A self-doubling optical parametric oscillator based on aperiodically-poled lithium niobate

Tolga Kartaloğlu, Z. Gürkan Figen and Orhan Aytür
Department of Electrical and Electronics Engineering, Bilkent University
TR-06533 Bilkent, Ankara, Turkey
Telephone: +90 (312) 266 4307 Fax: +90 (312) 266 4192 e-mail:aytur@ee.bilkent.edu.tr

Simultaneous phase matching of multiple nonlinear interactions that can be achieved in bulk and periodically poled materials is limited in extent [1,2]. Although quasi-periodic structures relax this limit [3-5], a general solution that allows the simultaneous phase matching of arbitrary interactions depends on the use of aperiodic grating structures [6].

In this experiment, we construct a self-doubling optical parametric oscillator (SDOPO). It is based on a $LiNbO_3$ crystal that has a one-dimensional aperiodic grating structure. This grating structure is designed to quasi-phase-match both optical parametric oscillation (OPO) and second harmonic generation (SHG) processes simultaneously for a propagation direction along the x-axis of the crystal. When a beam at a wavelength of 790 nm pumps the SDOPO, a signal beam at a wavelength of 1140 nm and an idler beam at a wavelength of 2573 nm are generated along with the SHG of the signal beam at a wavelength of 570 nm. Waves corresponding to both interactions are polarized parallel to the c-axis of the crystal in order to utilize the highest nonlinear coefficient, d_{33}.

The $LiNbO_3$ crystal is 20 mm-long and 18 mm of this length contains the grating structure. The design of the grating structure is based on a construction of a function by summing up two cosine functions with arbitrary phase and amplitude. The period of each cosine corresponds to the period of a grating structure that can quasi-phase-match only a single interaction. This constructed function is aperiodic when the ratio of the periods of the cosines is an irrational number. By adjusting the ratio of the amplitudes of the two cosine functions, it is possible to adjust the ratio of the magnitudes the Fourier transform peaks corresponding to the two interactions. We select this ratio based on the ratio of the coupling coefficients of the two interactions, $\beta = \kappa_b/\kappa_a$ defined in Ref. [7]. Although the polarization geometries considered in the plane-wave theory of the SDOPO were described for birefringent phase matching, the coupled-mode equations governing the interactions in this experiment also belong to class-A [7].

Our experimental setup shown in Figure 1 is based on a singly resonant ring cavity formed by four mirrors that are highly reflecting at the signal wavelength. Mirrors M1 and M2 are 100-mm radius-of-curvature concave, and M3 and M4 are flat. The aperiodically poled $LiNbO_3$ crystal (APLN) is positioned at the intracavity focus between M1 and M2 and has antireflection coatings for the pump, signal and second-harmonic wavelengths on both surfaces. A mode-locked Ti:Sapphire laser with 180 fs-long pulses at a repetition rate of 76 MHz provides the pump beam at 790 nm.

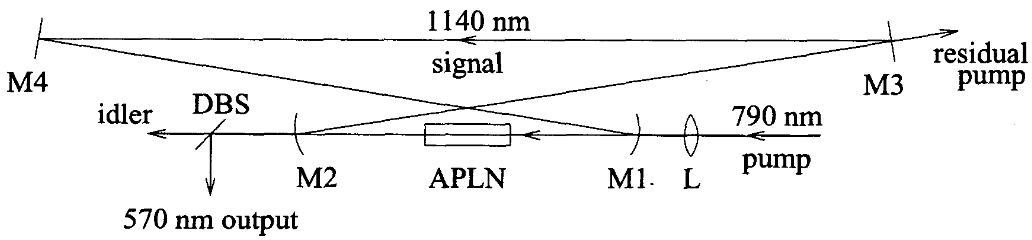

Figure 1: Self-doubling OPO setup

The pump beam is focused with a lens (L) of focal length 50 mm and enters the cavity through M1. We achieve the synchronization of signal pulses inside the cavity with pump pulses by moving M3 with a piezo-electrically controlled mount. The mirror M2 has also coatings for transmission of the second-harmonic beam and reflection of the pump beam. The residual pump beam is separated from the second-harmonic beam as it passes through M2. The residual pump beam exits the cavity through M3. A dichroic beam splitter (DBS) separates the second-harmonic beam from the idler beam.

The wavelengths of the pump, signal and second harmonic beams are verified to be same with the ones chosen for the design. Figure 2 shows the conversion efficiency as a function of the input power for $\beta = 0.65$. The threshold of the OPO is 18 mW which is independent of the SHG. Our device produces 27 mW of maximum output power for the second-harmonic beam when the pump power is 250 mW. At this point, the corresponding power conversion efficiency is 10.8%, but the maximum conversion efficiency, 14.1%, is achieved at 110 mW of pump power. This type of behavior is as expected from the plane-wave theory of the class-A SDOPO [7]. Although we use 180 fs-long pump pulses, the second-harmonic beam has a pulse-width of 2.4 ps. We believe this broadening is mainly due to the group velocity mismatch between the signal and second-harmonic pulses and the fact that signal pulses generate second-harmonic pulses over the whole length of the grating.

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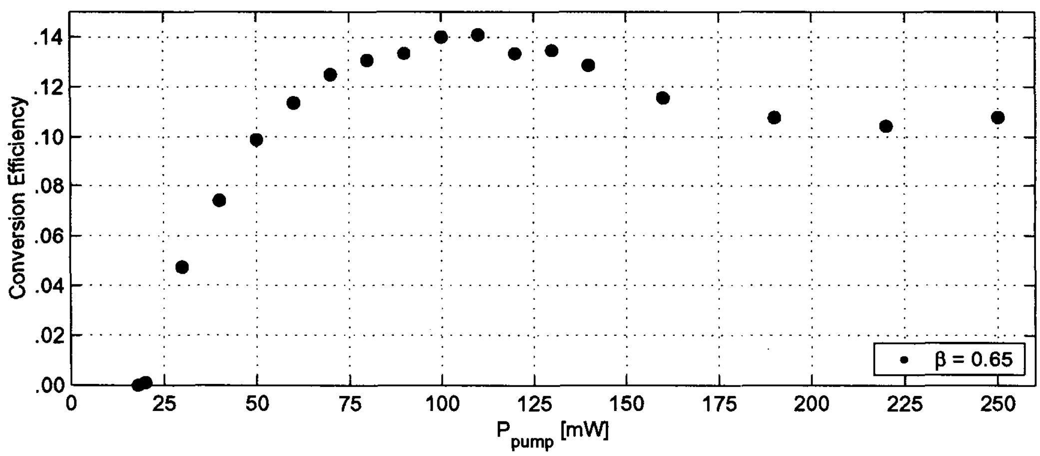

Figure 2: Conversion efficiency as a function of the input power

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