

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

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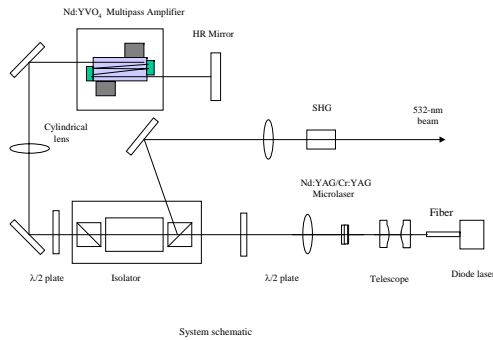
Diode-pumped, passively Q-switched micro lasers are simple, compact and reliable sources of near-infrared sub-nanosecond pulses. To date, low-energy, (0.3 to 3  $\mu$ J/pulse) and mid-energy (30 to 180  $\mu$ J/pulse) microchip lasers have been reported [1] with pulse durations of 200 to 500 ps and 650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

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

To satisfy all these requirements, we have developed a master-oscillator/power-amplifier configuration (MOPA). For the master oscillator, we use a passively Q-switched Nd:YAG micro laser, with a Nd:YVO<sub>4</sub> multipass-slab amplifier serving as the power amplifier. In our initial design, reported earlier [3], the system used quasi-cw pumping of the micro laser to control the pulse rate and reduce thermal loading and a cw, diode-pumped, water-cooled multipass Nd:YVO<sub>4</sub> 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- $\mu$ J, <400-ps pulses at 1064 nm with 60% efficiency harmonic conversion to the visible, was installed on the SLR2000 Transceiver Bench at NASA GSFC.

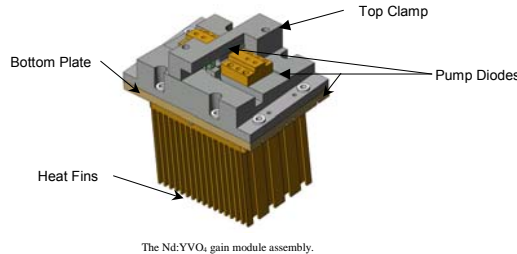
We continued development of the laser transmitter to make it suitable for operation in the unattended environment planned in the SLR2000 program, with the following goals:

- Reduce the laser footprint
- Eliminate all water cooling
- Increase the pulse energy to 270 - 300  $\mu$ J @ 532 nm
- Further reduce the laser pulsewidth
- Provide additional computer control and monitoring interfaces



The microchip laser output was collected by a spherical lens, which gradually focused the beam into the amplifier stage. The beam then passed through a YGG 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 was 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 beam was back-reflected through the amplifier with a flat high reflector, and made 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<sub>4</sub>, is particularly well suited for amplifying pulses with energies below 100  $\mu$ J because of its extremely high gain. The amplifier design employs a slab-geometry gain module with transverse pumping. The slab was quasi-cw side-pumped by two 30-W diode laser bars emitting at 808 nm, with top and bottom heatsinking. 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<sub>00</sub>-mode beam.

We focused our attention on the mechanical design of the Nd:YVO<sub>4</sub> gain module as the elimination of water-cooling was one of the more difficult aspects of this effort. Figure 2 shows an assembly drawing of the gain module. In our air-cooled design, the pump diode lasers and Nd:YVO<sub>4</sub> 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.



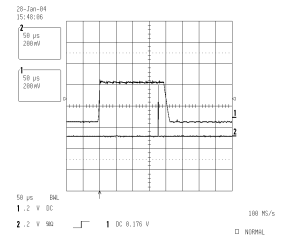
The Nd:YVO<sub>4</sub> gain module assembly.

1. J. J. Zaynowski, "Passively Q-switched microchip lasers and applications," Rev. Laser Eng., v. 26, pp. 841-846 (1998). J. J. Zaynowski, C. Dill III, C. Cook, J. L. Daneu, "Mid- and high-power passively Q-switched microchip lasers," in OSA Trends in Optics and Photonics on Advanced Solid-State Lasers, v. 26, M. M. Fejer, H. Injnan, and U. Keller (eds), (Optical Society of America, Washington DC, 1999) pp. 178-186.
2. J. Degnan, J. McCarty, T. Zagwodski, et al., "Design and performance of an airborne multikilohertz photon-counting, micro laser altimeter," International Society for Photogrammetry and Remote Sensing Workshop "Land Surface Mapping and Characterization Using Laser Altimetry," vol. 34, part 2W4, pp. 9-16, Annapolis, Maryland, 2001.
3. Y. Isyanova, J.G. Mann, D. Weltorf, M. Jassan, and J. Russell, "High-Power, Passively Q-switched Micro Laser - Power Amplifier System," OSA Trends in Optics and Photonics Vol. 50, Advanced Solid State Lasers, Christopher Marshall, ed. (Optical Society of America, Washington, DC 2001), pp. 186-190.

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) 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 HFC-2000 temperature controller for the doubling crystal, and a Q-Peak designed micro-controller board.

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 (with a Spicon M<sup>2</sup> meter) using the "50/10 knife-edge" method. M<sup>2</sup> in the horizontal and vertical planes were measured to be 1.38 and 1.28, respectively.

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



The dimensions of the laser head are 20"(L) x 10"(W) x 8"(H).



The dimensions of the Q-Peak MPL controller is 20"(L) x 17"(W) x 7"(H).



Phase II system installed on SLR2000 Transceiver Bench

A cw, 3.3-watt, fiber-coupled diode laser supplied by Unique Mode was used as a pump source for the Cr:YAG passively Q-switched Nd:YAG micro laser. Pump light emerging from the 100- $\mu$ m, 0.22 NA fiber was collected and focused into the microchip using two AR-coated aspheric lenses. The fiber was 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 micro laser output, we used a demagnifying optical system with ratio of 4:3.

Two different monolithic microchip oscillator designs supplied by Northrop Grumman Poly-Scientific were evaluated. The parameters of these microchips are listed in Table 1. 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- $\mu$ scc pump pulse, even when the double-pass amplifier was on.

Table 1. Micro laser parameters.

| Group #          | 1                    | 2                     |
|------------------|----------------------|-----------------------|
| Size             | 5 x 1.5 x 2 mm       | 5 x 1.5 x 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 $\alpha$  | 0.9 cm <sup>-1</sup> | 2.43 cm <sup>-1</sup> |

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  $\mu$ J. The Group 2 microchips produced pulsewidths that were ~70 ps with energies per pulse similar to the Group 1 microchips. The pulsewidth were measured with a 18.5-ps-response InGaAsShotky 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<sup>2</sup> 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 Group 1 microchip was used to construct the oscillator - double-pass-amplifier system.