Dual-Frequency Faraday Laser with THz Frequency Separation

Jianxiang Miao, Jia Zhang, Tiantian Shi, Duo Pan, 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

Xiumei Wang
Shen Zhen SoC Key Laboratory
PKU-HKUST Shen Zhen-Hong Kong Institution
Shenzhen, China
wangxiumei@siom.ac.cn

***Abstract*—We propose an experimental scheme for realizing a dual-frequency Faraday laser with a large frequency separation between the two output modes, on the order of several THz. By utilizing an ultra-broadband laser diode in the Faraday laser setup consisting of a Faraday Anomalous Dispersion Optical Filter (FADOF) inside the laser cavity, the laser gain covers two transmission peaks of the intra-cavity FADOF corresponding to two different transitions, for instance the 780 nm 5S1/2-5P3/2 and the 795 nm 5S1/2-5P1/2 transitions of rubidium. Since the two output modes share the same laser cavity, they should retain their frequency coherence despite the large frequency separation. This THz-separation dual-frequency Faraday laser can be utilized to simultaneously interrogate two atomic transitions, and the beat signal between the output modes can be used for high-stability THz signal generation.**

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

I. Introduction

The Faraday laser is an extended cavity diode laser that uses a FADOF as its intra-cavity frequency selection element. The frequency of the Faraday laser is determined by the transmission profile of the FADOF, and is therefore immune to current and temperature fluctuations of the laser diode [1]. When the transmission spectrum of the FADOF has two peaks of similar strength both within the laser gain bandwidth, the Faraday laser can work in the dual-frequency (DF) regime, simultaneously lasing on two frequencies. Our group realized a DF Faraday laser, with the two output modes at transmission peaks corresponding to cesium’s $6^2S_{1/2}(F = 4) \rightarrow 6^2P_{3/2}$ and $6^2S_{1/2}(F = 3) \rightarrow 6^2P_{3/2}$ transitions [2]. In such a setup, the frequency separation of the output modes is on the order of several GHz, the same order as the separation between hyperfine levels.

When the laser diode’s gain bandwidth covers two transitions, each with a FADOF transmission peak, the Faraday laser can produce output frequencies at these two transitions. In such a setup, the frequency separation between the two output modes far exceeds previous DF Faraday lasers. Compared to previous DF Faraday lasers relying on two similar-strength transmission peaks at two hyperfine components of the same transition, this two-transition setup is more robust against FADOF conditions and can operate under varied cell temperatures and magnetic field strengths, much like the single-frequency Faraday laser [3].

II. Methods

In our proposed experimental setup, we use a laser diode with a gain bandwidth of approximately 20 nm or larger, centered around 787 nm. Therefore, the laser gain covers both the 780 nm $5S_{1/2}$-$5P_{3/2}$ and the 795 nm $5S_{1/2}$-$5P_{1/2}$ transitions of rubidium. With each transition contributing a single transmission peak, the Faraday laser can achieve lasing on two modes with frequency separation of approximately 6.78 THz. Since the output modes are determined by the FADOF transmission peaks, which in turn correspond to atomic transitions, this DF Faraday laser can simultaneously interrogate two transitions of rubidium. Furthermore, with appropriate frequency stabilization of either one of the laser frequencies, the beat frequency is also stabilized and can be used for high-stability THz signal generation.

III. Discussion/Interpretation

For the rubidium $5S_{1/2}$-$5P_{3/2}$ and $5S_{1/2}$-$5P_{1/2}$ transitions, the required gain bandwidth will have to be larger than their separation of 14 nm, which is feasible with laser diodes. In other elements such as cesium, the $6S_{1/2}$-$6P_{3/2}$ and $6S_{1/2}$-$6P_{1/2}$ transitions have wavelengths 852 nm and 894 nm, requiring a gain bandwidth of over 40 nm. However, for some transitions such as the rubidium $5S_{1/2}$-$6P_{3/2}$ and $5S_{1/2}$-$6P_{1/2}$ transitions (wavelengths 420 nm and 421 nm) or the cesium $6S_{1/2}$-$7P_{3/2}$ and $6S_{1/2}$-$7P_{1/2}$ transitions (wavelengths 455 nm and 459 nm), the required gain bandwidth of the laser diode is reduced.

IV. Conclusions

In this paper, we propose an experimental setup for a DF Faraday laser simultaneously lasing on two transitions, therefore having a frequency separation on the THz level, far larger than previous DF Faraday lasers. This THz-separation dual-frequency Faraday laser can be utilized to simultaneously interrogate two atomic transitions, and the beat signal between the output modes can be used for high-stability THz signal generation.

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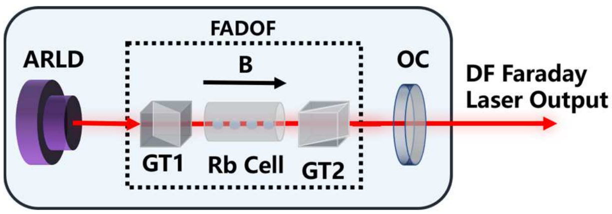

Figure 1. Experimental setup for the DF Faraday laser. The DF Faraday laser is composed of an ultra-broadband antireflection-coated laser diode (ARLD), covering the wavelength from 780 nm to 795 nm, a Faraday anomalous dispersion optical filter (FADOF), and an output coupler (OC). The FADOF consists of two orthogonal Glan-Taylor prisms (GT1 and GT2), a vapor cell filled with thermal rubidium atoms, and permanent magnets for providing a homogeneous magnetic field.

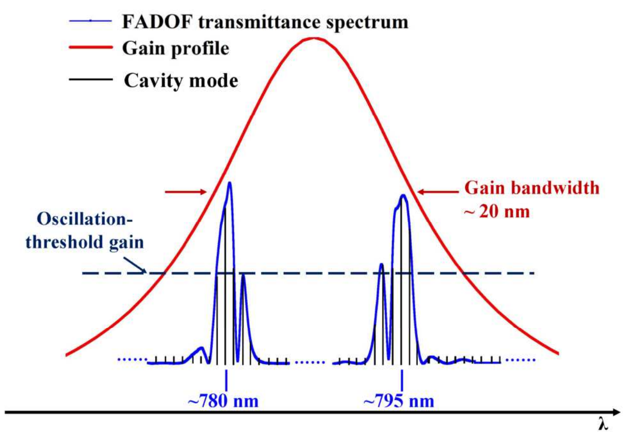

Figure 2. Two simultaneously lasing modes of the DF Faraday laser with Terahertz frequency separation. With the ultra-broadband diode laser as gain medium, two modes located within the two transmission peaks that are wide apart both achieve laser output.