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CONTROL OF LASER RADIATION PARAMETERS

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Linewidth-tunable laser diode array for rubidium laser pumping

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Abstract. **To optimise the pump source for a high-power diode-pumped rubidium vapour laser, we have designed a laser diode array (LDA) with a narrowed and tunable linewidth and an external cavity formed by two volume Bragg gratings (VBGs). Through controlling the temperature differences between the two VBGs, the LDA linewidth, which was 1.8 nm before mounting the two VBGs, was tunable from 100 pm to 0.2 nm, while the output power changed by no more than 4%. By changing simultaneously the temperature in both VBGs, the centre wavelength in air of the linewidth-tunable LDA was tunable from 779.40 nm to 780.05 nm.**

Keywords: *alkali lasers, laser diode array, volume Bragg gratings.*

1. Introduction

Diode-pumped alkali lasers (DPALs) have attracted recent interest due to their potentials from the point of view of high power, excellent beam quality and low thermal lens effect [1, 2, 3]. A 1-KW caesium vapour laser with closed-cycle laser-active medium circulation was reported by the Russian Federal Nuclear Centre in 2012 [4]. One of the critical issues is matching the linewidth and centre wavelength of the pump diode laser with that of the alkali vapour's absorption line [5, 6]. Alkali vapour's absorption line (D2) is broadened by buffer gases (such as helium and methane) due to collision broadening. Meanwhile, the linewidth of commercially available laser diodes should be narrowed to the subnanometre region in order to achieve an efficient absorptivity. Research has shown that there is a radial temperature gradient in the active medium under high power pumping [7, 8]. Changing the temperature can result in a shift of the alkali vapour's absorptive peak wavelength. In fact, the shift has been observed in the 1-KW caesium vapour laser [4]. For individual diode bars in different positions of the KW-level system, the centre wavelength was different due to the caesium absorption line's shift. As a result, the diodes with an ultranarrow linewidth may not pump efficiently than the diodes with a wider linewidth in a high-power alkali laser system. It is quite important to search for the optimal matching point of the two spectra. However, the external cavities formed by plane gratings or a single VBG have difficulties in tuning the linewidth with suppressing the subresonator longitudinal modes and maintaining the same output power [9, 10].

In this paper, we report an LDA which will overcome the facing problems and give a method for optimising the pump source for a high-power alkali-vapour laser.

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2. Basic principle and experimental setup

For a plane wave incident on an unslanted reflecting Bragg grating, the diffraction efficiency (DE) can be described as follows [11]:

$$\eta(\lambda)_{\lambda_0} = \left\{1+\frac{1-[\lambda_0 f^2(\lambda-\lambda_0)/(2n_{\rm av}\delta n)]^2}{\sinh^2\left\{[2\pi n_{\rm av}t\delta n/(\lambda_0^2 f)]^2-[\pi f t(\lambda-\lambda_0)/\lambda_0]^2\right\}^{1/2}}\right\}^{-1}, \tag{1}$$

where t is the grating thickness; $n_{\rm av}$ is the average refractive index of the VBG; δn is the amplitude of refractive index modulation; f is the spatial frequency of the grating, which can be acquired through the Bragg equation; and λ_0 is the Bragg wavelength. By setting $\lambda = \lambda_0$ in equation (1), the maximum DE is obtained:

$$\eta_0 = \tanh^2\frac{2\pi n_{\rm av}t\delta n}{\lambda_0^2 f}. \tag{2}$$

In order to make the bandwidth of the VBG's feedback tunable, a feedback system of two parallel VBGs is considered. Assuming there is no second reflection on both VBGs, the DE can be derived for the feedback system as follows:

$$\eta_1(\lambda) = \eta(\lambda)_{\lambda_1} + [1-\eta(\lambda)_{\lambda_1}]^2\eta(\lambda)_{\lambda_2}, \tag{3}$$

where λ_1 and λ_2 are the Bragg wavelengths of the two VBGs. According to equation (2), (3) and one-dimensional Bragg equation, the bandwidth and DE's maximum of the two VBGs can be described as is shown in Fig. 1. In the calculation, the two VBGs have the same parameters [bandwidth $\Delta\lambda$ = 0.1 nm, η_0 = 0.21, t = 1.89 mm, λ_1 = 779.50 nm, λ_2 is the variable wavelength considered in accordance with the wavelength differences $(\lambda_2-\lambda_1)$] except their centre wavelength. As follows from Fig. 1, both the bandwidth and the DE can be changed through tuning the differences of the two VBGs' centre wavelengths.

A VBG is a holographic component based on photo-thermo-refractive (PTR) glass. Thermal variation of the refractive index in PTR glass is approximately 5×10^{-8} K^{-1}, which leads to a thermal shift (about 7 pm K^{-1}) of the Bragg

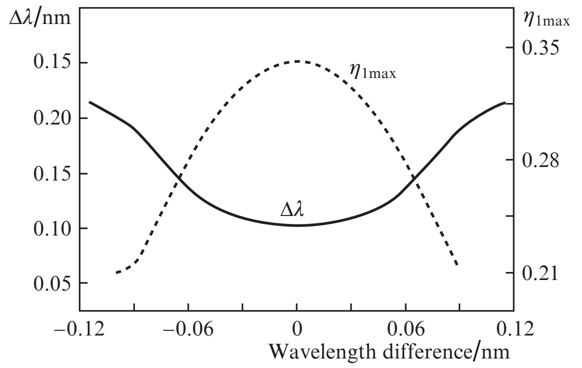

Figure 1. Bandwidth Δλ and maximum DE η_{1max} of two VBGs with different centre wavelength for a plane wave.

wavelength in the VBGs [12]. The centre wavelength differences can be varied by tuning temperatures of the two VBGs while the bandwidth of them remains unchanged. As a result, the linewidth of the LDA can be varied by controlling the temperature differences of the two VBGs.

The experimental setup is presented in Fig. 2. The LDA (DILAS) consisted of 19 emitters with 1-cm-wide bar length. The laser output facet of the LDA was not antireflection coated and had a reflection coefficients as normal LDAs. The two VBGs were fabricated by PD-LD with a diffraction efficiency of 21%, a thickness of 1.89 mm and a surface dimension of 15 × 1.75 mm. The centre wavelength of the VBGs is 779.4 nm at room temperature. The distance from the LDA to VBG1 and VBG2 are 4 mm and 7 mm, respectively. The VBGs and the fast axial collimator are all antireflection coated at 780 nm. To control the temperature of VBGs efficiently, each of the VBG is mounted on a thermo-electrically cooled aluminium heat sink with temperature control accuracy of 0.1 K. The heat sinks were fixed to 6-axis flexure platforms, respectively. A focusing lens and an integrating sphere are added to the spectrum analysing system in order to acquire the whole spectrum characteristics of the LDA.

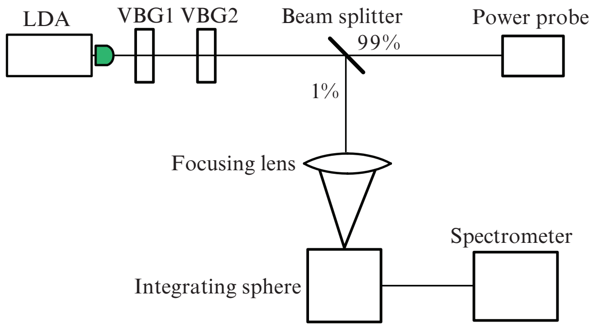

Figure 2. Experimental setup for studying the LDA with two volume Bragg gratings.

3. Experimental results

Spectra of a free-running LDA, a LDA with VBG1 and with two VBGs at the same temperature are shown in Fig. 3 at a driving current of 30 A. The pump–current characteristics of the three LDAs are shown in Fig. 4. From the figures, we can see that VBG2 helps to improve the LDAs linewidth reduction. The linewidth is reduced by 21% approximately compared with that of the LDA with only one VBG. Meanwhile, the slope efficiency decreases only by 0.10 W A^{-1}, no more than 10% of the LDA with VBG1. This is mainly due to the improved DE caused by adding another VBG. As the calculation shows, the DE increases to 35% from 21%. A higher DE has advantages in suppressing the subresonator modes at a high driving current.

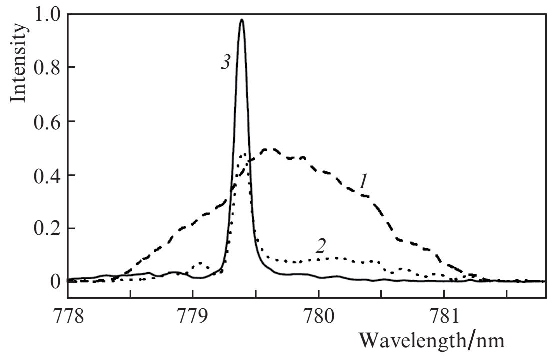

Figure 3. Spectra of a free-running LDA [(*1*), Δλ = 1.8 nm], a LDA with a single VBG [(*2*), 0.13 nm] and two VBGs [(*3*), 0.10 nm].

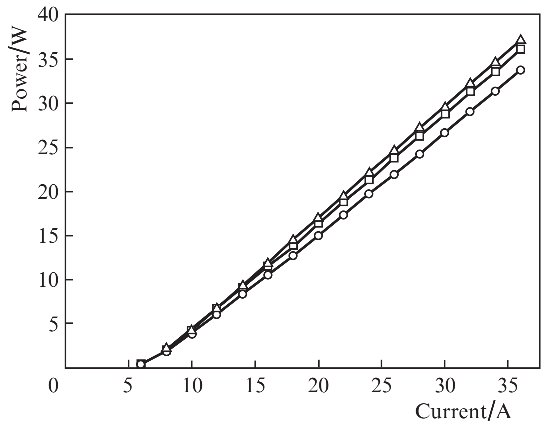

Figure 4. CW output power of a free-running LDA (△, differential efficiency of 1.24 W A^{-1}), a LDA with a single VBG (□, 1.19 W A^{-1}) and two VBGs (○, 1.09 W A^{-1}) vs. driving current.

When the driving current was 36 A, the spectrum characteristics of the LDA at different temperature differences are depicted in Fig. 5. By setting suitable temperatures of the two VBGs, the linewidth is tunable while the centre wavelength is unchanged. The linewidth can be tunable from 0.10 nm (equal to the bandwidth of the VBG) to 0.22 nm, which is 2.2 times of the VBG's bandwidth. Larger temperature differences result in a double-peak spectrum of the LDA. During the tuning of the linewidth, the output power of the LDA grows higher as the linewidth is broadened. However, the improvement in the power is no more than 4%.

Since the alkali vapour's absorption line varies with gas pressure and type, the wavelength of the pump source for a high-power alkali laser should be tunable. Tuning of the wavelength is realised with the linewidth unchanged by adjusting the temperatures of the two VBGs. As follows form Fig. 6, a tunable range of 0.62 nm from 779.43 nm to 780.05

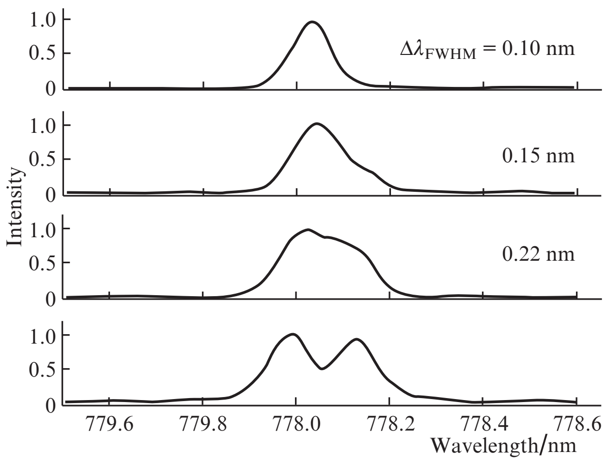

Figure 5. Spectra with different linewidths of the LDA with two VBGs.

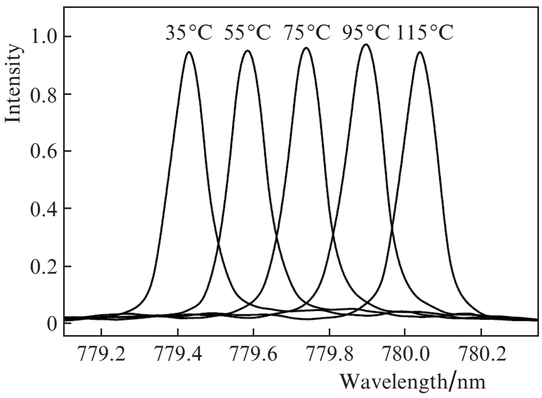

Figure 6. Emission spectra of the LDA with two VBGs at different grating temperatures of VBG2.

nm was achieved with the linewidth of 0.10 nm at a driving current of 36 A. In fact, other linewidths can also be realised by keeping a certain temperature difference.

4. Conclusions

A linewidth-reduced LDA with the external cavity of two VBGs is realised. Compared with LDAs whose feedback component employs one VBG, the LDA has better performance in supressing subresonator modes at a high driving current. Its linewidth can be tuned by setting the temperature differences of the two VBGs while the output power changes little. Experiments also show that the centre wavelength of the LDA can be tuned by adjusting the VBGs' temperatures at any linewidth in the range of 0.10 nm to 0.22 nm.

Since the structure of double VBGs can also be used in narrowing a laser diode stack, the stucture offers a means for matching spectra of the pump source and alkali absorption line, and will help to build an efficient high-power alkali-vapour laser.

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