Frequency-locked tunable LD laser with a broad bandwidth

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Using lock-in amplifer and proportional, integral, and derivative (PID) electric circuit, the frequency of diode laser is stabilized on a highly mechanical stable Fabry-Perot (FP) cavity transmission peak. When the frequency locking system is on, the frequency tunable range of the laser is about 4 GHz around the $D1$ transition of Rb. The laser frequency tuning is implemented by scanning the FP cavity length. The fluctuation of frequency of the output laser is less than 1 MHz, and the drift of the center frequency is less than 1.5 MHz in 1.5 min. This system has great potential of the application in the experimental investigation of the interaction between light and atoms, especially, for the case of far off the atomic resonance.

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Tunable diode lasers are widely used in high-resolution spectrum[1], laser cooling and trapping of atoms[2], quantum frequency standard[3], and quantum interference of atoms[4,5] because of their high efficiency, narrow linewidth, and simplicity of configuration. High frequency stability of diode lasers is necessary requirement for performing these researches. In general, the frequency of laser is locked to a high-stable reference frequency, such as a resonant absorption line of atom or a Fabry-Perot (FP) cavity transmission peak. However, both of the techniques have their strengths and weaknesses in applications. The former can keep the frequency of laser at a given absorption line of atom for a long time without mode hopping, but it is not easy to be tuned. However, in a lot of experiments, we need to lock laser the frequency on a certain offset from the hyperfine transition frequency of atoms. Although by means of acoustic-optic modulator (AOM), the laser frequency can be shifted[6−10], as that used in the systems of cooling atoms, the reachable frequency offset lies within a typical range of 100 MHz and with the maximum transmission ratio of 70% due to the limitation of the devices. For some experiments, such as the nonlinear effect in electromagnetically induced transparency (EIT)[4,5] and slow light in the Raman process[11], a broader range of frequency tuning around the atomic resonant absorption line is required, so the locking technique with saturation absorption line is not suitable. For the later, the laser frequency locked to the FP cavity transmission peak[12], a broader range of frequency tuning can be easily achieved by varying the length of FP cavity. But it is difficult to keep the laser frequency always be stably locked to a certain offset from atomic resonant absorption line as the length drift of FP cavity. So a high quality locking system is required. In this way, the laser frequency should be tuned to the resonant transition frequencies of the atoms firstly, and then locked it on the FP cavity by using the electric feedback circuit. The parameters of the electric feedback circuit must be optimized to make the laser frequency continuously tunable in a broader rang without mode hopping. The mechanical stability of a FP cavity must be excellent for keeping the cavity length almost unchanging in a longer time. To achieve these goals, we utilized the following techniques: 1) the frequency error signal was obtained by using locking amplifier; 2) A homemade proportional, integral, and derivative (PID) electric circuit was used to select the proper bandwidth and gain of the error signal. The parameters of electric circuit and the stability of electric feedback loop were optimized; 3) The FP cavity was constructed with invar and enclosed in a solid box for improving the mechanical stability and reducing the effect due to the fluctuation of the environment temperature. In the experiments, at first, we tuned the frequency of the free-running diode laser to the $D1$ absorption line of Rb atom by means of observing the signal from atomic saturated absorption spectrum. Successively, we adjusted the length of FP cavity to the state resonating with the laser frequency and then locked the laser frequency to the FP cavity transmission peak. At last, by scanning the length of FP cavity, we achieved the broad frequency tuning range of 4 GHz, which can be monitored by observing the saturated absorption spectrum of Rb atom, during the tuning process the laser always maintained at the frequency-locked state.

The experimental setup is shown schematically in Fig. 1. The laser is a single-mode, narrow linewidth diode laser with grating feedback (German, Sacher MLD100,

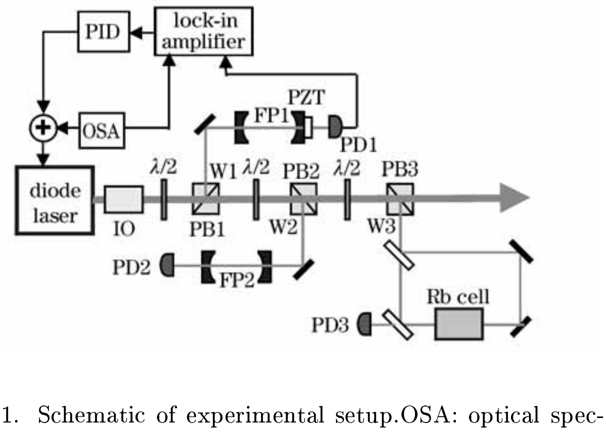

Fig. 1. Schematic of experimental setup.OSA: optical spectrum analyzer.

linewidth is less than 1 MHz). The laser frequency tuning range is about 4 GHz in free running. The maximum output power at 795 nm is nearly 30 mW. The laser beam firstly passes through an optical isolator (IO) (Isowave Model I-80T-5L) to avoid the influence of feedback from the surface of the optical element on the stability of laser. A small part W1 split out from the output laser with a polarizing beam splitter PB1 is sent to a FP1 cavity for locking the laser frequency. Another small part W2 is split out by a polarizing beam splitter PB2 to another FP2 cavity for monitoring the laser frequency. The remainder laser beams are separated into two parts by PB3, a small amount of power is used for observing the signal of the saturated absorption spectroscopy, other most is used in the experiment of interaction between light and atoms.

The length stability of the FP cavity will directly affect the stability of laser frequency when the laser frequency is locked. To minimize the effect of the temperature variation, the FP1 cavity is made of invar with best thermal stability. The two concave cavity mirrors are tightly fixed inside an invar cylinder of 30-mm diameter and 120-mm length. In this configuration the influence from air blow can be minimized. The distance between the two mirrors is 100 mm. One of mirrors is mounted on a piezoelectric transducer (PZT) for scanning the length of the FP cavity. The free spectrum range of the cavity is 750 MHz. The invar cylinder is enclosed in an isolated box to further reduce the effect due to the temperature variation and air blow, so the length of FP cavity can stabilize for a long time. The transmission peak from the FP1 is detected by a photo-diode detector (PD1) and then the detected signal is sent into the lock-in amplifier to generate error signal. The light beams W2 and W3 are respectively injected into the FP2 and the saturation absorption setup for monitoring and measuring the laser frequency detuning from atomic transition line.

At first, the diode laser is tuned to the frequency near the D1 resonant absorption line (795 nm) of Rb atom by adjusting current of the laser driver. In order to obtain the error signal, a sinusoidal modulate signal at the frequency of 13 kHz (dither voltage signal) generated by the oscillator is applied to the PZT mounted upon the grating of laser. The signal drives the feedback angle of the grating to modulate the frequency of laser with the 13-kHz dither signal. The laser with the modulation signal is injected into the FP1 cavity and then we adjust the length of FP1 cavity to make cavity resonant with the laser frequency. The FP1 cavity transmission peak is detected by the PD1, and the detected photocurrent is sent to the lock-in amplifier to mix with the 13-kHz dither signal produced by the same signal generator to produce the error signal. The error signal is sent to PID circuit system for optimizing the parameters (such as amplitude, phase, and bandwidth) of the error signal. Then the error signal is combined with the modulation signal by a zero-degree power combiner. The combined signal is applied to the input port of laser to drive PZT. Thus, the angle of the grating will be rotated by the PZT to enforce the laser frequency matching the resonant frequency of FP1 cavity, i.e. the laser frequency is locked to the FP1 cavity transmission peak. We use a zigzag voltage with frequency of 4 Hz to scan the length of FP1 cavity. During scanning process the frequency of laser always is locked on the FP1 cavity and synchronously tuned along with varying of the length of the FP cavity. Using this system, the continuous frequency tuning of 4-GHz without mode hopping is achieved.

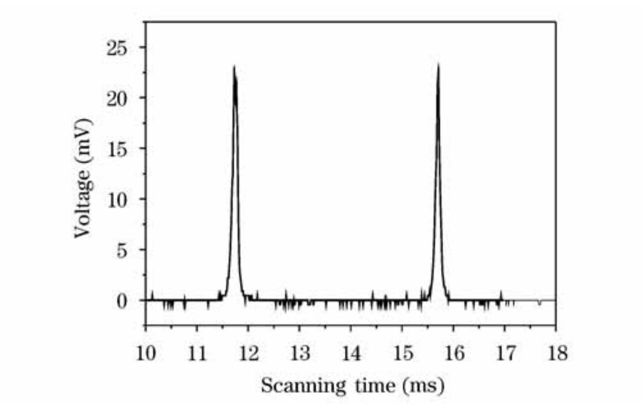

Fig. 2. Transmission peaks of FP cavity.

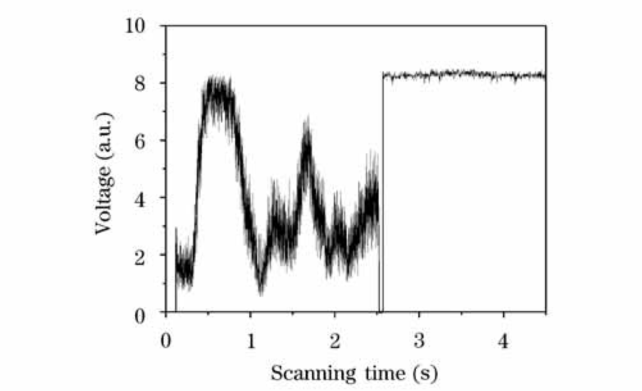

Fig. 3. Frequency fluctuations in the case of laser free-running (t<2.5 s) and locking (t>2.5 s).

Figure 2 shows the FP1 cavity transmission peaks during scanning cavity length. The free spectral range and the finesse of the cavity are 750 MHz and 35, respectively. The fluctuations of output power from FP1 cavity recorded by PD1 are shown in Fig. 3, from 0−2.5 s the laser is in free-running, from 2.5−4.5 s with locking system on, respectively. It is obviously, the stability of the output laser is improved greatly after the laser frequency is locked. From the recorded fluctuation in Fig. 3, and the values of free spectrum range and finesse of FP1 measured in Fig. 2, the frequency excursions of laser are calculated, which are 1 MHz with the locking system on and about 10 MHz with free running. When the frequency of laser is tuned by scanning the length of FP1 cavity with locking system on, the experimental results of continuously tuning is shown in Fig. 4. Curve (a) is the signal detected by PD1 from the output power of the FP1 cavity, curve (b) is the signal of the saturated absorption spectrum of Rb atom, and curve (c) is the FP2 cavity transmission peaks detected by PD2. The free spectral range of 750 MHz for the FP2 cavity is obviously presented. From these measured data, we can infer that the continuously tunable rang of laser frequency is about 4 GHz around Rb atomic resonance lines at the state of laser frequency locking. For locking the laser to a frequency

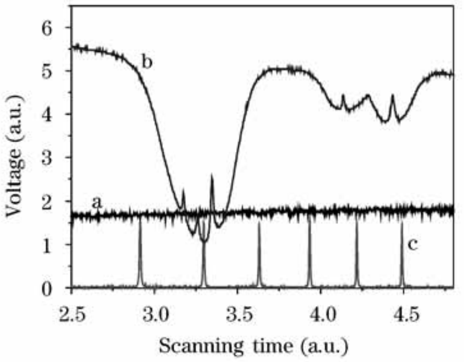

Fig. 4. The spectra of Rb when scan diode laser under the frequency locked condition. Curve (a) is detected by PD1; (b) is absorption of Rb; (c) is detected by PD2.

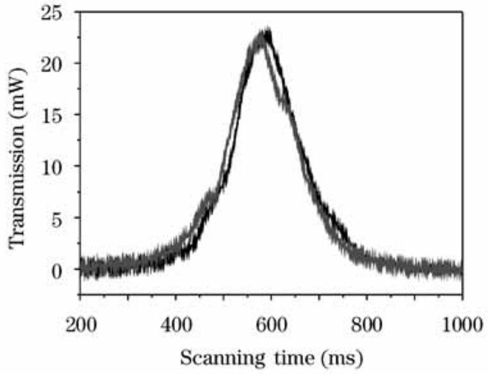

Fig. 5. The drift of the transmission peak of FP cavity in 1.5 min.

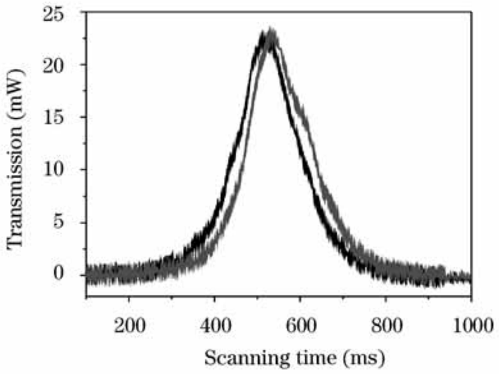

Fig. 6. The drift of the transmission peak of FP cavity in 3 min.

offset the resonant line of atoms, firstly, we can tune the laser frequency to the hyperfine sublevel of the Rb atom by changing the DC voltage applied on PZT of the FP1 cavity, then record the position of the transmission peak of cavity FP2 with an oscilloscope during scanning FP2 cavity length. Successively, we tune the laser frequency by changing the bias of voltage applied on PZT of the FP1 cavity. In this case the laser frequency becomes the state of detuning from the resonant absorption line of atoms. The detuning can be measured by the shift value of the transmission peak position of cavity FP2 and thus the laser can be locked according our requirement.

It is important to make sure the long-stability of the laser frequency locking system. To check the long stability of the laser frequency stabilized system, we measured the drift of the FP1 cavity length. At first, the frequency of laser is locked to a saturated absorption line of Rb atom by the above mentioned lock-in electric circuit, so the frequency of laser can serve as a frequency standard. Then, the excursion of FP1 cavity length is measured by observing the drift of the FP1 cavity transmission peaks during scanning the length of cavity. The measured drifts of transmission peak of FP1 cavity are shown in Figs. 5 and 6, respectively. The excursions of frequency are about 1.5 MHz in 1.5 min and 3 MHz in 3 min, respectively.

In conclusion, the frequency of diode laser with grating feedback is locked to a special-designed FP cavity with solid mechanic configuration and good thermal stability. By scanning the FP cavity length, the continuously tuning range of 4 GHz has been achieved at the state of laser frequency locking. Exploring the laser system of broad tuning range, we obtained the saturated absorption spectrum of Rb atom and realized the offset locking of the laser frequency from the resonant absorption line of atom. The excursion of frequency is about 1.5 MHz in 1.5 min. The presented system can be used for the research in the interaction of light and atoms.

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