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Quasi-white-light Generation in Optical Superlattice Using All-solid-state Laser Technique

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Abstract: A quasi-white laser was generated by frequency doubling and tripling a dual-wavelength Nd:YVO_4 laser, where an optical superlattice in a $LiTaO_3$ crystal was regard as a frequency converter for the generation of three-primary-color.

OCIS codes: (140.3480) Lasers, diode-pumped; (190.2620) Frequency conversion

The compact white-light laser combined with red, green and blue (so-called RGB) three-primary-color will lead to many advanced application in opto-electronic technology such as full-color laser display and high-resolution laser printing. Various methods have been proposed for this goal. The representative one is the generation of RGB directly based on the frequency conversion of a dual-resonance Nd:YVO_4 laser at 1064nm and 1342 nm, where a single aperiodically optical superlattice as a nonlinear crystal to achieve the frequency doubling and tripling at such two fundamental waves[1], simultaneously. However, the results above only mentioned the generation of RGB at the same time and failed to combine RGB in a proper proportion to generate white light. In this work we will report that a quasi-white laser, comprising RGB, was generated by directly frequency doubling and tripling a dual-wavelength Nd:YVO_4 laser, where an optical superlattice in a $LiTaO_3$ crystal was regard as the nonlinear crystal for the generation of three-primary-color.

Nd:YVO_4 is an attractive candidate for multi-wavelength operation due to the fact that it has three emission lines at 914 nm, 1064 nm and 1342 nm as excited by 808 nm diode-laser. The dual-wavelength lasers at 1342 and 1064 nm with this host crystal have been realized by using a set of proper cavity mirrors[2]. Experimentally, frequency doubling the dual-wavelength laser has generated the red at 671 nm and green at 532 nm, respectively, and the frequency-tripling of the 1342 nm output has realized the blue at 447 nm by the adding of the red at 671 nm and the fundamental at 1342 nm[1]. Thus a quasi-white light can be generated by mixing the red, green and blue output in a proper proportion.

In this paper we will propose a scheme that can simultaneously generate RGB in a superlattice by frequency doubling and tripling the dual-wavelength outputs of a Q-switched Nd:YVO_4 laser at 1064 nm and 1342 nm, respectively. The superlattice in the same $LiTaO_3$ crystal wafer consists of two different structures in series as shown in Fig.1. The first one has a phase-reversal structure(also called as dual-periodic structure) that includes two differently modulated periods of 10.09 and 32.3 μm[3], respectively. This structure can be used for simultaneous frequency doubling of two fundamental waves at 1064 nm and 1342 nm, respectively. The second one consists of seven parallel channels with different periods ranging from 4.85 to 4.89 μm in step of 0.005 μm. The structure is used for blue light generation at 447 nm by quasi-phase-matched sum-frequency process in seven different operation temperature, in which two added waves are the harmonic at 671 nm generated from the first structure and remnant fundamental at 1043 nm. Utilizing this scheme, one can not only simultaneously obtain RGB outputs, but also adjust the proportion of red to green outputs by changing operation temperature and the intensity of blue light by selecting a proper channel through translating the crystal wafer to the fundamental beam. Thus, the quasi-white light could be realized from the scheme by mixing RGB in a proper proportion in terms of the chromaticity principle.

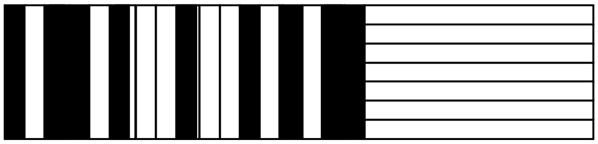

Fig.1. The superlattice consist of two different structure in series: the first one is a phase-reversal structure(also called as dual-periodic structure, see Ref.[3] for detail), and the second one contains seven parallel channels, each one is a periodic structure and seven channels have different periods range from 4.85 to 4.89 μm in steps of 0.005 μm.

The experiment setup is shown in Fig. 2. The fundamental source is a Q-switched dual-wavelength laser pumped by an 18 W fiber-coupled diode laser (OPC-D015-FPCS-808) emitting at 808 nm with a numerical aperture of 0.12. The laser host was an *a*-cut, 0.5 at. % Nd^{3+}-doped $Nd:YVO_4$ crystal with the dimension of $3\times3\times5$ mm^3. The two-mirror resonant cavity was used for dual-wavelength operation. The input mirror M1 was a concave mirror with radius of curvature of 500 mm. The entrance surface of M1 was coated to be highly reflective for both laser wavelength of 1342 and 1064 nm (R>99.8%) and highly transmit at 808 nm (T>95%). In order to improve the frequency conversion efficiency, *Q*-switched operation was implemented. The acoustic-optical *Q*-switch crystal in the cavity was used to turn the output light into the quasi-continuous pulses, with the duration of about 90 ns at 1342 nm and 50 ns at 1064 nm, and a repetition rate of 15 KHz. The laser host and the *Q*-switch had high transmission coating (T>95%) at 1342, 1064, and 808 nm on both sides. The output coupler plane mirror was coated for transmission T= 4% at 1342 nm and T=72% at 1064 nm. The cavity length between M1 and the output mirrors was 11 cm. The high loss at 1064 nm is favorable to balance the proportion of red and green. The focal length of the lens was 25 mm, and the diameter of the waist spot in the sample was estimated to be approximate 50 μm. The superlattice sample was put in an oven and heated by a temperature controller with an accuracy of 0.1 ºC. The two light-pass faces of the sample were polished but not coated, and the fundamental light was polarized along the z axis, propagated along the x axis of the $LiTaO_3$. The advantages of this scheme lie in a very simple setup and easy control circuits.

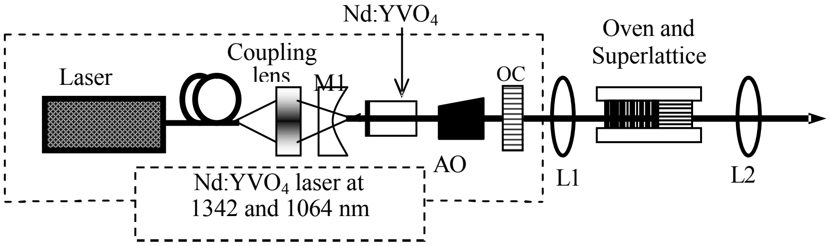

Fig.2. Schematic of the experimental setup for quasi-white light generation(a detailed analysis of this laser dynamics of dual-wavelength operation was presented in Ref. [2]).

Temperature tuning curves of red, green and blue lasers were first measured under the diode pump power of 18 W under which the powers of the fundamental 1342 nm and 1064 nm are 2.49 W and 2.05 W, respectively. The results plotted in Fig. 3 showed the maximum output powers of 481mW for red, 360 mW for green and 38 mW for blue from the end face of the third channel, and they occurred at 120.5, 115.9, and 119.3 ºC, respectively. The curves overlapped each other in a temperature range. The average red light power of 477 mW, green light power of 21 mW and blue light power of 32 mW in the proportion of 15:0.7:1 were obtained at 120.1 ºC from the third channel, which mixed into a quasi-white laser with total power of 530 mW. When the operating temperature was tuned to 119 ºC, the total output fell to 433 mW with the RGB proportion of 7.5:1.2:1, the output was then very close to the daylight as shown in the chromaticity diagram. One can find that there is a quasi-white light region around the point of daylight in chromaticity diagram. The measured results showed that the proportion of RGB generated from the superlattice located within the region as the operating temperature was changed from 118 to 120 ºC. No obvious degradation of the beam quality was observed when the operating temperature was tuned in above temperature range. High beam quality and applicable power level shows that this may be a potential way to establish a compact and efficient all-solid-state quasi-white laser.

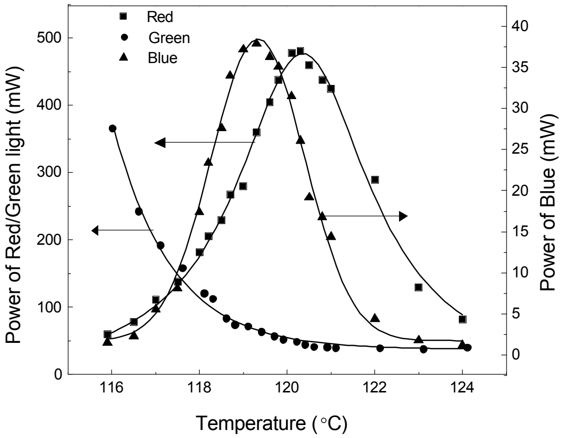

FIG. 4. Measured power dependences of RGB light on operating temperatures. A simple fit for three sets of data is to guide eye.

The stability of the quasi-white light output within one hour was measured under the pump power of 18 W. Fluctuations were found to be 4.04% for red, 4.16% for green, and 3.46% for blue, which attributed to the fluctuation in dual-wavelength output through the gain competition. Another possible cause leading to the fluctuation was the mode hopping among the different fundamental longitudinal modes. Both factors mentioned came from the over-simple structure of two-mirror cavity. According to above analyses for the present results, there is still great potential in the increase of quasi-white lights output and in the improvement of output stability. The potential high efficiency and simple configuration make this scheme reliable to realize a compact quasi-white laser. Further works to get higher power and stable output are in process.

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