# Proposal of switchable multiwavelength laser with continuously tunable spacing in MgO: APPLN waveguide

**Yubin Tang (唐喻斌), Yuping Chen (陈玉萍)*, Haowei Jiang (蒋淏苇), and Xianfeng Chen (陈险峰)****

*State Key Laboratory on Fiber Optic Local Area Communication Networks and Advanced Optical Communication Systems, Department of Physics, Shanghai Jiao Tong University, Shanghai 200240, China*

**Corresponding author: ypchen@sjtu.edu.cn; **corresponding author: xfchen@sjtu.edu.cn*

Received December 8, 2012; accepted February 25, 2013; posted online May 30, 2013

A switchable multiwavelength laser with a continuously tunable spacing is proposed and illustrated based on cascaded interactions of the second harmonic and difference-frequency generations in an aperiodically poled MgO-doped lithium niobate (MgO:APPLN) waveguide. The wavelengths and wavelength spacings of the four outputs are continuously varied and controlled by changing the two input pump wavelengths and spacings within a 3-nm flattop bandwidth of MgO:APPLN. In addition, the switchable states of the four outputs can be selected by inputting proper powers of the two pumps. The number of output wavelengths can also be increased by choosing the proper APPLN structure, the total length of MgO:APPLN, and higher powers of input pump lights.

*OCIS codes:* 130.3730, 130.7405, 190.0190.
*doi: 10.3788/COL201311.071301.*

Multiwavelength lasers are attractive because of their potential applications in test and measurement, optical sensing and spectroscopy, optical communications, and, especially, in dense-wavelength-division-multiplexed (DWDM) optical networks[1]. Switching and routing are two essential functions in the construction of a dynamic and transparent network in large DWDM networks. In addition, achieving wavelength conversion with high speed, low noise, complete transparency to the input signal formats, absence of spontaneous noise caused by transition between energy levels, low crosstalk, and so on, is possible using the quasi-phase-matching (QPM) technique[2−4]. Effective QPM-based wavelength converters have been demonstrated with periodically poled $LiNbO_3$[5]. However, these converters have small QPM-wavelength and temperature tolerance[6]. Thus, an aperiodic optical superlattice (AOS) structure is an effective solution to this problem because it can supply much more reciprocal vectors for multiple QPM than that of periodically poled crystals[7]. Therefore, the nonlinear $\chi^{(2)}$ process involving cascaded second-harmonic generation (SHG)[8] and difference-frequency generation (DFG)[9] (cSHG/DFG) in AOS is an attractive and effective way to realize multiwavelength conversion. This multiwavelength converter can be beneficial to fiber communication systems and all-optical networks because of its ultrafast response and integration compatibility.

In this letter, a tunable and switchable multiwavelength laser in an aperiodically poled 5-mol% MgO-doped lithium niobate (MgO:APPLN) waveguide via cSHG/DFG process is proposed. Figure 1 shows the schematic of the proposed multiwavelength laser in the MgO:APPLN waveguide. Two pumps participate in the MgO:APPLN waveguide, and converted waves are generated after the cSHG/DFG nonlinear interactions. The polarization controller (PC) inserted before the MgO:APPLN waveguide ensures that the two pumps are extraordinary light when injected into the waveguide. Two tunable filters (TFs) are used to select the two pump waves that are not used in the previous process. These two selected lights are amplified by two erbium-doped fiber amplifiers (EDFAs). Two variable optical attenuators (VOAs) serve as the power controllers. The optical bandpass filter (OBPF) is used to suppress the homogeneous line broadening in the EDFAs.

The total length of the MgO:APPLN waveguide in the proposed device is 19.8 mm, which is divided into uniform domains with the same thickness $L_0$. The smaller the domain width is, the better the performance of the optimal AOS grating will be. However, a domain width less than 3 $\mu$m will introduce poling difficulties and errors, which may result in the poor performance of the device. We consequently chose $L_0$= 3 $\mu$m as the unity domain width for the trade-off between the fabrication errors and good performance, which is also less than the coherence length of the DFG process, to ensure effective QPM conversion efficiency. The up or down arrow in each layer stands for the poling orientations of QPM, corresponding to the signs of the nonlinear optical coefficient. The poling orientation can be determined by the simulated annealing (SA) method when selecting an appropriate object function[10]. The aperiodical domain-inverted structure is advantageous over the periodically poled crystals because the AOS structure can provide desirable reciprocal lattice vectors for QPM to meet the expected phase matching conditions.

In our design, the flattop bandwidth of the spectra in the SHG QPM (Fig. 2) is significant because the flattop bandwidth determines the number and the wavelength spacing of the outputs. The prescribed 3-nm broaden flattop bandwidth with the central wavelength $\lambda_c$=1560.25 nm at 21 °C is obtained after a specified calculation by carefully choosing the optimal arrangement to ensure the realization of SHG with high conversion efficiency and multiple wavelength outputs. The maximal effective nonlinear coefficient, $d_{\mathtt{eff}}$, corresponding to the maximal conversion efficiency, is approximately 3.024.

The angular frequencies of the input pumps, P1 and

 

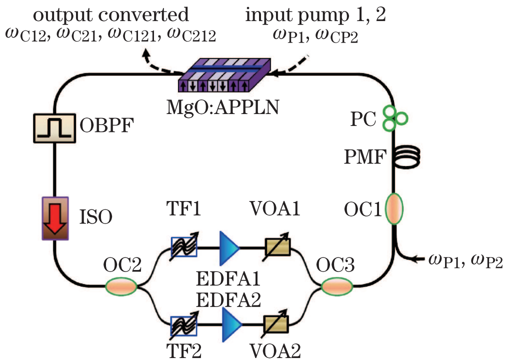


Fig. 1. Schematic of the proposed multiwavelength laser in MgO: APPLN waveguide. OC: optical coupler; PMF: polarization-maintaining fiber; ISO: isolator.

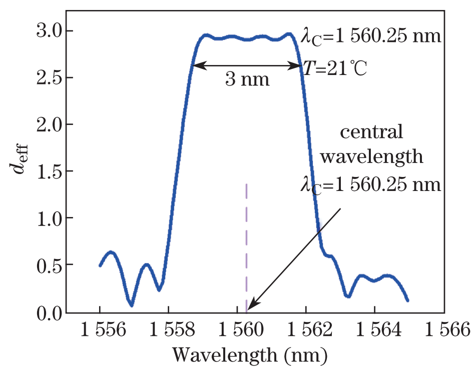


Fig. 2. 3-nm flattop bandwidth with central wavelength of 1 560.25 nm at 21 °C in MgO:APPLN.

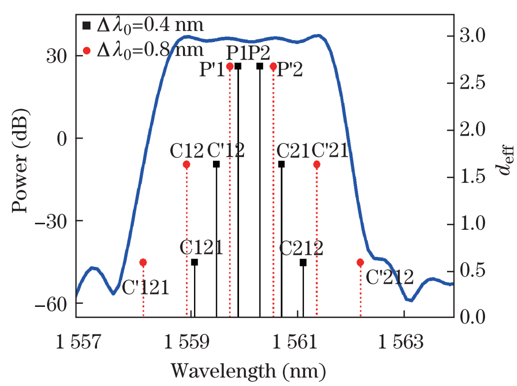


Fig. 3. (Color online) Powers of the converted waves versus input pumps with different wavelength spacings of 0.4 and 0.8 nm at 21 °C.

P2, are $\omega_{\rm P1}$ and $\omega_{\rm P2}$, respectively, and the angular frequency spacing is $\Delta\omega_0$ ($\Delta\omega_0$=$\omega_{\rm P1}-\omega_{\rm P2}$). $\omega_{\rm C12}$, $\omega_{\rm C21}$, $\omega_{\rm C121}$, and $\omega_{\rm C212}$ denote the angular frequencies of C12, C21, C121, and C212, respectively, which can be calculated by

$$\omega_{\rm C12}= 2\omega_{\rm P1} - \omega_{\rm P2}, \tag{1a}$$

$$\omega_{\rm C21}= 2\omega_{\rm P2} - \omega_{\rm P1}, \tag{1b}$$

$$\omega_{\rm C121}= 3\omega_{\rm P1} - 2\omega_{\rm P2}, \tag{1c}$$

$$\omega_{\rm C212}= 3\omega_{\rm P2} - 2\omega_{\rm P1}. \tag{1d}$$

From Eqs. (1a)-(1d), $\omega_{\rm c12}, \omega_{\rm c21}, \omega_{\rm c121}$, and $\omega_{\rm c212}$ are determined by the angular frequencies of the input pumps, $\omega_{\rm P1}$ and $\omega_{\rm P2}$ .

The wavelengths of the converted waves, C12 and C121, are calculated using

$$\lambda_{\rm C12}=\frac{\lambda_{\rm P1}\lambda_{\rm P2}}{2\lambda_{\rm P2}-\lambda_{\rm P1}}, \tag{2a}$$

$$\lambda_{\rm C121}=\frac{\lambda_{\rm P1}\lambda_{\rm P2}}{3\lambda_{\rm P2}-2\lambda_{\rm P1}}. \tag{2b}$$

Similarly, the wavelengths of the converted waves C21 and C212 are calculated by

$$\lambda_{\rm C12}=\frac{\lambda_{\rm P1}\lambda_{\rm P2}}{2\lambda_{\rm P1}-\lambda_{\rm P2}}, \tag{2c}$$

$$\lambda_{\rm C121}=\frac{\lambda_{\rm P1}\lambda_{\rm P2}}{3\lambda_{\rm P1}-2\lambda_{\rm P2}}. \tag{2d}$$

In our designed AOS structure, the 3-nm flattop bandwidth with the central wavelength is at 1 560.25 nm, and the effective nonlinear interaction area is $A_{\tt eff}$=50 $\mu$m$^2$. We can utilize a similar derivation process[11] to obtain the analytical solutions to gain insight into the device operation. The input powers of the two pumps are both set at 400 mW. The calculation powers of the converted waves at 21 °C are illustrated in Fig. 3. $\Delta\lambda_0$ ($\Delta\lambda_0$=$\lambda_{\tt P2}-\lambda_{\tt P1}$) is the wavelength spacing of the two pump inputs. The solid lines represent the powers when $\Delta\lambda_0$=0.4 nm ($\lambda_{\tt P1}$=1 560 nm and $\lambda_{\tt P2}$=1 560.4 nm). The powers of the converted waves, C12, C21, C121, and C212 are –9.37, –9.38, –44.77, and –44.77 dBm, respectively, with corresponding wavelengths of 1 559.6, 1 560.8, 1 559.2, and 1 561.2 nm. The powers of the converted waves, C12, C21, C121, and C212 become –9.37, –9.38, –44.76, and –44.77 dBm, respectively, when $\Delta\lambda_0$ is increased into 0.8 nm ($\lambda_{\tt P1}$=1 559.85 nm and $\lambda_{\tt P2}$=1 560.65 nm). The corresponding wavelengths are 1 559.05, 1 561.45, 1 558.25, and 1 562.25 nm (shown as dotted lines in Fig. 3). The maximum wavelength spacing of the two pumps can reach 1 nm (with corresponding frequency spacing of 125 GHz), while C12 and C21 are maintained inside the flattop bandwidth for the maximal output powers.

Figure 4 demonstrates the power variation in the form of three-dimensional surfaces of output lasers C121 and C212. Both the powers of P1 and P2 change from 200 to 500 mW. The green and red areas in each surface denote powers above and below –45 dBm, respectively. The powers below –45 dBm can be neglected in practical measurement. Hence, the effective outputs above –45 dBm stand for the “on” states, and the non-effective outputs below –45 dBm represent the “off” states. The outputs can be conveniently controlled by just tuning the pump powers.

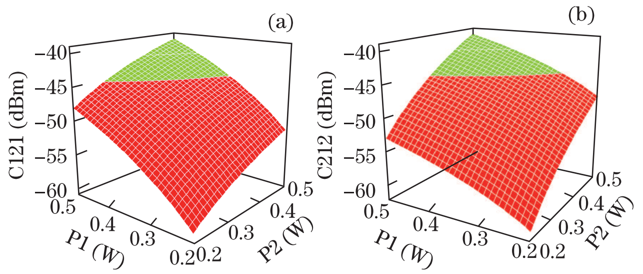


Fig. 4. (Color onlion) Power variations of C121 and C212 by changing P1 and P2 from 200 to 500 mW. The green and red areas denote powers above and below –45 dBm, respectively.

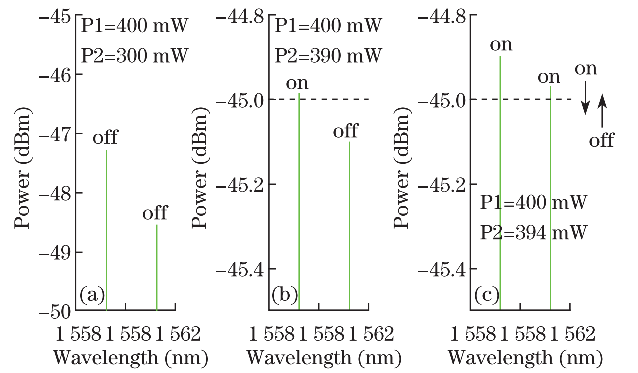


Fig. 5. (Color online) Powers of C121 and C212 corresponding to the "on" and "off" states with different input pump powers.

Figure 5(a) demonstrates clearly that when P2 is 300 mW, lower than the two turning points of C121 and C212, C121, and C212 are both at the "off" states, with the powers of –47.26 and –48.52 dBm, respectively. However, increasing P2 to C121's turning point power of 390 mW (the calculated power is shown in Fig. 5(b)), the power of C121 is –44.98 dBm, which is at the "on" state and C212 is –45.10 dBm, which is still at the "off" state. Increasing P2 to 394 mW, C121 and C212 become –44.90 and –44.97 dBm, respectively, in which both C121 and C212 are at the "on" states, as illustrated in Fig. 5(c).

In conclusion, a new scheme to fulfill a continuously tunable and switchable multiwavelength laser based on the cascaded nonlinear process cSHG/DFG in MgO:APPLN waveguide is proposed and demonstrated. The 3-nm flattop bandwidth of MgO:APPLN is obtained by designing the optimal arrangement of APPLN. The wider flattop bandwidth can be designed to achieve more effective wavelength generation by choosing a proper APPLN structure. In addition, we can obtain more outputs by improving the conversion efficiency through increasing the total length of MgO:APPLN and pump powers. Moreover, the same switchable function on outputs can also be realized by shifting the working temperature of the device.

This work was supported by the National Natural Science Foundation of China (No. 11174204) and the Shanghai Jiaotong University Innovative Practical Program.

## References

1. L. Chen, IEEE Photon. Technol. Lett. **16,** 410 (2004).
2. K. Mizuuchi, K. Yamamoto, M. Kato, and H. Sato, IEEE J. Quantum Electron. **30,** 1596 (1994).
3. J. Xie, Y. Chen, W. Lu, and X. Chen, Chin. Opt. Lett. **9,** 041902 (2011).
4. M. H. Chou, I. Brener, M. M. Fejer, E. E. Chaban, and S. B. Christman, IEEE Photon. Technol. Lett. **11,** 653 (1999).
5. J. Zhang, Y. Chen, F. Lu, and X. Chen, Opt. Express **16,** 6957 (2008).
6. G. Schreiber, H. Suche, Y. L. Lee, W. Grundkötter, V. Quiring, R. Ricken, and W. Sohler, Appl. Phys. B **73,** 501 (2001).
7. Y. W. Lee, F. C. Fan, Y. C. Huang, B. Y. Gu, B. Z. Dong, and M. H. Chou, Opt. Lett. **27,** 2191 (2002).
8. M. M. Fejer, G. A. Magel, D. H. Jundt, and R. L. Byer, IEEE J. Quantum Electron. **28,** 2631 (1992).
9. D. Hofmann, G. Schreiber, C. Haase, H. Herrmann, W. Grundkötter, R. Ricken, and W. Sohler, Opt. Lett. **24,** 896 (1999).
10. S. Kirkpatrick, C. D. Gelatt, and M. P. Vecchi, Science **220,** 671 (1983).
11. J. Wang, J. Sun, X. Zhang, and D. Huang, J. Lightwave Technol. **26,** 3137 (2008).