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Singly Resonant Optical Parametric Oscillator Pumped By a Nanosecond-to-Microsecond Pulsewidth-Tunable Source

G. Aoust,[1] C. Couvin,[1,2] X. Délen,[2] M. Raybaut,[1] J.-B. Dherbecourt,[1] J.-M. Melkonian,[1] G. Gorju,[1]
F. Balembois,[2] P. Georges,[2] A. Godard[1,*]
[1] *ONERA–The French Aerospace Lab, F-91123 Palaiseau cedex, France*
[2] *Laboratoire Charles Fabry, Institut d'Optique Graduate School, CNRS, Université Paris-Saclay, 91127 Palaiseau cedex, France*
[*] *Corresponding author: antoine.godard@onera.fr*

Abstract: Optimal pumping parameters for a singly resonant optical parametric oscillator are experimentally investigated using a hybrid master oscillator-power amplifier pump laser whose pulsewidth is varied from 4 ns to 4 µs and analyzed with modeling.

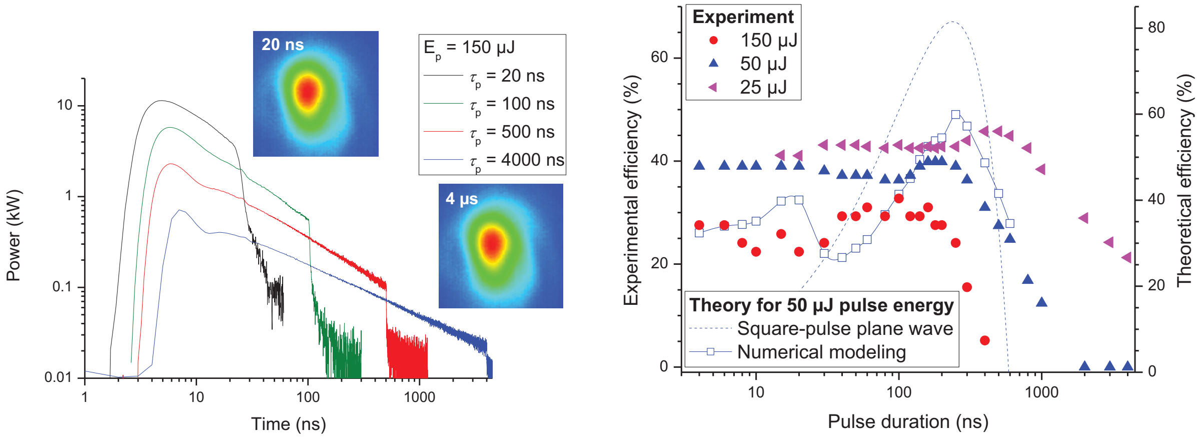
1. Introduction

The way the pump energy is distributed in time is a key feature to achieve a high conversion efficiency with a pulsed optical parametric oscillator (OPO). If the pump pulse is too long, the small resulting peak power induces a long buildup time during which the pump energy is lost. Conversely, if the pulse duration is too short, strong saturation of the parametric gain is expected. The capabilities of tailoring pulse shape and duration offered by master oscillator power amplifier (MOPA) laser sources are thus very attractive to optimize the pumping parameters of OPOs [1–3]. In [3], using a commercial fiber-based MOPA, such investigations were carried out in the case of a doubly-resonant OPO with a pulse duration ranging from 40 ns to 10 µs. In particular, it was shown that microsecond pulses allow more efficient pumping than nanosecond pulses. However, the 50-W peak power limitation of the MOPA system used in this previous work was too low to carry out a similar study in the case of the singly-resonant OPO.

Here, owing to a specifically designed pulsewidth-tunable hybrid MOPA system, we investigate the optimal pulse duration (from 4 ns to 4 µs) to pump a singly-resonant OPO. In addition, numerical modeling enables us to confirm the critical influence of temporal, spectral and spatial adaptation effects on the device performance at high peak powers.

2. Experiment

The MOPA system is based on a gain-switched pulsed laser diode emitting at 1064 nm followed by a two-stage ytterbium-doped fiber amplifier and a Nd:YVO$_4$ booster for the generation of high-peak-power pulses. This architecture is close to the one reported in [4] with the Nd:YVO$_4$ amplifier used in single pass and an additional fiber amplifier to improve the pulsewidth tunability. Fig. 1(a) illustrates such a tunability for a pulse energy of 150 µJ (available peak power is as high as 12 kW) at the OPO input (after isolation and beam transport optics).



(a) (b)

Fig. 1. (a) Various temporal pulse shapes emitted by the hybrid MOPA system for a pulse energy of 150 µJ (inset: beam profiles for pulse durations of 20 ns and 4 µs). (b) Idler photon conversion efficiency of the OPO as a function of the pump pulse duration for constant pump pulse energies: experimental data for pump energies of 25, 50 and 150 µJ; theoretical calculations for a pump energy of 50 µJ (dashed lines: plane wave theory with a square pulse shape; open squares: FDTD numerical calculation with a transverse mode expansion to treat spatial effects).

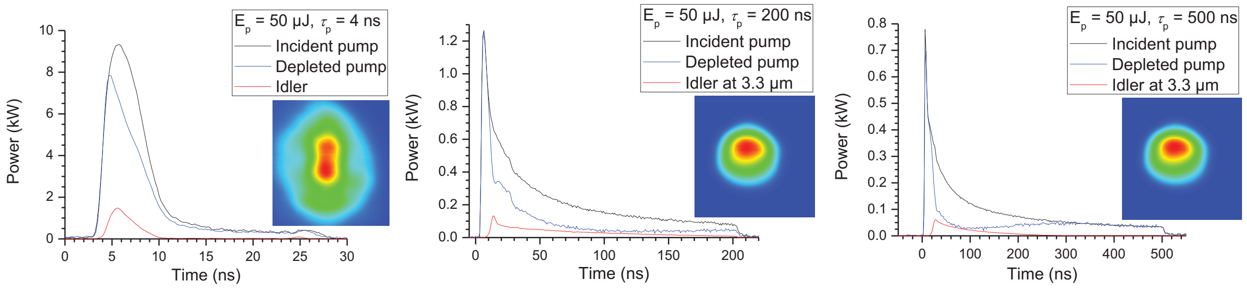


Fig. 2. Experimental OPO temporal profiles and idler beam profile (inset) at 3.3 µm with different pump durations, for a pump energy of 50 µJ.

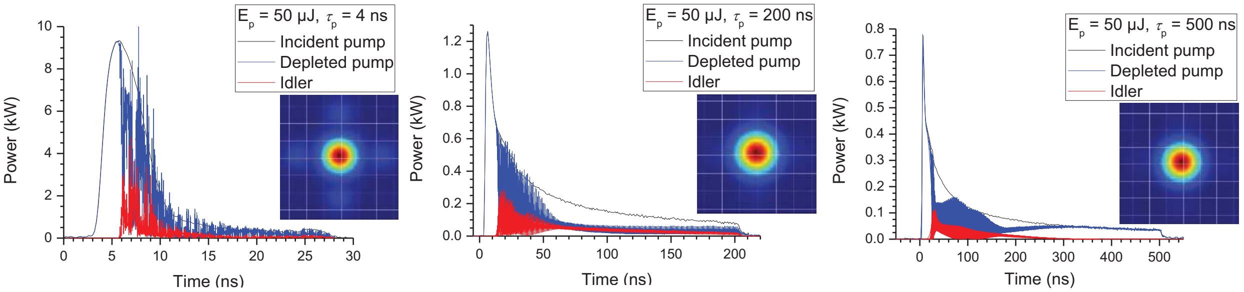


Fig. 3. Calculated OPO temporal profiles and idler beam profile (inset) at 3.3 µm with different pump durations, for a pump energy of 50 µJ.

The OPO is based on an antireflection-coated 60-mm long MgO-doped PPLN crystal with a quasi-phase matching period of 30.54 µm. The OPO is singly resonant at the signal wave (~ 1.57 µm) with a resonator based on two spherical mirrors (300-mm radius of curvature). The pump beam is focused in the middle of the nonlinear crystal with a radius at $1/e^2$ of ~180 µm.

Owing to the pulsewidth tunability of the MOPA, we can investigate the influence of the pulse duration on the OPO efficiency for constant incident pump energies. As shown in Fig. 1(b), the optimal duration increases with the pulse energy. However, in disagreement with monochromatic plane-wave theory, the experimental efficiency does not decrease significantly for short pulses. As shown in Fig. 2, this behavior is connected with the alteration of the idler beam profile emitted by the OPO at 3.3 µm for short pulse durations. We also observe a significant broadening of the OPO spectrum for short pulses (not shown here). Our study nonetheless shows that, for each pump energy, there is an optimum pulse duration to maximize the conversion efficiency and avoid beam profile degradation. In addition, for a given average power, it is preferable to deliver long-duration high-energy pulses at a lower repetition rate than short-duration low-energy pulses at a higher repetition rate.

3. Modeling

To analyze the result and explain the efficiency plateau for short pulses, we also carry out numerical modeling with a home-made simulation code based on finite difference method in time domain to solve the coupled nonlinear equations and where spatial effects are treated with a transverse mode expansion approach. As shown in Figs 1 and 3, spatial, temporal, and spectral effects have to be taken into account to properly explain the experimental results. Please note that the fast modulations seen in calculated temporal profiles are too fast to be experimentally measurable due to the finite detection response time of 2 ns (see Fig. 2). These predicted modulations, due to group velocity effects, are consistent with well-established previous modeling of nanosecond OPOs [5].

More experimental and numerical details (temporal, spatial and spectral properties) will be given. We will also discuss how to further optimize the pulse shape and duration to make the most of the available pump pulse energy.

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