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# EO solution to overcome the transient regime of a "cavity dumped" UV source, or how to work in chopped mode outside the transient regime?

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**Abstract.** The "cavity dumped" laser architecture is a very efficient solution for having a high-efficiency pulsed laser source with a shorter pulse duration than a classic Q-Switch laser architecture. This solution makes it possible to obtain laser beams of almost constant pulse duration independently of the repetition rate and the pumping rate and to obtain very good conversion efficiency at 2w and 3w. Unfortunately, this architecture suffers from a handicap with a duration of the transient regime that can exceed ten milliseconds. The very long duration of this transient state makes this architecture incompatible with inherently transient applications such as marking or laser micro-machining. We propose here an electro-optical solution to decorrelate the transient state specific to the CD architecture and that of introduced by the application.

## 1 Introduction

Laser marking or micro-machining applications require the availability of compact and efficient laser sources working in nanosecond pulse mode. Usually their architecture is based on an Nd-doped crystalline solid medium pumped by a continuous laser diode, often a fiber laser diode. Pulse operation is generally of the Q-Switch type with modulation of the cavity losses obtained either by an electro-optic modulator (EO Q-Switch) or by an acousto-optic modulator (AOM Q-Switch). The pulse durations obtained are typically of the order of one or a few tens of nanoseconds when the population inversion is significant. Unfortunately, this duration is very dependent on this population inversion and therefore on the pumping and the repetition rate of the laser. There is an alternative, a more complex architecture, which makes it possible to obtain shorter pulses and whose duration depends almost only on the length of the laser cavity: this is the cavity dumped architecture (CD). This operating mode, which is different from the classic Q-switch mode, is based on a laser cavity that is alternately totally open or totally closed. By playing on the duration of the cavity closure (equivalent to a 100% output mirror), we allow the appearance of a giant laser pulse oscillating following one or a few return trips in the cavity. When the energy of the pulse is maximum, the laser cavity is suddenly opened (output mirror equivalent to 0% reflection) and the pulse is extracted. The duration of this pulse is then almost exclusively dependent on the cavity length, when the gain changes (different pumping or repetition rate) only the cavity closing time is adapted. In general, the duration of the pulses is divided by a factor of 3 to 10 compared to the classic Q-Switch operation. The energy per pulse is equivalent but the peak power is greatly increased. Although more complex to implement compared to Q-Switch, this solution also has the advantage of being very efficient to obtain a laser beam at 2w or 3w (for example at 532nm and 355nm with a fundamental emission at 1.06µm)

In many laser applications there is a need to quickly turn the laser source on and off. For example, during laser marking, the laser emission must be interrupted while moving between two characters. This mode of operation leads to working only in the transient mode of the laser, hoping that this mode is short enough not to impact the energy of the laser pulses. In Classic Q-Switch mode this problem is well known and easily managed because the impact is only visible on the first pulse which is often much more important than the following ones, the first pulse much more energetic being issued from a greater population inversion when switching the laser back on only between two successive pulses. This effect, which can produce over-marking, can be easily corrected by introducing additional losses for this first pulse, or even by modulating the pumping temporarily. In CD mode the transient is much longer and can reach about ten milliseconds which corresponds to a few hundred pulses @ 10kHz for example. The visual impact in laser marking is then catastrophic (Fig.1). Correcting this effect is therefore a priority for a CD source to be usable in

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transient applications. We will present the results obtained without and with the correction device (based on EO and dedicated electronics) in the case of a laser source developed at the ICB laboratory based on Nd:YVO4 pumped by fiber laser diode @ 880nm, triggered EO by a RTP cell and doubled and tripled in frequency via two LBO crystals.

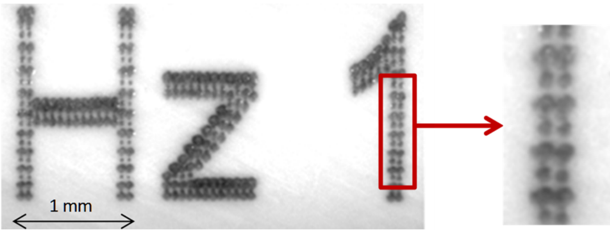


**Fig. 1.** Example of marking obtained, corresponding to the transient state of the laser.

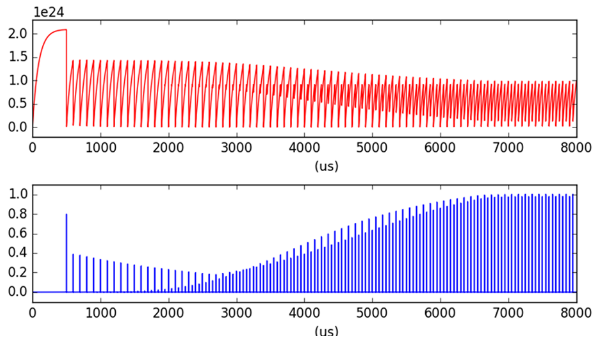


**Fig. 2.** Example of simulation of population inversion (top) and pulse energy (bottom) in function of time after laser ON.

## 2 Laser setup

The diagram of the laser cavity and the associated non-linear stages is given in figure 3a as well as a photo of the complete source. Figure 3b gives an example of a temporal profile of a laser pulse @355nm. The performance of the laser can be summarized as follows: emission $TEM_{00}$, Average Power @ 355nm = 2W max, typical pulse duration at 355nm = 1.7ns, repetition frequency from 10 to 50kHz (limited by the control electronics).

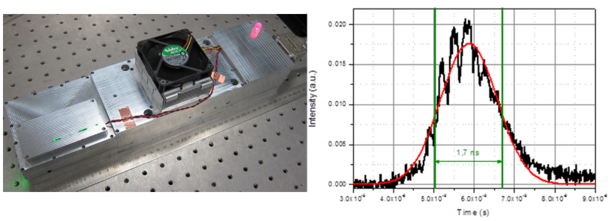


**Fig. 3.** Photo of the laser head (a), typical pulse duration @355nm (1.7ns FWHM @20kHz)

To partly correct the malfunctions observed in transient state, it is possible to adapt the duration of closure of the laser cavity. Unfortunately, this modification depends on the time the laser is OFF / ON (duty cycle), the repetition frequency and the level of pumping. We can thus obtain an almost acceptable operation with good shot-to-shot reproducibility except for the first shot, which is clearly under-energized (Fig. 4) and also with a greatly reduced average power, i.e. less energy per pulse.

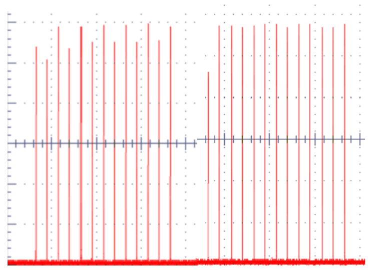

**Fig. 4.** Example of a pulse train with a duty cycle of 50% for the normal (36ns) and optimized (43ns) closing time. The first pulse unfortunately remains under-energized and the energy per pulse is greatly reduced (-30%), (a.u.)

## 3 Transient correction setup

The proposed solution is to dissociate the transient state of the laser from the transient state specific to the application. For this, it is proposed to keep the laser in permanent operation, i.e. outside the transient state, observed only once at start-up. To obtain the series of shots, an RTP Pockels cell and waveplates placed between the infrared output of the laser and the frequency conversion stages are used. By default, the polarization is turned so as not to have effective conversion (99% extinction). During use, a voltage pulse is applied to rotate the polarization to find the best frequency conversion. The transient states of the converter stages being negligible / choppy operation obtained, fault-free operation is indeed obtained, i.e. with peaks of the same energy throughout the marking sequence.

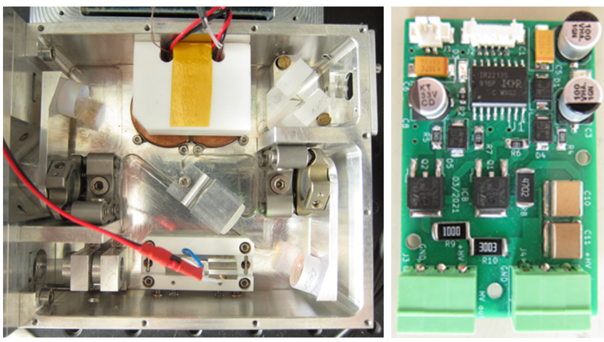

**Fig. 5.** Views of the assembly with the additional EO stage in front of the NL stages, and the electronic control board.

We will present the optical assembly, the specially developed electronics and the performances obtained which will be compared to those observed with the initial operation, i.e. in transient state.