Electro-Optic Controlled, Highly Spectrum Narrowed Multiline Intracavity Optical Parametric Oscillators

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Abstract: An electro-optically spectrum narrowed, multiline optical parametric oscillator was built based on a novel aperiodically poled lithium niobate device. The power spectral density of the EO controlled system is enhanced by a factor of ~7.8.
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1. Introduction

Coherent light sources emitting at dual or multiple lines are in demand for many applications such as remote sensing, optical communications, interferometry, biomedicine, and terahertz wave generation. In contrast to laser systems that usually offer limited spectral bands and range, optical parametric oscillators (OPOs) are favorable sources providing broad and continuous (single and idler) bands as the basis for the multiple wavelength selection and oscillation. While the quasi-phase-matching (QPM) technology have contributed greatly to the construction of efficient OPOs, the highly engineerable characteristics of the technology also enable the manipulability of the phase-matching spectra of OPOs (e.g., multiple phase-matching channels in an OPO have been created using a cascade or an aperiodic QPM domain structure [1]). Besides, the access to the electro-optic (EO) properties of a QPM material opens up new application frontiers for the QPM technology, where we have realized novel OPOs whose output spectra can be narrowed and tailored via the fast EO control [2, 3].

High brightness OPOs are of particular interest for those applications aforementioned but usually realized in a pulsed pumping scheme, having broad spectral bandwidth (>~1 nm) that makes against the building of a high resolution/precision/coherence system requesting a narrow-line source. The pulsed multiline source in [1] has a broad output spectral linewidth (~0.8 nm), while the electro-optically spectrum narrowed OPOs in [2, 3] work only on a single signal line. In this work, we have developed a novel aperiodically poled lithium niobate (APPLN) integrating two multiline QPM-device functionalities in an all solid-state laser system to realize an EO controlled, highly narrowed multiline pulsed intracavity OPO (IOPO) source.

2. Core device design, system construction, and performance characterization

In this study, a domain structure (an APPLN) simultaneously satisfying the QPM conditions of an EO polarization mode converter (PMC) and an optical parametric down converter (OPDC) working on the same (multiple) spectral lines has been derived using the aperiodic optical superlattice technique [4]. The built-in EO QPM PMC [2] functions here as a multi-channel, narrowband notch-type spectral filter for narrowing the gain bandwidths of the down-converted signals at the corresponding channels. Figure 1 shows the Fourier spectrum of the calculated domain structure in $LiNbO_3$ (which is an APPLN, as schematically shown in the inset). The total length of the structure is 3 cm. The thickness of the unit domain block for constituting the structure is 4 μm. Two target spatial frequencies at 0.03344 and 0.03332 μm^{-1}, required for phase-matching the 1064-nm pumped 1540/3442 and 1550/3393 nm signal/idler optical parametric generation processes at 40ºC, are resolved from the Fourier analysis, while another group of frequencies at 0.04736, 0.04731, 0.04702, and 0.04697 μm^{-1} is also resolved as expected for phase-matching the corresponding EO PMC processes (at wavelengths 1539.39, 1540.66, 1549.38, and 1550.62 nm at 40ºC) for achieving the desired gain spectrum tailoring. Figure 2(a) shows the calculated single-pass *e*-wave transmission spectrum at E_y=150 V/mm and OPO signal spectrum based on 7 cavity roundtrips for signal buildup at E_y=0 V/mm when an *e*-polarized wave with a flat spectrum over 1520-1560 nm (calculation range) and a 6 MW/cm^2 *e*-polarized wave at 1064 nm are incident at the domain structure, respectively. The result achieves the goal of spectral narrowing by suppressing the lower gain portions while maintaining the peak gain regions of the signal oscillation bands. Figure 2(b) shows the calculated output signal spectrum (blue line) from an IOPO constructed using the APPLN device at E_y=150 V/mm. The result shows the spectral peak heights and widths of the signals have been increased and reduced by ~3.5 and ~80 times, respectively, in contrast to those from the system operated in the passive mode (i.e., at E_y=0 V/mm), leading to a great enhancement of the signal power spectral density.

We then fabricated the APPLN in a 30-mm-long, 1-mm-wide, and 0.5-mm-thick *z*-cut $LiNbO_3$ chip by using the standard electric-field poling technique. The two *y* faces of the crystal were sputtered with NiCr alloy as the electrodes for the E_y application. Figure 3 shows the schematic arrangement of an EO spectral-line controlled/narrowed, multiline OPO achieved using the constructed APPLN in a diode-pumped, EO Q-switched $Nd:YVO_4$ laser. The laser gain medium is a 9-mm-long, a-cut 0.3-at. % $Nd:YVO_4$ crystal. The pump laser is an 809-nm fiber-coupled diode laser. A 15-cm radius-of-curvature meniscus dielectric mirror (M1) and a plane-plane dielectric mirror (M2) form a laser resonator for oscillating the 1064-nm wave (refer to Fig. 3 for mirrors specifications). The down-converted multiline signals build up in an IOPO formed by mirror M1 and an output coupler (M3). Figure 4 shows the measured signal spectrum (blue line) of the IOPO when E_y=150 V/mm is applied to the APPLN device at ~5 W diode power. The values of the spectral linewidths of the dual signals from the IOPO under the EO control have both reached the resolution limit (0.06 nm) of the employed optical spectrum analyzer, though even narrowed linewidths of 0.01 nm have been predicted (see Fig. 2(b)). Thus the measured spectral linewidths have been remarkably narrowed by a factor of >8 and >8.7, while the peak spectral intensities have been enhanced by ~2.5 and ~1.6 times, for the 1540 and 1550 nm signals, respectively, when compared to the output of the system in passive mode. We estimated an enhancement of the power spectral density of the EO controlled system to be a factor of ~7.8 [5].

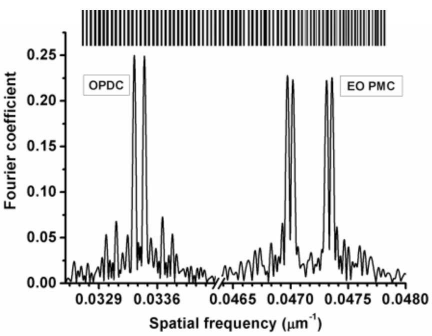

Fig. 1 Fourier spectrum of the calculated APPLN domain structure. The inset schematically shows a section of the domain structure.

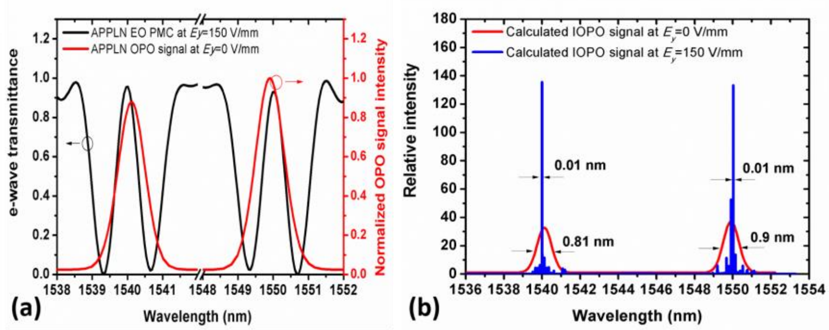

Fig. 2. (a) Calculated single-pass *e*-wave transmission spectrum at E_y=150 V/mm and OPO signal spectrum at E_y=0 V/mm. (b) Calculated output signal spectra from an IOPO constructed using the APPLN device at E_y=0 V/mm (red line) and 150 V/mm (blue line).

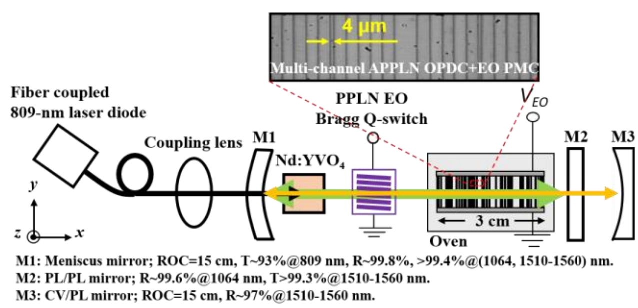

Fig. 3 Schematic arrangement of an EO spectral-line controlled/narrowed, multiline OPO achieved using the constructed APPLN in a diode-pumped, EO Q-switched $Nd:YVO_4$ laser.

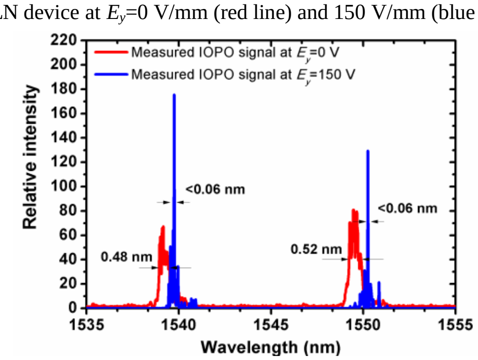

Fig. 4 Measured signal spectra of the IOPO when the APPLN device is applied with E_y=0 V/mm (red line) and 150 V/mm (blue line).

3. Conclusion

We have constructed a novel EO controlled, highly narrowed multiline pulsed IOPO using an APPLN working simultaneously as a multi-channel EO PMC and a corresponding multi-channel OPDC. We obtained from the system under the EO control the output of dual signals at 1540 and 1550 nm whose linewidths are narrowed by a factor of >8 and >8.7, while the peak spectral intensities are enhanced by ~2.5 and ~1.6 times, respectively, in contrast to the system in passive mode, indicating a largely increased power spectral density of the source.

4. References

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