

CHARACTERIZATION AND PERFORMANCE OF A HIGH-POWER SOLID-STATE LASER FOR A HIGH-CURRENT PHOTO-CATHODE INJECTOR

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Abstract

We report the characterization and performance of a diode-pumped, high-power, picosecond laser system designed for high-current photo-cathode accelerator injector at repetition rates of both 75MHz and 750MHz. The characterization includes measurement of the amplification gain, thermally induced beam mode variation, harmonic conversion efficiency, system's amplitude stability, beam pointing stability, beam profile, and pulse width for both frequencies.

INTRODUCTION

Jefferson Lab's Free-electron-laser Facility has been successfully upgraded to the 10kW level in 2004, following the break-through of over 2kW CW output power in 2000. Recently, the 100kW system has been under intensive study while the installation of a 1kW class ultra-violet beam line is underway. The laser power increase requires higher average electron beam current. To reach the 100kW laser output power level, a new injector that is capable of delivering over 100mA current is necessary. The present injector consists of a photo-cathode electron gun driven by a CW mode-locked Nd:YLF laser pumped by flash lamps (Coherent Antares laser made in early 90's). Although this laser can routinely produce up to 5W second harmonic (SH) at a 75MHz pulse repetition rate with about 30ps pulse width, it is far away from the requirement for future high current injectors. We need a new drive laser with over 20W green output power at both 75MHz and 750MHz with same pulse width and better stability, including the amplitude and phase stability. With the fast development of the new laser materials, ultra-fast laser systems and diode-pumped solid-state laser techniques, there seems to be no question of the feasibility of such a drive laser. However, in view of the specific parameters, the choices are basically quite limited.

Apparently, the laser fundamental wavelength is decided by the available materials and should be around 1 micron. Therefore, the fundamental power should be on the level of 50W in order to easily meet the SHG power. This is not trivial for most picosecond (ps) laser oscillators. To change the pulse repetition rate means to change the cavity length and presents even more difficulty for such a very high average power short pulse laser system. So the traditional master-oscillator-power-amplifier (MOPA) concept seems to be a natural way for the task. With a stable and easy-to-handle oscillator, the output power can be boosted to the expected power by a few amplifiers while maintaining the initial seed pulse

property with a well-designed system. Different from most of the common high peak power and low repetition rate systems, thermal loading is a critical issue to be solved.

In this paper we will describe the testing and characterization of an all solid-state ps laser system initially designed to meet above-mentioned requirements.

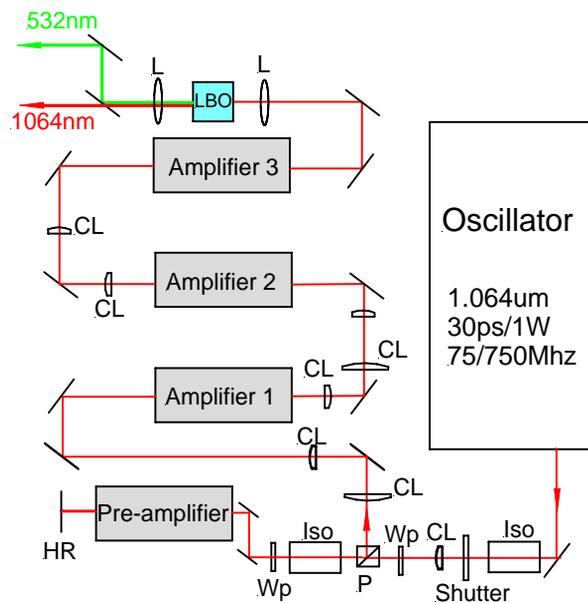


Figure 1: Optical schematic of a diode-pumped all-solid-state MOPA system. Iso, isolator. Wp, wave-plate. P, polarizer. HR, high reflector. L, spherical lens. CL, cylindrical lens.

SYSTEM DESCRIPTION

The overall optical schematic of the MOPA laser system[1-2] is shown in Figure 1. This diode-pumped all-solid-state laser system can be divided into three parts, the oscillator which produces seed pulses, the amplification chain that includes four amplifiers, and the second-harmonic generator (SHG). The diode-pumped Nd:YVO₄, passively mode-locked oscillator gives over 500mW power at 1064nm for both 74.85MHz and 748.5MHz repetition rates (Time-Bandwidth Product, Model GE100-VAN-74.85/748.5-CLX). Compared with other widely used Nd:doped materials, Nd:YVO₄ has shorter upper-state life time and higher gain, which helps to establish stable mode-locking when the semiconductor saturable-absorber mirror (SESAM) is used in high pulse repetition cavities. The pulse duration of each individual pulse is about 25ps. The laser can be locked to an external rf

source to actively adjust the cavity length. The phase noise is below 0.7ps. The optical configuration has to be changed in order to switch to a different pulse repetition rate. The output beam profile appears elliptical, but the M^2 is usually about 1.2 on both axis (Figure 2).

The amplification chain contains four identical diode-pumped amplification modules (Qpeak MPV gain module). Each module is a three-pass Nd:YVO₄ amplifier as shown in Figure 3. The laser crystal slab is pumped from both sides by diode laser bars. Cylindrical lenses are placed between each module in order to compensate the thermal effect and collimate the beam into the subsequent laser crystal. After amplification, the fundamental 1064nm beam is tightly focused into a non-critical phase-matched(NCPM) LBO crystal for frequency doubling to 532nm. The fundamental and the second harmonic beam are separated by two dichroic beam splitters. The unconverted residual fundamental beam goes into a beam dump.

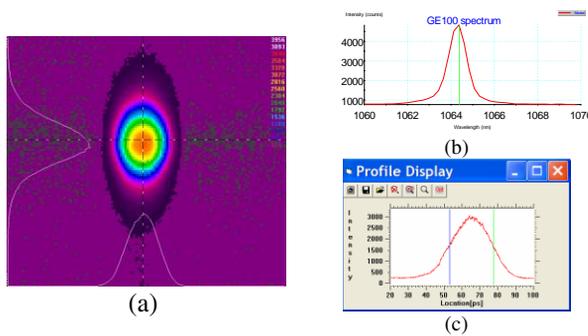


Figure 2: (a) A near field beam profile of GE100 laser. (b) Output spectrum. (c) A measured pulse waveform.

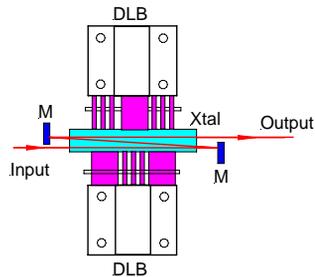


Figure 3: An illustration of a 3-pass amplifier module. Xtal, Nd:YVO₄. DLB, diode laser bar. M, mirror.

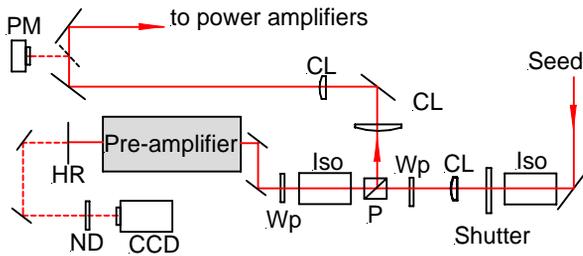


Figure 4: Schematic of the 2-pass configuration and diagnostic devices. PM, power meter. ND, attenuator. CCD, Cohu camera. Others, the same as in Figure 1.

MEASUREMENT

Beam Mode Change

First, we take a look at the unavoidable thermal effect that commonly exists in any high average power laser systems. Because of the crystal's large refraction index gradient with temperature, the thermal load into the crystal induced by the tightly focused pump beam causes strong aberrated thermal lensing effect. To know how the thermal lens affects the amplified beam shape is crucial to the design of compensation optics. By placing a camera at the back of the pre-amplifier as shown in Figure 4, we are able to look at the leakage beam from the high reflector. The beam profiles and beam sizes at different diode current are recorded in Figure 5. The dramatic pattern evolution clearly shows the severe thermal effect in the gain medium. That's why the cylindrical lenses are placed along the beam path at each stage.

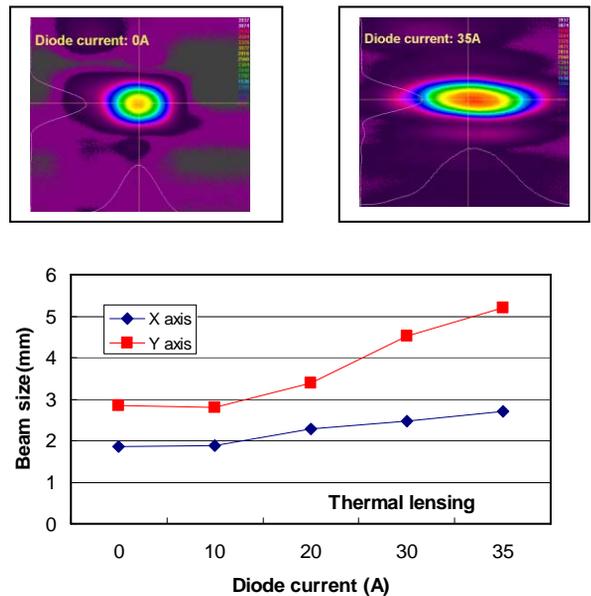


Figure 5: Beam size (FWHM) changes induced by thermal lensing effect in amplifiers. Repetition rate, 74.85MHz.

Amplification Gain

Gain is the most important parameter for an amplifier. We took the pre-amplifier as a test module to do the measurement. Power meters are used to read both the seed and the amplified beam power at the seed input and the amplifier output. Figure 4 is the layout of the setup. The results for 74.85MHz and 748.5MHz are given in Figure 6. In both cases, output power increases linearly with the input seed power. Only a slight sign of saturation trend appears when the seed power reaches maximum. The diode current threshold for amplification is about 10A. The pre-amplifier gives about 12W at 35A, indicating an overall gain of 17. The laser pulses experience 6 passes in the pre-amplifier which works in a high-gain small-signal region. The loss measurement shows each stage has a 70% to 85% throughput, so the actual gain is higher. As

for the power amplifiers, the gain characteristics are very close at both repetition rates with almost equal curve slope. Unlike the pre-amplifier, power amplifiers have much lower gain, but high extraction efficiency. The

excellent power scaling linearity in Figure 6 indicates that the amplifiers have the potential for higher pass amplification to increase the gain.

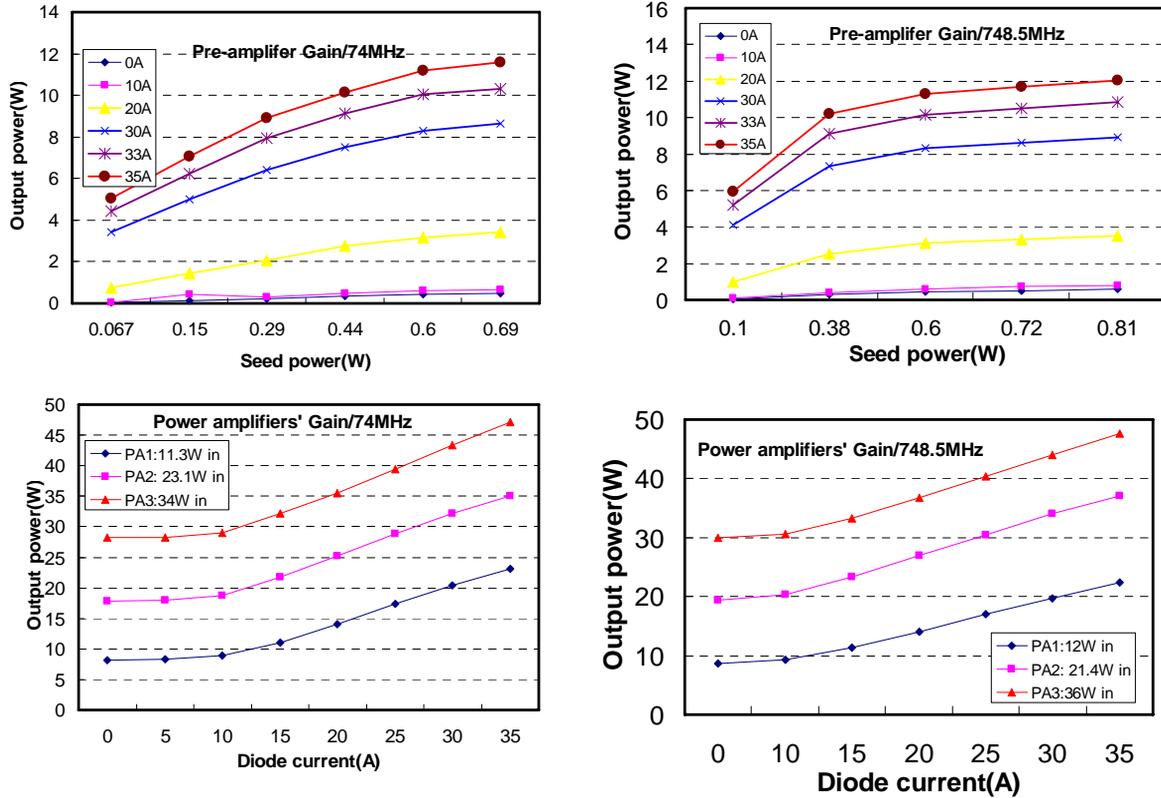


Figure 6: Measured pre-amplification and multi-stage amplification gain at both 74.85MHz and 748.5MHz pulse repetition rates. PA, power amplifier.

Second Harmonic Generation

The amplified 1064nm fundamental pulse is frequency doubled in a 20mm long NCPM LBO crystal mounted in a temperature stabilized oven. The SHG power and the efficiency as a function of diode current are shown in Figure 7. The difference between the data at two repetition rates is obvious although their 1064nm power remains pretty much the same. At 74.85MHz, the SHG power and conversion efficiency are 24W and 55%, respectively. They decrease to nearly half this at 748.5MHz. The lower energy in each pulse is the direct cause. We are now looking at the new nonlinear material such as PPLN to solve this problem.

We measured the pulse width for the amplified fundamental and the SHG pulses by a fast streak camera. From Figure 8 we can see little difference between them, including the seed pulses. They are about 22 to 26ps. The expected pulse shortening in SHG can not be seen here.

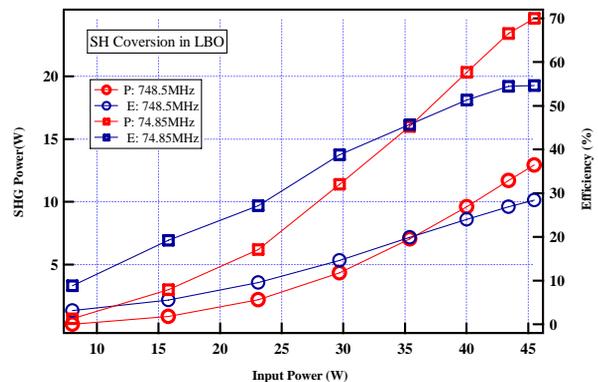


Figure 7: SHG power and conversion efficiency vs. diode current for two pulse repetition rates. P, power. E, efficiency.

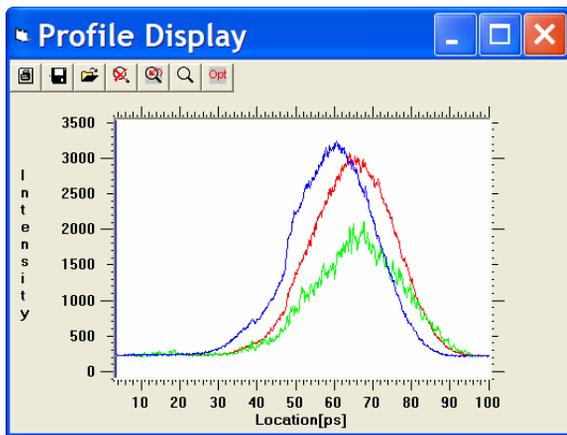


Figure 8: Streak camera traces for the input seed (red), the amplified (blue), and the SHG (green) at 74.85MHz.

Stability

Both the output power and the laser beam pointing stability are measured and are presented in Figure 9. The power stability is usually better than 1% and may fluctuate slightly with the room temperature. The pointing stability is performed by recording the standard deviation of beam trace centroids on a camera over many hours. For a distance of 1.5 meters from laser exit to the camera, the overnight testing shows 20 μ rad on horizontal axis and about 40 on vertical axis.

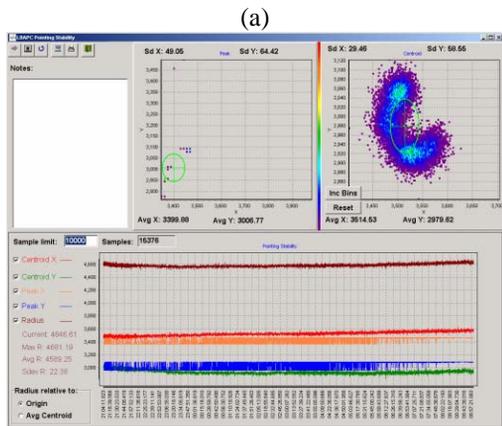
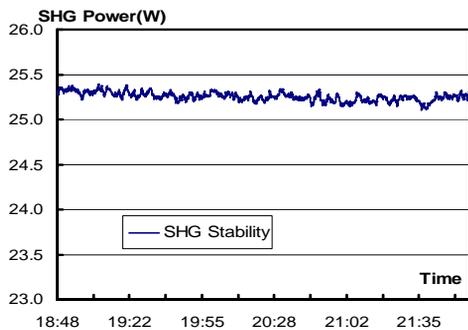


Figure 9: (a) SHG power stability test graph. (b) Overnight beam pointing stability test data sheet.

The SHG beam profile measurement shows an elliptical pattern, as shown below in Figure 10 (right picture).

Sometimes fringes can be seen across the beam (left picture). We found the lenses at the two sides of the harmonic generator did not work well and need to be replaced. Another important task that has not been done so far is the system phase noise measurement. It is expected the amplification chain will not add noticeable timing jitter to the amplified seed pulse, but the experimental verification is still necessary.

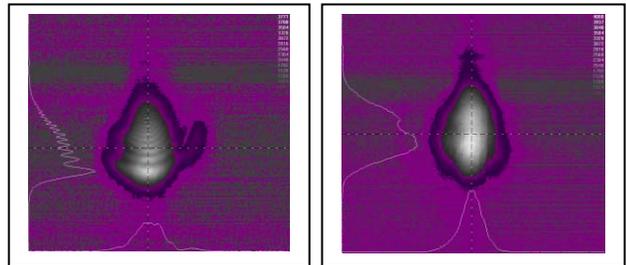


Figure 10: Beam profiles of the SHG beam.

SUMMARY

We presented detailed measurement and characterization for a diode-pumped all solid-state ps laser system that provides high average power and excellent stability at two different repetition rates. Our goal is to solve the issues we have found through characterization and study in order to meet all the specifications required by the high current injector.

ACKNOWLEDGEMENT

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