High-Power, Short-Pulse, Compact SLR2000 Laser Transmitter

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Abstract: This paper reports on the design and performance of the SLR2000 laser transmitter consisting of a Cr:YAG passively Q-switched Nd:YAG microlaser and a $Nd:YVO_4$ power amplifier. The transmitter produces 500-μJ, 350-ps pulses at 1064 nm at a 2-kHz repetition rate. Nonlinear conversion to the second harmonic with 47% efficiency results in ~270-ps pulses.

KEY WORDS: (140.3480) Lasers, diode-pumped; (140.3540) Lasers, Q-switched; (190.0190) Nonlinear optics

Introduction

Diode-pumped, passively Q-switched microlasers are simple, compact and reliable sources of near-infrared sub-nanosecond pulses. To date, low-energy (0.3 to 3 μJ/pulse) and mid-energy (30 to 180 μJ/pulse) microchip lasers have been reported [1] with pulse durations of 200 to 500 ps and 650 to 2000 ps, respectively. In order to meet the needs of photon-counting laser ranging instruments, particularly the SLR2000 Satellite Laser Ranging system [2], the microlaser-based transmitters have to satisfy the following requirements:

- High-energy pulses, up to 360-440 μJ/pulse,
- Pulse durations approaching 200 ps,
- Stable multi-kilohertz repetition rates,
- Eyesafe power levels.

In order to satisfy all these requirements, we used a master-oscillator/– power amplifier configuration (MOPA). For the master oscillator, we used a passively Q-switched Nd:YAG microlaser, and a $Nd:YVO_4$ multipass-slab amplifier as the power amplifier. In our initial design, the system used quasi-cw pumping of the microlaser to control the pulse rate and reduce thermal loading. The system used an efficient cw diode-pumped, water-cooled multipass Nd:YVO4 amplifier for a two order-of-magnitude increase in pulse energy. The output of the amplifier was frequency doubled using non-critically phase matched lithium triborate. The prototype laser transmitter, producing 335-μJ, <400-ps pulses at 1064 nm with 60% efficiency harmonic conversion to the visible, was developed [3], delivered, and installed on the SLR2000 Transceiver Bench at NASA GSFC. The work was performed with support from a Phase II NASA SBIR contract.

We continued development of the laser transmitter with support from a Phase III NASA SBIR program with the following goals:

- Reduce the laser footprint
- Eliminate all water cooling
- Increase the pulse energy to 270 - 300 μJ @ 532 nm
- Further reduce the laser pulsewidths
- Provide additional computer control and monitoring interfaces

The Phase III laser transmitter, which was built and delivered to NASA in May 2003, is described in detail below.

System description and experimental results

Figure 1 shows a schematic layout of our MOPA system. A cw, 3.3-watt, fiber-coupled diode laser supplied by Unique Mode is used as a pump source for the Cr:YAG passively Q-switched Nd:YAG microlaser. Pump light emerging from the 100-μm, 0.22 NA fiber is collected and focused into the microchip using two AR-coated aspheric lenses. The fiber is positioned at the front focal plane of the first lens, and the microchip at the nominal back focal plane of the second lens. In order to optimize the microlaser output, we used a demagnifying optical system with ratio of 4:3.

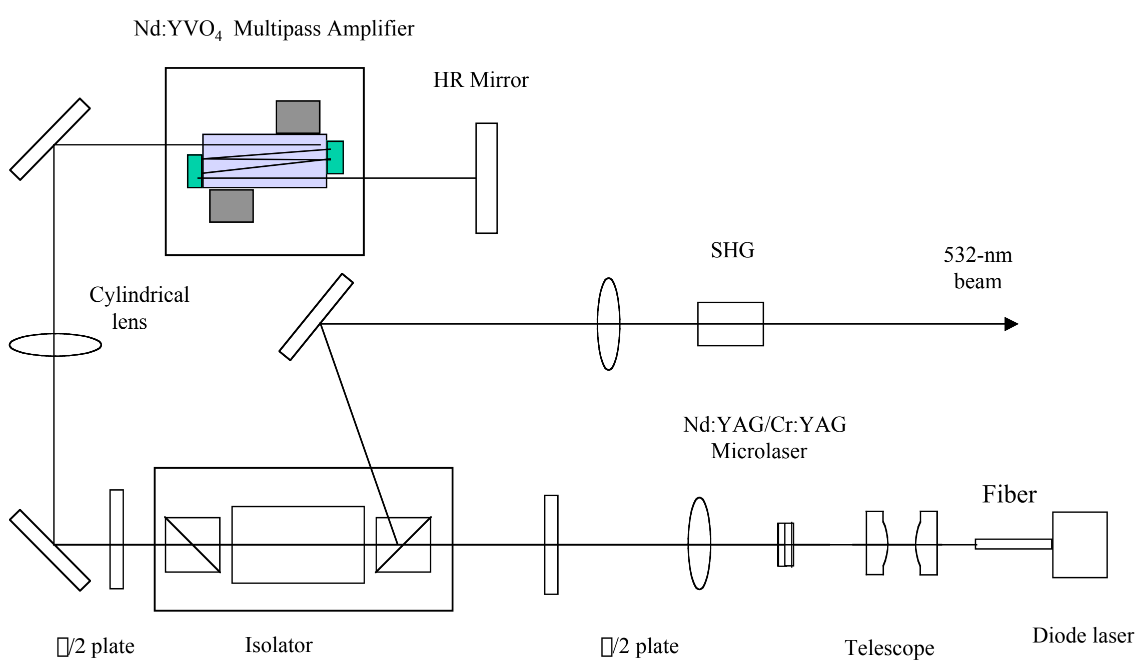

Figure 1. The laser schematic.

Two different monolithic microchip oscillator designs supplied by Northrup Grumman Poly-

Scientific were evaluated. The parameters of these microchips are listed in Table 1.

Group #	1	2
Size	1.5 x 1.5 x 2 mm	1.5 x 1.5 x 2.2 mm
Nd:YAG Thickness	1.2 mm	1.78 mm
Nd Concentration	2.5%	2.7%
Cr:YAG Thickness	0.8 mm	0.42 mm
Cr:YAG □	6.9 cm^{-1}	4.43 cm^{-1}

Table 1. Microlaser parameters.

The microchip lasers were quasi-cw pumped with 2.5-W peak-power pulses, at a 2-kHz pulse repetition rate. The width of the diode pump pulse was adjusted to ensure single-pulse oscillation at the end of a ~100-□sec pump pulse, even when the double-pass amplifier was on. We were able to achieve lasing with the Group 1 microchips pumping with 3.5 A, and measured a 350-ps pulsewidth and an energy per pulse of ~15 _J. The Group 2 microchips produced pulsewidths that were ~700 ps with energies per pulse similar to the Group 1 microchips. The pulsewidth were measured with a 18.5-ps-response InGaAs/Shottky photodetector (New Focus Model 1454-50) and a Tektronix sampling oscilloscope. Light was delivered to the detector with a 60-micron-core multimode fiber. The measurement system had a pulse response of 40 – 50 ps. Measurements of M^2 resulted in values of ~1.4 for each axis. Frequency doubling a small fraction of the light to 532-nm using a KTP crystal resulted in pulses with widths of ~270 ps using the Group 1 microchips. A typical oscilloscope trace of a Group 1 microchip pulse is shown in Fig. 2.

Figure 2. Oscilloscope trace of 350-ps oscillator pulse.

A Group 1 microchip was used to construct the oscillator - double-pass-amplifier system. The microchip laser output was collected by a spherical 50-mm focal length lens, which gradually focused the beam into the amplifier stage. The beam then passed through a TGG Faraday isolator constructed with Glan-laser polarizers. A half-wave plate positioned before the collimator lens adjusted the polarization angle of the microchip beam as it entered the first polarizer of the isolator. A second half-wave plate adjusted the polarization angle of the beam emerging from the second polarizer. The beam is turned 90° by a 45°-incidence high reflector and sent through a +150 mm focal length cylindrical lens that focuses the beam in the vertical plane. Next the beam was incident on a second 45°-incidence high reflector and entered the 3-pass amplifier stage. The cylindrical lens was positioned about 150 mm from the center of the amplifier crystal, taking into account the fact that the beam makes three passes through the crystal (the separation between the crystal assembly's miniature fold mirrors is about 20 mm, and the crystal is about 15 mm long). The beam was back-reflected through the amplifier with a flat high reflector, and mad another 3 passes through the amplifier slab.

The back-reflected, double-pass amplified beam passed back through the optical system and into the Faraday isolator. The plane of polarization at the first polarizer was now rotated 90° relative to the input microchip laser polarization. The double-pass-amplified beam was coupled out the system at the first polarizer, and emerged with a polarization vertical to the plane of the figure.

Our amplifier gain material, Nd:YVO_4, is particularly well suited for amplifying pulses with energies below 100 μJ because of its extremely high gain. The amplifier design employs a slab-geometry gain module with transverse pumping. The gain module consisted of an a-axis-cut, 2-mm high by 3-mm wide by 15-mm long $Nd:YVO_4$ slab. The slab was quasi-cw side-pumped by two 30-W diode laser bars emitting at 808 nm, with top and bottom heatsinking. The side faces of the slab were polished and antireflection coated at 808 nm for maximum coupling of the pump light. The outputs of the diode laser bars were collimated, in the highly divergent direction, by a cylinder lens to produce a nearly rectangular excitation region in the laser crystal. The laser mode was passed three times through the length of the excitation region, using a pair of miniature external mirrors, essentially transverse to the pump beam. This design allows for efficient extraction of the stored energy in a TEM_{00}-mode beam.

We have focused our attention on the mechanical design of the $Nd:YVO_4$ gain module as the elimination of water-cooling is one of the more difficult aspects of this program. We designed the gain-module mount by modeling the temperature distribution that is generated by the pump diode laser emission incident on the $Nd:YVO_4$ slab. Two pump diode lasers (2 V each) powered at 30 A peak current with a 40% duty cycle contribute 48 W of total heat flux. 20 W is dissipated in the volume of the slab, 28 W (14 W per diode) is conducted directly into the bottom plate (Fig. 3). For modeling, we used a commercially available finite element analysis program, Cosmos/Works. Our goal was to minimize the thermally induced wedge in the slab by limiting the temperature difference between the top and the bottom of the slab to ~3 ^{o} C. We increased the thickness and contact area of the Top Clamp (shown below in Fig. 3) to reduce this temperature difference.

Figure 3 shows an assembly drawing of the gain module. The upper part of the gain module is similar to what was used in the Phase II program except that we have eliminated the water-cooling channels. In our air-cooled design, the pump diode lasers and $Nd:YVO_4$ crystal were mounted on a solid block of Ni-plated copper. A Ni-plated copper clamp held the crystal in place. The bottom copper plate was cooled by thermo-electric coolers (hidden from view by the mounting structure) and the air-cooled fins of the heat sink dissipated the heat from the thermo-electric coolers. The entire structure was designed to be bolted onto the laser base plate as a single unit.

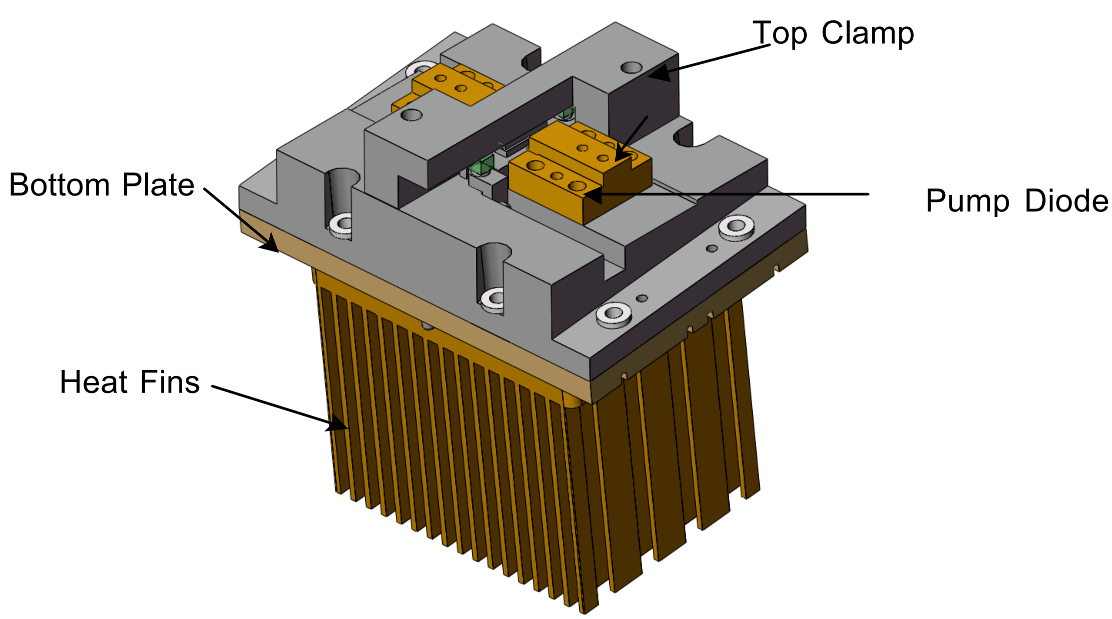

Figure 3. The $Nd:YVO_4$ gain module assembly.

The laser controller was a customized version of Q-Peak's MPL Control Unit. It contained a diode laser driver/temperature controller (DEI Model PCO-6510-E, purchased through Northrup Grumman) for the Unique Mode fiber-coupled laser, a DEI Model PCO-6140 Q-CW Diode Driver to power the Nd:Vanadate amplifier, a Q-Peak-designed bi-polar temperature controller for the amplifier, a Wavelength Electronics HTC-3000 temperature controller for the doubling crystal, and a Q-Peak designed micro-controller board. The micro-controller board featured a Z-World "Smart-Core" processor programmed in DynamicC, and has an RS-232 serial interface that either communicates with a Visual Basic program running on a personal computer or, alternatively, can be used with simple mnemonic commands. The micro-controller board independently sets and monitors the peak current driving the Unique Mode laser and the two pump diode lasers in the amplifier. The pulsewidths and relative timing of the current pulses were factory set, but the repetition rate can also be adjusted by the micro-controller, as well as switching to external-trigger mode, the expected mode of operation in the field. The micro-controller also monitors and displays the temperature of the amplifier copper block on which are mounted the $Nd:YVO_4$ crystal and the two diode bars, as well as the interlock status. The safety interlock was implemented in hardware (a latching relay), and immediately disables both diode drivers if it is tripped. The micro-controller monitors and displays the safety interlock status, and must be operating properly for the relay to be latched-up, but is not involved with a safety related shut down. The PCO-6510-E also has four interlocks that are monitored and automatically reset when necessary by the micro-controller. The MPL Control Unit was connected to the laser head with three cables providing in addition to the controls listed above power to the fans, an emission indicator, and an electronic shutter.

With 30 mW of microchip laser power, the double-pass amplifier power was about 1 W at an amplifier current of 35A. The beam quality of the double-pass-amplified beam was measured (wit a Spiricon M^2 meter) using the "90/10 knife-edge" method. M^2 in the horizontal and vertical planes was measured to be 1.38 and 1.28, respectively.

For second harmonic generation (SHG) we used a pair of critically-phase-matched, Type I LBO crystals, with dimensions of 3 x 3 x 10 mm, arranged in a walkoff compensated configuration. At an input power of 1 W, the output power of SHG was 470 mW, which corresponds to ~ 47% conversion efficiency. The pulse durations decreased to 270 ps as compared to ~ 350-ps from the microlaser.

The dimensions of the laser head are 20"(L) x 10"(W) x 8"(H) and the laser assembly is shown in Fig. 4.

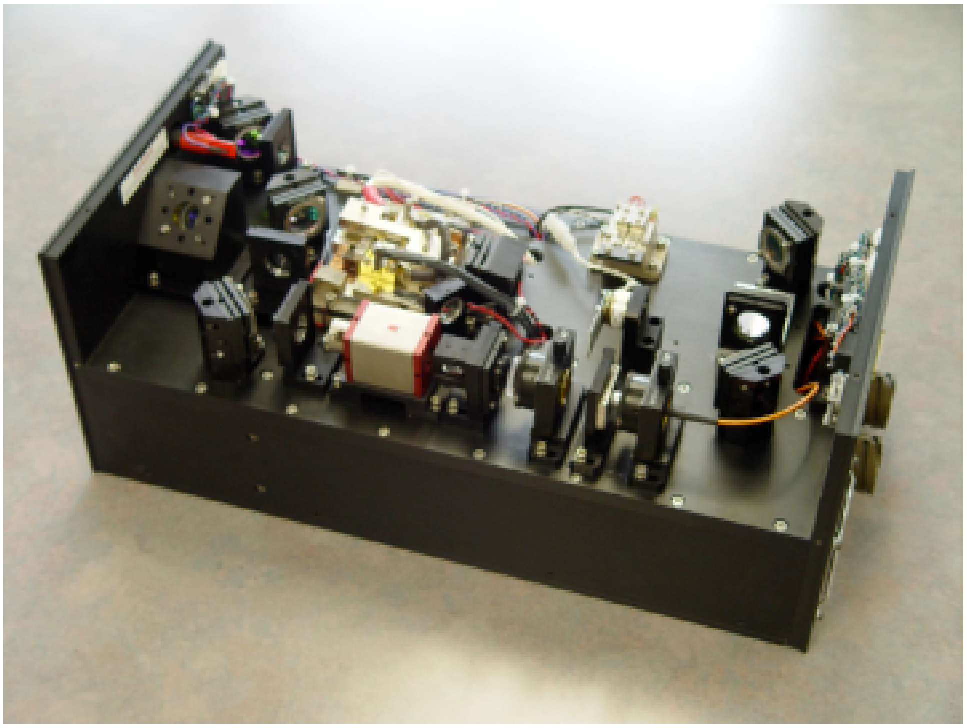

Figure 4. The assembled laser system.

Conclusion

We have designed and constructed a highly efficient diode-pumped, short-pulse, energetic, compact SLR2000 Laser Transmitter based on a microlaser-amplifier configuration. This design approach, we believe, will permit us to achieve even shorter (~ 200 ps) pulses, higher-energy per pulse, and increased harmonic conversion efficiency.

Acknowledgments

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