A high-performance 852 nm Voigt anomalous dispersion optical filter for external-cavity diode laser

Hangbo Shi[1], Zijie Liu[1], Xiaolei Guan[1], Tiantian Shi[2], Jingbiao Chen[1,3]

Email: shihangbo@stu.pku.edu.cn liuzijie@stu.pku.edu.cn xiao960924@stu.pku.edu.cn tts@pku.edu.cn jbchen@pku.edu.cn

[1]State Key Laboratory of Advanced Optical Communication Systems and Networks, Institute of Quantum Electronics, School of Electronics, Peking University, Beijing, China

[2]National Key Laboratory of Advanced Micro and Nano Manufacture Technology, School of Integrated Circuits, Peking University, Beijing, China

[3]Hefei National Laboratory, Hefei, China

***Abstract*—The transmission spectrum of Voigt anomalous dispersion optical filter (VADOF) corresponds to atomic transition lines and VADOF has a smaller size and simpler structure than Faraday anomalous dispersion optical filter (FADOF). We investigate the transmission spectrum of VADOF under different magnetic fields, temperatures and laser intensities. The results show that as the magnetic field increases, the transmittance of VAODF transmission spectrum decreases. At low temperatures, the transmittance of VAODF transmission spectrum becomes larger with the increase of temperature. With the increase of laser intensity, the transmission spectrum of VAODF becomes smoother, and the number of peaks becomes fewer. VADOF can be used as a frequency-selective element to build external-cavity diode lasers (ECDLs), which automatically align the laser frequency to the atomic transition lines and are more compact than Faraday lasers.**

Keywords—magneto-optic effect, Voigt anomalous dispersion optical filter, external-cavity diode laser

I. INTRODUCTION

Voigt anomalous dispersion optical filter (VADOF) [1]-[5] plays a very important role in optical communication and precision measurement because of its narrow bandwidth and high transmittance. Compared with the traditional Faraday anomalous dispersion optical filter (FADOF) [6], the VADOF has a simpler structure and smaller size. The magnets of VADOF don't need to be punched, and the whole pieces of magnets can be directly placed on the two sides of the atomic vapor cell. It is easier to realize a larger and more uniform magnetic field with this structure, which makes the magneto-optical effect more significant and stable.

Meanwhile, the VADOF also demonstrates its great value as a frequency selecting element for external-cavity diode lasers (ECDLs), because the transmittance spectra of VADOF correspond to atomic transition lines, and the bandwidth of the transmittance spectra of VADOF can reach several GHz. Thus, they can be well immune to mechanical vibrations and current and temperature variations, avoiding the drawbacks of conventional ECDLs. The laser frequency is also directly aligned with the atomic transition lines.

This work was funded by the China Postdoctoral Science Foundation (BX2021020); the Innovation Program for Quantum Science and Technology (2021ZD0303200).

II. METHODS

As shown in Fig. 1, we investigate the characteristics of 852 nm VADOF, which consists of a cesium vapor cell, magnets, and two polarization beam splitters (PBSs). The diameter of the cesium vapor cell is 10 mm, and its length is 30 mm. The vapor cell is heated by a heating wire and thermally isolated by Teflon. The magnets are placed on both sides of the cesium vapor cell and fixed in the Teflon box to provide a magnetic field perpendicular to the direction of light propagation. Compared to the FADOF magnets, the VADOF magnets are smaller and do not require drilling. The distance between the magnets is also shorter, allowing a larger magnetic field to be generated. Because of the magneto-optical effect, the polarization direction of laser rotates inside the cesium vapor cell, and the PBSs placed on both sides of the VADOF can select a laser whose frequency corresponds to the atomic transition lines. We used a grating laser to probe the transmission spectrum of the VADOF. The grating laser is divided into two beams by the PBS, and one beam is detected by the photoelectric detector (PD) after passing through the VADOF. The other beam is used to]

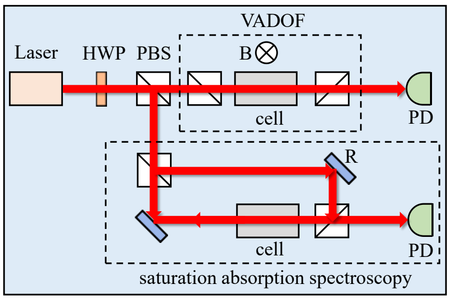

Fig. 1. Schematic of the experiment setup. The 852 nm VADOF consists of a cesium vapor cell, magnets, and two PBSs. HWP: half wave plate, PBS: polarization beam splitter, cell: cesium vapor cell, PD: photoelectric detector, R: high-reflection mirror, B: magnetic field.

Firstly, we investigate the characteristics of the transmission spectra of VADOF under different magnetic fields. The transmission spectrum of VADOF is detected at magnetic fields of 2000 Gs, 2500 Gs and 3500 Gs, respectively. The temperature of the cesium cell is fixed at 62°C, and the laser intensity is fixed at 10 mW/mm^2. As shown in Fig. 2, When the magnetic field is low, the transmission spectrum of VADOF mainly consists of four transmission peaks, and the transitions $6s^2S_{1/2}|F=3\rangle-6p^2P_{3/2}$ and $6s^2S_{1/2}|F=4\rangle-6p^2P_{3/2}$ correspond to two transmission peaks, respectively. When the magnetic field is larger, the magneto-optic effect is more obvious, so these transmission peaks are split and the bandwidth of individual peaks becomes smaller. As the magnetic field becomes larger, the transmittance of the transmission peaks decreases.

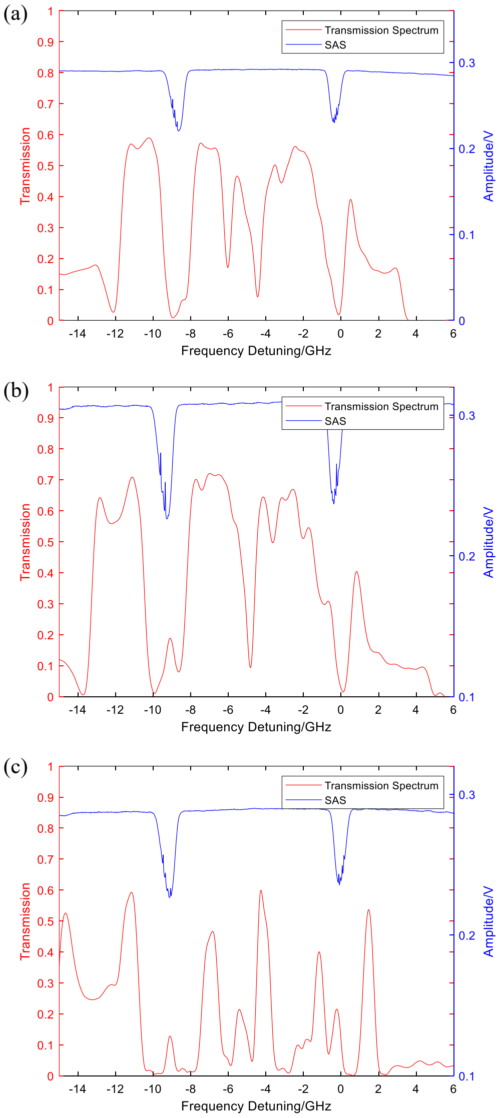

Fig. 2. VADOF transmission spectra at different magnetic fields. The magnetic fields in three figures are 2000 Gs, 2500 Gs, and 3500 Gs from top to bottom. The temperature of the cesium cells is set at 62 °C, and the laser intensity is set at 10 mW/mm^2.

Firstly, we investigate the characteristics of the transmission spectra of VADOF under different magnetic fields. The transmission spectrum of VADOF is detected at magnetic fields of 2000 Gs, 2500 Gs and 3500 Gs, respectively. The temperature of the cesium cell is fixed at 62°C, and the laser intensity is fixed at 10 mW/mm^2. As shown in Fig. 2, When the magnetic field is low, the transmission spectrum of VADOF mainly consists of four transmission peaks, and the transitions $6s^2S_{1/2}|F=3\rangle-6p^2P_{3/2}$ and $6s^2S_{1/2}|F=4\rangle-6p^2P_{3/2}$ correspond to two transmission peaks, respectively. When the magnetic field is larger, the magneto-optic effect is more obvious, so these transmission peaks are split and the bandwidth of individual peaks becomes smaller. As the magnetic field becomes larger, the transmittance of the transmission peaks decreases.

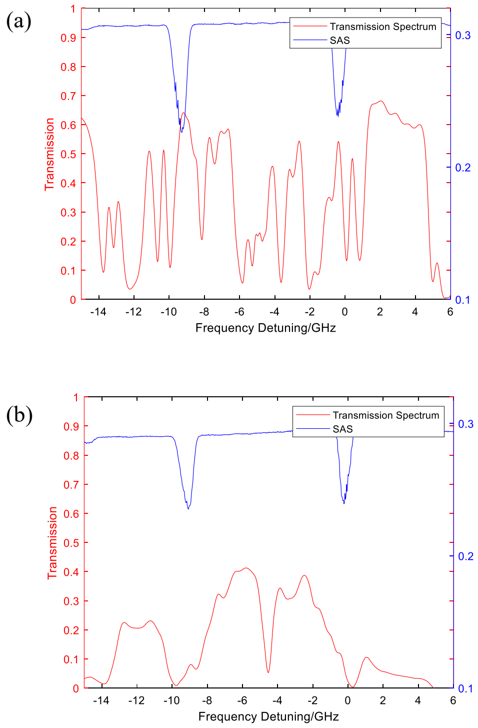

Fig. 3. VADOF transmission spectra at different laser intensity. The laser intensities in two figures are 10 mW/mm^2 and 200 mW/mm^2 from top to bottom. The magnetic fields is set at 2000 Gs, and the temperatures of the cesium cell is set at 80℃.

We investigate the transmittance of the VADOF transmission spectra at different laser intensities. We obtain the transmission spectrum of VADOF at 10 mW/mm^2 and 200 mW/mm^2, respectively. The magnetic field of the cesium cells is fixed at 2000 Gs, and the temperature of the cesium cells are fixed at 80℃. As shown in Fig. 3, an increase in laser intensity leads to a decrease in the transmittance of the transmission spectrum. The increase of laser intensity also reduces the number of transmission peaks in the transmission spectrum, which makes the transmission spectrum become smoother. We get the transmission spectra of VADOF at different magnetic fields and temperatures, and this rule is generally applicable.

We also investigate the characteristics of the VADOF transmission spectrum at different temperatures. As shown in Fig. 4, at temperatures lower than 68 °C, the transmittance of the VADOF transmission spectrum increases with the temperature of the vapor cell, and the transmission spectrum always consists of four peaks. When the temperature is greater than 68 °C, the VADOF transmission spectrum becomes more complex and the number of transmission peaks becomes larger, which is due to the more pronounced

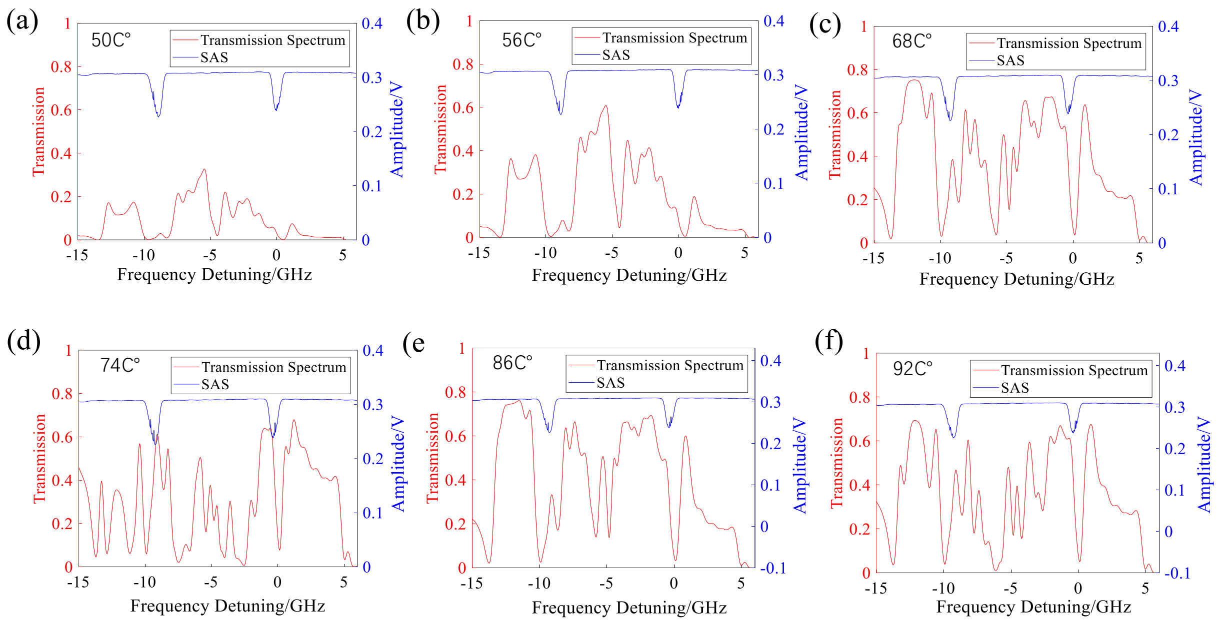

Fig. 4. VADOF transmission spectra at different temperatures. The magnetic field is set at 2500 Gs, and the laser intensity is set at 10 mW/mm^2. The VADOF transmission spectra at 62℃ and 80℃ are shown in Fig. 2 and Fig. 3

magneto-optic effect caused by the increase in temperature. At temperatures between 50 and 80 °C, the transmittance of the corresponding transmission peak at the transition $6s^2S_{1/2}|F=4\rangle-6p^2P_{3/2}$ is increasing.

III. Discussion

The transmission peaks of the VADOF correspond to atomic transition lines. If an ECDL is built using VADOF as a frequency-selective element, the output frequency of the laser will naturally correspond to that of atomic transition lines. This characteristic has been demonstrated in Faraday lasers [7]-[9], while the VADOF is more compact and smaller in size. Therefore a laser with VADOF as the frequency-selective element will be smaller than the Faraday laser. After comparison, VADOF at some parameters can be tried to build a ECDL, such as the VADOF at a magnetic field of 2500 Gs and a temperature of 80 °C.

IV. Conclusion

We investigate the properties of VADOF at different magnetic fields, laser intensities, and temperatures. An increase in the magnetic field leads to a decrease in the transmittance of the transmission peaks of VADOF. An increase in laser intensity causes the transmission spectrum to become smoother and decreases the transmittance of the transmission spectrum. An increase in temperature leads to an increase in transmittance. In addition, the VADOF exhibits the possibility of being used as a frequency-selective element to build 852 nm ECDLs, whose frequency can automatically correspond to the atomic transition lines for easy operation.

References

[1] J. Menders, P. Searcy, K. Roff, and Eric Korevaar, "Blue cesium Faraday and Voigt magneto-optic atomic line filters," Opt. Lett. vol. 17, pp. 1388-1390 , 1992.

[2] F. A. Jenkins, and H. E. White, "Fundamentals of optics." Indian J. Phys., vol. 25, pp. 265-266, 1957.

[3] F. S. Ponciano-Ojeda, F. D. Logue, and I. G. Hughes, J. Phys. B, vol. 54, pp. 015401, 2021.

[4] J. Keaveney, F. S. Ponciano-Ojeda, S. M. Rieche, M. J. Raine, D. P. Hampshire, and I. G. Hughes, “Quantitative optical spectroscopy of ^{87}Rb vapour in the Voigt geometry in DC magnetic fields up to 0.4 T.”, J. Phys. B, vol. 52, pp.055003, 2019.

[5] K. Muroo, T. Matsunobe, Y. Shishido, Y. Tukubo, and M. Yamamoto, JOSA B, vol. 11, pp. 409, 1994.

[6] Y. Ohman, “On some new auxiliary instruments in astrophysical research vi. a tentative monochromator for solar work based on the principle of selective magnetic rotation,” Stockholms Obs. Ann, vol. 19, pp. 9–11, 1956.

[7] X. Miao, L. Yin,W. Zhuang, B. Luo, A. Dang, J. Chen, and H. Guo, “Note: Demonstration of an external-cavity diode laser system immune to current and temperature fluctuations,” Rev. Sci. Instrum., vol. 82, pp. 086106, 2011.

[8] P. Chang, Y. Chen, H. Shang, X. Guan, H. Guo, J. Chen, and B. Luo, “A Faraday laser operating on Cs 852 nm transition,” Appl. Phys. B, vol. 125, pp. 1–6, 2019.

[9] M. D. Rotondaro, B. V. Zhdanov, M. K. Shaffer, and R. Knize, “Narrowband diode laser pump module for pumping alkali vapors,” Opt. Express, vol. 26, pp. 9792–9797, 2018.