A 780 nm Dual-Frequency Faraday Laser

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***Abstract*—We demonstrate a dual-frequency (DF) Faraday laser operating on 780 nm using an ^{87}Rb Faraday anomalous dispersion optical filter (FADOF) as the frequency selection element. The frequencies of the two modes correspond to the transition of ^{87}Rb $5^2S_{1/2}$ (F=1) to $5^2P_{3/2}$ and $5^2S_{1/2}$ (F=2) to $5^2P_{3/2}$, respectively. The output laser wavelength has good robustness to the laser diode's current and temperature fluctuations. The frequency difference between the two modes is tunable with the temperature of ^{87}Rb vapor cell and cavity length. Besides, the two modes share good coherence with the most probable linewidth of the beat-note spectra being 3 kHz. Such a 780 nm DF Faraday laser can be used in precision measurement, such as, laser frequency stabilization, optical microwave generation, and coherent population trapping (CPT) atomic clocks.**

Keywords—Faraday anomalous dispersion optical filter (FADOF), Faraday laser, dual-frequency laser

I. Introduction

Semiconductor laser system with fixed frequency and high stability is essential in quantum precision measurement and laser spectroscopy. In order to detect the quantum transition line accurately, the laser linewidth should be narrower than the linewidth of the transition line. In addition, the laser is required to have good monochrome and high frequency stability. The external cavity diode laser (ECDL) has the advantages of narrow linewidth, high frequency stability and tunable frequency compared with the traditional semiconductor lasers, which well meets the above requirements and is the preferred laser light source for quantum precision measurement. The commonly used ECDLs use gratings [1], interference filters [2], Fabry-Pérot (FP) etalons [3] and so on as frequency selection devices, which can achieve narrow linewidth and tunable frequency. However, they are easy to be affected by the ambient factors, such as the diode current and temperature fluctuations and mechanical vibration, which lead to problems in outdoor and long-term applications.

Faraday laser is an external cavity semiconductor laser using FADOF as the frequency selection element. With the advantages of narrow linewidth, strong robustness of output wavelength to laser diode temperature and current, and tunable frequency to atomic resonance spectrum, it has quite promising applications in quantum precision measurement, atomic clock, laser spectroscopy, and so on [4]. Faraday lasers mainly operate in single-frequency mode [4] [5] [6]. If the laser gain bandwidth could cover two peaks of the FADOF transmission spectrum and the transmittance of the two peaks approximately equal, an output laser with two modes can be obtained, thus further expanding the application range of the Faraday laser. An 852 nm dual-frequency (DF) Faraday laser working on the Cs D2 line was proposed in 2021, with two modes corresponding to Cs's $6^2S_{1/2}$ ($F = 4$) → $6^2P_{3/2}$ and $6^2S_{1/2}$ ($F = 3$) → $6^2P_{3/2}$ transition, respectively [7]. The frequency difference between the two laser modes is tunable within 1.4 GHz by changing the Cs cell's temperature, and the most probable linewidth of the beat-note frequency is 902.95 Hz. In 2022, the frequency stabilization of the 852 nm dual-frequency Faraday laser was realized, where the linewidth of the beat-note was narrowed to 85 Hz after locking [8]. It has potential applications in microwave atomic clocks and optical microwave sources.

In this work, a 780 nm DF Faraday laser based on ^{87}Rb FADOF is realized for the first time. The frequencies of the two laser modes depend on the two transmission peaks of the FADOF transmittance spectrum, which are corresponding to $5^2S_{1/2}$(F=1) → $5^2P_{3/2}$ and $5^2S_{1/2}$(F=2) → $5^2P_{3/2}$ transitions. The wavelength of one of the output laser modes is measured, which shows good robustness to the diode current and temperature fluctuations. The frequency difference between the two modes is tunable, and the two modes share good coherence with a 3 kHz beat-note linewidth. Such a 780 nm DF Faraday laser

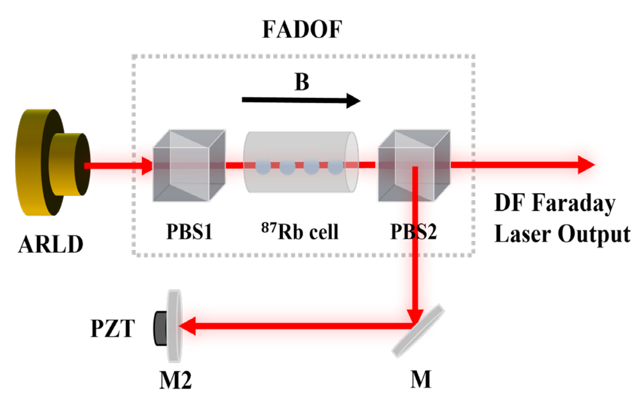

Figure 1. Experimental setup for the 780 nm DF Faraday laser in folded cavity scheme. The DF Faraday laser consists of an anti-reflection coated laser diode (ARLD), a Faraday anomalous dispersion optical filter (FADOF), a reflection mirror (M), and an external-cavity mirror (M2) mounted on a piezoelectric ceramic (PZT). The FADOF is composed of a pair of polarizing beam splitters (PBS1 and PBS2), a vapor cell filled with ^{87}Rb atoms, four bar permanent magnets forming a homogeneous axial magnetic field, and a temperature control module for the ^{87}Rb cell.

extends the wavelength range of the DF Faraday laser, and can be used in atomic physics experiments and applications.

II. METHODS

We demonstrate a 780 nm DF Faraday laser in folded cavity scheme, as shown in Fig. 1. It is composed of an anti-reflection coated laser diode (ARLD), a FADOF, a reflection mirror M and an external-cavity mirror M2 glued with a piezoelectric ceramic (PZT). The ARLD is used as the gain medium, and FADOF is located in the cavity to realize frequency selection. The resonant cavity is composed of the rear facet of ARLD M1 and the external-cavity mirror M2 with a reflectivity of 99% at 780 nm. The total cavity length of the laser is 60.5 cm, and it is tunable by the piezoelectric ceramic (PZT). The ARLD is coated with anti-reflection film to eliminate the interference of the internal cavity modes.

The key to generating a dual-frequency laser is to adjust the magnetic field and temperature of the atomic vapor cell in FADOF, to produce two approximately equal transmission peaks corresponding to the two transitions of $5^2S_{1/2}$ (F=1) → $5^2P_{3/2}$ and $5^2S_{1/2}$ (F=2) → $5^2P_{3/2}$. After simulations and experiments, we set the magnetic field at 300 Gs and the temperature at 57 ℃. The FADOF consists of a pair of polarizing beam splitters (PBSs), a vapor cell filled with ^{87}Rb atoms for 30 mm in length and 15 mm in diameter, four bar permanent magnets forming a 300 Gs axial magnetic field, and a temperature control module with control precision of 0.1°C. The light emitted from ARLD is polarization-rotated by FADOF. Then, the filtered light with frequency corresponding to the FADOF transmission peak can be reflected by PBS2, and passes back to ARLD under the reflection of M and M2. Finally, the 780 nm DF Faraday laser outputs from PBS2. The wavelength and beat-note signal of the output laser can be detected by the wavelength meter (Bristol 671A) and the microwave spectrum analyzer (Keysight N9935A) together with the photodetector (Thorlabs PDA8GS), respectively.

III. DISCUSSION

After demonstrating the 780 nm DF Faraday laser, we measured its output power, wavelength and beat frequency signal of two laser modes. Figure 2 shows the characteristics of the output laser power. The threshold current of the 780 nm DF Faraday laser is about 55 mA, and the maximum output power reaches 43 mW. The wavelength characteristic is measured as shown in Figs. 3(a) and (b). Limited by the performance of the wavelength meter, only the mode with higher intensity can be measured and displayed, which is related to $5^2P_{1/2}$ (F=2) → $5^2P_{3/2}$ transition. Under the condition of laser diode current ranging from 55 mA to 129 mA, the central laser wavelength of the mode is 780.2458 nm, with a standard derivation of 0.6 pm. When the laser diode temperature change from 15°C to 30°C, the output laser wavelength varies within 0.8 pm. It shows good robustness of the DF Faraday laser wavelength to the diode current and temperature variations. The frequency of the beat-note signal of the two modes is close to the frequency difference between ^{87}Rb ground state $5^2P_{1/2}$ F=1 and F=2, and it is tunable by changing the cell temperature and the cavity length, as these changes would change the transmission spectrum of the FADOF.

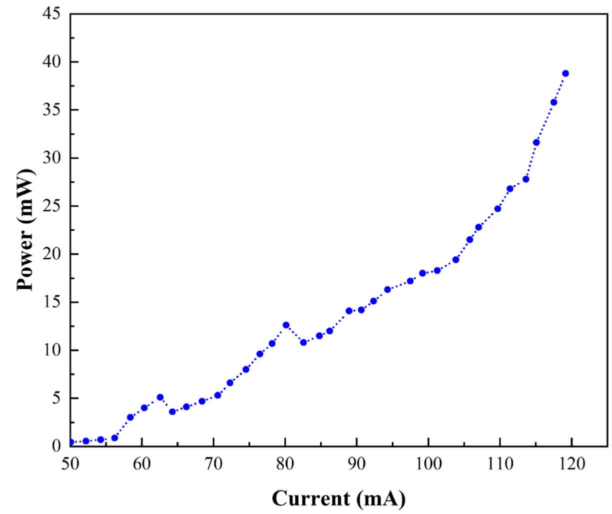

Figure 2. Laser output power as a function of ARLD current at 21℃.

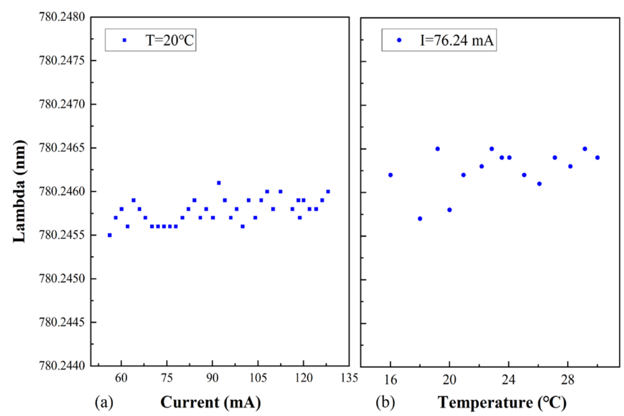

Figure 3. (a) Laser wavelength of one single mode as a function of ARLD current, where the ARLD temperature is 20℃. (b) Laser wavelength of one single mode as a function of ARLD temperature, where the ARLD current is 76.24 mA.

Under a fixed vapor cell temperature at 53℃ and cavity wavelength at 60.5 cm, we measured the power spectrum of the DF Faraday laser two modes beat-note signal. The measuring span and frequency resolution bandwidth (RBW) of the spectrum analyzer are set to 0.9 MHz and 750 HZ, respectively. 75 groups of beat-note frequency spectrum were measured here, and fitted with Lorentzian curve to evaluate the linewidth. Fig. 4(b) shows the distribution of the 75 groups of beat-note linewidth, which is fitted with gaussian curve. The most probable linewidth of the beat-note signal is 3 kHz when the ^{87}Rb cell temperature remains 53℃, which indicates a good coherence between the two modes. Fig. 4(a) shows a typical beat-note spectrum with the linewidth of 3 kHz.

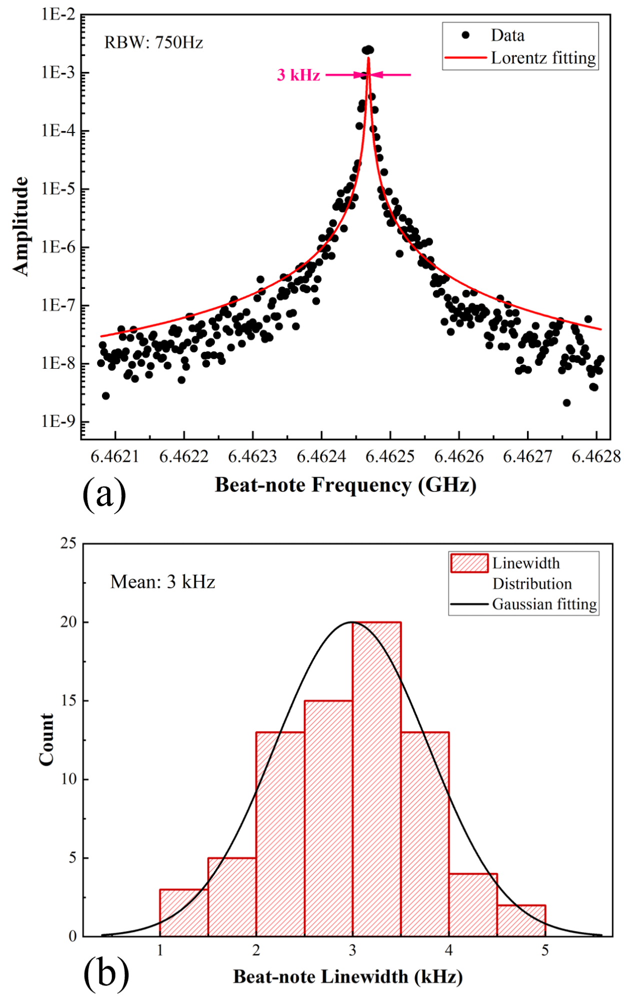

Figure 4. (a) An example of the beat-note signal between two modes of 780 nm DF Faraday laser (black dots) with Lorentz fitting (red solid curve) linewidth of 3 kHz. (b) The linewidth distribution of 75 groups of beat-note spectrum between two modes of 780 nm DF Faraday laser, where the most probable linewidth is 3 kHz. The span bandwidth is 0.9 MHz, and the resolution bandwidth (RBW) is 750 Hz.

IV. Conclusions

We demonstrate a 780 nm DF Faraday laser operating on ^{87}Rb atom D2 line for the first time. The central frequencies of the two laser modes mainly correspond to ^{87}Rb FADOF transmission peaks of the ground state F=1 and F=2. The output wavelength of one laser mode fluctuates within 0.8 pm with the change of diode current and temperature. The frequency difference between the two modes is tunable with the vapor cell temperature and the laser cavity length. Furthermore, the most probable beating linewidth of the two modes is 3 kHz with vapor temperature at 53℃, which shows a good coherence between the two modes. This work extends the working wavelength range of the DF Faraday lasers, and has widely application future in laser frequency stabilization, CPT atomic clocks and optical microwave generation.

Acknowledgment

This work was supported by the Innovation Program for Quantum Science and Technology (2021ZD0303200), China Postdoctoral Science Foundation (BX2021020), and Wenzhou Major Science and Technology Innovation Key Project (ZG2020046).

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