BUILDING A MOPA LASER FOR H- BEAM SHAPING

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Abstract

We present the design and initial amplification stages of a seeded Master Oscillator Power Amplifier (MOPA) laser for H- beam shaping applications. Customizable modulation of the input (seed) laser pulse shape will be shown at the nanosecond level, allowing for high speed 'notching' or 'trimming' of photo-ionized H- bunch shapes after sufficient optical amplification. By matching the laser pulse train shape to the inverse of the desired H- bunch shape, the design of our laser system could be applied to the selective longitudinal neutralization of low energy (1 MeV) H- beams. Theoretically needed pulse energies for high percentage photo-ionizations above 99.9% will be presented and challenges for reaching the required laser pulse energies and repetition rates will be discussed.

INTRODUCTION

RFQ Bunching Output

In simulations of the LAMP RFQ output it has been noted that significant satellite pulses will likely be generated. This concept is qualitatively shown in Figure 1. The satellite bunches will have an approximate 1.5 ns duration and 5 ns spacing. We are mainly concerned with the first three pairs of satellite bunches, and will concentrate on removing only those bunches, without effecting the centeral signal bunch.

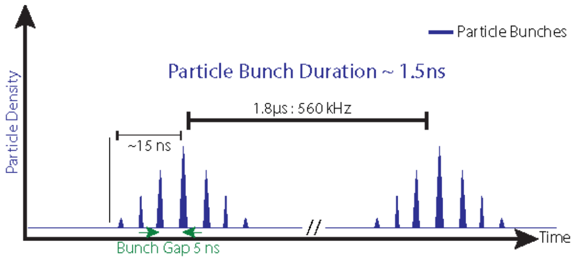

Figure 1: Notional structure of RFQ output illustrating satellite structure formation with ~1.5 ns micro-spacing and 1.8 µs macro-spacing.

Laser / Bunch Overlap

The question we are staring to ask in this work is, is it possible to accurately overlap laser pulses with bunch satellites without affecting the center (signal) bunch. In Figure 2 we are illustrating the concept of overlapping tailored, high power laser pulses to photo-detach the secondary electron in the H- anion. Tailoring the pulse shapes becomes important when estimating the amount of laser energy needed to neutralize the H- density by 99%. Even with only 50 µJ/pulse energy in a continuous pulse train of 2ns bunches at a 600 MHz (1.6 ns spacing) the average output power of such a laser system is 30 kW. A laser power that becomes challenging to manage due thermal and nonlinear losses. As shown below pulse energies much greater than 50 µJ will be needed to efficiently neutralize all satellite bunches with an efficiency > 99%.

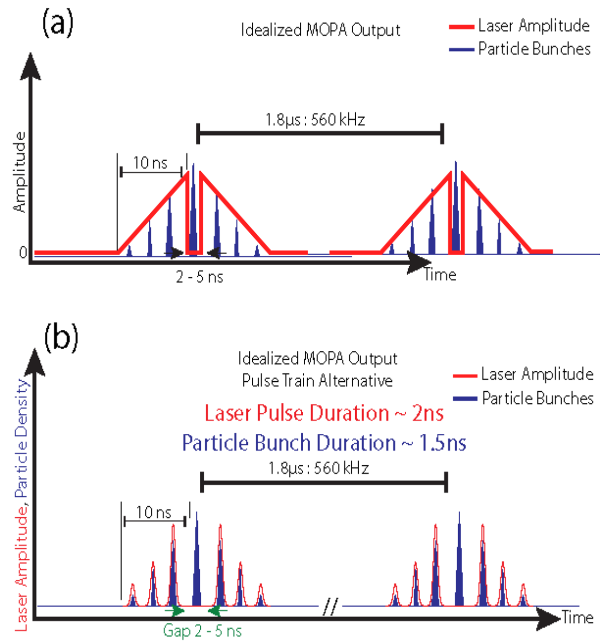

Figure 2: laser pulse overlap concept. (a) Double triangle pulse train with a center gap. (b) Exact pulse to bunch matching.

THEORY OF LASER STRIPPING

Laser-based Neutralization

A strong laser beam intersecting an H- bunch can neutralize a fraction, F_{H^-}, of the hydrogen anions. The neutralization fraction can be calculated using [1]:

$$\frac{\mathbf{dn_{H^0}}}{\mathbf{dt}} = -\boldsymbol{\sigma}_{\mathbf{N}}\ \mathbf{n_{ph}}\ \mathbf{n_{H^0}v}$$

$$F_{H^{-1}} = \frac{N_{H^0}}{N_{H^-}} = 1 - e^{-\frac{4\,\sigma_N\,E_{cm}\,(1-\beta\cos\theta)}{\pi\,d\,\beta\,c\sin\theta}}$$

and the laser bunch intersection geometry shown in Figure 3. Where σ_N is the photo-detachment cross section [2], n_{ph} is the photon flux density, n_{H^0} is the density of generated neutrals, and v is the speed of the particles. F_{H^-} is the fraction of remaining negative hydrogen anions, N_{H^0} is the number of generated neutral hydrogens, N_{H^-} is the number of negative hydrogen anions, and E_{cm} is the center of mass energy of the photons in the particle rest frame.

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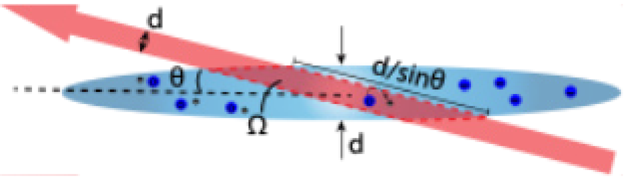

Figure 3: Laser neutralization interaction geometry of a laser with diameter d intersecting an H- bunch of diameter d with a uniform particle density of n_{H^-}, traveling with a relativistic boost, β, at an intersection angle θ forming and intersection volume Ω.

With this model we can calculate the pulse energy density (photon flux) required to neutralize 99% of a $d = 1$ mm particle bunch traveling at 0.1 c, using a 1064 nm laser with a matching diameter, is 8.6 mJ / pulse / bunch.

METHODS

Overview

We have assembled COTS components to begin generating custom pulse trains and pre-amplifying the pulse train up to 10 dBm. Utilizing a high-speed laser diode controller (AeroDiode Shaper) and a large bandwidth photodiode detector (Thorlabs DET01CFC) we have started by characterizing the seed laser pulse output shapes vs input waveforms, quantifing the limits of the laser diode and controller to generate pulses in the 1 – 20 ns pulse width range.

Laser Diode and Controller

A Thorlabs DBR1064PN narrow line-width laser diode, driven by an Aerodiode Shaper controller with a 500ps update rate, is shown in Figure 5. As shown in Figure 5(b) it is necessary to carefully solder the laser diode to the controller board to ensure the fastest possible modulation. The solder joints must be as close to the edge of the board as possible to avoid inductive feedback, and control waveform shape broadening.

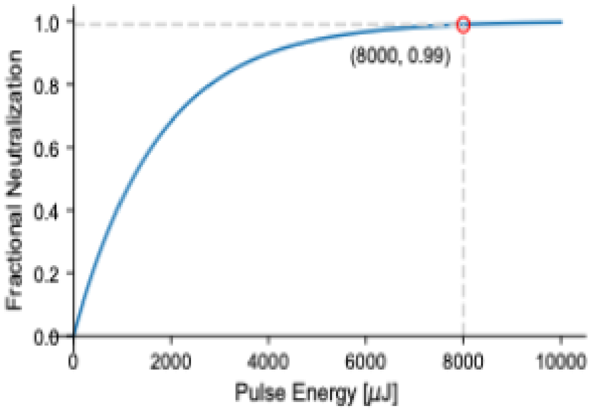

Figure 4: Fractional neutralization percentage vs. input pulse energy for a d=6.5 mm laser beam and particle bunch. 8.0 mJ/pulse required to neutralize ~ 99% of H- anions.

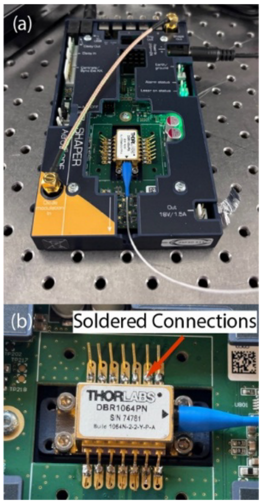

Figure 5: (a) AeroDiode Shaper high-speed diode controller. (b) Thorlabs 1064nm laser diode with pins soldered to controller.

Fiber Laser Amplifier Design

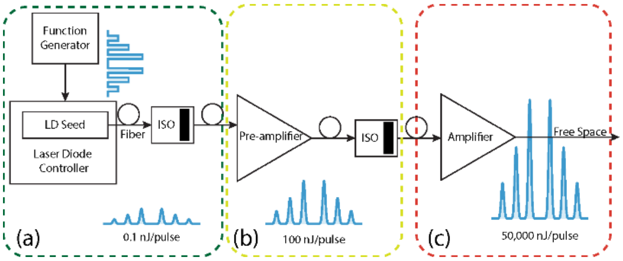

Figure 6: Fiber amplifier design layout. (a) Seed laser pulse results described here. (b) Second stage pre-amplifier parts on hand. (c) Final fiber stage ordered.

A Thorlabs YDFA-PM Yb-doped fiber amplifier has been purchased and will be used to pre-amplify the seed pulse output up to 10 dBm (100mW average power). This pre-amplifier output is required to meet the input requirements of the planned first stage fiber amplification system. The full concept layout of the master oscillator power amplifier (MOPA) fiber system is illustrated in Figure 6. We have highlighted the program progress by indicating in Figure 6 which items in the design are under test, and which parts we are waiting on order. We anticipate a output pulse train of 6, 2 ns pulses with 50 µJ per pulse at 560 kHz would be generated by this amplifier system. This would result in a 20W average power laser, with 25 kW peak power.

RESULTS

In Figure 7 we plot the measured output seed pulse shapes with the programed input pulse overlapped. The Aerodiode update rate is 500 ps. Programing a basic square wave shows input spikes (gain switching) and output tails. Pulses with durations down to 2 ns where generated. Rise times < 1 ns are observed.

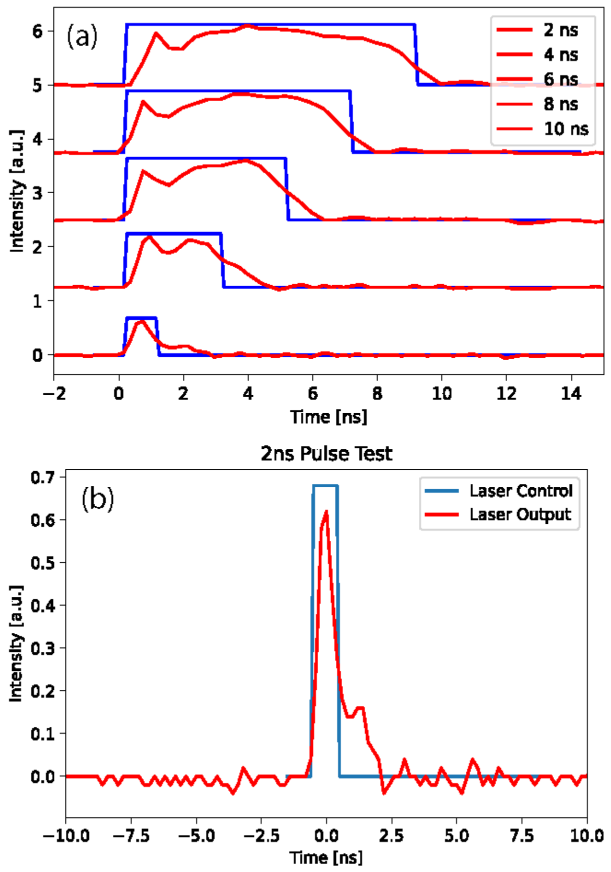

Figure 7: Pulse duration test. Input wave forms (blue) and output seed laser pulses (red).

More complex seed pulse shapes were also generated to demonstrate small gaps with sufficiently fast rise and fall time, as shown in Figure 8. Figure 8(a) demonstrates that rise and fall times less than 1 ns can occur even for larger duration, nominally square wave pulses. Double pulses and ramps Figure 8(b) with gaps were tested showing 5 ns gaps with no laser energy. Gaps down to 3ns were generated (not shown here).

CONCLUSIONS

Initial testing of programed pulse shapes vs. measured seed laser pulse outputs show success in generating pulses with sufficient fast rise/fall times to interact with satellite bunches while avoiding the center bunch. We have demonstrated initial amplification of these laser pulses. There are unwanted artifacts and pulse shape deviations seen in the measured data. These need to be addressed before implementing further amplification as they will be problematic during the future amplification stages.

ACKNOWLEDGMENTS

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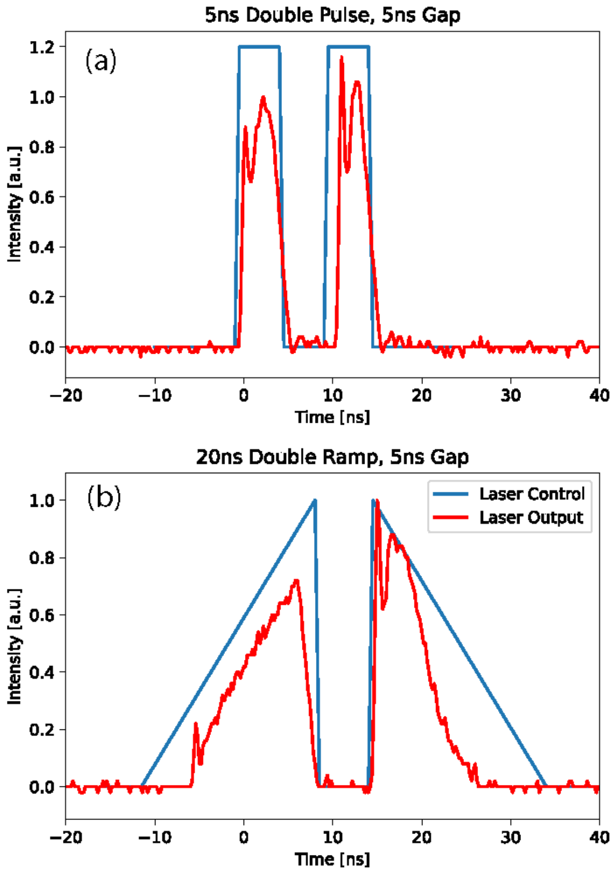

Figure 8: Double pulse with gap waveform comparisons. (a) double input square waves with 10 ns duration and a 5 ns gap. (b) Double ramp waveforms with a 15 ns duration and a 5ns gap.

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