

## High Energy 2-micron Laser Developments

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There are many specific applications for 2-micron lasers in atmospheric surveillance and medical therapy such as wind/CO<sub>2</sub> measurements and hard and soft tissue ablation [1-2]. As coherent Doppler wind lidars, they can be used for wake vortex and clear air turbulence detection providing air transport safety. Solid-state 2-micron laser is a key subsystem for such lidar systems.

Recently, significant advancements in the 2-micron laser development have been made in terms of high energy demonstrations. A 1.2-joule-per-pulse Q-switched 2-micron laser system has been recently demonstrated. This high energy 2-micron laser system comprises an oscillator and two power amplifiers. The Master Oscillator Power Amplifier (MOPA) system is a typical way to achieve high energy, and at the same time to preserve good beam quality required by the nature of coherent lidars. There is no single oscillator that can produce Joule energy at 2-micron wavelength without coming across the problem of optical damage.

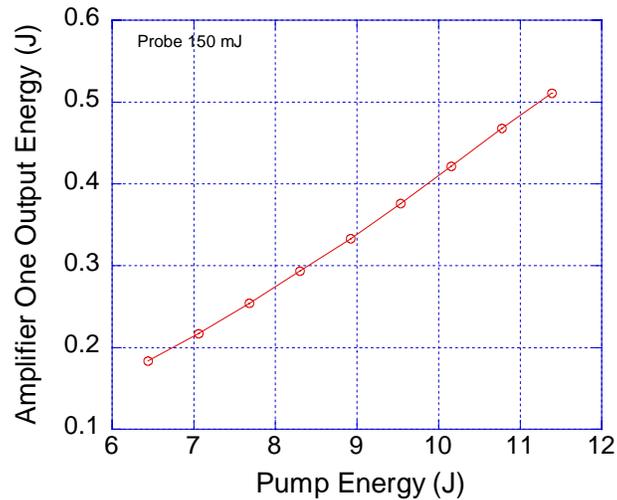
The laser and amplifiers are all designed in side-pumped rod configuration, pumped by back-cooled conductive packaged GaAlAs diode laser arrays. The symmetry afforded with side-pumped rod geometry helps to produce a high quality, circularly symmetric Gaussian beam output. The laser oscillator and amplifier modules are in monolithic design. The conductively cooled diode arrays were directly mounted on aluminum modules, cooled by flowing water. The wavelength of the pump diodes is controlled by the coolant temperature. The efficiency of the diode laser arrays was in the range between 38% and 44%. Recently, advancement of diode laser technologies led to higher than 50% efficiency for such quasi CW diode lasers.

The gain medium of the laser system is Tm:Ho:LuLiF<sub>4</sub> crystal. A detailed study of the Tm:Ho co-doped crystals of YLiF<sub>4</sub> and the isomorphs LuLiF<sub>4</sub> and GdLiF<sub>4</sub> revealed that small changes in the thermal population of the lower laser level in ground state terminated lasers can significantly alter the laser performance [3]. The larger host ion size of Lu leads to larger crystal fields and, as a result, larger crystal field splitting of lanthanide series ions. Thus, the LuLiF<sub>4</sub> host crystals provide better laser performance compared with YLiF<sub>4</sub> or GdLiF<sub>4</sub> based lasers [4]. The lower the laser crystal temperature is, the better performance of the laser will be for this quasi-four laser system. The pump laser diode arrays and the laser crystal rods are cooled in different chiller loops, so the temperatures of diodes and rods can be independently controlled.

The oscillator uses a stable ring resonator configuration to obtain a Gaussian spatial profile beam. A stable resonator design is less sensitive to external vibrations and other mechanical perturbations in terms of laser performance. To obtain single longitudinal mode oscillation that a coherent Doppler wind lidar requires, an injection seeding technique is applied. This injection seeding is based on a ramp and fire technique. By injection seeding, not only a single longitudinal mode oscillator was obtained, but unidirectional output of the ring resonator was achieved as well. However, for simplifying this experiment, the injection seeding is not implemented. A retro reflector is used to obtain unidirectional output.

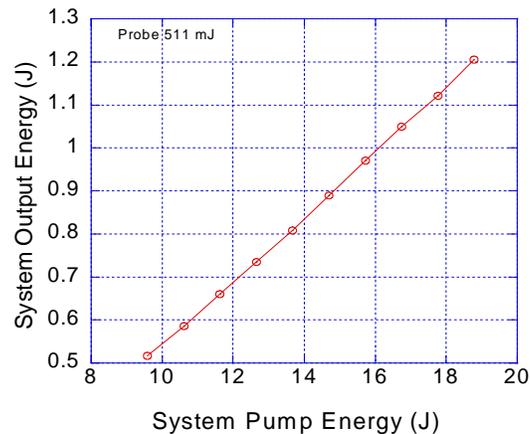
To maximize the extracted energy, the two amplifiers shall be operated near saturation. Both of the amplifiers are configured at double pass to increase amplifier efficiency. Under three-side pumping geometry, the gain profile peaked at the rod center and lower at edges. Some portion of the area around the edge of the rod where it did not directly face the diodes may not even reach the threshold of the population inversion, resulting in net loss in these areas. Thus, the optimal mode matching between the probe beam and the pump volume is an important factor. Mode matching is realized by selecting the

radius of curvatures of the reflect mirrors between the amplifier stages such that the beam sizes at amplifiers are little larger than 3.0mm.



**Figure 1.** Amplifier one performance

Figure 1 depicts amplifier one's performance for single Q-switch operations at a laser rod coolant temperature of 8°C. The probe energy from the oscillator output is ~150mJ with full width half maximum of the pulse measured at 240 ns. The pump energy includes the oscillator and amplifier one's pump diode incident energy. The amplifier did not produce gain until the pump energy increased to 4.03J. At the total maximum pump energy of 11.3J, 511mJ of output energy is obtained, representing extracted energy of 361 mJ.



**Figure 2** Amplifier two performances

The performance of second amplifier is shown in Fig. 2. The input energy for the amplifier two is 511 mJ. Without the pumping power, only 93mJ passes through the amplifier due to ground state absorption. The optical transparency is achieved at pump energy 3.759J, where the amplifier just overcomes the ground state absorption loss. For a total MOPA system pump energy of ~18.5J, 1.205 J of single Q-switched output energy is achieved. The optical to optical conversion efficiency is 6.5%. Amplifier two extracts

more than twice as much as energy than that of the amplifier one at the similar pump conditions. Nearly 700mJ energy is extracted from the amplifier two.

This 2-micron laser system provides nearly transform limited beam quality. The beam quality of the MOPA system is characterized by scanning knife edge technique measuring the beam diameters at 11 planes on both sides of the focus point for a 500mm focal length lens under full power condition. At the last amplifier stage, the beam quality is 1.4x transform limited.

## References

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