Efficient widely-tunable operation of an all-solid-state synchronously pumped optical parametric oscillator

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Abstract

A continuous train of ~1ps pulses tunable over the range 0.72 - 1.91μm with up to 89mW average power has been obtained from a singly-resonant LBO OPO driven by a laser-diode-pumped Nd:YLF laser.

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The synchronously pumped optical parametric oscillator (OPO) is potentially the ideal source for the many applications requiring widely tunable ultrashort pulses. For high stability, cw pumped operation is required, with only one of the two generated waves being resonated in a singly resonant oscillator (SRO) (1-6). For a practical, efficient, reliable and compact device, an all-solid-state pump source is favourable (7). Lithium triborate (LBO) has the attractive property of temperature-tuned exact noncritical phase matching over much of its transparency range. Robertson *et al.* recently achieved the impressive tuning range of 0.65-2.7μm from an LBO OPO, but little other information for the SRO was reported (8). We recently reported the efficient, widely tunable operation of a similar device, including temporal and spectral data for the singly resonant OPO (9). However, in that work we only coupled out the nonresonated wave as an output. Here, we report the operation of a singly-resonant synchronously-pumped LBO OPO accessing both of the generated waves as outputs. We also report the use of a Brewster angled crystal, thus avoiding the well known problems associated with antireflection coatings on LBO, and allowing essentially constant output across a broad tuning range.

The laser pump source was a frequency-doubled self-starting additive-pulse-mode-locked Nd:YLF laser pumped by a laser diode. This laser produced an average power of up to 360mW in pulses of 2ps duration at 523nm wavelength. The OPO cavity was a standing wave configuration as shown in figure 1. Three of the OPO mirrors were high reflectors (R > 99.9%). The fourth mirror was a planar 3% transmission output coupler. Two mirror sets were available, covering the wavelength ranges 800-1000nm and 700-850nm. Both these sets were highly transmitting (T > 96%) at the pump wavelength of 523nm. The first LBO crystal was 3x3mm^2 aperture by 12mm long. The crystal was cut for temperature-tuned type I noncritical phase matching propagating along the crystallographic x axis ($\theta=90°$, $\phi=0°$). The crystal was antireflection (AR) coated on both the entrance and exit faces at 1047nm and 523nm. The reflectivity at 1047nm was 0.4% per surface, and 3.1% per surface at 523nm. The LBO crystal was mounted in an oven which could vary the crystal temperature between ambient and ~200°C with a stability of ±0.1°C.

At a resonated wavelength of 970nm, the reflection loss of the LBO crystal was 0.5% per surface, giving a round trip loss of 5.0% for the resonated wave. The threshold pump power at 523nm for this resonated wavelength was 90mW incident on the pump focusing lens. The slope efficiency for the resonated wave was 36%. This resulted in an average output power of 43mW at 970nm through the output coupler at 250mW pump power. In addition, 33mW of the nonresonated wave at 1140nm was coupled out through the rear curved mirror. Autocorrelation measurements of the output pulse train fitted accurately to a sech^2 pulse shape. At a wavelength of 970nm, the resonated wave pulse duration was 1.2ps, with a time-bandwidth product of 0.9, indicating excess bandwidth.

The OPO was tuned by varying the temperature of the crystal oven. The OPO mirrors only allowed the shorter wavelength wave to be resonated thus ensuring singly resonant operation over the tuning range. Under this singly resonant operation, the OPO spectrum at each wavelength showed a single peak, and was of a smooth profile over the tuning range. In addition, the singly resonant operation resulted in excellent amplitude stability in the OPO output. Using only the long wavelength mirror set, the tuning range for the AR coated LBO OPO was 810-1480nm. The OPO output dropped on tuning away from degeneracy, primarily due to the antireflection coatings on the LBO crystal becoming ineffective at the resonated wavelength *e.g.* at 810nm, the round trip reflection loss from the LBO crystal had increased to 9.4%.

Since the efficiency and tuning range of the OPO was limited by the AR coatings on the LBO crystal, we replaced the AR coated crystal with a Brewster angled crystal, for which the reflection loss for the resonated wave would be considerably reduced across the entire tuning range. The 13mm long Brewster angled crystal used was of rather poor quality, with a total single pass loss of 0.8% and requiring careful transverse positioning to locate a beam path giving acceptable performance. The reflection loss from each Brewster surface contributed only 0.1% loss. Using two different mirror sets, the threshold pump power was measured at three different resonated wavelengths (960nm, 870nm, 855nm) to be 170mW average power. The slope efficiency for the resonated wave was 40%, giving rise to an average output power of up to 89mW at 850nm for a pump power of 340mW. Using the two mirror sets, the resonated wave could be tuned over the range 978-816nm and 853-721nm, with the nonresonated wave tuning over the range 1126-1460nm and 1355-1911nm. The resonated wave output through the output coupler was >50mW over the range 978-744nm as shown in figure 2, with the nonresonated wave output through the rear curved mirror being >30mW over the range 1164-1813nm. Autocorrelation measurements of the output pulse train again fitted accurately to a $sech^2$ pulse shape. At a wavelength of 787nm, the resonated wave pulse duration was 1.5ps, again with a time-bandwidth product of 0.9.

In conclusion, we have demonstrated efficient, widely tunable operation of a synchronously pumped OPO in LBO with an all-solid-state laser pump source. In particular, the Brewster angled LBO OPO has shown very efficient operation across a large portion of its potential tuning range, in spite of the poor quality of the crystal used in these experiments. We are at present looking into methods of controlling the excess bandwidth of the OPO so as to achieve transform limited pulses. Possible avenues of investigation are the use of shorter pump pulses, or longer LBO crystals, either of which would lead to a valuable reduction in the threshold average pump power. Thus, with a few modifications to the OPO, this device should become a practicable and reliable source of subpicosecond pulses across the entire tuning range of 0.65-2.7μm.

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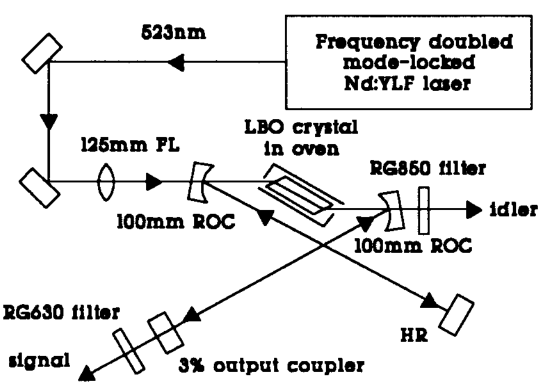

Figure 1. Schematic diagram of the Brewster angled LBO OPO

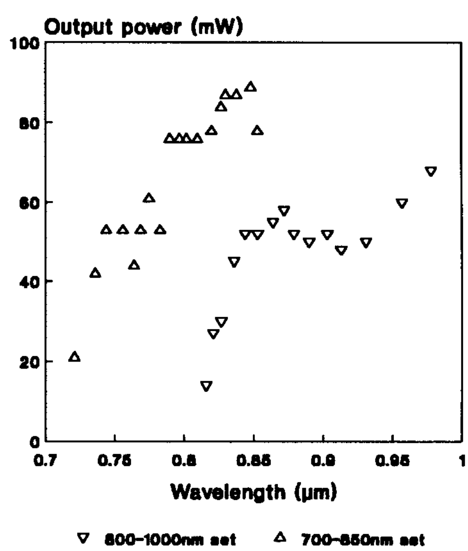

Figure 2. Variation of the resonated wave output power across the tuning range.