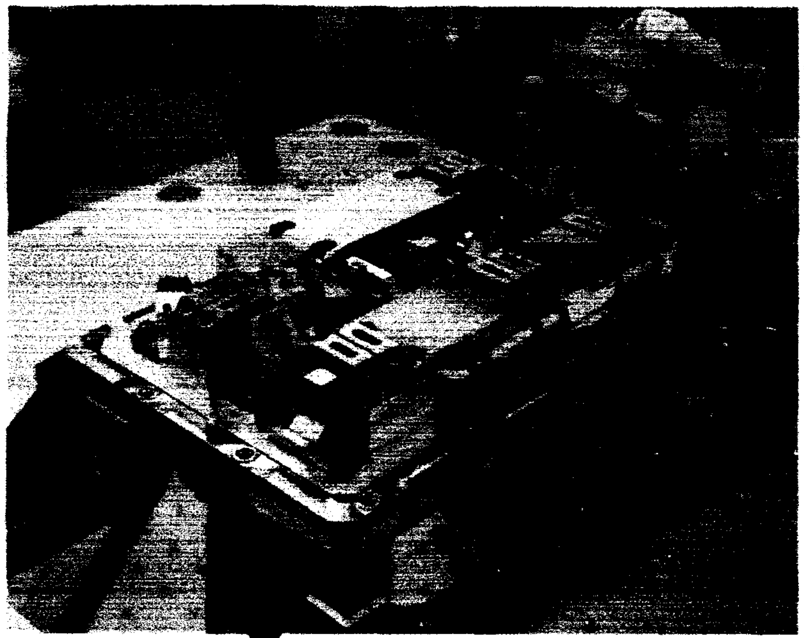

Figure 2. View of the laser bench.

The oscillator output beam undergoes a 2X beam expansion and is amplified 8.7 dB by a Nd:Cr:YAG amplifier slab. The slab is double-passed with the first pass being p-polarized with respect to the Brewster end faces and the second pass being s-polarized with respect to the end faces. The input and output faces of the slab are coated to achieve low loss in both p- and s- polarizations. The amplifier slab is pumped by two, four-bar stacks of GaInAsP laser diode bars (Coherent G-4). The pump arrays for the oscillator and amplifier sections are operated in series, electrically. The isolation of the amplifier output beam from its input beam is accomplished by polarization. A 0.57 retardation waveplate together with the porro prism reflector provide a polarization change of the back-reflected beam to the orthogonal linear polarization. Size and weight constraints precluded the use of a Faraday isolator. Because the isolation level achieved in this approach is only about −17dB, we found it necessary to offset the pointing of the input and output beams of the amplifier so that the back-reflected energy from the amplifier does not overlap the oscillator mode in the Q-switch. Overlap of the two beams results in a pre-mature bleaching of the passive Q-switch in the oscillator and lessening of the output energy. We used beam stops in key locations to intercept back-reflected energy. Unlike the oscillator pump array, there is no direct control of the amplifier pump array temperature. Therefore the output wavelength and pumping efficiency of the amplifier pump arrays varies with the optical bench temperature.

A 15X beam expander is mounted to the underside of, and perpendicular to, the laser optical bench (See Figure 2). A quarter-wave plate between the beam expander and the laser prevents back-reflected energy from external optics from entering the amplifier. The output polarization of the laser subsystem is therefore circular. On the backside of the optical mount for the exit mirror, i.e. the mirror that directs the output beam to the 15X beam expander, we attached a diffuser plate to intercept the leakage through the exit mirror. A quadrant photo-diode staring at this diffuser plate provides: (1) a timing signal for terminating the laser diode pump pulse, (2) laser energy monitoring, and (3) a start signal for the ranging electronics.

The mechanical design of the laser utilizes a beryllium optical bench (9.27 cm by 14.1 cm by 1.1 cm) for lightness and thermal performance. A titanium spacer is used to optimize the thermal isolation of the laser bench from the rest of the instrument subsystem; and a small heater ensures that the laser bench starts each science observation period at a temperature of 15C. The weight allocations of 0.52 kg for the laser and 0.32 kg for the laser electronics were satisfied. The laser bench is smaller in footprint than a 4-inch by 6-inch index card.

III. PERFORMANCE OF THE LASER SUBSYSTEM

The environmental tests of the laser subsystem consisted of vibration and thermal vacuum testing. Vibration testing consisted of three-axis random vibration to 8.0 g's rms in x and y, 10.7 g's rms in z, with full evaluation of the laser pointing, power, and divergence before and after each test. The first attempt at vibration testing revealed the necessity of improving the attachment of the 15X beam expander. We increased the torque on the fasteners that attach the 15X beam expander and provided more robust staking. The vibration test was repeated and successfully completed.

The thermo-vacuum testing involved a non-operational warm soak at 40C, a non-operational cold soak at 5C, followed by a cold start, a hot start at 35C, and 4 operational thermal sweep cycles, all in vacuum conditions. During this testing, the output power, divergence, beam pointing, and pointing stability were measured continuously. A 4-meter focal length off-axis parabola was employed in the evaluation of beam pointing and divergence. The baseline for beam pointing measurements was provided by the normal-incidence reflection of a collimated Helium-Neon beam off a reference mirror bonded to the base of the laser bench. We independently verified that the reference mirror axis was aligned to the mechanical axis of the laser bench to within approximately 20 μrad. Wavelength was measured at each stabilized temperature using a Burleigh pulsed wave meter.

Figure 3 shows the output energy of the laser subsystem, over a temperature sweep between 10C and 35C. The periodicity in the data is due to thermal expansion of the laser resonator through Fabry-Perot resonances. Due to the short cavity length, the laser tends to run in a single longitudinal mode, The overall shape of the curve is due to changes in output wavelength of the amplifier pump array and consequent changes in absorption efficiency.

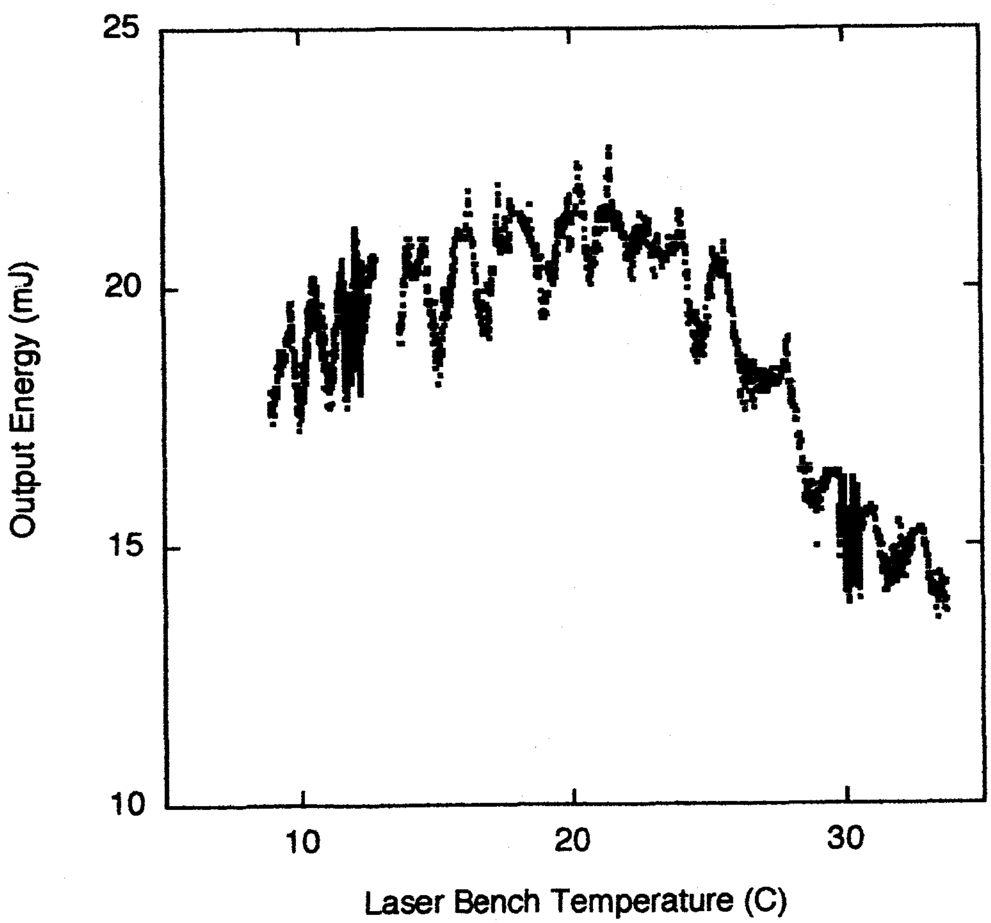

Figure 3. Laser output energy versus bench temperature, measured in vacuum.

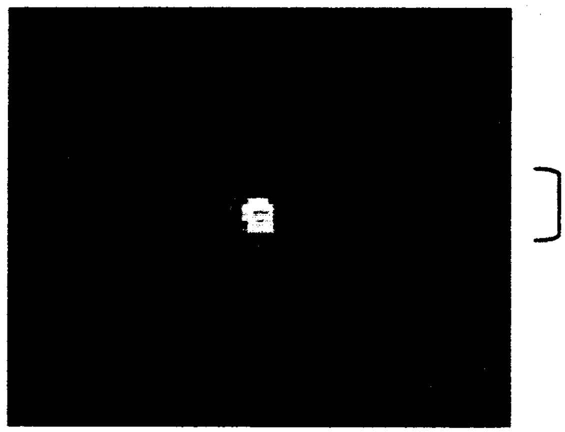

Figure 4. Laser output mode.

The laser maintained a stable TEMoo spatial mode over the entire range of the thermal sweep (see Figure 4). The best fit gaussian fit divergence was 75 urad (~1.67 times diffraction limit). Encircled energy measurements revealed that there was approximately 25 percent energy outside the 75 urad gaussian core (compared to an ideal of 13.6 percent). The non-ideal character of the encircled energy was not fundamental to the design and probably could have been corrected with addtional work. It was decided, however, to accept this level of beam quality as entirely satisfactory for the meeting the measurement requirements of the mission.

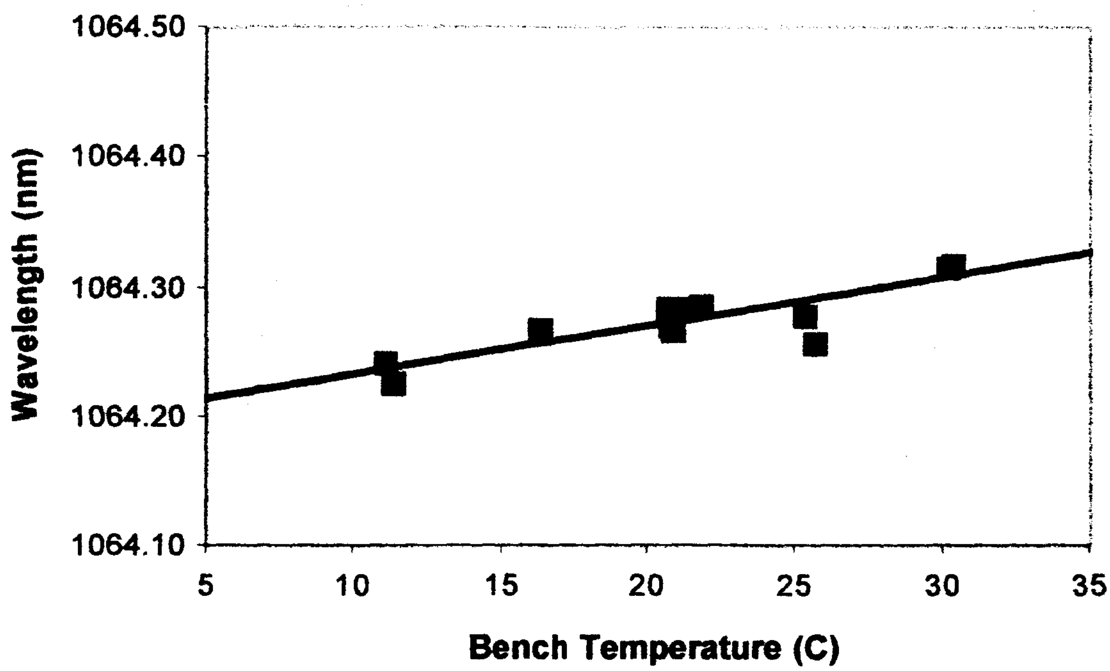

Figure 5. Laser output wavelength versus bench temperature.

The output wavelength of the laser subsystem versus temperature is shown in Figure 5. The receiver system incorporated a filter with a 0.7 nm (FWHM) bandwidth. Hence it was important to verify laser wavelength stability. The pulsewidth of the laser was in the range of 4.6-5.0 nsec and was quite stable. The overall efficiency of the laser subsystem, including the electronics, thermo-electric cooler, and quadrant detector, was 2.8 percent. The efficiency of the laser head alone was 5.4 percent.

IV. CONCLUSION

We report a highly compact and lightweight laser source for ranging applications in space missions. The laser meets its key requirements for output energy, beam quality, pulse width, pointing stability, and wavelength.

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