

# Investigation into diode pumped modelocked Nd based laser oscillators for the CLIC photoinjector system.

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*The photo-injector system envisaged for the proposed CLIC linear e<sup>+</sup>-e<sup>-</sup> accelerator at CERN has a demanding set of specifications on output pulse structure, power and timing stability. This paper reports on results obtained with quasi-CW diode pumped laser oscillators with output stabilisation. A 300W 804nm diode array stack is used to side pump Nd:YLF (1047nm) crystals with 200 $\mu$ s pulses at 100Hz repetition rate. Using feedback from the laser output to control an acousto-optic loss modulator in the cavity, start-up spiking and Q-switched behaviour is suppressed. Preliminary results obtained on incorporation of a saturable absorbing mirror for passive modelocking are presented.*

## Introduction

One approach for generating the main e<sup>-</sup> drive beam for the future CLIC linear e<sup>+</sup> e<sup>-</sup> accelerator could be a photoinjector system comprising a quadrupled amplified picosecond laser pumping a photocathode<sup>1</sup>. As with most applications requiring amplified modelocked pulses, the photoinjector does not need a cw source of picosecond pulses: a burst of pulses <100 $\mu$ s long at a burst repetition rate of ~100Hz is desired. The usual approach to tackling such a requirement would be to develop a low-power cw modelocked oscillator to 'seed' the lower repetition rate amplifier stages. Unfortunately this would require an intermediate regenerative amplifier stage in order to obtain a pulse of sufficient power to saturate the gain medium of the final amplifier stage.

A simple solution to this would be to scale up the laser oscillator stage to a high-power system to eliminate the need for a regenerative amplifier. The main obstacle to achieving this is the resulting high heat load on the gain medium causing strong thermal induced aberrations to the laser mode. In the case of the CLIC photoinjector, a Nd:YLF amplifier is used and therefore the seed oscillator must also be based on Nd:YLF to match the wavelength requirement (1047 nm). YLF has a relatively low thermal conductivity, is physically brittle and is therefore likely to break under high heat loading.

A more elegant solution that is enabled by the use of reliable passive modelocking using a Saturable Bragg Reflector (SBR), would be to only pump the laser oscillator for short time intervals that correspond to the requirements of amplified system. In the case of the CLIC system this could be bursts of hundreds of microseconds duration repeated at 100Hz. In this way, the overall average thermal load on the gain medium could be lowered by two to three orders of magnitude while generating modelocked pulse bursts of high effective average power. The main drawback of this is the delay before a quasi-

cw modelocked laser stabilises after the start of the pump pulse; strong spiking occurs at laser turn-on resulting in Q-switched modelocked behaviour.

Recently, Schibli et al.<sup>2</sup> have reported an active feedback loop to control the Q-switching dynamics of SBR modelocked lasers. This involves modulating the laser diode drive current in response to changes in the output power of the laser. Here we report a technique aimed at suppressing the much stronger relaxation oscillation driven spiking which follows laser turn on in quasi-cw laser systems. An intracavity travelling wave acousto-optic Q-switch was used to modulate the laser loss in response to laser spiking. This technique is similar to the prelase spike suppression scheme reported by Bollig et al.<sup>3</sup>, but its application to a modelocked laser is new.

## Experimental details

A schematic of the laser oscillator used to assess the stabilisation scheme with the Saturable Bragg Reflector (SBR) is shown in figure 1. The pump source was a stack of 8 fast-axis collimated 40W diode bars operating at 804nm<sup>4</sup>, giving 300W incident on the Nd:YLF crystal. The pump light was double passed through the crystal to increase total absorbed power to ~80%. The diodes were operated quasi-cw (200µs at 100Hz) at a peak power of 300W.

The intracavity lens for focusing on the SBR was not AR coated for 1047nm hence the parasitic cavity losses were not minimised. An acousto-optic Q-switch (Isle-Optics) comprising a 30mm Brewster cut quartz element permitted rapid modulation of the cavity losses. The cavity beam

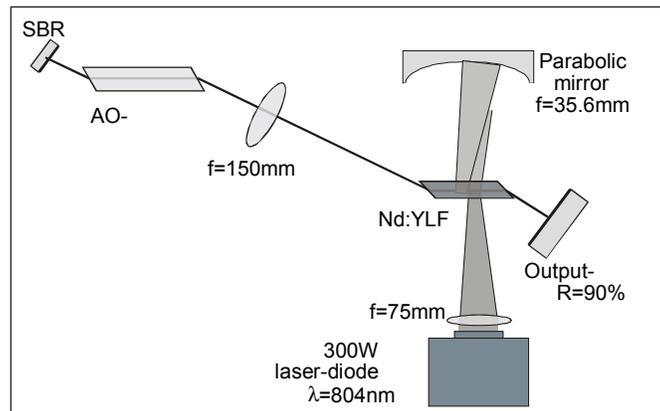


Figure 1: schematic of laser oscillator

was focused through this and positioned as close as possible to the piezo-electric drive element to minimise the response time of the laser to the modulating signal. This is essential if suppression of 'spiking' is to be effective. The total cavity length was 37cm.

For passive modelocking, a high-damage threshold strain compensated InGaAs/GaAsP

double quantum well absorber in the top layer of a 30 layer Al<sub>0.8</sub>Ga<sub>0.2</sub>As/GaAs Bragg-reflector structure was used (SBR)<sup>5</sup>.

The feedback loop comprised a broad-band silicon photodiode with 1ns risetime (Thorlabs DET210) to detect a fraction of the laser output from the output coupler. A simple circuit mixing a combination of differential and proportional signals with variable bandwidth based around an LM7171 op-amp generated the modulating drive voltage for a Gooch and Housego (ODE-080-AI) AOM Q-switch driver. In this scheme, up to 20% cavity loss could be modulated.

## Results and discussion

Initially, this stabilisation scheme was assessed in a laser system without the intracavity focusing lens and SBR<sup>6</sup>. Encouragingly, the incorporation of the modulator and application of the stabilisation signal caused negligible reduction in average output

power (60W peak from a 20% output-coupler (OC) with or without stabilisation for Nd:YLF pumped with 300W peak). Stabilisation to a steady ‘spike-free’ cw-state was achieved within 10 $\mu$ s of the laser first reaching threshold. With the intracavity lens to focus onto an end-mirror SBR, the highest output power in a TEM<sub>00</sub> mode was reduced to ~15W peak from a 10% OC. Further cavity optimisation should significantly increase this value but it served to assess the stabilisation performance.

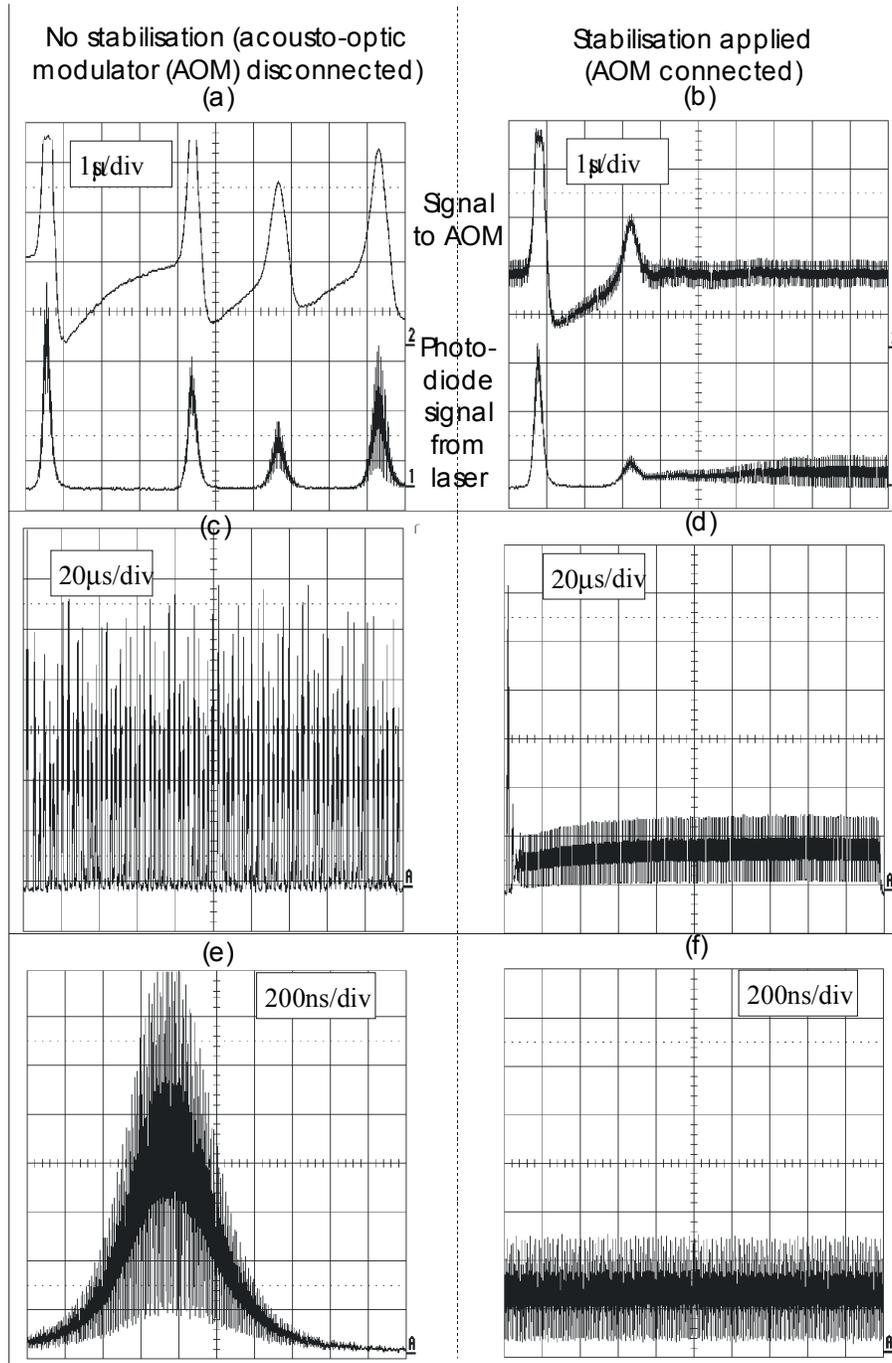


Figure 2: Comparison of modelocked laser performance, without (a,c,e) and with (b,d,f) active suppression of Q-switching at turn-on (see text for explanation).

Optimised performance of the stabilisation is straightforward to accomplish once single transverse mode operation of the laser is ensured. The dramatic effect of applying stabilisation to a quasi-cw modelocked picosecond system is shown in figure 2. In figure 2a, which shows the spiking on the leading edge of the 'macro-pulse' the build up of Q-switched modelocked operation is clearly visible as modulation on the 3<sup>rd</sup> and 4<sup>th</sup> spikes. The stabilisation signal derived from this output is shown above and shows no sensitivity to the modelocked signal on the spikes. On connecting the AOM driver, the laser stabilises to cw modelocking after 2 spikes, NB. the noise on the stabilisation signal present on connecting the AOM driver is the AOM drive signal at 80MHz leaking through to the input line.

In figures 2c and 2d, the entire 200  $\mu$ s macro-pulse is shown. Without stabilisation, no stable cw modelocking is present; this implies the cavity may not fall within the parameter range for stable cw modelocking. This situation changes on applying stabilisation; stable cw modelocking is evident within 20 $\mu$ s of reaching threshold. This is shown in detail in figures 2e and 2f which are both taken 25 $\mu$ s after the start of the pump pulse to the laser diode. Clearly the Q-switched modelocking evident in figure 2e has been completely suppressed by the stabilisation. Note that aliasing by the digital storage scope prevented the recording of the actual pulse train in figure 2f. The pulse period was measured to be 2.57ns corresponding to a pulse repetition rate of 388MHz.

## Conclusions

Preliminary results of active stabilisation of a quasi-cw passively modelocked laser system have been presented suggesting this to be a promising technique for developing high effective average power modelocked lasers with reduced thermal load on the gain medium. Further work will concentrate on optimising the laser for higher power in a TEM<sub>00</sub> mode and minimising the pulse duration within a compact geometry. This technique should also be beneficial to developing higher average power femtosecond seed oscillators for e.g. multipass amplifiers.

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