Red and Blue Light Generation in an $LiTaO_3$ Crystal with a Double Grating Domain Structure *

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Simultaneous red and blue light generation in an $LiTaO_3$ crystal with a double grating structure is reported for the first time. The double grating consists of two separate domain reversal sequences (superlattices) in series and is fabricated by the field poling technique at room temperature. Using a picosecond 532 nm laser as a pump source, the red light at 631 nm and blue light at 460 nm are generated at the same time. A possible application of the superlattice crystal is presented.

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Along with the rapid development of the poling technique for ferroelectric materials, the optical superlattices with various domain reversal structures in $LiNbO_3$, $LiTaO_3$ and KTP crystals have been used to realize quasi-phase matched (QPM) second harmonic generation (SHG),[1] direct third harmonic generation[2] and high-efficiency optical parametric oscillator (OPO).[3] Recently, Zhu and his co-workers reported a multi-wavelength SHG (blue, green, red and infrared) from a Fibonacci optical superlattice,[4] showing a possible scheme to obtain the multi-wavelength laser output. In this scheme, a tunable OPO is used as a fundamental source. The multi-wavelength outputs are achieved through tuning the fundamental wavelength to match separate QPM conditions provided by the different reciprocals of Fibonacci structure; however, the output of multi-wavelength is not achieved at the same time.

Red and blue are two basic colours among the three primary element colours. Simultaneous generations of red and blue are important in contemporary electro-optic technology. In this letter, we report a novel scheme, i.e. arranging two superlattices with different periods in series to realize blue and red generations simultaneously based on QPM theory. In the configuration, a 532 nm laser is used as a pump source. The pump beam passes through these two superlattices in sequence. The QPM parametric fluorescence is generated in the first superlattice. The wavelengths of created signal and idler are 631 nm (red) and 3392 nm, respectively. Whereas the blue at 460 nm is generated in the second superlattice through a QPM sum-frequency process by mixing the remnant fundamental at 532 nm and the idler at 3392 nm. In this way, simultaneous red and blue outputs can be realized from the double grating structure.

The double grating structure is designed as follows. The first superlattice is used for the QPM optical parametric process. For a collinear interaction, the first-order QPM condition is

$$k_{\mathrm{p}} - k_{\mathrm{s}} - k_{\mathrm{i}} - \frac{2\pi}{\Lambda_1} = 0, \tag{1}$$

where Λ_1 is the period of domain reversal, and k_{p}, k_{s} and k_{i} are the wave vectors of pump, signal and idler, respectively. In addition, in a three-wave nonlinear interaction the frequencies of parametric waves are related by

$$\omega_{\mathrm{p}} = \omega_{\mathrm{s}} + \omega_{\mathrm{i}}, \tag{2}$$

where ω_{p}, ω_{s} and ω_{i} are the frequencies of pump, signal and idler, respectively, and $\lambda_{\mathrm{p}} = c/\omega_{\mathrm{p}}$, $\lambda_{\mathrm{p}} = 532$ nm is the pump wavelength. According to Eqs. (1) and (2), red light at 631 nm as a signal and infrared light at 3392 nm as an idler can be obtained at room temperature if the period Λ_1 of the superlattice is set at 11.9 μm.

The second superlattice should be charged with a QPM sum-frequency process where two added parametric waves are the idler at 3392 nm and the pump at 532 nm, respectively. According to energy conservation, the generated wave is blue light at 460 nm. The QPM condition corresponding to the sum-frequency process is

$$k_{\mathrm{a}} - k_{\mathrm{i}} - k_{\mathrm{p}} - \frac{2\pi m}{\Lambda_2} = 0, \tag{3}$$

where k_{i}, k_{p} and k_{a} are the wave vectors whose corresponding wavelengths are 3392, 532 and 460 nm, respectively, and m is the order of QPM. The period of the second superlattice, Λ_2, can be established from Eq. (3).

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Because there are some uncertainties in the Sellmeier equation[6] and the operation temperature of the crystal, the second superlattice was designed with a multi-grating structure: four parallel gratings, each 1 mm wide, with periods ranging from 8.74 to 8.80 μm with a step of 0.02 μm. The perfect phase-matching of the sum-frequency process was accomplished by translating the gratings through the pump beam during the measurement.

The sample with two serial superlattices was fabricated by pattern poling an $LiTaO_3$ crystal wafer at room temperature.[5] Two superlattices were respectively poled to make their duty cycles uniform on account of their different domain periods. The thickness of the crystal wafer was about 0.5 mm and the lengths of the first and second superlattices were 2 and 1 cm, respectively. After poling, two end-faces of the crystal wafer were polished for optical measurement, but not coated.

The schematic set-up for the measurement of red and blue light is shown in Fig. 1. The 532 nm pump radiation was generated from the second harmonic output of an Nd:YAG laser (PY61-10, Continuum, Santa Clara, California) with a pulse width of 43 ps and a repetition rate of 10 Hz. The pump beam was z-polarized and propagated along the x-axis of the sample as shown in Fig. 1. The beam was weakly focused and coupled into the polished incident end-face of the sample. The radius of the beam waist inside the sample was 0.1 mm.

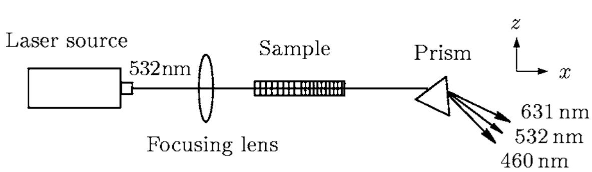

Fig. 1. Experimental set-up used in this study.

The red and blue lights were detected from the output end-face of the sample simultaneously. Figure 2 shows the red and blue spectra at the pump wavelength of 532 nm. The spectra were recorded by a CCD spectrograph. The peak of red light is located at 631.0 nm with the full width at half maximum (FWHM) of 1.2 nm (Fig. 2(a)). The wide linewidth shows that the red light was of fluorescent nature. The peak of blue shown in Fig. 2(b) is located at 459.8 nm with the FWHM of 0.2 nm. The narrow linewidth at blue implies that only a portion of idler participated in the QPM sum-frequency process due to the wide linewidth of the idler and narrow acceptable bandwidth of the superlattice. When the pump power was adjusted to 1.2 mW, the red and blue lights reached 0.38 mW and 55.6 μW, with conversion efficiencies of 31.7% and 4.6%, respectively. There is an obvious difference between the efficiencies of red and blue, therefore it is necessary to increase the conversion efficiency of blue light. Further improvement in this aspect is expected by laying the sample into a cavity with high reflection at 631 nm to let the parametrical red light come and go in the sample, which can compress the linewidth of the red light, therefore, generating brighter blue light.[7]

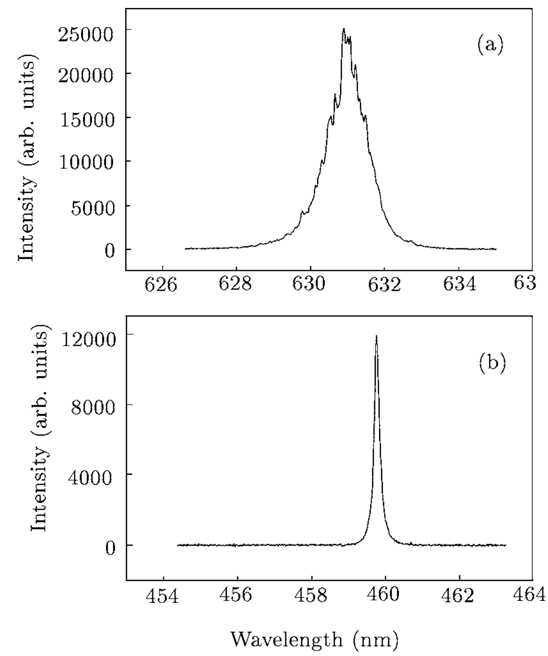

Fig. 2. Output of our experiment. The 631 nm red light was generated from the first superlattice as a signal, and the 460 nm blue light was generated from the second superlattice by adding the idler and the pump laser of the first superlattice.

There is another merit of this scheme. For fixing the pump wavelength at 532 nm, the wavelengths of red and blue lights can be changed by selecting different superlattice periods. For instance, if the periods of the first and second superlattices are 11.50 and 8.05 μm, respectively, a red light at 640 nm and a blue light at 455 nm can be generated at room temperature. Moreover, the wavelengths of red and blue lights can also be tuned by changing the operating temperature of the sample. Therefore, the sample may be placed into an oven to change its output wavelengths in a limited range by adjusting the operation temperature.

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