Proc. SPIE, Vol. 4913 (2002) p.172 ~ p.176

Frequency Stabilization of DBR Laser Diode to Cesium D_2 Line by the Third-Order Deviation Locking without Dither

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ABSTRACT

The third-derivative saturation absorption spectrum (SAS) of cesium D_2 line is demonstrated via the third-harmonic technique by applying the frequency modulation to an external AOM (acousto-optical modulator). By employing the frequency discrimination of the third-derivative SAS, frequency of DBR diode laser at 852nm is locked to the hyperfine component of cesium $6S_{1/2}F=4 \rightarrow 6P_{3/2}F'=4,5$. Frequency jitter of less than ±350kHz in 10 seconds is estimated based on the error signal after locking in the preliminary stabilization.

Key words: the third-harmonic locking, saturation absorption spectrum (SAS), DBR laser diode, frequency locking without frequency dither

1. INTRODUCTION

Laser diodes have been widely used in the fields of communication, information science, measurement, laser spectroscopy and fundamental research. Now more attention is focused on the application of the laser diode with narrow linewidth and high frequency stabilization in the field of high-resolution spectroscopy, quantum frequency standard, and laser cooling and trapping of neutral atoms or ions [1,2].

In many fields, laser diode has to be frequency locked to the atomic absorption line. Usually, the frequency modulation is directly adopted on laser diode. By carrying the phase sensitivity detection, the first deviation signal can be used as frequency discriminating signal for locking. But in this process, either current or voltage dither added on laser diode or

Semiconductor Lasers and Applications, Yi Luo, Yoshiaki Nakano, Editors, Proceedings of SPIE Vol. 4913 (2002) © 2002 SPIE · 0277-786X/02/$15.00

piezo-electric transducer (PZT) will inevitably cause frequency disturbance and amplitude modulation of the laser output. New methods are thus needed in order to get rid of the additional noise. One way is to modulate externally the longitudinal magnetic field of alkali atom vapor cell by Zeeman effect [3,4]. Another way is to modulate an external electronic-optical modulator (EOM) or acousto-optical modulator (AOM)[5]. Especially in magneto-optical-trap (MOT) experiment, multiple controls of the laser beams should be accomplished by AOM. For example, alternative red detunning range of 0~50MHz need be applied on the laser beams in different operation phase. So, it is a relative simple experiment scheme to adopt the modulation on the AOM.

Another problem is that the frequency shift due to the Doppler background will decrease the precision of locking. Usually, a reference beam and an additional DC offset can be used to balance the frequency shift. But all these cannot eliminate it thoroughly. The third-order deviation began to be employed in the frequency locking. Similar to the first-order

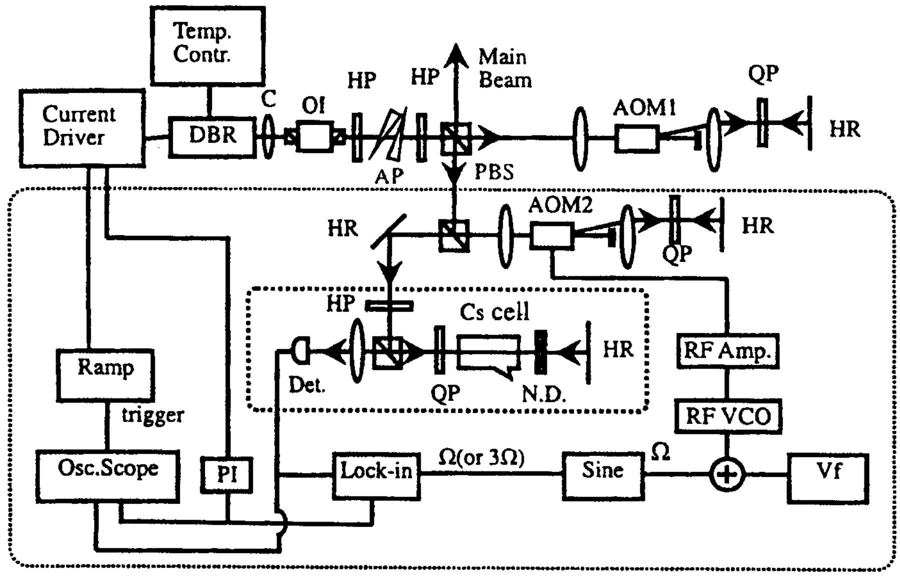

Fig.1. Experimental setup. DBR: DBR diode laser; C: collimator; OI: optical isolator; HP: half-wave plate; AP: anamorphic prism pair; AOMs: acousto-optical modulators; QP: quarter-wave plate; HR: high reflectivity mirror; N.D.: neutral density filter; RF Amp: radio-frequency power amplifier; RF VCO: radio-frequency voltage controlled oscillator; Vf: DC voltage for frequency control of RF VCO; Sin: sine-wave reference signal; Lock-in: lock-in amplifier; PI: proportion and integration amplifier; Ramp: ramp signal; Osc.: oscilloscope; PBS:

deviation locking, the modulation frequency is Ω, but the demodulation frequency is 3Ω. The Doppler background can be eliminated obviously in this way. Compared with the first-order deviation, the slope of the third-order deviation signal near the absorption peak is larger. In theory, the 1/f noise at 3Ω is smaller than it is at Ω.

2. EXPERIMENT

The experiment scheme is showed in Fig.1. A DBR laser diode (SDL-5712-H1) operated at 852nm is temperature stabilized and driven by a constant current source. A collimator with a focal length of 7mm is used to collimate the divergent output beam. Optical feedback is avoided by a 40dB optical isolator. The polarization of the output is rotated with a half-wave plate to avoid losses at the anamorphic prism pair, which is used to circularize the beam spot.

A half-wave plate and a PBS cube split the output beam. The reflected beam (< 2 mW) double passes through an AOM

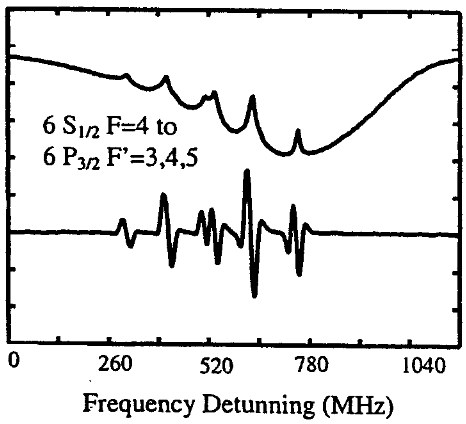

Fig.2 Typical saturation absorption spectrum of cesium D_2 line (upper curve) and the corresponding third-derivative frequency-discriminating curve (lower curve).

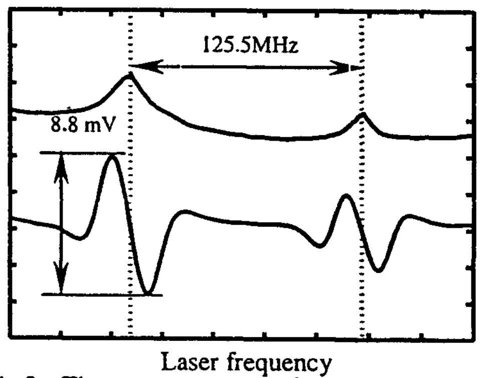

Fig.3 The upper curve is the saturation absorption spectrum of cesium hyperfine transition $F = 4 \rightarrow F' = 4{,}5$ crossover (left peak) and $F = 4 \rightarrow F' = 5$ (right peak). The lower one is the corresponding third-derive discriminating signal.

with the efficiency of single pass of about 70%. Changing the modulation frequency, diffractive efficiency and the status of RF power, it is easy to realize the required operations, such as frequency detunning, intensity modulation and switch. Here, two AOMs were employed to realize the small detunning. AOM1 is used to shift the laser frequency to –80MHz whereas AOM2 is used to shift it back to the offset point.

RF driving signal for AOM is generated with a homemade RF voltage controlled oscillator (RF VCO). A constant voltage about 9V is input to generate a sine wave signal at 80MHz. In the second AOM(AOM2), an additional modulation with low frequency (Ω) is carried on the constant voltage. The RF signal is then power-amplified and brought to drive the AOM.

The frequency modulated laser beam passes through the device of saturated absorption spectrum (dot box in fig.1). When the laser frequency is scanning by a triangle voltage, the PIN photodiode detects the SAS of cesium vapor cell. Demodulated with high-order harmonic of modulation signal, the first-order or the third-order deviation signal can be extracted. The laser diode can be locked by employing the deviation signal to frequency locking. This method eventually removes the disturbance of laser diode itself due to direct modulation on driving current and was then called frequency locking without dither.

3. EXPERIMENTAL RESULTS

The laser frequency is locked bias to hyperfine F=4→F'=4,5 crossover, for the large SNR and large frequency gap with other transitions. Fig.2 is the typical SAS of cesium D_2 line when Doppler background is present and the corresponding third-order deviation signal without frequency dither (modulation frequency Ω=13.5KHz, the demodulation frequency 3Ω=40.5kHz). Compared with the typical first-order derivation signal of SAS, the dispersion baseline of Doppler background is eliminated effectively. And the slope at the center of deviation is larger than that of the first-order deviation.

To estimate the frequency jitter with and without locking, let's focus on the F=4→F'=5 and F=4→F'=4,5 hyperfine transition (see fig.3). Because the frequency scale between these two lines is 125.5MHz, we can estimate that the frequency

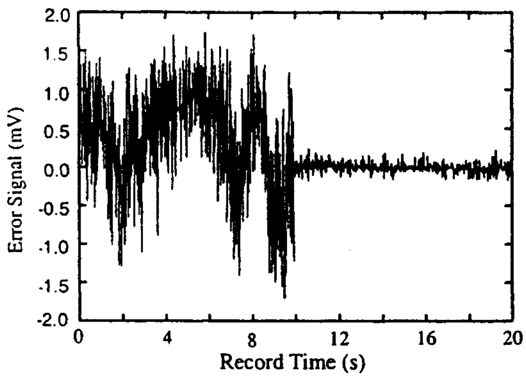

Fig. 4 Typical error signal as the DBR diode laser is free running (left side) and locked(right side). The estimated frequency jitter under free running is about 7MHz and about ±350KHz when it is locked. All error signals are recorded in 10 seconds.

range of linear part near the $F = 4 \to F' = 4{,}5$ crossover is 17MHz. The corresponding voltage is 8.8mV, so the slope is 0.52mV/MHz.

Fig.4 shows the error signal of DBR laser diode under the condition of free running and locking. The recording time is 10 seconds. The typical voltage of error signal is less than 3.6mV, so the estimated frequency fluctuation of free running laser is about 7MHz in that period of time. Compared with general diode laser systems, this frequency stability is not too bad. This may due to the high precision temperature controller and low-noise constant current supplies. When the laser diode is offset-locked to the hyperfine transition $F = 4 \to F' = 4{,}5$ crossover in close loop, the frequency jitter is less than ±350KHz. This result can fulfil general requirements for laser cooling and trapping.

This is the preliminary result of frequency stabilization of DBR diode laser to cesium hyperfine transition by the third-order deviation technique without dither. Higher frequency stability can be obtained in principle by various optimizations, such as lowering the intensity of both pump and probe beams, improving the low-noise detector and filter, optimizing the parameters of PI circuit. And this technique can be used in other laser systems of frequency locking.

Acknowledgements: We would like to thank Prof. Kunchi Peng for stimulative discussions and careful reading of the manuscript. This work is financially supported by the National Natural Science Foundation of China (approve number: 60178006), the Natural Science Foundation of Shanxi Province (project number: 20021030), and Shanxi Provincial Research Funds for Returned Scholar Abroad.

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