Measurement of frequency stability in tunable lasers by using an F-P interferometer*

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A method for measuring the frequency stability of tunable laser is proposed by using confocal Fabry-Perot (F-P) interferometer. The F-P interferometer is used to get the output frequency of the laser as a reference, and the method eliminates the need of an independent optical source as a frequency reference. Using this technique, the frequency stability of the tunable external-cavity diode laser (ECDL) is measured to be 2.26×10^{-9} with an integration time of 20 ms.

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The optical frequency stability of a laser is one of the most critical indicators about the light source performance. Optical spectrum analyzer can not be an appropriate candidate to detect the optical frequency stability of a laser, because it can not offer high resolution measurements with high scan rates. Therefore, the optical frequency stability of a laser is generally obtained by detecting heterodyne mixing of two independent laser sources. However, the reliable measurements only can be obtained when the reference laser is significantly more stable than the laser under test[1-3]. Fortunately, a method is provided to measure optical frequency stability of a laser by using two same type laser sources[4]. Even so, two independent laser sources are mandatory. Recently, another method for directly mapping the fluctuation of the optical frequency in a laser to the radio frequency (RF) domain has been reported[5] using an etalon-based optoelectronic oscillator. Although this technique does not require an independent laser source as a reference, the measurement range is limited to half of full width at half maximum (FWHM) of the etalon. In 2013, WANG et al[6] reported a method for measuring the optical frequency stability by using the spectral-hole burning technique, but the spectral-hole burning[7-9] can only be performed in the cryogenic temperature range.

In this letter, a new novel method for measuring frequency stability of tunable lasers is proposed by using confocal Fabry-Perot (F-P) interferometer. Compared with other methods mentioned above, the proposed method is more practical and cheap, which potentially can be used in many fields, such as industry and sensor.

We use a periodic drive signal loaded into the laser to sweep the spectrum of the F-P interferometer. According to the relationship of frequency and time, we obtain the output frequency of laser. The method has a wide measurement range which is limited to the free spectral range (FSR) of the interferometer.

The Allan variance is the most common method for measuring the frequency stability in time domain. Similar to the standard variance, it can be used to measure the fractional frequency fluctuations, and has the advantage of being convergent for most types of clock noise. So the expression for frequency stability can be given by the Allan variance as[10]

$$S_f\left(\tau\right)=\frac{1}{f_c}\left\{\frac{1}{M-1}\sum_{i=1}^{M-1}\frac{\left(f_{i+1}-f_i\right)^2}{2}\right\}^{1/2}, \tag{1}$$

where f_c is the nominal frequency of laser, f_i is the measured frequency of laser, and $M\geq100$ represents the times of measurement.

Confocal F-P interferometer consists of two parallel spherical mirrors with distance of d between them. Refractive indices of the two mirrors are both n. The light beams after multiple reflections and transmissions can interfere with each other in the cavity.

When the refractive indices of two mirrors are the same, the intermediate medium is air and the light is incident perpendicularly, phase difference δ is a function of wavelength λ, and the resonance transmission windows only appear in the vicinity of some particular wave-

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lengths, namely, it satisfies[11-13]

$$f = m\frac{c}{4d}, \qquad m = 1,2,3\cdots, \tag{2}$$

where d is the length of the F-P interferometer, and c is the speed of light.

In order to obtain the resonance transmission window, we use a drive signal $u(t)=u(t+T)$ with cycle of T loaded into the laser to sweep the spectrum of the F-P interferometer. According to the relationship of frequency and time, we obtain the laser output frequency as

$$f(t) = f_i + \gamma u(t) = m\frac{c}{4d}, \tag{3}$$

where γ is the PZT tuning coefficient of laser. Therefore, the frequency of the laser is then given by

$$f_i(t) = m\frac{c}{4d} - \gamma u_i(t), \tag{4}$$

where $u_i(t)$ is the voltage of drive signal at time t.

For demonstrating the above concept experimentally, a external-cavity diode laser (New Focus TLB-6017) is used in the setup shown in Fig.1. An arbitrary waveform generator (AWG) creates a periodic triangular wave with peak-to-peak value of $u_{p\text{-}p}$=80 mV to drive the tunable laser with good tuning characteristics. The output of the measured laser with the wavelength centered at 793 nm is focused into the confocal F-P interferometer. Finally, an oscilloscope is used to obtain the information of the resonance transmission window of the confocal F-P interferometer, as shown in Fig.2. The location of resonance transmission window is then processed. By extracting the change of the location of resonance transmission window, the frequency stability of the measured laser can be obtained.

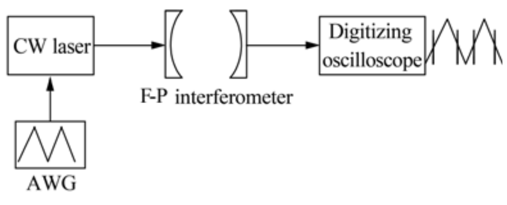

Fig.1 Schematic diagram of the experimental setup

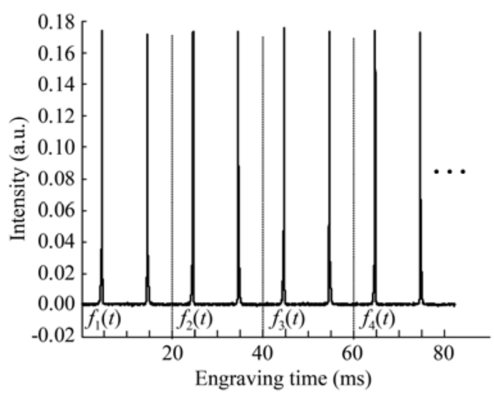

Fig.2 Experimental results of resonance transmission window of the confocal F-P interferometer

Calibration is necessary in order to obtain the PZT tuning coefficient. For this purpose, the optical frequency f_c is modulated by radio frequency f_{rf}=100 MHz using an electric-optic modulator (EOM)[14]. So the span between the optical frequency f_c and the first upper sideband frequency f_c+f_{rf} is Δv=100 MHz, and the corresponding drive voltage shift Δu is measured and found to be 3.77 mV, as shown in Fig.3. This results in a PZT tuning coefficient of $\gamma = \frac{\Delta v}{\Delta u} \approx 26.5$ MHz/mV. The PZT tuning coefficient also represents the sensitivity of the measurement system: the smaller the PZT tuning coefficient, the larger the sensitivity of the system to optical frequency changes.

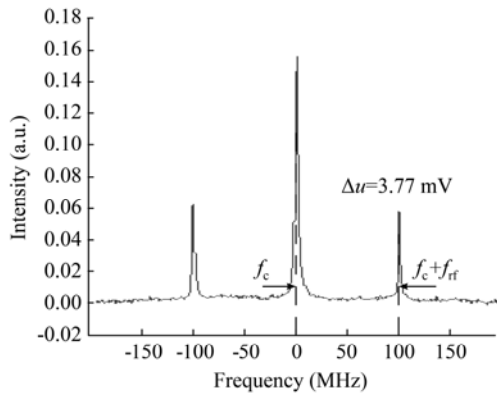

Fig.3 The experimental result of the modulated output signal (The optical carrier frequency is normalized.)

The frequency stability is determined by recording the change of the location of resonance transmission window and then performing the statistical analyses based on Eq.(1). For integration time of τ=20 ms, the frequency stability can be computed as 2.26×10^{-9}.

For integration time between 20 ms and 800 ms, we calculate the Allan deviation of 100 samples, which means the frequency stability of the measured external-cavity diode laser (ECDL) as shown in Fig.4. With the increase of integration time, the frequency stability of the measured ECDL gradually deteriorates because of mechanical, thermal and electric noises. To substantially improve the frequency stability, a typical Pound–Drever–Hall stabilization scheme can be carried out[15].

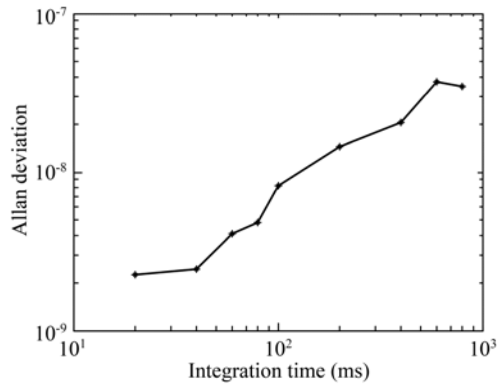

Fig.4 Measured frequency stability of the ECDL which is given as the Allan variance

In summary, a method for the measurement of optical frequency stability is presented. The resonance transmission window of a confocal F-P interferometer is used as a reference, and is utilized for mapping the optical frequency fluctuations of a tunable laser. The measurements performed on an ECDL laser show that the frequency stability is about 2.26×10^{-9} when the duration is 20 ms. Moreover, this technique provides a wide measurement range, which can be used in many fields, such as industries and sensor.

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