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^{87}Rb D$_1$ 线法拉第反常色散光学滤波

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摘　要：为了得到在高背景噪音下对弱信号光的提取，实验研究了基于^{87}Rb D$_1$ 线 $5S_{1/2}\,F=2\rightarrow 5P_{1/2}\,F'=1$ 跃迁的 795 nm 法拉第反常色散光学滤波器．充铷的样品池所含^{87}Rb 的比例高于自然铷，样品池处在均匀的磁场中并且夹在两个相互正交的偏振片之间．入射的探测光通过样品池，与原子相互作用，由于法拉第旋转效应实现滤波功能．改变实验条件，透射结果随之明显变化．当温度从 340 K 升高到 360 K，透射谱的变化情况被细致记录，并且分析了导致透射情况变化的原因．在适当的工作温度以及磁场条件下，得到线宽为约 220 MHz 的超窄带透射谱线，谱线透过率约为 48％．^{87}Rb D$_1$ 线的实验结果优于^{85}Rb 的吸收线．

关键词：滤波器；反常色散；超精细结构；法拉第旋转
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Faraday Anomalous Dispersion Optical Filter at the ^{87}Rb D$_1$ Line

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Abstract: To obtain the weak signal light detection from the high background noise, a study on ultra-narrow bandwidth Faraday anomalous dispersion optical filter (FADOF) at the ^{87}Rb D$_1$ line, $5S_{1/2}F=2\rightarrow 5P_{1/2}\ F'=1$transmission (795 nm) is demonstrated experimentally. A sample cell filled with Rubidium atoms in which the proportion of ^{87}Rb is greater than that of the nature rubidium is placed in a homogeneous magnetic field between two crossed Glan-Thompson polarizers. The incident probe light goes through the sample cell, and interacts with the atoms. Because of the Faraday rotation, the function of the filter can be realized. When the experiment condition changed, the result of transmission spectrum changed accordingly. With the temperature rising from 340 K to 360 K, the variation of the transmission spectrum is recorded particularly. And the reason for the variation is analyzed carefully. At a proper temperature and magnetic field, a transmission spectrum narrowed to ～220 MHz is obtained, and the peak transmission is about 48%. The performance of the^{87}Rb D$_1$ line is better than that of the ^{85}Rb.

Key words: Filter; Anomalous dispersion; Hyperfine structure; Faraday rotation

0　Introduction

Atomic optical filter plays a key role in modern communication systems such as free-space quantum key distribution (QKD)[1-2], remote sensing[3-4], and lidar systems[5]. Narrowband optical filters based on the Faraday anomalous dispersion effect have many advantages such as ultranarrow-bandwidth transmission, high transmission rate, high background rejection, wide field of view and it will be able to adapt to the demand of communication technology[4, 6]. There for, as a very efficient filter device, Faraday anomalous dispersion optical filters (FADOFs) have been developed for several atomic resonances-Na D lines[7], Three K lines [8], Rb D$_1$ and D$_2$ lines[9,4], Cs D$_2$ lines[10] and Ca lines[11]. To obtain a narrower bandwidth, several advanced

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approaches have been utilized to the FADOF, such as ultranarrow-bandwidth atomic filter with Raman light amplification[12], and narrowband switchable dual-passband atomic filter with four-wave mixing optical amplification[13]. By utilizing advanced approaches did enable to obtain narrower bandwidth, but the experimental facility become multifarious and are not so easy to control.

In this letter, we demonstrate an experimental study on FADOF at the wavelength of 795 nm operating at the $5S_{1/2}$ $F=2\rightarrow 5P_{1/2}$ $F'=1$ transmission in ^{87}Rb D_1 line. Most research work is performed in ^{85}Rb for ^{85}Rb holds a higher proportion in nature. In our experiment, we particularly made a sample cell that ^{87}Rb hold a higher concentration proportion than that of the natural Rubidium. With very simple setup, a transmission spectrum narrowed to ~ 220 MHz was obtained.

1 Experimental facility

A schematic of the apparatus is shown in Fig. 1. A probe light of 795 nm is generated by a ECDL (DL100), and the polarization state of the light is vertical. A half-wave plate makes the vertical polarization into a horizontal polarization. And we use an attenuator to change the intensity of probe light. Between two crossed Glan-Thompson polarizers P_1 and P_2 is a sample cell filled with Rb atoms in which the proportion of ^{87}Rb is greater than that of the nature rubidium. Along the laser propagation direction a homogeneous magnetic field is generated by the solenoid current around the sample cell. A temperature controller is also inserted beside the sample. The transmitted light is detected by a photodiode detector, and the output was recorded by a digital oscilloscope.

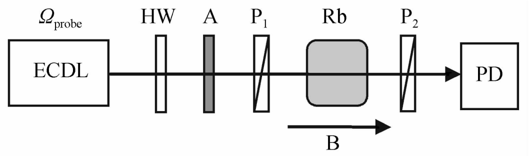


Fig. 1 Experimental setup

2 Experiment principle

2.1 Rubidium D_1 line

The natural Rubidium has two isotopic elements, ^{85}Rb (72.15%) and ^{87}Rb (27.85%). The Rb D_1 transition hyperfine structure is shown in Fig. 2. For ^{85}Rb, the excited-state hyperfine splitting is less than the Doppler broadening, so the two states $5P_{1/2}$ $F'=2$ and $F'=3$ can be regarded as a single-level, so we can only see two absorption spectrums of ^{85}Rb. While the hyperfine splitting space of ^{87}Rb is 816 MHz, which is larger than the Doppler broadening of 530 MHz. Thus six atomic absorption peaks can be observed as Fig. 3 shows. In our experiment, we focus on the transmission of $5S_{1/2}$ $F=2\rightarrow 5P_{1/2}$ $F'=1$ of ^{87}Rb.

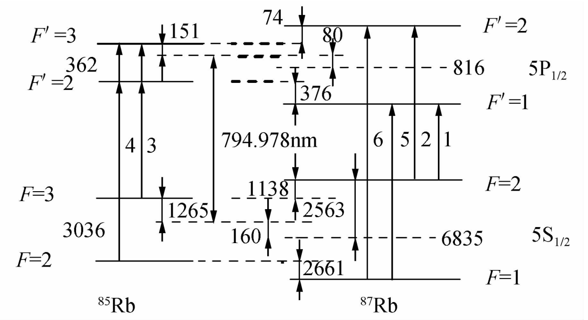
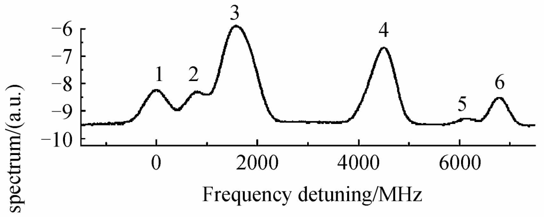
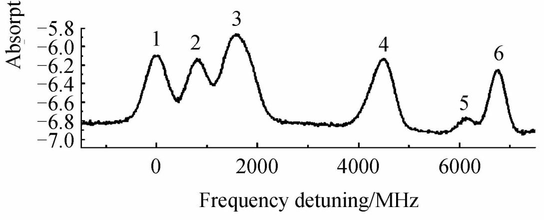


Fig. 2 Rubidium D_1 transition hyperfine structure(unit: MHz)

In our experiment, we adjust the attenuator to weaken the incident light. At a low light level, we got the absorption spectra of Rb D_1 line as Fig. 3 shows. Fig. 3 (a) is the absorption spectrum of natural Rubidium. Because ^{87}Rb hold a larger proportion in our sample cell, the absorption spectrum has been improved as is shown in Fig. 3 (b): the intensity of peak 1, peak 2, and peak 5, peak6 are stronger than those of the natural Rubidium in Fig. 3 (a). In naturally occurring rubidium, the isotope ^{87}Rb composes only 27.85%, the intensity of the absorption is so weak that the superior FADOF performance is not so easy to be found. While in our experiment, ^{87}Rb gives a better performance of FADOF.



(a) The natural rubidium



(b) The Rb sample with high concentration proportion of ^{87}Rb

Fig. 3 Probe laser absorption spectra of Rb sample

2.2 Experiment principle of FADOF

To realize the function of the filter, a laser beam passes through the Glan-Thompson polarizer P1 and becomes a linear polarization light. The linear polarized light goes through the Rb sample, acts on the atoms, and can be regarded as a left and a right circularly polarized light. The magnetic-field splits the energy levels, as Fig. 4(a) shows, resulting in separate absorption lines for left and right circularly polarized light. And accordingly the dispersion curve of the left and right circularly polarized light have a shift to left and right respectively for the Faraday anomalous-dispersion always happen in the center of the absorption line, as shown in Fig. 4(b), the dashed line is corresponded to the left circularly polarized light, and the dotted line is corresponded to the right circularly polarized light. For the incident linear polarization light frequency, the refractive index is certain and is equivalent for the left and right circularly polarized light without the magnetic-field as the solid dispersion curve in Fig. 4(b) shows.

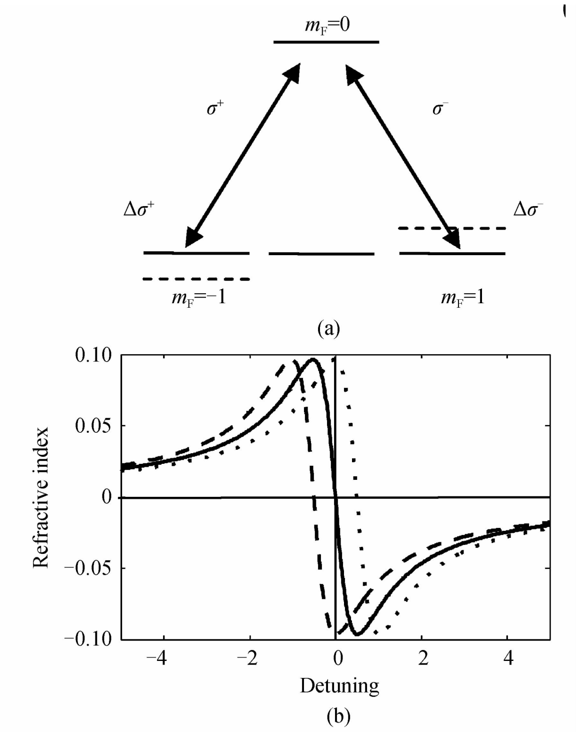


Fig. 4 (a) The atomic transmission in the magnetic field; (b) The anomalous-dispersion curve

While under the action of the magnetic-field, the refractive index of the left and right circularly polarized light are different at the central frequency as shown in Fig. 4(b) for the dispersion curve of the left and right circularly polarized light have shifted. We have

$$\varphi_R = \frac{2\pi}{\lambda} n_R l$$

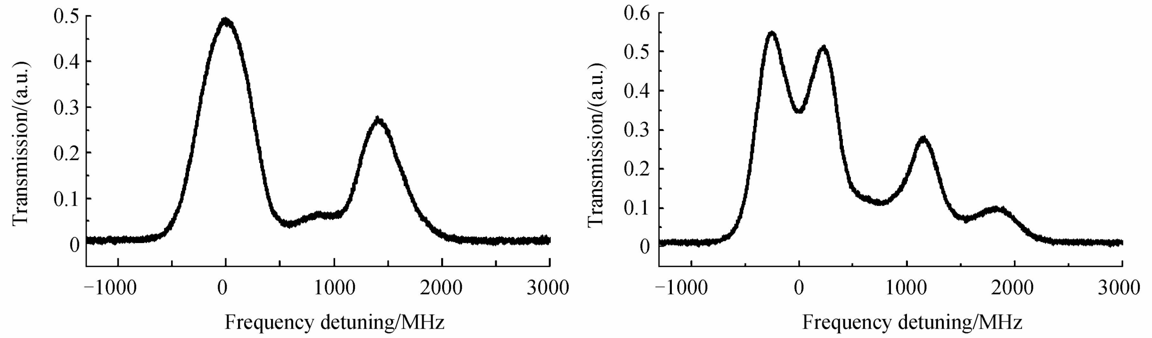
$$\varphi_L = \frac{2\pi}{\lambda} n_L l$$

$$\varphi = \frac{1}{2}(\varphi_R - \varphi_L) = (n_R - n_L)\frac{\pi l}{\lambda}$$

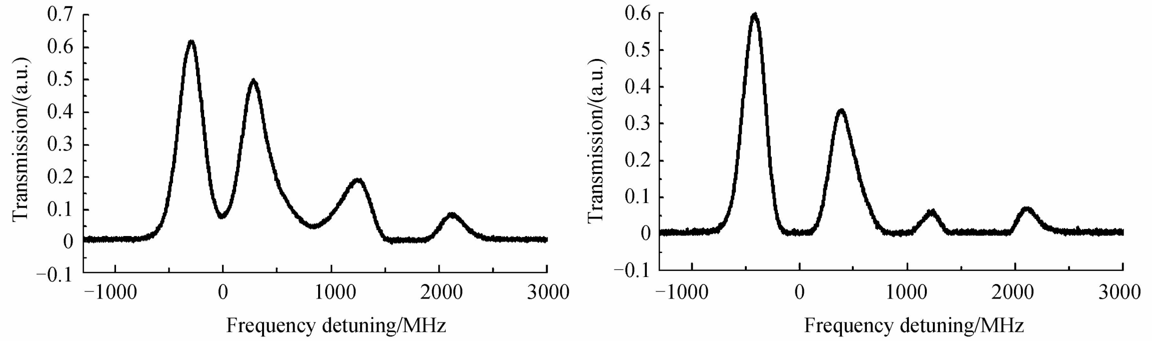
Here l is the length of the cell, λ is the wavelength of the light, n_L and n_R represent the refractive index of left and right circularly polarized light respectively. Only the light that has a maximum rotation of $\pi/2$ can go through the Glan-Thompson polarizer P_2 and detected by PD. Faraday rotation can be only detected in the vicinity of the resonance absorption line for anomalous-dispersion just happened at the resonance line. With temperature increasing, the absorption will be enhanced, and the transmission spectra will be split to doublets in the wings of the resonance.

3 Experimental results

Transmission spectrum for FADOF is represented in Fig. 5 where the spectrum is recorded in different temperature. Fig. 5(a) shows the transmission spectrum at a relatively low temperature of 340 K. Three peaks were observed: a strong peak and a relatively weak peak are corresponding to the first and the third absorption peaks in Fig. 3 respectively; between the two peaks, a pianissimo spectrum corresponding to the second absorption in Fig. 3 is so weak that it is not easily to be explored. We focus on the first and the strongest peak. With the temperature rising, the atomic density increased, and the absorption is enhanced. When the temperature reached 347 K, we can see clearly the change of the transmission spectrum in Fig. 5(b) compared with Fig. 5(a). The higher temperature, the higher absorption as Fig. 5(c) shows. At the temperature of 360K, we got an ultranarrow-bandwidth transmission peak in the wings of the resonance as presented in Fig. 5(d). The transmission spectrum in Fig. 5 is recorded by a digital oscilloscope. The axis of abscissa in oscilloscope represents the time, so we cannot read the frequency detuning directly. But we know the time corresponds to the current intensity of the scanning field signal, and the current intensity relatives to the light frequency. The space between the first and the second absorption peaks in Fig. 3 corresponds to the energy level of $5P_{1/2}$ $F'=2$ and $F'=1$(^{87}Rb). The hyperfine splitting space of ^{87}Rb is 816 MHz and so the distance in the abscissa axis between the fist and the second absorption peaks in Fig. 3 is equivalent to 816 MHz. The proportionate relationship is suitable for the transmission spectrum in Fig. 5 so that we got the laser absorption spectra at a same abscissa. With this method we figure out that the bandwidth of the transmission is ~220 MHz.



(a) 340K (b) 347K



(c) 353K (d) 360K

Fig. 5 Transmission spectrum variation for different temperatures

The magnetic field intensity also has an effect on the transmission spectrums. In our experiment, the magnetic field strength is produced by the solenoid current. We adjust the magnetic field strength by regulating the coil currents. When the coil currents changed, the transmission spectrum changed accordingly. The experimental results in Fig. 4 are detected at a magnetic intensity of ~12 Gauss in which we got a good performance.

4 Conclusion

In summary, we have demonstrated a FADOF operating at the ^{87}Rb D_1 line. This filter gives a ~220 MHz transmission bandwidth and simultaneously 48% transmission. We analyzed the Rb D_1 transition hyperfine structure: for ^{85}Rb, the two excited-states are too close that we could not separate one from another. After the Faraday rotation, the transmitted spectrum is also the superposition of the two resonance absorptions; while this problem does not exist in the isotope ^{87}Rb. The Faraday anomalous dispersion optical filter at the ^{87}Rb D_1 line gives better performance than that of the ^{85}Rb and other lines.

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