Optimization of Faraday Laser's Performance by Adjusting Incident Light Intensity

Zhiyang Wang, Huifang Hou, Hangbo Shi, Zijie Liu, Xiaomin Qin, Zhihong Gao, Tiantian Shi, and Jingbiao Chen
State Key Laboratory of Advanced Optical Communication Systems and Networks, School of Electronics
Peking University
Beijing, China
tts@pku.edu.cn, jbchen@pku.edu.cn

***Summary*—We propose an experimental scheme for optimizing the Faraday laser's performance, including short- as well as long-term frequency stability, the range of wavelength with the change of laser diode's current, the stability of Faraday laser's output power, and so on. We can change the intensity of the light that is incident into the Faraday anomalous dispersion optical filter (FADOF) and the output coupler by putting two half-wave plates in the laser cavity, before the first polarizer and the second polarizer of FADOF, respectively. Since the Faraday laser's performance directly corresponds to the light intensity injected into the external cavity, we can optimize it through the change of light intensity.**

Keywords—Faraday anomalous dispersion optical filter (FADOF); Faraday laser; Laser performance

I. INTRODUCTION

Faraday anomalous dispersion optical filter (FADOF) is an atomic filter that was reported in 1956 by Öhman [1], he noticed that the resonant Faraday effect combined with two crossed polarizers placed before and after the vapor cell which is surrounded with an axial magnetic field could be used to achieve the filter's function. Since the theorical model was established as well as the experimental apparatus was achieved [2,3], FADOF was revived and a lot of researchers were interested in it, finally leading to great development. It can be used in a lot of applications, such as atmospheric lidar sensing systems [4,5], free space optical communications [6,7], quantum key distribution [8], and so on. Besides, it can also be used to achieve frequency selection in external cavity diode lasers (ECDLs) [9-17], which are named as Faraday laser [18]. Ideally, Faraday laser is immune to the fluctuations of laser diodes' temperature and current because FADOF can limit the cavity mode to the Doppler-broadened atomic line. FADOF directly corresponds to the performance of Faraday lasers. Light intensity is an important parameter that affects the profile of FADOF's transmission spectra, when the light intensity is weak, the pumping effect of atoms inside FADOF can be negligible [19]. While in the application of Faraday lasers, FADOF needs to be placed inside the laser's external cavity, so the signal power injects into it is usually at least at the level of mW with a diameter of several mm. Under this condition, the pumping effect among hyperfine states cannot be ignored because the system does not satisfy the weak signal condition [20]. These works [21,22] have proved that the transmission spectra of FADOF in weak and strong signal conditions vary significantly through practical experiments. The existing theorical modes used to calculate the profile of FADOF's transmission spectra are also based on the weak signal condition, and Faraday lasers have potential applications in a lot of areas, such as atomic clocks, atomic magnetometers, cold atoms, atomic gravimeters, and so on. It is necessary to experimentally optimize the performance of Faraday lasers by changing the light intensity injected into the external cavity.

Here, we propose an experimental scheme to get the relationship among the signal intensity injected into the external cavity, the intensity percentage used to achieve feedback, and the performance of Faraday lasers. Through changing the light intensity mentioned above, we can compare the performance, such as short- as well as long-term frequency stability, the range of wavelength with the change of laser diode's current, and the stability of Faraday laser's output power, under different light intensity. This method can be used to find the best light intensity condition for Faraday lasers under different temperature and magnetic field in FADOF, thus can optimize the Faraday lasers' performance.

II. EXPERIMENTAL PRINCIPLE AND SETUP

The experimental scheme used to optimize the performance of Faraday lasers is shown in Fig. 1. The Faraday laser is composed of an antireflection-coated laser diode (ARLD), a Faraday anomalous dispersion optical filter (FADOF), and an output coupler. Two half-wave plates (HWP) are placed before the first and second polarizing beam splitter (PBS), respectively. The first HWP combined with the first PBS can tune the signal intensity injected into the external cavity. The second HWP combined with the second PBS can tune the signal intensity used to establish the feedback, which means that the signal intensity inside the external cavity can be changed as needed. In this way, the intensity ratio of p-polarization and s-polarization can also be obtained, and the stability of output power could be estimated through it. When we remove the HWP2, the phase difference between p-polarization and s-polarization could be used to estimate the Faraday rotation angle through Faraday rotation spectroscopy [23]. And this information could also be used to improve the performance of Faraday lasers.

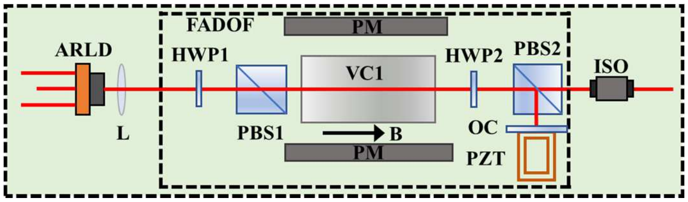

Figure 1. The experimental scheme used to optimize the performance of Faraday lasers. ARLD: antireflection-coated laser diode; L: lens; HWP: half-wave plate; PBS: polarizing beam splitter; PM: permanent magnet; ISO: isolator; OC: output coupler; PZT: piezoelectric transducer.

III. Experimental Results

We measured the transmission spectrum under different incident light intensities to get the influence of light intensity to transmission profile. Fig. 2 shows the FADOF's transmission spectrum under different incident light intensities, and the working parameters of this FADOF are 30 mm cell length, 1000 Gs working magnetic strength, 52 °C vapor-cell temperature, respectively. The vapor cell is filled with pure cesium atoms. It was shown that the transmission profile of FADOF is influenced by the incident light intensity. And when the incident light intensity is weak, there will be two peaks with the similar transmittance. The transmittance will change to the smallest one when the incident light intensity is change to the biggest level. The peak transmission occurs when the incident light intensity is at the middle level, so in the application of Faraday laser, it will be a big problem need to be improved.

Figure 3 shows the FADOF's transmission spectrum under different incident light intensities, and the working parameters of this FADOF are 30 mm cell length, 900 Gs working magnetic strength, 69°C vapor-cell temperature, respectively. The vapor cell is filled with cesium atoms as well as 10 torr Ar. Compared with the FADOF whose cell is only filled with pure cesium atoms, the transmission profiles are smoother and the peaks are more remarkable. The peak transmission also occurs when the incident light intensity is at the middle level. And the transmittance will also be the smallest one when the light intensity is at the biggest level.

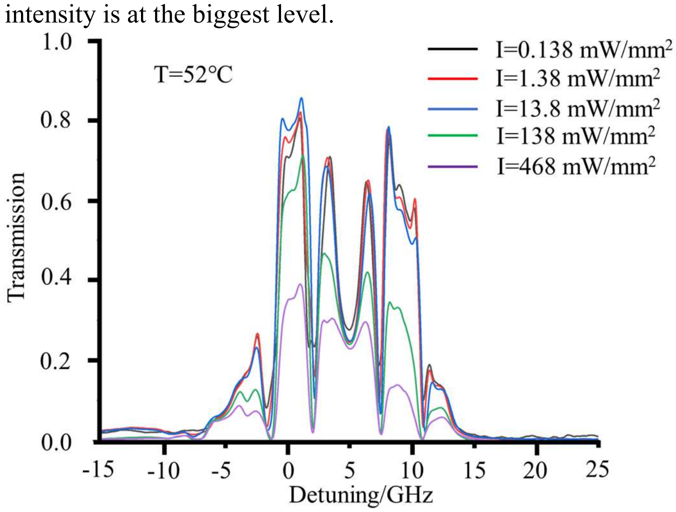

Figure 2. Transmission spectrum of the FADOF with 30 mm cell length, 1000 Gs working magnetic strength, 52 °C vapor-cell temperature, and the vapor cell is filled with pure cesium atoms.

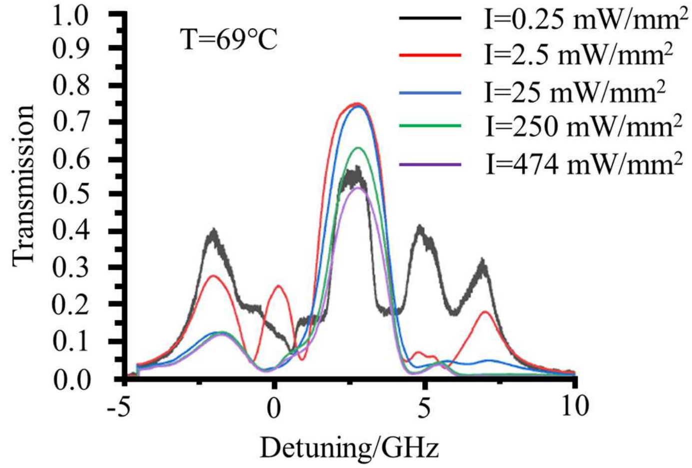

Figure 3. Transmission spectrum of the FADOF with 30 mm cell length, 900 Gs working magnetic strength, 69 °C vapor-cell temperature, and the vapor cell is filled with cesium atoms as well as 10 torr Ar.

IV. Discussion

In the application of Faraday lasers, the free spectral range (FSR) is usually at the level of several hundred MHz, which means that the tunable range (range of no mode hops) of wavelength is at the same level. The wavelength tunable range of Faraday lasers is an important aspect to expand the applicable fields of it. The experimental scheme proposed in this paper may be can also be used to adjust the Faraday lasers' wavelength for the profile of FADOF's transmission spectra directly corresponding to the light intensity injected into the external cavity. The profile of FADOF's transmission spectra will change as the intensity changes, so the wavelength will change at the same time. Further research will focus on it and try to make clear the relationship between light intensity and wavelength in so-called strong signal condition. And we will try to make clear what the transmission profile under the application of Faraday laser is to improve the Faraday laser's performance. In the future, modulated transfer spectroscopy (MTS) can be used to stabilize the frequency of Faraday lasers. Compared with the PDH-locked method, it can be more compact with lower cost.

V. Conclusion

We propose an experimental scheme used to optimize the performance of Faraday laser in the change of light intensity. We measured the transmission profile of FADOF under different incident light intensities to get the influence of light intensity on the profile. Compared with the conventional Faraday lasers, we add two HWPs inside the external cavity to achieve optimization. And this maybe can be used to tunable the wavelength of Faraday lasers. Also, such an optimized Faraday laser is expected to improve the laser power stability to 10^{-7} Hz$^{-1/2}$ level.

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