LASER SYSTEM DESIGN AND OPERATION FOR SNS H^- BEAM LASER STRIPPING*

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Abstract

A high-efficiency laser assisted hydrogen ion (H^-) beam stripping has been recently demonstrated on a 10-μs, 1 GeV H^- beam at the Spallation Neutron Source. Here we report the laser system and its operation for the laser stripping experiment.

INTRODUCTION

The Spallation Neutron Source (SNS) accelerator complex utilizes charge-exchange injection to stack a high-intensity proton beam in the accumulator ring for short-pulse neutron production. A foil-less charge exchange injection method was researched at SNS by using a laser assisted hydrogen ion (H^-) beam stripping scheme [1]. Recently, a high-efficiency laser stripping was carried out on a 10-μs H^- macropulse [2]. The experiment was not only an important step toward foil-less H^- stripping for charge exchange injection, it also served as a first example of using megawatt ultraviolet (UV) laser in an operational high power proton accelerator facility [3].

In this talk, we describe the design, implementation, and commissioning results of the macropulse laser system, laser transport line, and laser operation for the laser stripping experiment. We have delivered UV pulses with the pulse widths varying between 34 to 54 ps and a maximum peak power close to 4 MW. Laser operation including transport line, remote control and monitor of laser parameters will be described.

LASER SETUP AND PERFORMANCE

The SNS laser stripping scheme consists of three steps: First, H^- ions are converted to H^0 by stripping off the first electron in a magnetic field; then H^0 atoms are excited from the ground state ($n = 1$) to an upper level, i.e. $n = 3$, by a laser, and finally the excited states H^{0*} are converted to H^+ by stripping the second electron in a second magnetic field. The laser parameters are determined by laser-hydrogen interaction configuration and the SNS accelerator. Specifically, for 1 GeV H^- beam, the wavelength of the laser light in the H^0 atom rest frame can be lowered to around 355 nm if the laser and H^0 beams interact with each other at 37.5°. Such a wavelength can be readily achieved by tripling the frequency of an Nd:YAG laser which is one the most popular high power pulsed lasers. To minimize average laser power, the laser beam is designed to have an identical temporal structure with the ion beam. The stripping efficiency also depends on the laser beam divergence angle in the interaction plane (assumed in the horizontal plane) and the laser beam size in the perpendicular (vertical) plane. To obtain stripping efficiency of 90% and above, we need to prepare a UV laser beam with a peak power of 1 MW, a (horizontal) divergence angle (RMS) around 0.5 mrad and a (vertical) beam size of 0.2 mm (RMS).

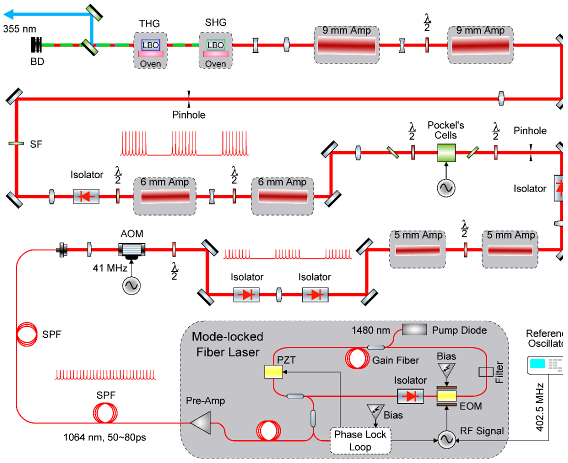

Figure 1: Schematic of macropulse laser system. EOM: electro-optic modulator, AOM: acousto-optic modulator, PZT: piezo-electric transducer, λ/2: half-wave plate, SPF: single-mode polarization-maintaining fiber, SF: spatial filter, SHG: second-harmonic crystal, THG: third-harmonic crystal.

Figure 1 shows a schematic of the stripping laser system. The laser has a master oscillator power amplifier (MOPA) configuration. Primary segments include fiber seed laser, a macro-pulse generator, multiple-stage Nd:YAG amplifiers, and harmonic conversion crystals. The seed laser, i.e., the master oscillator, is an actively mode-locked fiber laser pumped by 1480 nm diode lasers. The gain medium is a Ytterbium-doped fiber which supports generation of laser light at λ=1.064 μm. The output from the mode-locked laser is pre-amplified by a fiber amplifier. The seed laser output power is over 200 mW. An example of the seed laser output waveform is shown in Fig. 2. The pulse width is about 80 ps. The pulse width is adjustable over 50 - 85 ps.

The mode-lock pulses from the seed laser have a very low peak power (~ 1 W) at the wavelength of 1064 nm. To generate MW peak power at 355 nm required by the laser stripping, an amplification factor of ~ 10^7 is needed to directly amplify the seed laser. In this work, we per-

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form such an amplification over a macropulse using solid-state amplifiers. Both the macropulse generation and amplification are conducted in free space. Since the macropulse width is much narrower than the pumping pulse width, pulse shaping of the macropulse is required to achieve a flat macropulse. An acousto-optic modulator (AOM) is employed to generate macropulses with adjustable pulse durations, repetition rates, and arbitrary pulse shapes. The AOM is driven by a voltage controlled RF amplifier at a fixed frequency close to the resonance frequency (41 MHz) of the crystal while the amplitude of the RF signal is controlled by an arbitrary waveform generated on a computer. Fig. 3 shows a typical macropulse waveform of the UV beam with the peak power of ~ 2 MW and the corresponding control voltage waveform on the AOM [4].

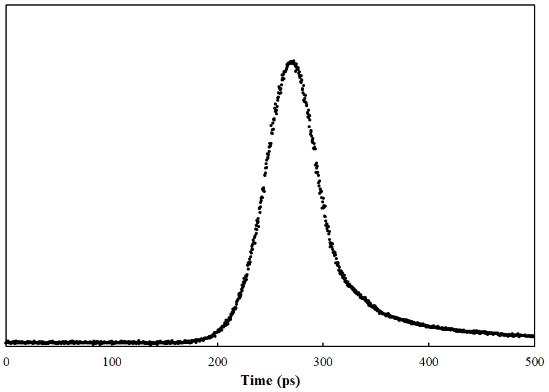

Figure 2: Micro-pulse from seed laser.

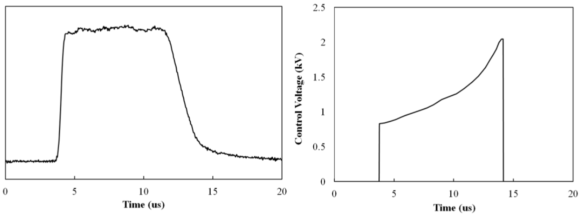

Figure 3: Macropulse (left) and its control waveform (right).

The amplified infrared (IR) macropulses are converted to the UV light using a 25 mm long LBO doubler and a 30 mm long LBO tripler. A multifunctional optical correlator has been developed to investigate the pulse width and peak power of the UV beam as a function of the seed pulse width [5]. As shown in Fig. 4, when the seeder pulse width is narrowed from 85 to 55 ps, the UV pulse width changes from 58 ps to 34 ps and the peak power of the UV light dramatically increases from 1.2 MW to 3.1 MW. A maximum peak power of ~ 4 MW at the UV wavelength was obtained.

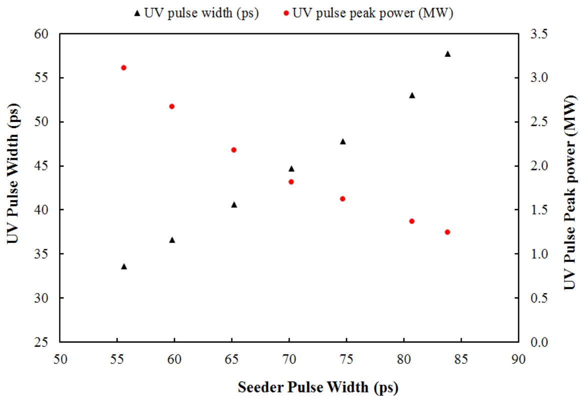

Figure 4: UV pulse width and peak power vs. IR pulse width measured by the multi-functional optical correlator.

LASER OPERATION FOR STRIPPING

The laser stripping experiment is carried out at about 20 meters upstream of the SNS ring injection area. To protect the laser from the radiation-induced damage, we located the macropulse laser system in the Ring Service Building (RSB). A laser transport line (LTL) has been installed to deliver the laser beam to the stripping chamber. The RSB is more than 10 meters above the beam line and shielded from the accelerator tunnel through a 20-meter thick concrete wall. The only available penetrations between the RSB and tunnel are penetration holes which were originally designed as cable chases. A schematic of the LTL is shown in Fig. 5. It consists of three parts: the first part transports the laser beam from the laser table to the entrance of the penetration hole in the RSB, the second part is a 21-m long cable chase, and the last part relays the laser beam from the exit of chase to the stripping chamber location in the Ring/HEBT tunnel areas. The entire LTL is enclosed in aluminum tubes and the entrance/exit of the LTL are sealed with 4” vacuum viewport windows that are AR-coated at 355 nm.

Since most of mirrors are very difficult to access due to radiation/high-voltage concerns, all relay mirror mounts except the first two are equipped with a pair of pico-motor driven actuators for beam steering and a compact analogue camera for monitor of the beam position on the mirror surface. Beam steering in the LTL is implemented using 7 pairs of pico-motor actuators. The Thorlabs open-loop motors have a very high radiation tolerance and all of them are controlled by one computer. Examples of of mirror box implementation are shown in Fig. 5.

Optimal transmission performance is obtained when the laser beam is focused close to the final destination. In this case, the laser beam is collimated to have beam diameters of about 10-12 mm along the LTL. The transmission efficiency was estimated to be around 75% with the major beam loss from mirror reflections and scattering in the air.

Table 1 lists primary laser parameters used in the experiment. Using the accelerator network, one can remotely turn on/off the laser operation, change amplifier settings, switch between different macropulse modes, and monitor status of amplifiers and optical crystals. The laser

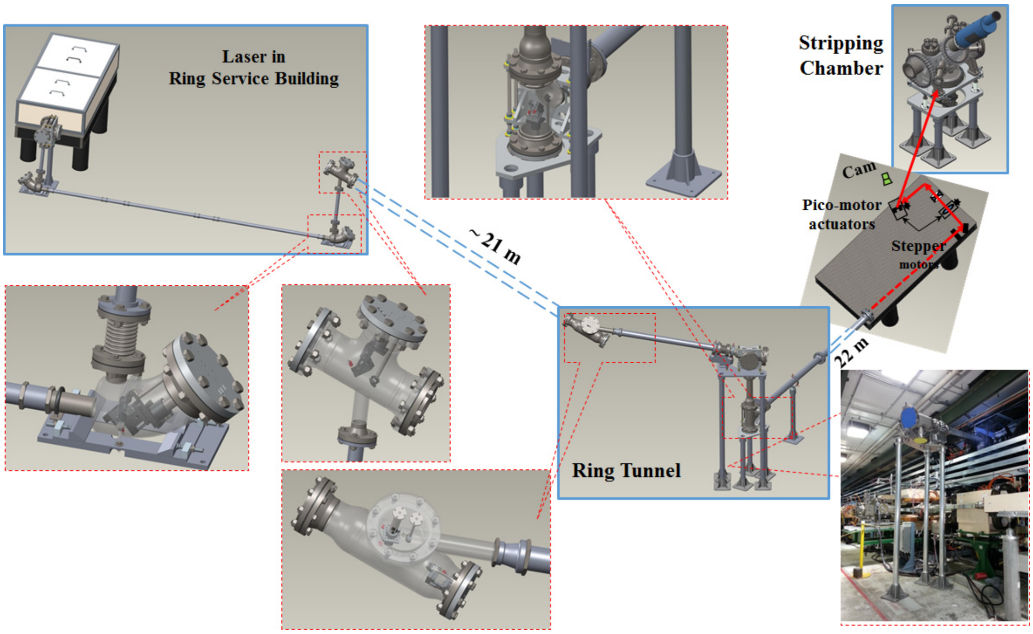

Figure 5: Outline of laser transport line for the laser stripping experiment. Inset drawings show examples of optics boxes.

power, beam size and divergence, laser-ion interaction angle and position are also remotely controlled. There are two levels of temporal synchronization. The micro pulses generated in the seeder are synchronized to the 402.5 MHz RF timing of the SNS accelerator. The phase difference can be remotely tuned using a computer controlled digital phase shifter with a precision of 0.1 degree (corresponding to ~ 0.7 ps). The macropulse is timed to a beam position monitor near the stripping chamber and the phase is also computer controlled in a nanosecond accuracy.

Table 1: Parameters of Stripping Laser

Parameters	Required	Delivered
Macropulse width	10 µs	10 µs
Micro-pulse width	> 30 ps	30 – 50 ps
Peak power	1.5 MW	~ 4 MW
LTL efficiency	> 60%	> 70%
Beam divergence (horizontal)	1.6 - 2.6 mrad	2.3 -3.0 mrad
Beam size (vertical)	1.0 – 1.4 mm	1.1 mm
Pointing stability		±0.1 mm (H) ±0.1 mm (V)
Maximum intensity on vac. windows	< 100 MW/cm^2	80 MW/cm^2

The laser stripping experiment has been successfully conducted using a 10-us laser macropulse. A stripping over 10 mini-pulses of the H^- beam has been observed with the maximum stripping efficiency close to 99%. Details of experimental results are reported in [2].

CONCLUSION

We have described the design and commissioning of a macropulse laser system and its transport line for the laser assisted H^- beam stripping experiment conducted at the proton accelerator of the Spallation Neutron Source. The macropulse laser has a MOPA configuration and consists of a mode-locked picosecond pulsed seed laser and a macropulse Nd:YAG laser amplifier. We have achieved UV pulses with the pulse widths varying between 34 to 54 ps and a maximum peak power close to 4 MW. A laser transport line is installed to deliver the UV beam to the laser stripping chamber. The LTL has a remote control and monitor of laser parameters including phase delay, beam power, beam size, beam divergence, and interactions angle. A transmission efficiency of 70% has been achieved. A successful stripping has been conducted over a 10 µs macropulse.

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