A Voigt Laser Operating on Cs 852 nm Transition

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***Abstract*—We investigate a "Voigt laser" at Cs-D2 resonance line 852 nm using a Voigt anomalous dispersion optical filter (VADOF) as frequency-selecting element. The wavelength of the Voigt laser is stabilized within transmission frequency region of 852 nm VADOF, and the peak of the transmission is corresponding to Cs atomic Doppler broadened line. It works stably over a range of laser diode (LD) current from 60 to 140 mA. Moreover, the Voigt laser frequency could be selected by adjusting the cell temperature of the VADOF. With excellent frequency stability and immunity to the diode laser current and temperature, the Voigt laser could contribute to the development of the compact optical frequency standard, and can serve for the atomic clocks, atomic gravimeters, and atomic gyroscopes.**

***Keywords*—Voigt anomalous dispersion optical filter; Voigt laser; frequency stability; optical frequency standard.**

I. Introduction

High-stability diode laser system is widely required in the field of atomic physics [1, 2]. Usually, the frequency of the laser is sensitive to the laser diode (LD) current and temperature. Once the laser loses lock to a particular atomic transition line, the frequency drifts may be serious, which limits the application for long-term operation of atomic clock.

Recently, the concept of Faraday laser is proposed, which utilizes the antireflection-coated laser diode (ARLD) as the gain medium, and the Faraday anomalous dispersion optical filter (FADOF) as the frequency selective device [3]. In contrast to typical diode laser with additional control systems, the Faraday laser offers stable output frequency exactly set by the peak transmission frequency of the Faraday optical filter. The system works stably over a range of LD current from 60 to 130 mA and the LD temperature from 14 to 35 ℃, as well as the 48-h wavelength fluctuation range of no more than ± 2 pm [4]. A most probable linewidth of 17 kHz with Lorentz fitting is obtained by beating between two identical laser systems.

Different with the Faraday laser, the "Voigt laser" uses a Voigt anomalous dispersion optical filter (VADOF) as the frequency-selective element. The Voigt effect rotates the polarization direction of the passing laser by applying a magnetic field perpendicular to the direction of laser propagation [5]. Therefore, the VADOF could construct a stronger and more homogeneous magnetic field, with less volume than the FADOF. In this work, we present a Voigt laser system operating on Cs 852 nm transition, the Voigt laser works at frequencies corresponding to the highest transmission frequency region of Cs 852 nm VADOF, neither the LD current nor the LD temperature of the laser diode has significant infuence on the output frequency. This scheme is firstly used on Cs atom, like the Faraday laser, the Voigt laser could also realize compact optical frequency standard, using modulation transfer spectroscopy (MTS) for frequency stabilization in the future.

II. Methods/Results

The experimental setup is schematically shown in Fig. 1(a). The Voigt laser is composed of the Cs 852 nm VADOF, ARLD, high-refection mirror (Rc) and piezoelectric ceramic tube (PZT). The VADOF includes a Cs vapor cell, a pair of permanent magnets (M1 and M2), and a pair of crossed Glan-Taylor prisms (G1 and G2). The shape of the Cs cell in the VADOF is a cylinder with diameter of 15 mm and length of 30 mm. Pure Cs vapor is adopted as cell vapor. The light emitted from the ARLD (Eagleyard EYP-RWL-0850-00100-1500-SOT12-0000) is filtered by the VADOF and fed back into the ARLD by Rc. The laser beam outputs from the second Glan-Taylor prism (G2). The temperature of the Cs cell is controlled by an electric heating element that allows to maintain the cell temperature within 0.1℃. The permanent magnets create a static radial magnetic field of 3000 G across the Cs vapor cell. There is a 45° angle between the magnetic field direction and the laser polarization direction.

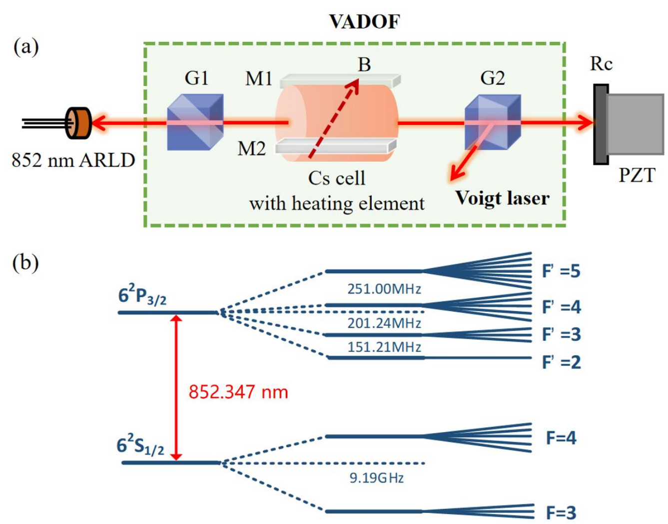

Fig. 1. (a) Schematic of the Voigt laser operating on Cs 852 nm transition. ARLD, anti-refection coated laser diode; G1 and G2, a pair of Glan-Taylor prisms; M1 and M2: a pair of permanent magnets; Rc, high-refection mirror for 852 nm; PZT: piezoelectric ceramic tube. (b) Relevant Cs energy level diagram.

The relevant energy levels of Cs atom are shown in Fig. 1(b). The ground state $6S_{1/2}$ has two hyperfine structure lines [6], e.g., F=4 and F=3, in which the central frequencies are separated by 9.19 GHz. To measure the performance of the VADOF, another homemade external cavity diode laser is used for transmittance detection. Before specific experiment, we first simulate the transmission spectrum of VADOF [7]. When the magnetic field intensity is fixed at 3000 Gs, we obtain the transmission spectrum shown in Fig. 2, with temperatures of 53 °C, 63 °C, 73 °C, and 83 °C for the vapor cell in VADOF.

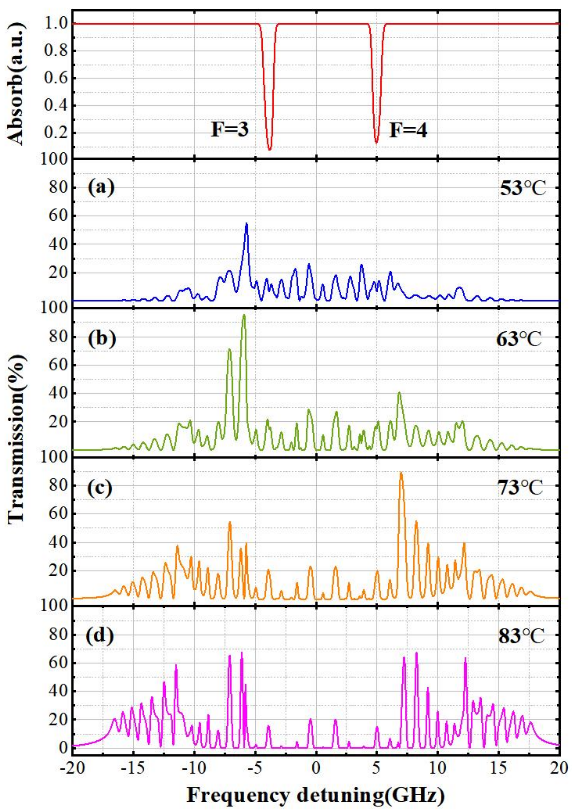

Fig. 2. The absorption spectroscopy of Cs-D2 line and the transmission spectrum of VADOF in different temperatures (The magnetic field is 3000 Gs). The diagram at the top shows F=3 and F=4 transition of Cs-D2 line. (a), (b), (c), and (d) represent the transmission spectrum at the cell temperature of 53 °C, 63 °C, 73 °C, and 83 °C, respectively.

As shown in Fig. 2, when the cell temperature is 53 °C, the laser is hard to oscillate because the peak transmission of VADOF is only 55%. When the cell temperature is 83 °C, mode hopping occurs and the working state is unstable because there are too many transmission peaks with approximately equal transmission. However, when the cell temperature is near 63 °C and 73 °C, this temperature range is more suitable for laser operation because there is only one transmission peak with a high peak transmission.

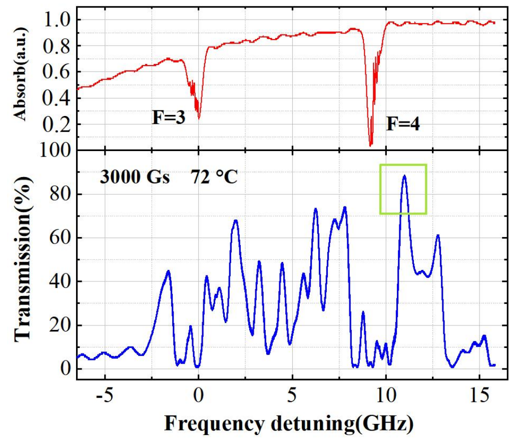

Fig. 3. Transmission spectrum of Cs 852 nm VADOF. The magnetic field is 3000 Gs, and the cell temperature is 72 °C.

Taking the simulation results as reference, the transmission spectrum of VADOF is measured experimentally, and the magnetic field intensity is still set at 3000 Gs. By changing the cell temperature over a wide range (25 °C-120 °C) and observing the changes of transmission spectrum, we finally determined that the optimal operating temperature of VADOF is 72 °C. The measured transmission spectrum is shown in Fig. 3, and the transmission peak marked by the green box correspond to the frequency point where the Voigt laser will eventually operate.

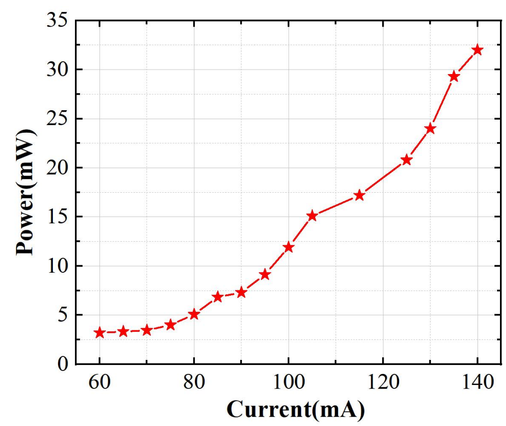

Fig. 4. Dependence of the Voigt laser's output power on current.

Under the working conditions of magnetic field of 3000 Gs and cell temperature of 72 °C, we measured the output wavelength of the Voigt laser to be 852.360 nm, which corresponds to the frequency of the highest transmission peak as shown in Fig. 3. We further measured the variation of the output power of the Voigt laser at different currents, and the measurement results are shown in Fig. 4. The Voigt laser works stably when the current is varied in the range of 60 to 140 mA.

III. DISCUSSION

The successful development of the 852 nm Voigt laster predicts potential possibility for the implementation of Voigt laser based on other alkali-metal atoms, such as Rb. In the Voigt laser system, the magnetic field of 3000 Gs is not a fixed value, then the optimal operating temperature of VADOF will also change, and accordingly, the transmission spectrum of VADOF and the working wavelength of Voigt laser will both change. Under a fixed magnetic field, the wavelength of the Voigt laser could also be selected by adjusting the cell temperature of the VADOF.

IV. CONCLUSIONS

In conclusion, a proof-of-principle Voigt laser system operating on Cs 852 nm transition is developed. By taking advantage of the transmission spectrum of the VADOF, the external control system that is usually required for a wavelength-stabilized diode laser for operating on atomic transition is no more needed. The cell temperature characteristics of the Voigt laser in a large magnetic field are explored. Results show that the VADOF works stably, and makes the Voigt laser immune to fluctuations of LD temperature and LD current. Moreover, the Voigt laser wavelength could be selected by adjusting the cell temperature. Owing to the high frequency stability and stable long-term operation, the compact Voigt laser predicts potential possibility for the application of atomic clocks [8, 9], atomic gravimeters, and atomic gyroscopes, etc.

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