A Scheme of 852 nm Faraday Laser with Kilometer Level Cavity Length

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***Summary*—We propose an experimental scheme for reducing the Faraday laser's frequency range of mode hop, which will both optimize the short- and long-term frequency stability. By increasing the cavity length of Faraday laser up to 1.2 km, the free spectral range (FSR) will be decreased at the same time, so that at least one cavity mode will always be near the peak transmission of the Faraday anomalous dispersion optical filter (FADOF). Because the FADOF is used as the frequency selective element in external cavity of Faraday laser, if there can always be a cavity mode near its peak transmission, the frequency jumps are hard to occur.**

Keywords—Faraday anomalous dispersion optical filter (FADOF); Faraday laser; long cavity length

I. Introduction

Since the Faraday anomalous dispersion optical filter (FADOF) was reported in 1956 by Öhman [1], there are a lot of applications, such as free space optical communications [2,3], atmospheric lidar sensing systems [4,5], quantum key distribution [6] and so on based on it for its advantages of high transmission, high noise rejection. Besides, the first application of FADOF is the intra-cavity frequency stabilization of the dye laser [7-10]. With the development of technology, FADOF also provides an alternative way to achieve frequency selection in external cavity diode lasers (ECDLs) [11,12]. Because FADOF can limit the transmitted cavity modes to the Doppler-broadened atomic line, ECDLs used the FADOF as the frequency-selective element have immunity to the fluctuations of laser diodes' temperature and current. Since 2015 when "Faraday laser" was named [13] to now, big steps have been made in the performance of Faraday lasers [14-21]. However, frequency jump in Faraday lasers is an important problem needs to be improved. The main reason for frequency jump in Faraday laser is that multiple cavity modes are usually contained in the transmission spectrum of FADOF, so that mode hop will occur because the cavity length is not stable enough. One way to avoid mode hop is to use a short cavity length and make the Faraday laser's free-spectral range is bigger than the transmission profile of FADOF, so that there will only one cavity mode in the transmission spectrum of FADOF. This method not only eliminate the mode hop, but also ensure the tunable range of Faraday laser. The disadvantage of this method is that the existing cavity mode may be not near the peak transmission spectrum of FADOF, so that a piezo-electric transducer (PZT) is needed to tunable the cavity when the Faraday laser is operated. The other method is to increase laser cavity length and the FSR will be decreased at the same time, so that at least one cavity mode will always be near the peak transmission of the FADOF. Although this method can not avoid mode hop and frequency jump will still exist, if the laser cavity is long enough, the FSR will decrease to kHz level. The relationship between long-term frequency stability of Faraday laser and the stability of cavity length will also be weakened [7]. The FADOF transmission profile is usually up to several MHz level or even GHz level, it is much larger than the FSR and this situation will ensure what has been mentioned above. As depicted in [12], when the laser cavity length increased from 1.2 m to 6 m, the performance of frequency stability also improved. In 2016, Z. Tao et al. [15] achieved a 780 nm Faraday laser using 1.2 km fiber as an extended cavity, and the laser frequency is always kept in the center of the transmission peak assigned to $5S_{1/2}(F=2)$-$5P_{3/2}(F'=1,3)$ of Rb.

Here, we propose a scheme for an 852 nm Faraday laser with a 1.2 km cavity length in free space or in fiber. The FSR can be calculated as FSR=c/2nl, where c is the speed of light in vacuum, n is the refractive index of air, l is the cavity length. If we assume n=1, so we can get FSR=125 kHz, which is much smaller than the transmission profile of FADOF. And the frequency stability, both short-term, and long-term will be increased at the same time.

II. Experimental Principle and Setup

The relationship between cavity modes and the transmission profile of FADOF is shown in Fig. 1. We set the frequency interval among cavity modes to 1.25 GHz as the example, when it becomes to 125 kHz, we can find that there will always be a cavity mode near the peak transmission spectrum, and the frequency jump will be restrained.

The experimental scheme is shown in Fig. 2. The 852 nm Faraday laser is mainly composed of an antireflection-coated laser diode (ARLD), a FADOF, and a corner-cube-reflector. The modulation transfer spectroscopy (MTS) is used to lock the frequency of Faraday laser to the atomic transition line. Besides, the Fabry-Pérot interferometer and wavelength meter is also used to evaluate the performance of the Faraday laser.

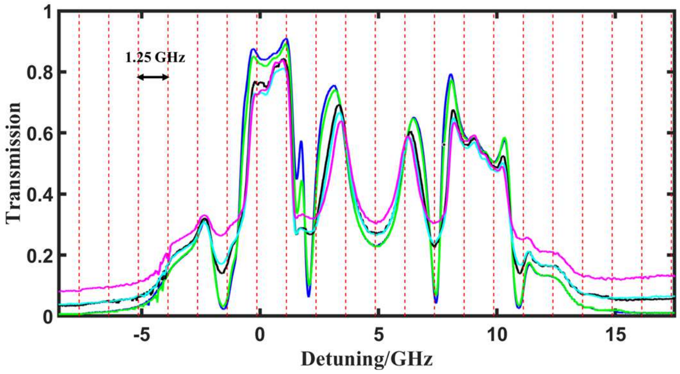

Figure 1. Transmission spectrum of FADOF with 1000 Gs working magnetic field strength, as well as 56.1 °C vapor-cell temperature; the red dotted line represents the cavity mode with 1.25 GHz FSR; the blue solid line corresponds to the light intensity of 4.91 mW/mm2; the green solid line corresponds to the light intensity of 1.96 mW/mm2; the black solid line corresponds to the light intensity of 0.819 mW/mm2; the turquoise solid line corresponds to the light intensity of 0.121 mW/mm2, the purple solid line corresponds to the light intensity of 0.05 mW/mm2

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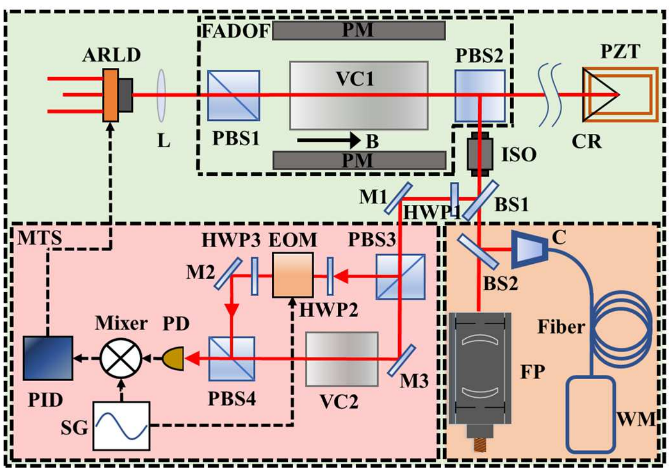

Figure 2. Experimental setup for an 852 nm Faraday laser with 1.2 km cavity length in free space. ARLD: antireflection-coated laser diode; L: lens; PBS: polarizing beam splitter; PM: permanent magnet; ISO: isolator; CR: corner-cube-reflector; PZT: piezoelectric transducer; BS: beam splitter; C: collimator; FP: Fabry-Pérot interferometer; WM: wavelength meter; HWP: half-wave plate; M: mirror; EOM: electro-optic modulator; VC: Cs vapor cell; PD: photodetector; PID: proportion-integral-derivative locking system; SG: signal generator; MTS: modulation transfer spectroscopy.

III. Experimental Results

We built an 852 nm Faraday laser whose cavity length is about 14 m in our laboratory. The parameters of the FADOF we use are 1000 Gs working magnetic field, 70°C temperature, 30 mm length, respectively. And when we fix the drive current of laser diode to 103 mA, we get both Fig. 3 and Fig. 4. Fig. 3 shows the wavelength fluctuations with time, Fig. 4 shows the wavelength fluctuations with the change of FADOF's temperature. From Fig. 3 we can see that the maximum difference is 1.65 pm within five hour's running, and when we change the temperature of FADOF from 70°C to 83°C, we can see that the output wavelength can be tunable from 852.375 nm to 852.379 nm, and the output power are always bigger than 30 mW.

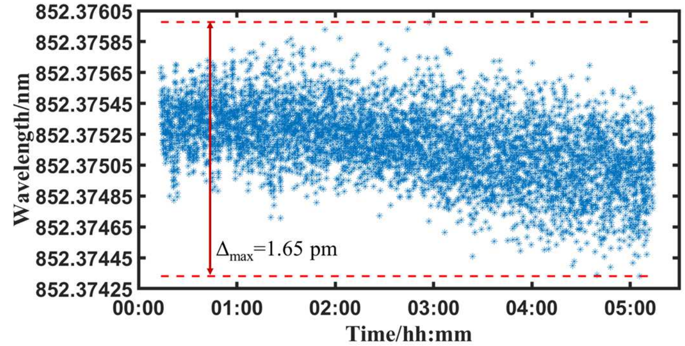

Figure 3. Wavelength fluctuations with time when we fix the drive current of laser diode to 103 mA.

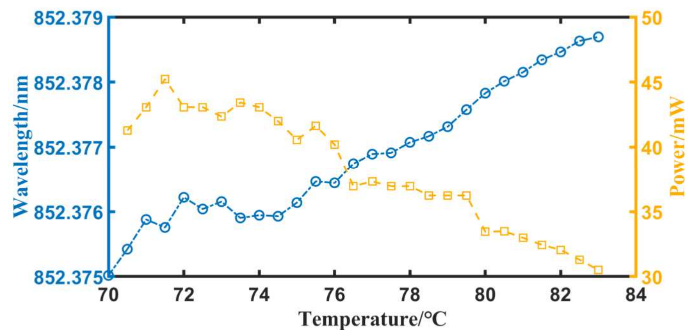

Figure 4. Wavelength and power fluctuations with the change of FADOF's temperature when we fix the drive current of laser diode to 103 mA.

IV. Discussion

Because of the decrease in FSR, the frequency jump can be restrained and the performance of Faraday laser will be improved at the same time. We achieved an 852 nm Faraday laser with 14 m cavity length in free space in our laboratory, and we need to do more work in the future for the kilometer level cavity length in free space or in fiber.

V. Conclusions

In this paper, we propose an experimental scheme for an 852 nm Faraday laser with a 1.2 km cavity length in free space or in fiber, therefore the FSR will decrease to 125 kHz and the frequency jump of this Faraday laser will be restrained. And we built a 14 m cavity length Faraday laser in our laboratory for the verification of oscillation. From this Faraday laser, we can see that the fluctuations of wavelength with time is only 1.65 pm, and the oscillation can always be established when the temperature of FADOF change from 70°C to 83°C, the output power can also always bigger than 30 mW. Next step, we will improve our experimental setup, such as using a powerful collimator for the collimation performance to ensure oscillation. We believe that when the cavity length change to the level of kilometer, the performance of the Faraday laser will be improved in a lot of aspects.

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