Compact solid-state laser to generate 5 mJ at 532 nm

Bhabana Pati*, James Burgess, Michael Rayno and Kenneth Stebbins
Q-Peak, Inc., 135 South Road, Bedford, Massachusetts 01730

ABSTRACT

A compact and simple laser has been developed to generate 5 mJ of energy and < 7ns pulses at 532 nm. A pump cavity has been uniquely designed to directly couple diode light to the laser crystal, thereby eliminating the need for mounting the diodes on sub-mounts and using a fast-axis collimating lens. An Nd:YAG crystal is side pumped by diode bars and the laser components are designed in order to extract the largest fundamental mode for better beam quality. The laser is passively q-switched by a Cr:YAG crystal. A type II KTP crystal is used to generate 532-nm wavelength.

Keywords: Compact, miniature solid-state lasers, passively q switched, side pumped, frequency conversion

1. INTRODUCTION

A compact, lightweight, and efficient laser is essential for space based applications and for man portable instruments where there are constraints on size weight and power (SWaP). The laser mentioned here has been specifically developed to perform elemental analysis on samples by means of Raman and laser induced breakdown (LIB) spectroscopy at a distance of 10 m. Remote detection of elements is a great asset for unmanned NASA missions. No sample preparation is necessary, simply point the laser towards the targeted area. The compact laser architecture developed by Q-Peak has the following parameters: energy, 5 mJ; pulse duration, < 10 ns; wavelength, 532 nm; beam quality, TEM_{00}; repetition rate, 1-20 Hz; volume, < 20 cm^3; and weight, < 120 g. The laser chassis is made of CuW in order to match with the heat sink material of the pump diode. CuW is also a good radiation shielding material, essential for space based applications. We used an Nd:YAG laser crystal as the gain medium. The laser crystal was side pumped by array of diode bars. The pump light was directly coupled into the laser crystal without any beam shaping optics for compactness and simplicity. The pump absorption was optimized by designing a unique crystal shape, size and doping level. The laser was passively Q-switched by a Cr^{4+}:YAG saturable absorber and a Potassium Titanyl Phosphate (KTP) non-linear crystal was used to double the laser frequency to generate green light at 532 nm.

2. LASER

The Nd:YAG laser crystal was side pumped by two diode lasers operating at 808 nm. Each pump diode had three bars stacked vertically and the beam diverged in the fast axis at full width at maximum (FWHM) of 42°. The cross-section of the laser crystal was shaped like "D" and was pumped through the curved surface of "D". The flat surface of the "D" was coated with a high reflector dielectric coating at 808 nm to reflect the unabsorbed pump light back to the laser crystal. We estimated the overall pump coupling efficiency of the laser is 92%. A top view of the CAD model of the laser is shown in figure 1. The dimensions are 80 × 32 × 9 mm in length × width × height. Both laser faces of the crystal were cut at Brewster's angle to obtain a linearly polarized light. A turning prism is used to fold the resonator for a compact laser housing. A Cr:YAG was used to q-switch the laser and the outer surface of it was coated with a partially reflective coating to serve as an output coupler. All the resonator optics were aligned with external tooling fixtures and were set in place. A type II KTP crystal was placed outside the resonator to generate green light at 532 nm. The KTP was cut to operate near room temperature and hence no active temperature cooling was applied to the KTP crystal. Two harmonic separators were used to separate 532 nm from the fundamental 1064 nm. Typical temporal and spatial beam profiles are shown in figure 2. As can be seen the pulsewidth is ~ 6 ns and the amplitude jitter is ± 10% (2σ estimated). For the amplitude jitter measurement we self-triggered the laser pulses and superimposed 256 pulses in the oscilloscope. In the inset a typical laser beam profile at 25 cm away from the laser output is shown. We measured the M^2 of the laser to be <2 in both axis. See figure 3. The optical-to-optical efficiency of the laser was calculated from the conversion of optical pump power to the 532-nm output power which was >5%.

*pati@qpeak.com; phone 1 781 275-9535; fax 1 781 275-9726; qpeak.com

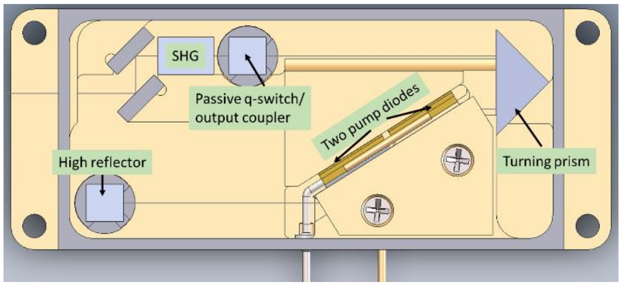

Figure 1: A top view of CAD model of the laser. Resonator was folded using a turning prism for compactness. Dimensions are 80×32×9 mm in L×W×H.

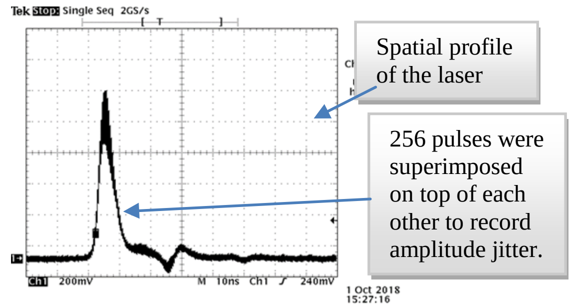

Figure 2: Temporal and spatial beam profiles. Pulsewidth is ~ 6 ns. M^2 is < 2.

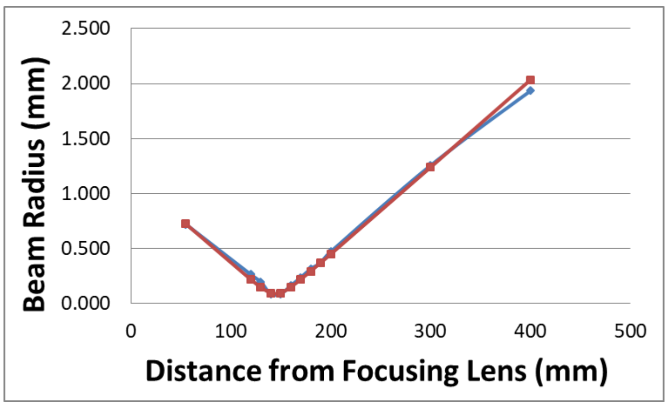

Figure 3: M2 measurement of the laser beam. M^2 is < 2 in both axis.

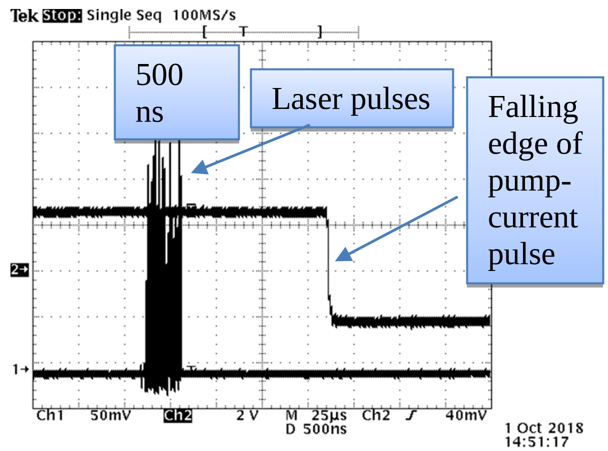

Figure 4: Pulse-to-pulse timing jitter is < 1 µs. Scale is 500 ns/div. Accumulation of 256 pulses.

An inherent quality of the passively q-switched laser is the inconsistent timing of the laser pulse. The emission of the laser pulse depends on several parameters such as gain in the Nd:YAG laser crystal, population inversion as a function of pumping time, and the saturation in Cr:YAG as function of pulse build-up time. In order to reduce the pulse-to-pulse timing jitter to < 1 µs we reduced the pump pulse width to 0.1 ms and increased the amplitude of the pump current to 120 A. Figure 4 shows an oscilloscope trace where 256 laser pulses were accumulated to show the pulse-to-pulse timing jitter. The oscilloscope was triggered by the rising edge of the current pulse to the pump diode and viewed in a delayed window after 0.1 ms. As can be seen the laser pulses emerge near the end of the pump pulse and all within 500 ns time window.

We analyzed the thermal distribution of the laser chassis using a finite element analysis (FEA) tool in Autodesk. As can be seen in figure 5, the most heat is generated by the pump diodes and the temperature rise is only 1 °C, since it is a low repetition rate system. Also using FEA we analyzed the stiffness of the laser chassis. As can be seen in figure 6, the center of the chassis bows to a maximum of 6 µm when the 4 mounting screws are attached and 50 psi force is exerted. There is not much bowing along the width of the laser because the mounting screws are only ~ 3 mm apart. The laser chassis is made of CuW in order to match the CTE of pump diodes. From the bowing due to mounting force we calculated the tilt of the mirrors. In this design the HR experiences a maximum tilt of 0.2 mrad. 0.2 mrad tilt of the resonator mirror was enough to drop the laser output power more than 10%. In order to avoid the loss of output power from the laser we mounted the chassis on a rigid heat sink with the prescribed torque to the mounting screws and then aligned the optics in the resonator. This mounting scheme is not practical for a commercial laser hence we slightly modified the laser chassis by folding the resonator in an orthogonal plane to make the chassis taller and inherently more rigid. In this new design the laser output power and beam profile were independent of the mounting scheme.

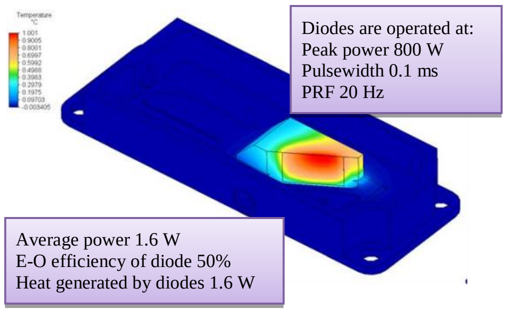

Figure 5: Heat distribution in the laser chassis.

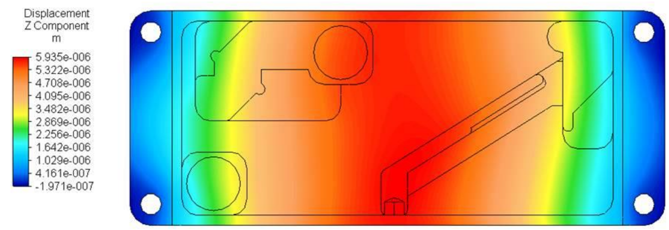

Figure 6: Stiffness analysis of the laser chassis when 50 psi force was exerted on each mounting hole.

In order to reduce the bowing of the laser chassis we modified the design using two turning prism in orthogonal planes to each other as can be seen in figure 7. Figure 8 shows the optical layout of the laser.

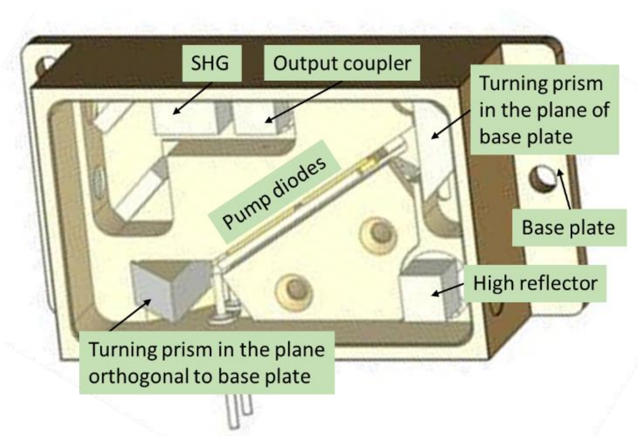

Figure 7: Improved laser chassis design. Dimensions are 67 × 32 × 18 mm.

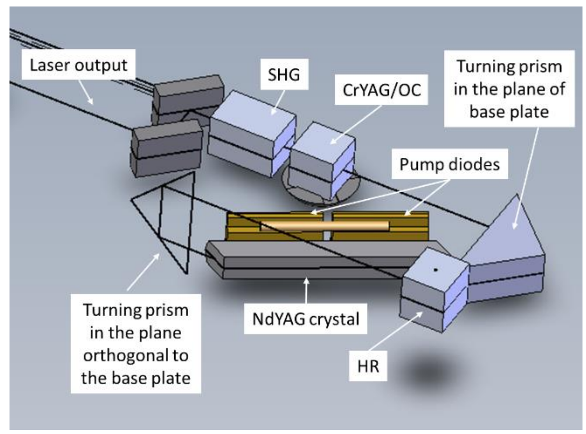

Figure 8: Optical layout of the laser.

We also analyzed the stress in the improved laser chassis when subjected to the random vibration at 14 Grms. Figure 9 shows the stress at various points on the laser chassis and the maximum stress is 1 MPa which is orders of magnitude lower than the tensile strength of CuW material. We also analyzed the modal frequency of the laser chassis and is shown in figure 10. The first modal frequency is at 30 kHz which is two orders of magnitude higher than the most common vibration specification of 300 Hz.

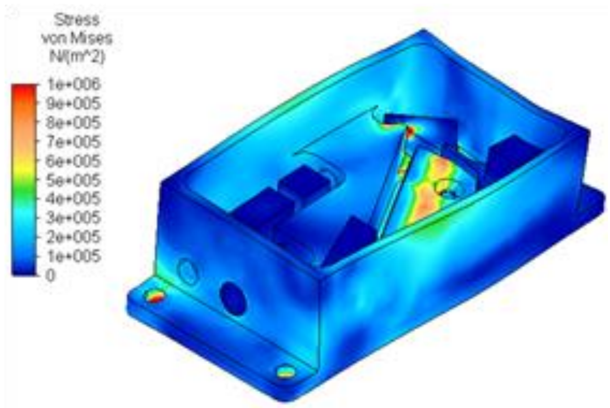

Figure 9: Stress in the laser chassis when subjected to random vibration of 14 Grms. Maximum stress is 1 MPa which is orders of magnitude below the tensile strength of CuW.

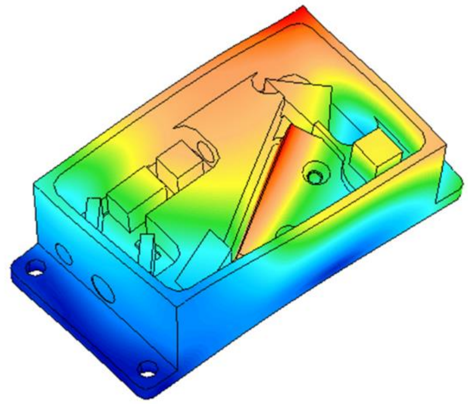

Figure 10: Modal analysis of the laser package. First mode is at 3 kHz.

3. POWER SUPPLY

Along with making the laser compact and robust we also designed and built a power supply with off-the-shelf and custom-made electrical components. The laser chassis and the associated electronics are packaged together for a complete turnkey system that is compliant to Center for Devices and Radiological Health (CDRH) regulations. At room temperature, without any active temperature control, the laser can be operated from single shot to a 20 Hz pulse repetition rate. Figure 11 shows the front and rear views of the power supply.

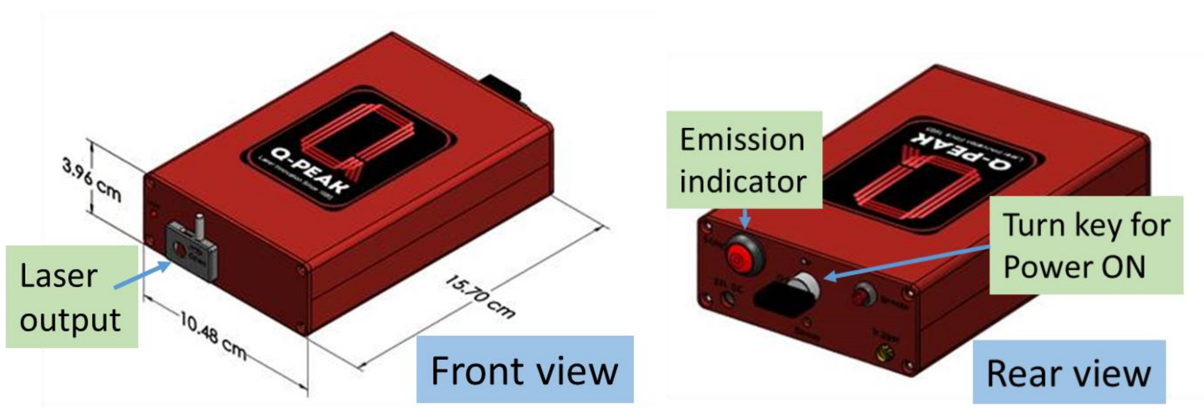

Figure 11: Front and rear view of the CAD model of the laser with assiciated electronics that is CDRH compliance.

4. CONCLUSIONS

In conclusion Q-Peak has built a compact, rugged, passively Q-switched, side-pumped Nd:YAG laser for space-based applications. The output wavelength was frequency upconverted by using a KTP nonlinear crystal. The small laser produced 5-mJ of energy per pulse at 532 nm. The pulse width of the laser is ~6 ns. The laser can be operated from single shot to a 20-Hz repetition rate. Novel features of this laser are its compactness, ease of assembly and alignment, and overall electrical to optical efficiency. The pump diodes and the laser crystal are uniquely designed to obtain a uniform deposition of pump energy in the laser rod for optimum extraction efficiency. Since the relative position of diode and crystal is not critical, the assembly of these components in the laser is particularly easy and does not require skilled labor during assembly. This will result in significant cost savings on assembly for volume production in the future.

The laser offers advantages such as smaller volume, lighter weight, and lower required power for operation. The laser can be built in the modular form factor and output energy can be scaled up by adding more pump diodes and increasing the laser rod length. If a certain mission requires more power then an additional amplifier stage can easily be integrated into the same architecture. If other wavelengths such as IR, eye-safe and/or UV are required then alternative nonlinear crystals can be substituted into the assembly without change in the basic design.

5. ACKNOWLEDGEMENT

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