Optical Society of Korea Summer Meeting (8.16~17, 2001)

준위상맞춤을 이용한 다이오드 펌프 연속 광매개진동자

Diode-pumped CW optical parametric oscillator based on quasi-phase-matching

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Optical parametric oscillators (OPOs) are important wavelength-tunable sources of coherent radiation in the near and mid-infrared range. Especially in the continuous-wave (CW) regime, the recent development of quasi-phase-matching (QPM) technique and of solid-state pump lasers, e.g. high-power diode lasers, has established new advances and applications for CW-OPOs. In this talk, we present two state-of-the-art CW-OPOs which clearly demonstrate this feature: a widely frequency-tunable singly-resonant OPO(1) as a high-power, high-resolution source for infrared spectroscopy, and a self-phase-locked OPO(2) for high-precision optical metrology. Both OPOs use a diode laser as the pump source, and are based on QPM using a periodically poled $LiNbO_3$ (PPLN) crystal.

An OPO converts a monochromatic wave, called pump wave, into two monochromatic waves with lower frequencies, called signal and idler wave, via the second-order nonlinear dielectric susceptibility of a medium. For an efficient conversion, however, a constructive interference of the generated waves with the pump wave is required along the entire propagation path in the nonlinear medium. To achieve this so-called phase-matching condition, QPM exploits a periodic modulation of the nonlinear coefficient of the medium, which results in a correction of the phases of the generated waves. In particular, the periodic reversal of the ferroelectric domain polarity by using external electric field (called E-field poling) has now become the standard technique to implement QPM in a bulk ferroelectric material, such as $LiNbO_3$. QPM provides the significant advantage that any interaction can be phase-matched within the entire transparency range of the medium, simply by choosing a suitable poling period of the medium. This feature results in efficient, widely tunable frequency-conversion devices, as demonstrated in this talk by the diode-pumped singly-resonant CW-OPO. In addition, QPM provides the new possibility of an engineered control of optical nonlinear processes by designing the poling structure. This is demonstrated by the self-phase-locked CW-OPO presented in the second part of this talk, where a two-section PPLN is used for simultaneous "cascaded" realization of OPO and second-harmonic generation (SHG) process in the same crystal.

The singly-resonant CW-OPO consists of a 38-mm long PPLN crystal in a cavity resonant only for the signal wave. As the pump source, an InGaAs diode master-oscillator power-amplifier (MOPA) system is used, providing output powers of up to 2.5 W at 925 nm in a high-quality single-frequency beam. The CW-OPO has a threshold pump power of 1.6 W and generates up to 480 mW of 2100 nm idler wave. A wide and rapid wavelength coverage from 1550 nm to 1700 nm (signal wave) and from 2030 nm to 2300 nm (idler wave) is achieved by tuning either the wavelength of the diode MOPA or the PPLN crystal temperature. In particular, a continuous tuning of the idler frequency without spectral mode-hops over 56 GHz is achieved with this singly-resonant CW-OPO through continuously tuning the diode MOPA frequency. This feature is used for recording up to 3 subsequent ro-vibrational absorption lines of N_2O gas at a wavelength of 2120 nm, which shows the high potential of the CW-OPO for the high-resolution infrared spectroscopy.

The second system, the self-phase-locked CW-OPO, demonstrates the application potential in precision optical metrology, by realizing a phase-coherent, all-optical by-three-division of an optical frequency. The frequency to be divided is provided by the pump laser, which is an AlGaAs diode MOPA system with output powers of up to 340 mW at 812 nm. The CW-OPO is based on QPM in a 38-mm long PPLN crystal which carries two sections with different poling periods, in order to simultaneously phase-match two different nonlinear processes. The first section is poled for the OPO process converting the pump laser wave into the signal wave at 1218 nm and idler wave at 2436 nm, with frequencies of approximately two-third and one-third of the pump frequency, respectively. The second section provides QPM for cascaded SHG of the idler wave, which generates an additional wave near the OPO signal frequency. When the frequency difference of these two waves is tuned to near zero by tuning the OPO output wavelengths, optical self-injection-locking takes place. As a result, the pump, signal, and idler waves are mutually phase-locked, oscillating phase-coherently with an exact frequency ratio of 3:2:1. The experimental proof of this all-optical self-injection-locking and the measurement of the achieved phase-stability of the frequency by-three-division of 8×10^{-14} is presented in the talk, showing the successful operation of the first optically self-phase-locked CW-OPO as an optical frequency divider.

In summary, the two CW-OPOs presented in this talk combine the compactness and efficiency of a diode laser pump source with the advantages of QPM, such as high conversion efficiency and wavelength flexibility. The applicability of the singly-resonant CW-OPO for molecular spectroscopy and of the self-phase-locked CW-OPO for precise optical frequency division demonstrate the high versatility of such devices. In conclusion, it can be expected that QPM-based CW-OPOs will prove useful for many applications requiring highly coherent, tunable and powerful radiation.

1. M. E. Klein, C. K. Laue, D.-H. Lee, K.-J. Boller, R. Wallenstein, "Diode-pumped singly-resonant CW optical parametric oscillator with wide continuous tuning of the near-infrared idler wave," Opt. Lett. 25, 490 (2000)
2. D.-H. Lee, M. E. Klein, J.-P. Meyn, P. Groß, S. Marzenell, R. Wallenstein, K.-J. Boller, "All-optical frequency-by-three-division with a diode laser pumped CW-OPO using PPLN," Proc. SPIE 3928, 25 (2000)