# $\chi^{(2)}$-Lens Mode-Locking of a Yb:YAG Laser Using Intracavity SHG in a LBO crystal

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**Abstract:** We demonstrate a diode-pumped Yb:YAG laser mode-locked by intra-cavity $\chi^{(2)}$-lens formation in a LBO crystal. Stable operation is achieved with output power of 260 mW, pulse duration of 1.4 ps at 105 MHz repetition rate.
**OCIS codes:** (140.3615) Lasers, ytterbium; (140.4050) Mode-locked lasers

## 1. Introduction

Ultrashort (picosecond or femtosecond) laser pulses with high average power (>1 W) have attracted significant attention because of their applications in precise micromachining, time-resolved spectroscopy, nonlinear frequency conversion and infrared SPOPOs pumping. Typically, multi-Watt operation of picosecond and femtosecond lasers has been demonstrated mainly using semiconductor saturable absorber mirrors (SESAMs) and Kerr lens mode-locking (KLM) techniques. SESAMs are well established devices for lasers emitting around 1 μm, however their residual absorption is an intrinsic drawback that limits the mode-locking reliability and power scaling. Although the Kerr nonlinearity can be used for mode-locking of lasers with broad amplification bandwidth, the flexibility of the cavity design is limited, because the value and the sign of such nonlinearity are fixed.

An alternative mode-locking technique is based on $\chi^{(2)}$-lens formation in a crystal for second harmonic generation (SHG). This technique is similar to KLM, but it utilizes second order nonlinearity, whose sign and magnitude are easily controlled by phase mismatched conditions of a SHG crystal [1]. The higher damage threshold of SHG crystals and their lower residual absorption in comparison with SESAMs enable operation at high average power, which is limited by the maximum one achievable in continuous-wave (CW) $TEM_{00}$ output [2,3]. However, it was demonstrated manly for Nd-doped crystalline lasers. Besides, $\chi^{(2)}$-lens mode-locking allows generation of transform-limitted pulses [4]. It can benefit from soliton-like pulse shaping without any dispersion compensating elements due to the intra-cavity self-phase modulation, introduced by phase mismatched SHG. This effect has been recently exploited in a SESAM mode-locked laser [5].

In this work we report $\chi^{(2)}$-lens mode-locking of a Yb:YAG laser using a LBO SHG crystal. The laser generates 1.4 ps pulses with output power of 260 mW at repetition rate of 105 MHz. To our knowledge, this is the first demonstration of a Yb-based laser, mode-locked by $\chi^{(2)}$-lens formation.

## 2. Experimental set-up

The design of the mode-locked laser is based on a 1.4 m long linear cavity (fig. 1). The active element is a 6 mm long 5 at. % doped Yb:YAG crystal with an aperture of 3 × 3 $mm^2$. Both sides of the crystal are antireflection coated for the laser and pump wavelengths. It is mounted in a copper holder maintained at temperature of 15°C by circulating water. The active element is end pumped by a 976 nm laser diode (LD), coupled in an optical fiber (OF) with core diameter of 200 μm. Two aspherical lenses (L1 and L2) ensure pump waist diameter of 240 μm in the active element.

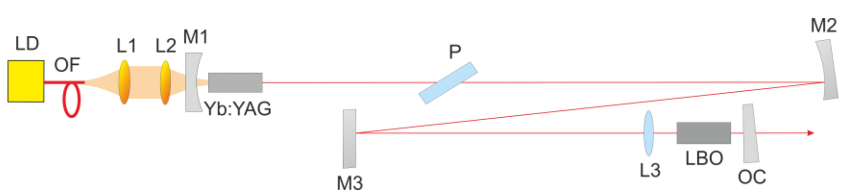


Fig. 1. Laser cavity layout. M1, M2, M3: highly reflective at 1064 nm; M1: highly transmitting at 980 nm, RC=150 mm (radius of curvature); M2: RC=600 mm; M3: flat mirror; L3: focusing lens (f3=50 mm).

The optical cavity ensures single transverse mode operation by overlapping the cavity mode size with the pump waist in the active element. A 3-mm thick glass plate (P) is inserted at Brewster angle ensuring linear beam polarization. The SHG crystal is a 20-mm long lithium triborate $LiB_3O_5$ (LBO) with an aperture of 3×3 $mm^2$ cut at

$\theta$=90° and $\varphi$=0° in the *x*-y plane for type-I oo-e noncritical phase-matching. Its both faces are AR-coated for the fundamental and the second harmonic wavelengths. The LBO crystal is mounted in an oven, whose temperature controls the phase matching conditions. The output coupler (OC) is a flat mirror with transmission of 5% at 1030 nm, optimized for maximum output power.

## 3. Experimental results

In order to obtain mode-locking (ML) operation, the LBO crystal is detuned from perfect phase-matching condition and the position of the output coupler is optimized. The output power in self-starting mode-locking operation is 260 mW at absorbed pump power of 23 W (fig. 2 (a)). The mode-locking operation is observed at the region of input–output characteristics close to the maximum achievable output power in CW operation, when the slope efficiency becomes negative. In this region increasing of the thermal lens power deteriorates the spatial overlap between the pump waist and cavity waist in the active element (fig. 2 (a) blue line). Therefore the efficiency drops due to non-optimum overlap with the pump waist. This non-optimum overlap however is compensated in mode-locking operation by the $\chi^{(2)}$-lens formation in the LBO crystal.

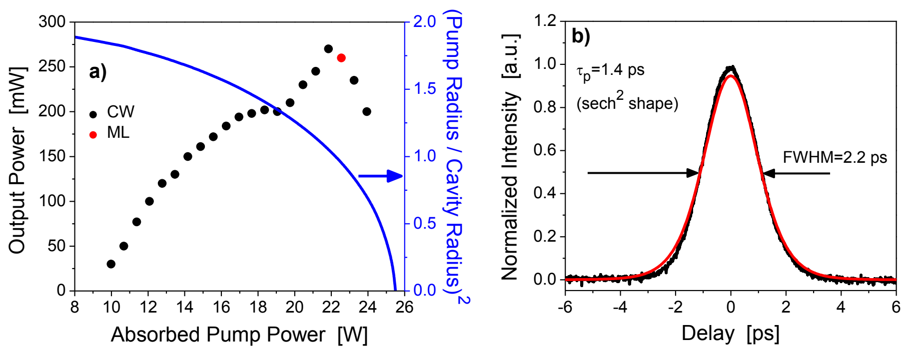


Fig. 2. (a) Input–output characteristics of the Yb:YAG laser (dots) and spatial overlap between pump waist and cavity waist in the position of the active medium (blue line); (b) autocorrelation curve (black), fit assuming sech$^2$ pulse shape (red) and optical spectrum (inset).

The pulse duration is 1.4 ps assuming sech$^2$ pulse shape calculated from the measured autocorrelation curve (fig. 2 (b)). The pulse repetition rate is 105 MHz, corresponding to a single pulse in the cavity.

## 4. Conclusion

We demonstrate $\chi^{(2)}$-lens mode-locking of a Yb:YAG laser using a LBO SHG crystal. We achieve self-starting operation with output power of 260 mW, pulse duration of 1.4 ps at repetition rate of 105 MHz. This is the first demonstration of a $\chi^{(2)}$-lens mode-locked Yb-based laser to the best of our knowledge.

## 5. References

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