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Stable 811.53 nm diode laser pump source for optically pumped metastable Ar laser

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ABSTRACT

A stable external cavity diode laser coupled with volume Bragg grating for metastable argon atoms pumping is presented. The measured maximum output power of the continuous wave is 6.5 W when the spectral width (FWHM) is less than 21 pm around 811.53 nm and the power efficiency is 68%. The tuning range of the emission wavelength is bigger than 270 pm. The calculated deviation in relative absorption efficiency caused by the fluctuations of wavelength and power is less than 4%.

1. Introduction

A new style of optically pumped gas laser with active medium based on rare gas atoms in metastable states produced by gas discharge was proposed and demonstrated by Han and Heaven from Emory University in 2012 [1]. The optically pumped metastable rare gas laser (OPRGL) has attracted considerable interests for its potential in generating high power laser with good beam quality and atmospheric transmittance [2–7]. Different metastable rare gas atoms (Ne^*, Ar^*, Kr^* and Xe^*) as laser media have been examined [1,6,8]. Among all of the rare gases, argon is the cheapest one and is conducive to large-scale application. As the absorption line is an atomic line, the first step for the high-power optically pumped metastable Ar laser (OPMAL) is to realize a high power pump source with narrow spectral width emitting around 811.53 nm.

Diode laser of high electro-optical efficiency, high power and small size, as pump source for diode-pumped alkali laser (DPAL), has enabled alkali vapor lasers to exhibit excellent properties [9]. Presumably, the development of OPRGL will move towards to the direction of diode-pumped metastable rare gas laser and the feasibility of diode pumped metastable rare gas laser was confirmed in 2013 [3]. The challenge for laser diode (LD) to be the pump source of OPMAL is to match the narrow absorption linewidth of metastable argon atoms with buffer gas He at atmospheric pressure or a little higher. Absorption linewidth (FWHM) of roughly 15.6 pm was obtained for OPMAL with buffer gas He at 300 K and 10^5 Pa from the pressure broadening coefficients reported by Mikheyev [7], which is much narrower than the spectral width of free running commercial LD. To ensure efficient absorption of pump laser and high electro-optical efficiency of OPMAL, the spectral width of LD must be narrowed. Nonetheless, pump spectral width less than absorption linewidth is not mandatory and pump sources with spectral width up to 2 or 3 times larger than the absorption linewidth can still yield a very high absorption efficiency [10]. In addition, the drift of the wavelength with temperature and current should also be controlled.

Wavelength stabilized LDs with narrow spectral width can be realized by volume Bragg Gratings (VBGs) as output couplers in external cavities and have been used in pumping of gas lasers including singlet delta oxygen laser and alkali vapor laser in the recent years. An maximum output power of 13.5 W with the spectral width narrowed to 13 pm for oxygen molecule pumping was demonstrated by employing a laser diode bar and a 25% reflectivity VBG with bandwidth of about 13 pm [11]. A large bandwidth (30 pm) VBG with higher reflectivity (70%) and a laser diode bar were used by Gourevitch et al. and a narrow spectral width of about 20 pm for Rb vapor pumping was obtained [12]. Both of the cavities mentioned above were in classical beam-collimated configuration and the laser diodes were anti-reflection coated with very low reflectivity (R=0.5%).

However, Classical external-cavity laser diode (ECLD) is more sensitive to mechanical instabilities which is against long term reliable operation. For a better stability, a configuration called “cat's eye” has been shown and proved to be very effective in ECLD [13–15]. Extended-cavity tapered lasers with VBG in focus configuration designed by Lucas-Leclin et al. [16] has demonstrated a

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wavelength-stabilized output with narrow linewidth less than 20 pm and studied the performance in bandwidth and threshold current under two different configurations.

In this paper, for the purpose of getting a stable LD pump source with narrow spectral width for OPMAL, we employed the method of external cavity based on a VBG in "cat's eye" configuration. Several parameters are measured and discussed including the spectral width, the power characteristic, the thermal tuning and the stabilities of laser output as well as their influence on absorption efficiency.

2. Experimental setup

Fig. 1 shows the schematic of the experimental setup. The VBG external cavity laser diode (VBG-ECLD) consists of a commercial available c-mount bare LD (Axcel Photonics, Inc.), an aspheric lens f_1 ($f=2.75$ mm, Thorlabs, Inc.), a cylindrical lens f_2 ($f=15$ mm, Thorlabs, Inc.) and a VBG (OptiGrate Corp.). The LD is a single emitter diode producing the maximum output power of 9.6 W when the current is 9.5 A at 25 °C. Regarding this LD, the front facet is covered with standard coating, $R=2.5\%$, while the back facet is covered with highly-reflecting coating of reflectivity, $R>95\%$. The emitting size of the chip is about $1\times 400\ \mu m^2$ with a 2 mm cavity length. The aspheric lens f_1 is used to collect the laser. For compensating the astigmatism between the fast and slow axis, the cylindrical lens f_2 is added to reduce the beam size along the slow axis. The VBG is used as the frequency feedback element and the output coupler (OC). The diffraction efficiency of the OC is about 70% for plane wave fronts at the resonant wavelength of 811.5 nm at 22 °C. The spectral selectivity is about 50 pm. All light-passing surfaces on lens and VBG are AR coated with left reflection less than 0.5%.

A home-made copper mount is used to support the VBG. Two separated thermoelectric coolers (TECs) are used to control the temperatures of VBG mount and LD heat sink with stabilities of 0.01 K. A high resolution spectrograph with resolution of 13 pm near 812 nm (modified from THR1500 of Jobin yvon with a Hamamatsu CCD array detector S10420-1106) is used for spectrum measurement. The laser beam is diffused by a frosted glass plate before entering the spectrograph for the full utilization of the resolving capability. The power is measured by a power meter (UP19K-30H-H5-D0, Gentec-EO) placed in the position of the attenuator.

3. Results and discussions

3.1. Spectral narrowing

Narrow spectral width is our primary goal during the experiments. The laser spectral characteristic is studied under both free running mode and external cavity operation. Fig. 2 shows the spectra at the status of free running and VBG external cavity when the injection current of LD is set to be 9.48 A close to the maximum operating current. The temperatures of LD and VBG are set as 25 °C and 17 °C respectively. As shown in Fig. 2 below, The reading of the LD spectral width (FWHM) is narrowed from 1.7 nm in free running mode to less than 21 pm in VBG external cavity though the gain at central wavelength of VBG is very small.

It is noted that the intrinsic cavity modes cannot be suppressed efficiently when the injection current of LD is aligned between 2 A and 8 A at the operating temperature of 25 °C as shown in Fig. 3. With the driving current rising, the ratio of the intensities of intrinsic modes and VBG-locked modes decreases gradually which means a transfer of power from intrinsic cavity to the external one. When the LD temperature is increased to be 31.5 °C at which the center wavelength of free running is red-shifted to 811.53 nm at 9.48 A, the current range of incomplete suppression narrows to be an interval from 2 A to 4 A. This phenomenon could be explained by the decrease of mismatch between the peak position of gain and the central wavelength of VBG when the LD temperature increases.

Lower reflectivity of front facet means stronger feedback of VBG into the intrinsic cavity and better suppression effect. After all, reflectivity of 2.5% at the LD emitting facet is much bigger than 0.5% or even lower used in other spectral narrowing experiments with gratings [11,12,17]. As is explained by Hjelme and Mickelson [18], the spectral width of external cavity laser diode is roughly proportional to the reflectivity of LD emitting face. Reducing the reflectivity of the emitting surface is conducive to the elimination of intrinsic cavity modes and narrower spectral width.

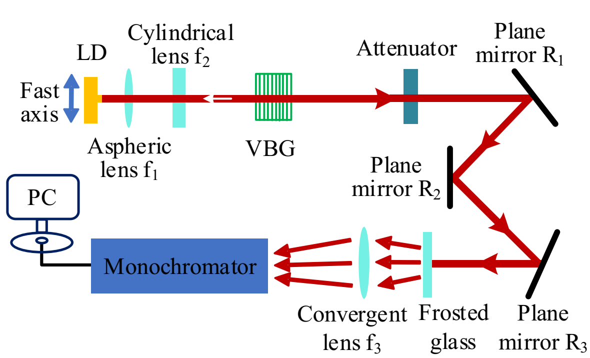

Fig. 1. Schematic diagram of the experimental setup for spectral narrowing.

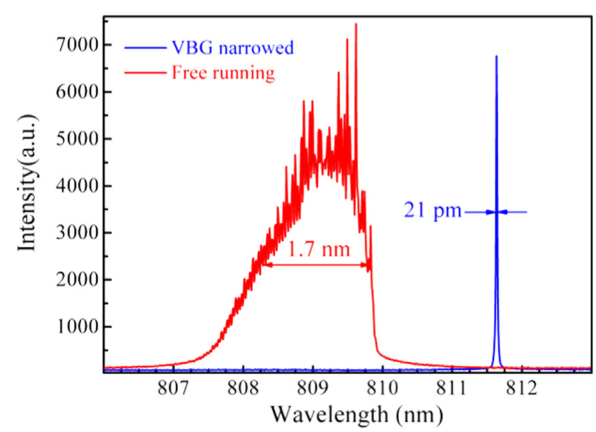

Fig. 2. High resolution spectrum of free running and VBG narrowed.

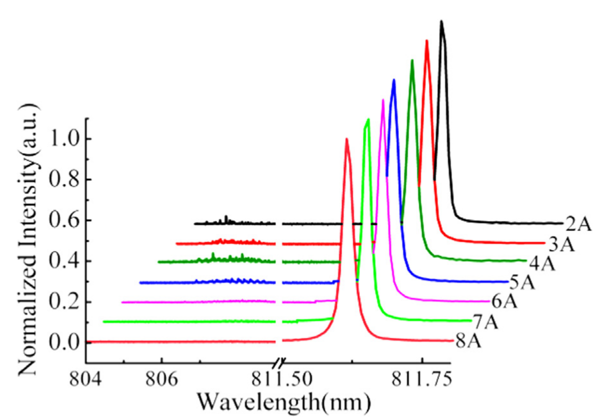

Fig. 3. Emission spectrum of VBG-ECLD for different driving current from 2 A to 8 A. Temperatures of LD and VBG are stabilized at 25 °C and 17 °C, separately.