# High conversion efficiency from qcw to Q-switched operation in a side-pumped Nd:YLiF$_4$ laser

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**Abstract:** YLiF$_4$ is widely known as the material of choice, from an application point of view, whenever high beam quality or high pulse power is requested. Side-pumped Nd:YLiF$_4$ laser have achieved record efficiencies, even higher than longitudinally pumped Nd:YLF lasers, thanks to a novel technology developed at our lab. Here we demonstrate a record 66% conversion efficiency from qcw to Q-switched operation whilst maintaining diffraction limited beam quality.
**OCIS codes:** (140.3540) lasers, Q-switch; (140.3530) lasers, neodymium

## 1. Introduction

The host crystal, Nd:YLF, develops a very small thermal lens under intense pumping due to a combination of positive end-face bulging and negative index change of the bulk. As a consequence, beam quality is nearly unaffected even when pump powers are near the fracture limit of the crystal. This host presents an upper state lifetime which is five times longer than other competitive crystals such as GdVO$_4$ and YVO$_4$, resulting in much higher pulse powers under Q-switched operation.

The only reason that oxide hosts have been preferred in q-switched solid-state lasers is the fact that in the past they achieved higher efficiencies even at low to medium repetition rates (> 1 kHz). However, we developed a new side-pumped resonator design that overcomes this deficiency and we have demonstrated more than 50% optical-to-optical efficiency and more than 60% slope efficiency [1-5]. These record efficiencies are even higher than in longitudinally pumped Nd:YLF lasers that traditionally show the highest performance.

Passively Q-switched resonators have the advantage of being extremely robust when compared to the frequent electronic failures experienced by high-voltage Pockels cells. On the other hand, passive q-switching is traditionally associated to jitter in pulse timing and amplitude. Pulse amplitude jitter can be almost completely eliminated to less than 2% (SD) by using only first pulses. In this operation mode, the pump laser is kept on only sufficiently long to produce one single Q-switched pulse per pump pulse. This pulse is knowingly of higher amplitude than the subsequent pulses and has a timing jitter of the order of 100 ns with respect to the start of the pump pulse. The advantage of this operational mode is that the pump pulses have negligible jitter (< 1ps) and therefore the overall jitter is still of the order of 100 ns even after hours of operation. Furthermore, by using pump pulse modulation techniques, the individual pulse jitter can be reduced to below 10 ns.

For a great many applications bursts of high energy, short duration Q-switched pulses at low duty cycle are necessary in order to provoke mainly non-linear effects in the sample whilst keeping thermal damage low.

Although power scaling of the Nd:YLF has proven to be problematic, because of the low thermal fracture limit of the YLF matrix, this problem can be overcome by employing our side pumping geometry that permits to spread the heat over a larger volume which, combined with qcw operation, avoids the risk of thermal fracture. In our previous works, we demonstrated that our laser setup shows power scalability of the TEM$_{00}$ mode, record optical-to-optical efficiency in quasi-continuous operation, high Q-switched pulse energy and kHz-level repetition rates [1-3].

In this communication we report, for the first, record conversion efficiency from the free running operation to the passively Q-switched operation.

## 2. Experimental set-up

The folded cavity design uses a second bounce of the intra-cavity beam at the pump facet inside the active medium to achieve stable fundamental mode operation (Fig. 1). This method, which was dubbed “double-beam mode-controlling” technique (DBMC) causes the intra-cavity beam to efficiently screen the inverted crystal-volume and, if the separation between both beams is correctly adjusted, higher order transversal mode operation is avoided without the necessity for additional losses inside the resonator in the form of hard or soft apertures [2, 3]. The schematic diagram of the laser is seen in Fig. 1.

The crystal was pumped by a 35 W diode bar that was temperature tuned for emission at 792 nm. The diode bar's pump beam with aspect ratio of 10000:1 originated from 19 individual emitters suffered conformation by a horizontal cylindrical lens and a spherical lens to achieve a pump spot size with approximate dimensions of 4 mm width and 0.1 mm height. A half-wave plate was used to match the diodes polarization to the highly absorbing π-orientation (c-axis orientation) of the crystal. For Q-switched operation an anti-reflection coated $Cr^{4+}$:YAG crystal of 10 mm diameter and with an initial transmission of 90% was employed. This passive Q-switch was inserted close to the output coupler because of space limitations in the cavity set-up. The output coupler with 40% transmission was a plane mirror as was the 100% reflective back mirror. The folding mirror had a radius of curvature (ROC) of three meters. Overall resonator length was of the order of 40 cm.

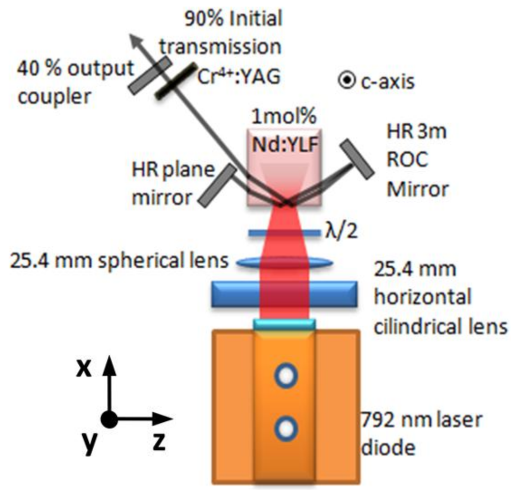


Fig. 1. Resonator layout showing diode bar, pump-beam conformation, the 1 mol% doped Nd:$YLiF_4$ gain-media and the intra-cavity beam confined by the three mirrors.

## 3. Results

With this set-up, a maximum qcw peak output power of 16 W at emission wavelength of 1053 nm was achieved at the mentioned pump power, corresponding to an optical-to-optical efficiency of 45% and a slope efficiency of 62%. Pump pulse duration was set to 1 ms. With the passive Q-switcher inserted in the cavity, the maximum average power achieved was 10.5 W. Beam quality was $TEM_{00}$ as observed with a CCD camera. The pulse repetition rate inside one burst was 26 kHz, as shown in Fig. 2.

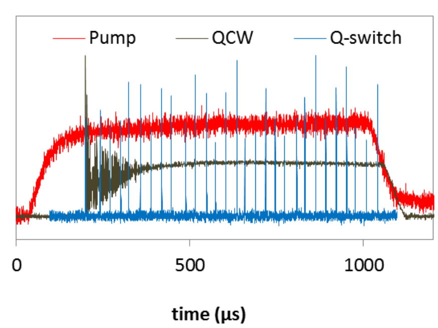


Fig. 2. Red: pump pulse of 1 ms duration; black: qcw pulse; blue: burst of Q-switched pulses.

Each burst of Q-switched pulses included approximately 25-30 individual pulses as requested by most practical applications. The burst repetition rate could be changed from 1 Hz to 100 Hz without noticeable thermal influence in pulse duration, peak power or beam quality. An average single Q-switched pulse energy of about 0.39 mJ was obtained, with pulse durations of about 41 ns FWHM (Fig. 3), corresponding to a peak power of 9 kW.

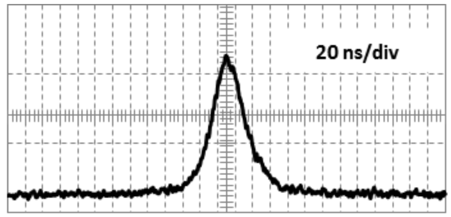


Fig. 3. Temporal pulse profile

The conversion efficiency from free running operation to Q-switched operation was 66 % corresponding to an optical-to-optical efficiency of 31%, which is higher than the conversion efficiency obtained in the D-rod resonator [6].

### 3. Conclusions:

In conclusion, we demonstrated an efficient side-pumped Nd:YLF laser, both under qcw and under Q-switched operation with diffraction limited beam quality. The conversion efficiency from qcw operation to Q-switched operation is, to our knowledge, the highest reported so far.

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