Laser Spectroscopy Induced by Bichromatic or Polychromatic Laser for Laser Frequency Stabilization

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***Abstract*—We proposed a new method of laser frequency stabilization based on laser spectroscopy induced by bichromatic or polychromatic laser. When the frequency difference of the bichromatic or polychromatic laser is close to the excited state hyperfine level interval, the main physical effect in the process is velocity selective resonance (VSR). However, when the frequency difference of the bichromatic or polychromatic laser is close to the ground state hyperfine level interval, the main physical effect in the process is velocity selective optical pumping (VSOP). Besides, we observed similar laser spectroscopy using a dual-frequency Faraday laser, the high amplitude of the error can be used laser frequency stabilization.**

Keywords—Dual-frequency laser; saturated absorption spectroscopy; modulation transfer spectroscopy; laser stabilization; optical pumping; crossover resonance

I. INTRODUCTION

Frequency-stabilized laser is an important component in atomic physics experiment, and they need to be tuned to specific atomic resonances. Most of laser frequency stabilization is based on single frequency laser [1-5], nevertheless, it is difficult to improve the atomic utilization. In 2012, Baklanov and co-workers proposed the saturated absorption spectroscopy method in the multimode regime [6]. In 2016, Hafiz and co-workers reported on Doppler-free laser spectroscopy in a Cs vapor cell using a dual-frequency laser system with frequency difference of 9.192631 GHz [7-9]. Most recently, our group demonstrate a dual-frequency Faraday laser on Cs D_2 line with the frequency difference of 7.43GHz-8.80 GHz [10]. Moreover, we proposed the laser frequency stabilization scheme based on the velocity-grating atomic spectroscopy [11]. Motivated by the works of Baklanov and Hafiz et al, and other spectroscopy experiment induced by two or three laser fields, we have studied the global crossover saturated absorption spectroscopy [12] and the inter-ground-state crossover resonances induced by dual-frequency laser [13]. In this work, we demonstrate laser spectroscopy induced by three kinds of bichromatic or polychromatic lasers, and discussed their difference.

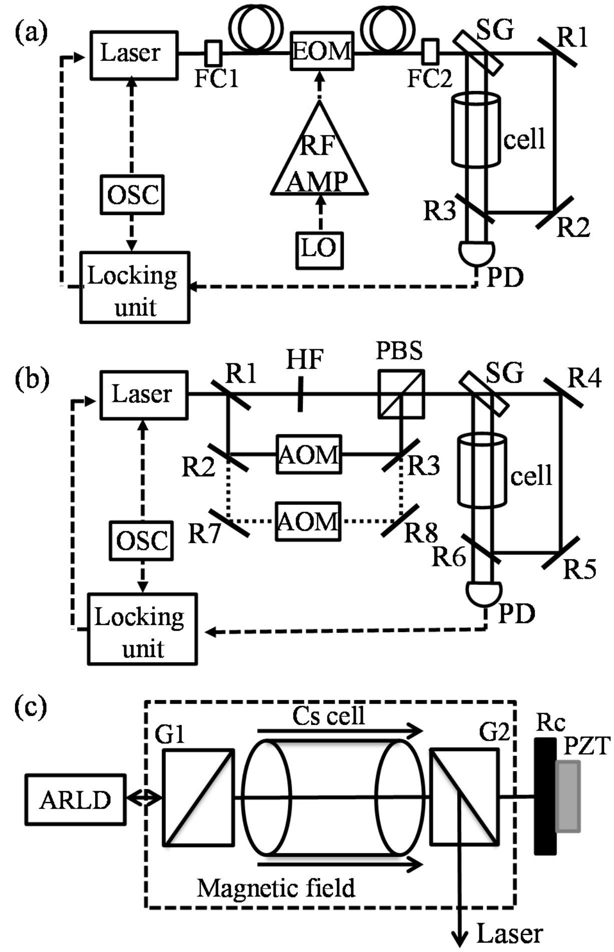

Fig.1 Schematic of the laser frequency stabilization scheme. (a) Based on velocity selective optical pumping, (b) Based on velocity selective resonance, (c) Based on the dual-frequency Faraday laser.

II. METHODS

Fig. 1(a) shows the experimental setup based on VSOP effect. The laser is a home-made single-mode external cavity semiconductor laser, FC1 and FC2 are two fiber collimators, connecting with the electro-optical modulator (EOM) using the single-mode polarization-maintaining fiber. the laser output from the EOM is introduced to the standard saturated absorption spectroscopy device. The dotted line indicates the electrical connection of the laser frequency stabilization scheme. Fig.1(b) shows the experimental setup based on VSR effect. The laser is the same as the laser in Fig. 1 (a), one of beam emitted from the laser is modulated by the acousto-optic modulators (AOM). Then, the combination of the unmodulated beam and modulated beam forms the dual frequency laser beam. And the dual-frequency laser beam is introduced to the standard saturated absorption spectroscopy device. Fig. 1(b) shows a method of experiment based on polychromatic laser, the laser is modulated by two AOMs with different modulation frequency. Fig. 1(c) shows the experimental setup of the dual-frequency Faraday laser. The laser emitted from the antireflection-coated laser diode is filtered by the twin-peak Faraday anomalous dispersion optical filter, and reflected by the cavity mirror. The piezoelectric ceramics is used to tune the cavity length. Fig. 2 shows the relevant Cs energy level.

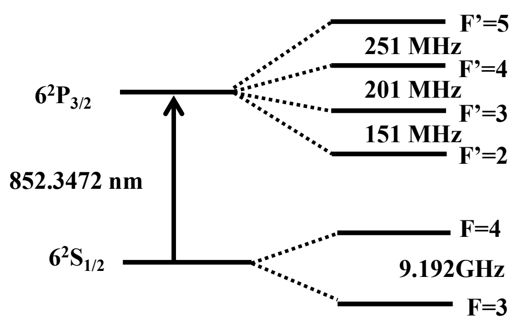

Fig.2 The relevant energy level.

III. RESULTS

Fig. 3 shows the typical spectrum signals detected by the photodiode (PD in Fig. 1(a)). The reversed peaks are formed by the non-zero-velocity group resonance with the dual-frequency laser, the reason of the peak inversion is the optical pumping. Since the frequency difference of the modulated dual-frequency laser is near to the ground state interval. The pump laser produce the optical pumping, thus increasing the atomic absorption.

Fig. 4 shows the typical spectrum signals detected by the photodiode (PD in Fig. 1(b)). The blue line is the saturated absorption spectroscopy induced by the dual-frequency laser, the number and shape of the peaks vary with the modulation frequency. The black line is the separated crossover signal from the dual-frequency saturated absorption spectroscopy. Because the frequency difference of the modulated dual-frequency laser is less than the doppler width, the pump laser and probe laser can produce the velocity selective resonance. The new type of crossover resonance is name as "global crossover saturated absorption spectroscopy" .

Fig. 5 shows the measured saturated absorption spectroscopy and modulation transfer spectroscopy error signal by the dual-frequency Faraday laser. The black line is the modulation transfer spectroscopy, the inversed peaks is induced by the dual-frequency laser, the main physical effects involved is optical pumping. In order to show the frequency difference of the dual-frequency Faraday laser, we measured the beat signal of the Faraday laser. As shown in Fig. 6, the center frequency of the beat signal is about 8.5 GHz, which is near to the ground state interval.

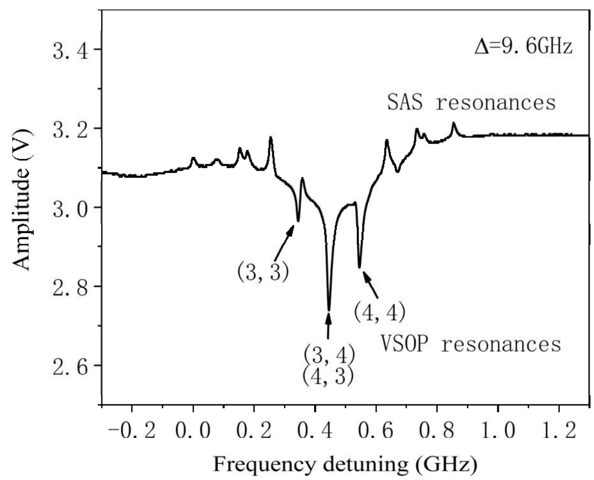

Fig.3 The measured SAS resonances by dual-frequency laser and velocity selective optical pumping resonances.

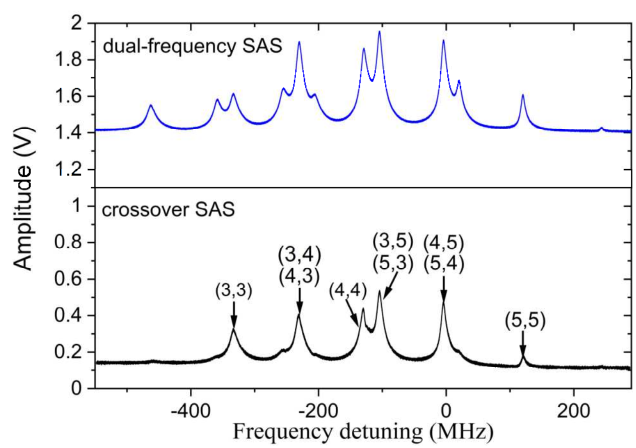

Fig.4 The measured SAS signal by dual-frequency laser and velocity selective resonances.

The inversed peaks in Fig. 3 and Fig. 6 are produced for the same reason, however, the dual-frequency Faraday laser does not require a modulator, only a twin-peak Faraday optical filter, can realize a dual-frequency laser. Besides, the frequency difference of the Faraday laser can also be adjusted by changing the temperature of the atomic vapor cell, which also puts forward high requirements for the temperature control accuracy of the atomic vapor cell. Only when the temperature of the atomic vapor cell is accurately controlled can the dual-frequency laser frequency interval remain stable. The crossover resonances are mainly determined by the frequency difference of the dual-frequency laser and the detuning of the atomic

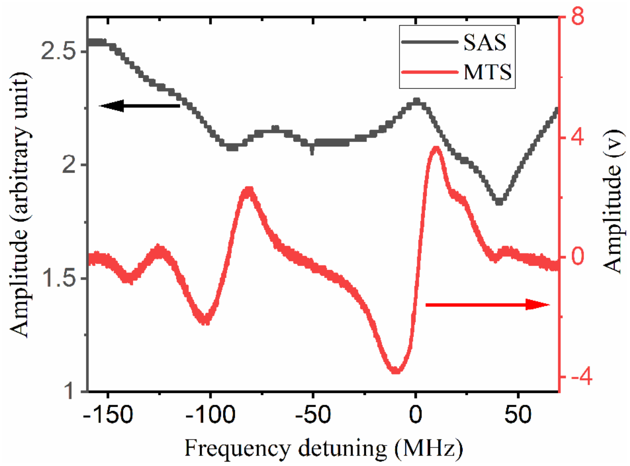

Fig.5 The measured modulation transfer spectroscopy signal and the error signal by the dual-frequency Faraday laser.

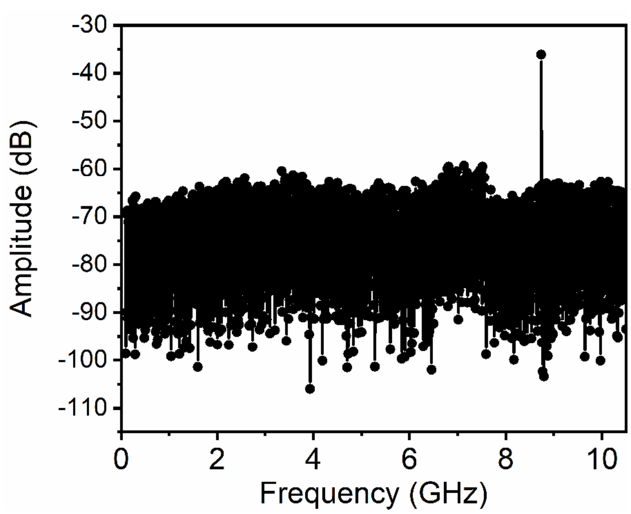

Fig.6 The beat signal of the dual-frequency Faraday laser.

transition. If the detuning between the dual-frequency laser frequency and the atomic transition is large, the non-zero velocity classes is not enough, the amplitude of the produced crossover resonance is low. Hence, we can control the frequency difference of the dual-frequency laser to control the crossover resonances. It is known from Ref [1], the bichromatic and polychromatic laser can improve the atom utilization, thus increasing the signal-to-noise ratio.

IV. Conclusions

In conclusion, we investigated laser spectroscopy induced by three kinds of bichromatic laser, the first two methods obtain dual-frequency laser by modulating the laser, The modulator not only has high cost, but also increases optical loss. Nevertheless, the twin-peak Faraday optical filter is a better candidate. In the future, we will continue to study the use of dual-frequency laser for laser frequency stabilization and look forward to better results. Moreover, the dual-frequency Faraday laser may be used for optical microwave generation [15,16].

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