

Fast Widely-Tunable CW Single Frequency 2-micron Laser

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Abstract: We have recently developed a fast widely-tunable diode-pumped solid-state laser architecture, called the *SWIFT*, or *Super-Wide Frequency-Tunable* laser. The laser architecture is compatible with operation using many different solid state laser crystals for access of various emission lines between 1 and 2.1 micron. We initially demonstrated the laser using Tm,Ho:YLF laser crystal near 2.05 micron wavelength and achieved 100 mW of output power with 50 GHz fast PZT tuning range. The fast 50 GHz tuning range can be centered at any wavelength from 2047-2059 nm using the Tm,Ho:YLF crystal. The frequency stability and power are sufficient to serve as the local oscillator laser in long-range coherent lidar systems. The rapid and wide frequency tunability meets the requirements for integrated-path or range-resolved differential absorption lidar or applications where multiple hard targets with significantly different line of sight velocities (Doppler shifts) must be tracked. We will describe the Tm,Ho:YLF SWIFT laser performance in detail in the presentation.

Keywords: Coherent Lidar, Single Frequency, Laser

1. Introduction

To address needs in the laser remote sensing community and for other laser-based applications requiring a small, efficient, very stable single-frequency cw Master/Local Oscillator source, Beyond Photonics has recently developed a very widely-tunable diode-pumped solid-state laser architecture, called the *SWIFT*, or *Super-Wide Frequency-Tunable* laser. These lasers have very wide mode-hop-free frequency tunability (up to as much as 50 GHz), high power (20-100 mW cw), narrow linewidth and good frequency stability (<10 kHz/ms), and can be readily adapted to different solid-state laser crystals to access wavelengths from the near IR to 2.1 micron and potentially beyond.

The frequency stability and power are sufficient to serve as the Local Oscillator (LO) laser in long-range coherent lidar systems where frequency measurement accuracy is paramount. The lasers are also rapidly frequency-tunable, meeting the requirements of many active remote sensing applications where transmitted frequencies separated by multiple GHz must be rapidly accessed for remote laser spectroscopy applications like integrated-path or range-resolved differential absorption lidar. [1, 2] Very frequency- and power-stable two-micron wavelength lasers are also being considered for use in next-generation gravitational wave detectors, to take optimal advantage of decreased thermal noise in silicon-based reference cavity optical coatings compared to shorter wavelengths. [3]

2. Laser Description and Performance

Key elements of the SWIFT laser are a diode-laser-pumped thin solid-state laser disk; a compact intracavity frequency filter element to inhibit lasing on all but a single longitudinal mode of the cavity and to permit broad frequency tunability; and an integral low-voltage piezoelectric (PZT) tuning element. To improve long term frequency stability, the entire resonator is thermally stabilized using a small thermo-electric cooler to about 1 millidegree C and housed in a hermetically sealed enclosure. Typically, the laser is

isolated using a compact high-performance Faraday isolator and coupled into polarization-maintaining single mode fiber. The laser disk can be selected to be thicker for improved pump absorption and increased laser output power or alternately to be thinner for increased mode-hop free frequency tuning range at the cost of reduced pump absorption and lower laser output power.

For the prototype demonstration of this new laser architecture, we chose to initially demonstrate 50 GHz fast frequency tuning range using a thin Tm,Ho:YLF solid-state laser disk operating near 2.05 micron wavelength. The single frequency output of the *SWIFT* laser can be spectrally tuned by three different means: piezoelectrically, thermally, and with changing pump diode current. Even with the thin disk, high cw output power levels are readily achievable at moderate diode-pump levels, as shown in Figure 1 below.

We determined that the piezo tuning sensitivity of the prototype Tm,Ho:YLF *SWIFT* is 0.0114 nm/V, or ~ 800 MHz/V in terms of laser frequency change, with applied PZT voltage. We observed up to 0.70 nm of mode-hop-free SLM wavelength shift (2051.123 nm to 2051.820 nm) using a piezo DC bias voltage that ranged from 33 V to 90 V. As shown in Figure 2, this corresponds to 50 GHz in laser frequency.

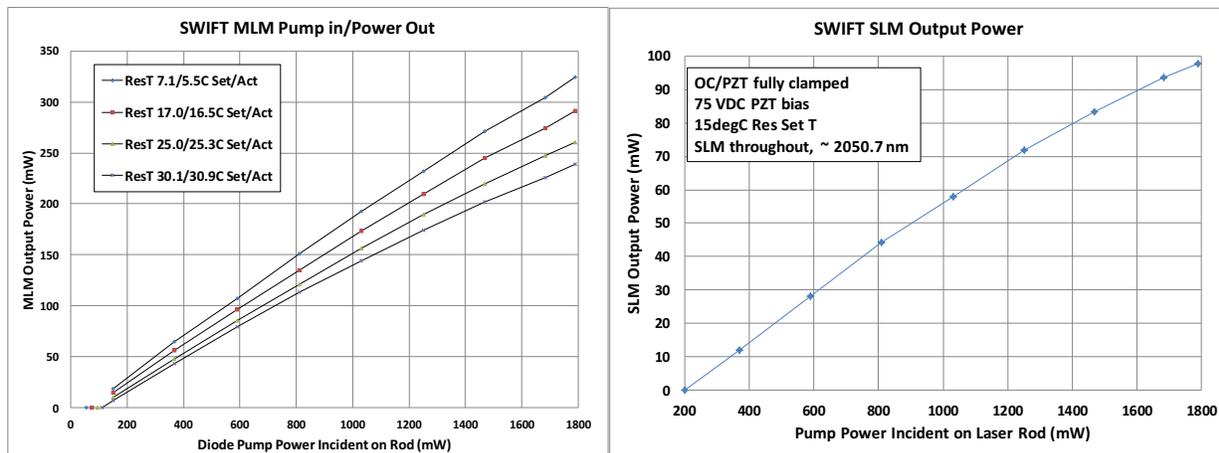


Figure 1. Prototype *SWIFT* multi-longitudinal mode (MLM) and SLM output power. The Tm,Ho-doped laser exhibits increasing slope efficiency with decreasing temperature due to its quasi-three-level operation. Power shown are directly from laser with no isolation or fiber coupling loss. Isolated and fiber coupled output power is typically about 70% of the power shown in the figure. Active temperature control temperature can be traded against output power performance for specific user applications.

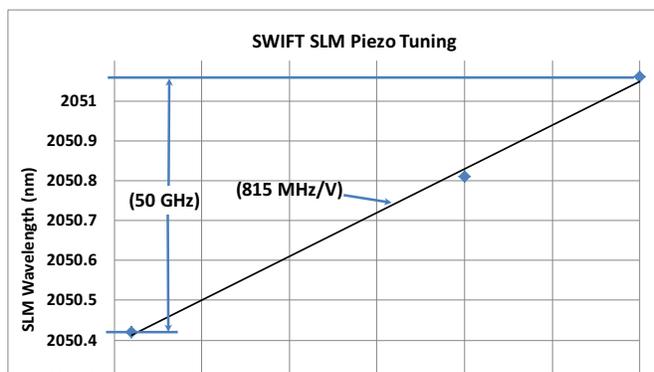


Figure 2. Prototype Tm,Ho:YLF *SWIFT* continuous SLM tuning; 50 GHz span.

We used an IR wavemeter to measure the piezo sensitivity of 815 MHz/V DC and the full tuning range of 50 GHz. We then used a cross-calibrated 80 GHz FSR, ~ 100 -finesse scanning/static Fabry-Perot interferometer to provide insight into the *SWIFT*'s ability to respond to “small-signal” sinusoidal modulation of the laser cavity length. Figure 3 shows the result of driving the *SWIFT* laser's PZT actuator with a low-frequency (2.5 kHz) sine-wave drive signal (0.5 V peak-to-peak applied to the PZT actuator, corresponding to ~ 400 MHz p-p laser frequency modulation). As expected, the laser frequency modulation (Channel 2) follows the

drive signal (Channel 1) perfectly at this low modulation frequency. As the sinusoidal drive frequency is increased, we eventually encounter mechanical resonances that induce phase delay and higher and lower modulation amplitude. The prototype *SWIFT* resonator assembly resulted in a first mechanical resonance at about 38 kHz. We expect to increase this first mechanical resonance frequency in the final product design by eliminating a non-optimal mechanical attachment of the laser output coupler in the prototype laser which will be corrected in the final product.

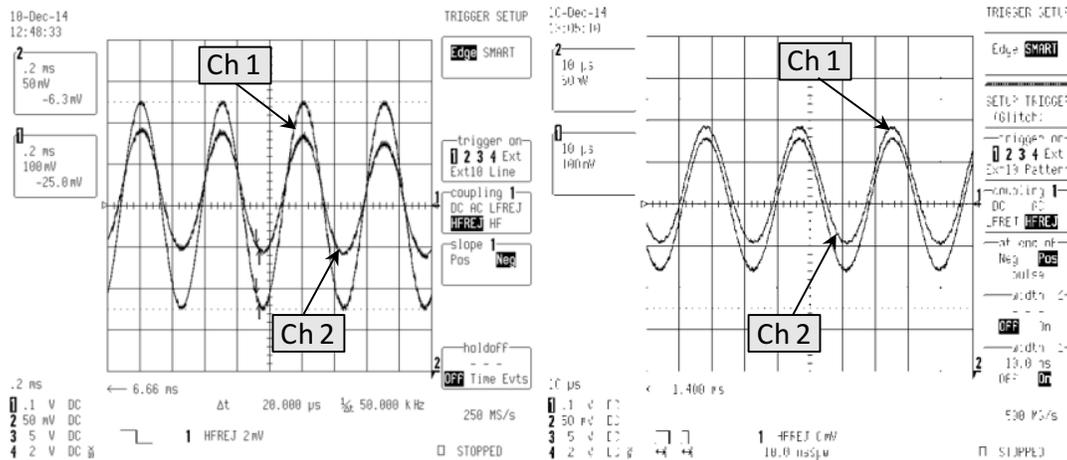


Figure 3. Prototype Tm,Ho:YLF *SWIFT* 0.5 V p-p sinusoidal drive (Ch 1) and response (Ch 2). Left: Laser frequency modulation of ~ 400 MHz p-p resulting from an initial 2.5 kHz sinewave drive signal applied to the ring actuator; no phase shift seen in response at this low drive frequency. Right: Well-behaved response is still exhibited at 35 kHz drive frequency.

Additionally, a larger-signal, 10 V p-p sine drive signal was applied at 3 kHz modulation frequency, corresponding to a peak to valley change in laser frequency of ~ 8 GHz in 167 μ s. The behavior is repeatable and doesn't exhibit any significant phase delay up to even 10 kHz rates (where we stopped in the prototype due to concerns that driving at such large displacements at even higher frequencies might damage the PZT).

We also investigated the frequency jitter and found the measured frequency stability is consistent with other stable lasers we have previously developed [4] prior to the laser cavity being enclosed in its hermetic enclosure and therefore we expect that the rms frequency jitter in the hermetically enclosed device to be better than 10 kHz/ms.

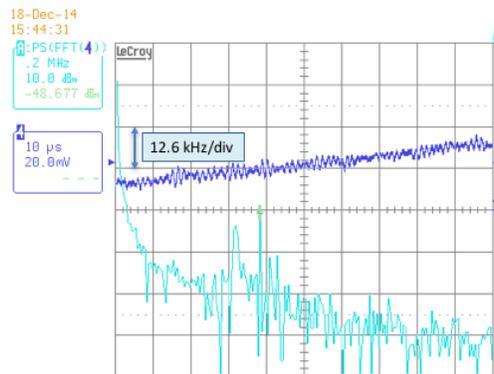


Figure 4. Prototype Tm,Ho:YLF *SWIFT* example frequency jitter and drift without hermetic enclosure and PZT shorted. Drift of ~ 12.6 kHz/100 μ s (see dark blue trace) dominates due to hermetic seal being removed for this sample capture time of 100 μ s. Lower light blue trace is FFT of the frequency vs time.

3. Conclusions

The initial SWIFT laser operating at 2.05 μm wavelength is immediately appropriate for use as a cw master/local oscillator source in current and future coherent laser radar systems. Multiple-tens of milliwatt output powers permit efficient use of the laser output for both injection-seeding higher-power pulsed transmitter lasers and as the LO source in the system's heterodyne detection circuit. The very broad and fast frequency tuning demonstrated is relevant to cw and pulsed differential absorption lidar applications where the transmitted laser frequency must be quickly switched between high- and low-transmission wavelengths relevant to measurement of molecular constituent concentrations in the atmosphere (CO_2 , water vapor, methane). The basic optically-pumped SWIFT format is also applicable to very compact, high peak power pulsed lasers appropriate for use as lidar transmitter sources for coherent winds and remote spectroscopy.

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