Continuous-Wave Alkali Vapor Laser Pumped by a Ti-sapphire Laser with Narrow Linewidth

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Abstract. We have experimentally demonstrated the continuous wave rubidium and cesium lasers pumped by a Ti-sapphire laser with the linewidth of about 5 MHz. The pump and laser beams were orthogonally polarized and they can be separated by a polarized beam splitter (PBS). Two 4-cm-long cells were respectively filled with metallic rubidium and cesium as well as 300 Torr ethane as a buffer gas. A series of output couplers at different cell temperatures have been used and the optimal parameters have been found for earning the highest output. As a result, we have achieved a maximum output power of 111 mW with the optical to optical efficiency of 18.4% for a rubidium laser and a maximum output power of 136 mW with the optical to optical efficiency of 30% for a cesium laser, respectively. By considering there are no anti-reflection coatings on the surfaces of two cell end-windows, the output should be improved if the transmission attenuation is effectively decreased in the future.

1. Introduction

The concept of a diode pumped alkali laser (DPAL) was first proposed by William F. Krupke [1]. In the recent years, DPALs have drawn a lot of attentions because they combine the positive features of both gas lasers (GLs) and diode pumped solid state lasers (DPSSLs) [2-4]. As a gas-state laser, the DPAL contains several kinds of buffer gases and the vapor medium of three kinds of neutral alkali such as potassium (K), rubidium (Rb), and cesium (Cs) [5]. In a DPAL, an alkali atom along with the two electric-dipole-allowed transitions participates in the laser action and the typical three electronic-level is formed as shown in figure 1 [6]. Until now, several reports on the experimental studies of CW alkali lasers pumped with narrowband Titanium surrogate lasers have been published for the gain media of cesium and potassium vapors [7-10]. But the experimental report about the rubidium vapor laser pumped by a light source with the linewidth less than 100 MHz is rare [11-12]. In this study, we experimentally analyze the output features of rubidium and cesium alkali lasers with an end-pumped configuration. The output power of our optically pumped resonance transition rubidium laser achieves 111 mW, which should be the first experimental demonstration of the rubidium laser with the linewidth of a pump source narrower than 100 MHz worldwide.
2. Experimental Setup
The schematic diagram of the experimental setup of an optically pumped alkali laser is presented in figure 2. A tunable Ti:sapphire laser with a linewidth of about 5 MHz is used to longitudinally pump the gain media inside a Rb cell and a Cs cell in the experiment. Adopting a narrow linewidth pump source is helpful to fit the absorption band of alkali gain media. In addition, the shift of the central wavelength of such a pump source with the linewidth smaller than 10 MHz is much more insensitive to the output performances of a DPAL than a normal narrow-linewidth LD (usually about ~100 GHz). The pump and laser beams were orthogonally polarized so that they can be separated by a polarized beam splitter (PBS). Both Rb and Cs cells are filled with 300 Torr ethane as the buffer gas to broaden the absorption line (the D₂ line) and hasten the fine-structure mixing rate between the \(^2\)P\(_{3/2}\) and \(^2\)P\(_{1/2}\) levels [13]. By using such configurations, we have experimentally realized the narrow-linewidth output of both Rb and Cs vapor lasers. As both end-windows of the cell are not coated with anti-reflection films, the cavity transmission losses would bring about some negative effects on the laser output performance.

3. Results and Discussions
3.1. Output Features of a Rb laser
As the number density of alkali vapor closely relates to the cell temperature, the output power of a Rb laser will be strongly governed by the vapor temperature. Figure 3 shows the output power versus the cell temperature for different reflectances \(R_{oc}\) of an output coupler (OC) in a Rb laser system. The data have been obtained when the pump power was kept as 569 mW. We can see that there are the optimal temperatures in all curves which are 120, 113, 113, and 109 °C for the OC reflectances of 4, 50, 70,
and 90%, respectively. The peak position corresponding to the maximum output shifts to the low temperature when the reflectance of an OC becomes higher.

![Graph showing output power versus cell temperature with different reflectances of an OC](image)

**Figure 3.** Output power versus the cell temperature by different reflectances of the output coupler in a Rb laser system.

In the study, we also investigate the output performances changing with the pump power. The results are depicted in figure 4. In the plot, the output power increases with the pump intensity without an evident saturation tendency for all curves. It can be seen that the higher the slope efficiency, the smaller the reflectance of an OC. One can deduce that the gain of a DPAL should be much higher than those of most conventional DPSSLs. We have achieved a maximum power of 111 mW with a reflectance of 4% of an OC. The corresponding optical to optical efficiency is 18.4% and the laser intensity profile is presented in figure 5. Such efficiency is not very high since the power of the pump source is relative small. We deduce the maximum optical to optical efficiency should become higher if the pump power is further increased. To the best of our knowledge, this is the first Rb laser pumped by a narrowband (<100 MHz) laser source in the world.

![Graph showing output power versus pump power](image)

**Figure 4.** Output power of a rubidium laser as a function of the pump power at different experimental conditions.
According to the kinetic model we established before [14-15], we have also undertaken the theoretical simulation. The calculated optical to optical efficiency for the rubidium laser is as high as 26.2%, which is higher than the measured one (18.4%) under the same conditions. We think the difference between the theoretical results and the experimental ones are mainly aroused by four uncoated surfaces of two side-windows of the cell.

3.2. Output Features of a Cs laser

Similar to subsection 3.1, we also experimentally tested the output performance of a Cs laser. In figure 6, the output power is expressed as a function of the cell temperature with different $R_{oc}$ while the pump power is 409 mW. We can see that the output power first increases and then falls as the cell temperature becomes higher. The optimal cell temperatures are 91, 93, 113, 100, and 103 °C with the corresponding reflectance of an OC of 4, 20, 50, 70, and 90%, respectively. As shown in figure 6, the maximum power is obtained when $R_{oc}$ is set to 4%. Some jaggednesses of the curves in both figure 3 and figure 6 can be seen and are thought to be mainly caused by the short waiting time in the measurement. We are planning to increase the waiting time during the measurement in the upcoming experiments.

![Beam profiles of a Rb laser in both three dimensions (left) and two dimensions (right).](image)

**Figure 5.** Beam profiles of a Rb laser in both three dimensions (left) and two dimensions (right).

![Output power versus the cell temperature by different reflectances of the output coupler in a Cs laser system.](image)

**Figure 6.** Output power versus the cell temperature by different reflectances of the output coupler in a Cs laser system.
The output power of a Cs laser at different pump conditions is diagrammed in figure 7. We can see that the slope efficiency decreases with increase of Roc. In addition, the lasing threshold is the lowest for Roc = 4% among five curves. Thus, an output coupler with the reflectance as low as possible should be probable for a Cs laser system. In this study, the maximum output power of a cesium laser has been achieved to 136 mW with the optical to optical efficiency of 30%. The intensity distribution of a Cs laser beam is recorded as shown in figure 8. The distribution profile of the cesium laser implies that the beam propagation factor is near to diffraction-limited.

![Figure 7](image7.png)

**Figure 7.** Output power of a cesium laser as a function of the pump power at different experimental conditions.

![Figure 8](image8.png)

**Figure 8.** Beam profiles of a Cs laser in both three dimensions (left) and two dimensions (right).

## 4. Conclusions

In this study, we have realized both cesium and rubidium vapor lasers pumped by a CW Ti:Sapphire surrogate laser. According to the experimental results, we discuss the influence of both the cell temperature and the OC reflectance on output features of an optically-pumped alkali laser system. It can be seen that the optimum cell temperature changes with the reflectance of an output coupler, which is similar to the conclusion from several prior researchers. We also find that the smaller output coupler reflectance is, the higher slope efficiency becomes. The research is thought to be helpful for design of a high-powered DPAL system with the narrow linewidth.
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