Diode Laser Optically Injected by Resonance of a Monolithic Cavity *

PENG Yu(彭瑜)[1,2**], ZHAO Yang(赵阳)[1,2], LI Ye(李烨)[1], YANG Tao(杨涛)[1], CAO Jian-Ping(曹建平)[1], FANG Zhan-Jun(方占军)[1], ZANG Er-Jun(臧二军)[1]

[1]*Center of Time and Frequency Metrology, National Institute of Metrology, 18 Beisanhuan East Rd., Beijing 100013*
[2]*Department of Precision Instruments and Mechanology, Tsinghua University, Beijing 100084*

(Received 18 August 2011)

We demonstrate a self-injection locking extended cavity diode laser (ECDL) using resonant optical feedback from the p-polarization of a monolithic folded Fabry–Perot parallel cavity (MFC). The full width at half maximum of the MFC resonance is 31 MHz. With the help of a narrow-linewidth reference laser, the linewidth of the ECDL is measured to be about 7 kHz. The frequency of the laser could be tuned at 160 MHz with an amplitude of 40 V by a PZT mounted on the monolithic cavity and the voltage tuning coefficient is about 4 MHz/V.

PACS: 42.55.Px, 42.60.Da, 42.60.By DOI:10.1088/0256-307X/28/11/114208

Diode lasers exhibit broadband frequency noise that can present a severe obstacle for locking their frequencies to atomic hyperfine transitions, molecular rotational and vibrational transitions, and typically have linewidths around kHz. For these purposes, self-injection locking[1−5] is used since its fast optical feedback enables a significant reduction of laser linewidth and can be very tightly packaged due to not requiring any electronics. In Refs. [1-5], the linewidth of extended cavity diode lasers (ECDL) was reduced by optical feedback with a resonant cavity.

In this Letter, we construct an ECDL using resonant optical feedback from the p-polarization resonance of a monolithic folded Fabry–Perot parallel cavity (MFC) made of optical quartz glass.[5−7] Our design combines the advantage of the all-optical feedback in Ref. [3] and the advantage of the low finesse cavity in Ref. [5], which makes this work more compact and easier. The p-polarization resonance line shape of the MFC with a full width at half maximum (FWHM) of about 31 MHz is used for feedback locking. The maximum axial modes of the resonance is applied for injecting in the ECDL.

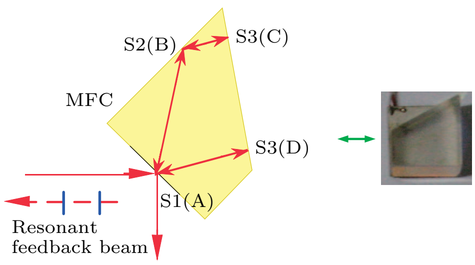

Fig. 1. (Color online) Scheme of resonant feedback and photograph of the parallel MFC. Parallel p-polarization lies parallel to the plane of incidence (blue line).

The parallel MFC is schematically shown in Fig. 1. The MFC, includes three optical planes, S1, S2 and S3, which define an F-P cavity. The coupling plane S1 has a reflectivity of 0.95 for p-polarization. Plane S2 is a total reflection surface and S3 is a parallel mirror with a reflectivity of 0.999. The geometric length of the MFC is 26 mm. The finesse of the MFC is 61 for p-polarization. The laser beam, with an external incidence angle of 46.7° at point A, travels along the route of ADABCBA. The self-injection locking beam is collinear with the incident light but in the opposite propagation directions. Because of its maximum intensity at the resonance frequency and narrow spectrum distribution, it is used to provide optical feedback. Figure 2 shows the resonance line shape of the MFC for injecting. In this figure, 3.97 GHz of the free spectral range is obtained by scanning the laser frequency.

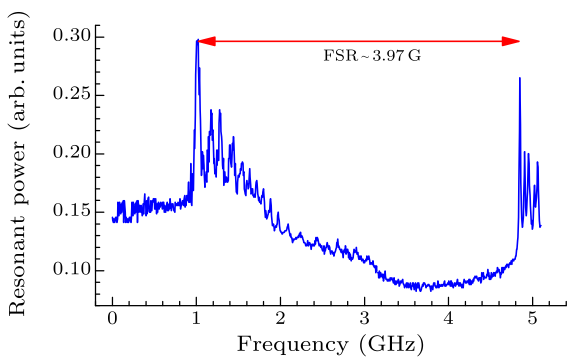

Fig. 2. (Color online) Resonant feedback and photograph of the parallel MFC.

Figure 3 schematically shows the ECDL setup operating at 689 nm. The LD is an antireflection-coated laser diode and G is a holographic grating. The zero-order diffraction is taken as the output beam with the power of 2.6 mW and the first-order diffraction with an

---

*Supported by the National Basic Research Program of China under Grant Nos 2010CB922902 and 2005CB724501, and the National Key Technology R&D Program in the 11th Five-Year Plan of China under Grant No 2006BAK03A20.
**Email: y-peng07@mails.tsinghua.edu.cn

angle of 71.2° is coupled into the MFC. Optical feedback power is controlled by a half-wavelength plate (HWP). The forward and backward beams of the MFC are spatially filtered by an aperture H. The P component feedback from the resonance of the MFC cavity is used for locking the ECDL. The temperature of the MFC is controlled to improve its stability.

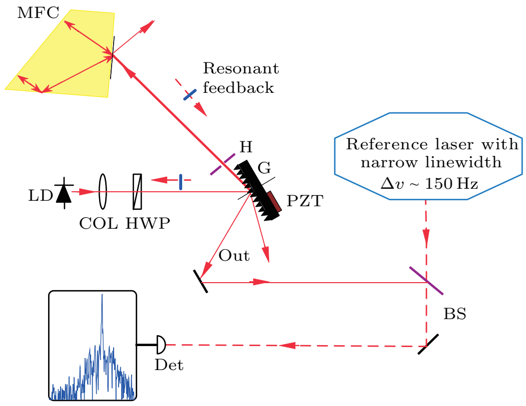

Fig. 3. (Color online) Schematic diagram of the experimental setup. LD: laser diode; Col: collimator; HWP: half-wave plate; G: grating; PZT: piezoelectric transducer; MFC: monolithic folded F-P cavity; H: aperture; Det: photodetector; BS: beam splitter.

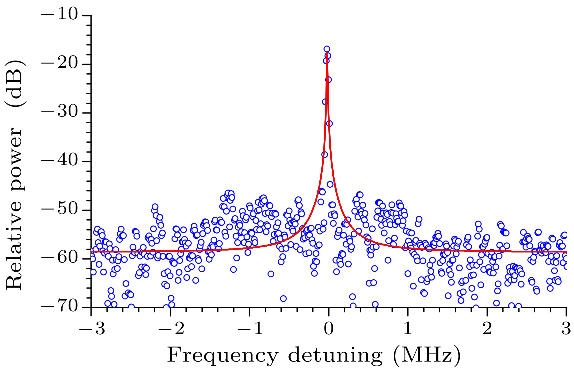

Fig. 4. (Color online) Line shape taken with 10 kHz resolution bandwidth. The skirts of the line are fitted with a 7 kHz Lorentzian envelope.

In order to demonstrate the linewidth of the ECDL, beat note measurement between this ECDL and a 689 nm reference ECDL laser is performed, as illustrated in Fig. 3. The 689 nm reference ECDL is locked to an ultra-stable high-finesse F-P cavity by using the Pound–Drever–Hall (PDH) method, its linewidth is narrowed to 150 Hz.[8] Figure 4 shows the beat note with a resolution bandwidth (RBW) of 10 kHz and the skirt of the measurement data is fitted with a Lorentzian curve[9] of 7 kHz FWHM. To estimate the characteristic of the phase and frequency noise, a signal source analyzer (Agilent E5052B) is employed to measure the phase noise, from which the spectral density of the frequency noise can be calculated. The curve (blue) in Fig. 5 shows the phase noise of the beat note signal. By the expression[10] $\int_{\Delta\nu_{\rm eff}}^{\infty} L(f)df = \frac{1}{2\pi}[\mathrm{rad}]^2$, where $L(f)$ is the single-side power density of the phase noise measured by the signal source analyzer, an effective laser linewidth $\Delta\nu_{\rm eff}$ can be calculated by the integral of $L(f)$ to be 8.3 kHz for relative linewidth, which in the same order as the linewidth of the experimental result. Large noise between 100 Hz and 500 Hz in Fig. 5 is attributed partially to thermal drift of the LD and the MFC crystal, partially to mechanical and acoustic noises in our laboratory.

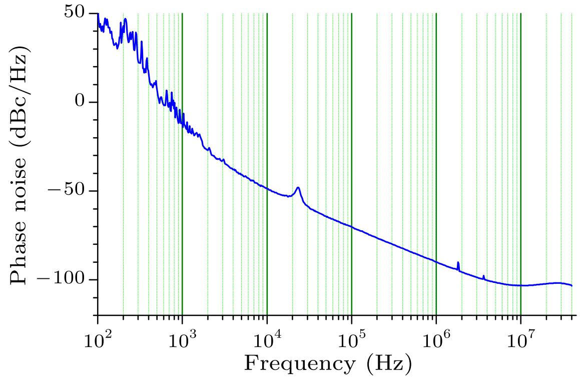

Fig. 5. Single-sided phase noise spectrum. Single-sided phase noise spectrum of the rf beat signal generated by the reference laser and the ECDL on a fast photodiode.

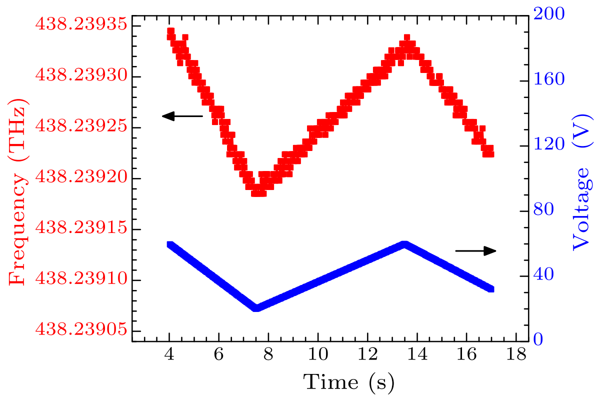

Fig. 6. The tunability of the ECDL by the PZT on monolithic. The frequency tunability is achieved by scanning the voltage.

In addition, the characteristics of the tunable semiconductor laser are described. The achievement of optically tunable single-frequency operation can be accounted by the use of strong optical feedback and good AR-coating. In order to demonstrate its tenability, we obtain the frequency change of the ECDL with a wavemeter (Toptica WS6-200) by driving a rectangular chip PZT with dimensions of $15 \times 15 \times 1\,\mathrm{mm}^3$, which is stuck to the top of the MFC. This kind of work about an extended cavity diode laser based on a monolithic cavtiy have not been reported before. Figure 6 shows the laser frequency versus voltage of PZT. The blue sawtooth trace is the ramp voltage of driving. The laser frequency can be modulated directly by voltage because the cavity length of the MFC is changed by PZT. It has a continuous change from 438.23918 THz to 438.23934 THz with no appearance of a mode hop, which is about 160 MHz single-mode tunability. The voltage tuning coefficient is about 4 MHz/V.

In summary, we have demonstrated a self-injection locking extended cavity diode laser (ECDL) using resonant optical feedback from the p-polarization of a monolithic folded Fabry–Perot parallel cavity (MFC). The FWHM of resonance of MFC is 31 MHz. With the help of a narrow-linewidth reference laser, the linewidth of the ECDL is measured to be about 7 kHz. The frequency could be tuned at 160 MHz with amplitude of 40 V by PZT on the monolithic. The voltage tuning coefficient is about 4 MHz/V. The lasers can be used as a master laser to pump high power lasers used for optical clocks and quantum metrology.

References

[1] Dahmani B et al 1987 *Opt. Lett.* **12** 876
[2] Hollberg L et al 1988 *Appl. Phys. Lett.* **53** 944
[3] Liang W et al 2010 *Opt. Lett.* **35** 2822
[4] Doringshoff K et al 2007 *Opt. Lett.* **32** 2876
[5] Zhao Y et al 2010 *Opt. Lett.* **35** 24
[6] Kane T J et al 1985 *Opt. Lett.* **10** 65
[7] Zang E J et al 2007 *Opt. Lett.* **32** 3
[8] Li Y et al 2010 *Chin. Phys. Lett.* **27** 074208
[9] Vassiliev V V et al 1998 *Opt. Commun.* **158** 305
[10] Hjelme D R et al 1991 *IEEE J. Quantum Electron.* **27** 352