Robust external cavity diode laser system with high frequency stability for Cs atomic clock

Jun Ruan, Jie Liu, Jie Ma, Zhijing Du, Changjiang Wu, and Shougang Zhang

National Time Service Center, Chinese Academy of Sciences, Xi’an 710000, China
Graduate University of Chinese Academy of Sciences, Beijing 100049, China

E-mail: ruanjun@ntsc.ac.cn
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A robust external cavity diode laser (ECDL) insensitive to mechanical vibration is built with an interference filter for selecting wavelength and a cat-eye reflector for light feedback. The free-running laser has a linewidth of 72 kHz. The laser frequency stability reaches $3 \times 10^{-12}$ at 1-s integration time in terms of relative Allan variance based on the saturation absorption spectrum.

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External cavity diode laser (ECDL) with high spectral purity has many applications in many fields, such as atomic physics, atomic clock, and coherent light communication\cite{1-6}. In atomic clocks, ECDLs are used to cool the atoms down to several microkelvin and detect the atomic population, which generates an error signal to stabilize the output frequency of atomic clocks. The quality of the laser directly impacts on the performance of atomic clock. Especially, the linewidth and frequency stability should be first considered\cite{7-9}.

In the most common ECDLs of the Littman or Littrow configuration\cite{1}, laser linewidth can be narrowed to a few hundred kilohertz. However, such a design is sensitive to the optical misalignment induced by mechanical vibration\cite{10}. This restricts the application of ECDLs under some special conditions, for example in space or commercial optically pumped Cs clock. Although a distribution feedback (DFB) laser or a distributed bragg reflector (DBR) laser with high mechanical stability has been developed for application in atomic clock, a typical linewidth of several megahertz\cite{11} may limit the further improvement of atomic clock.

In this letter, we present an ECDL with narrow linewidth and high mechanical stability. Moreover, to stabilize the laser frequency, a two-stage reliable servo loop is developed based on the saturation absorption spectrum. In our construction, an interference filter (IF), which consists of multiple thin layers of dielectric material, is used to select the wavelength, and a cat-eye reflector serves as the feedback mirror. This design firstly proposed by Zorabedian et al.\cite{12} has been chosen for space lasers in the PHARAO project\cite{13}.

The construction of the ECDL is shown in Fig. 1. The light emitted from laser diode (LD) is collimated by an aspheric lens (CL1) with large numerical aperture(NA). A lens (L1) focuses the collimated light on the partial reflector (R) which forms a cat-eye reflector. This reflector reflects partial light back to LD so that an external cavity is formed. The external cavity length is about 10 cm, which is adjusted by a piezoelectric transducer (PZT) attached on the reflector. The cat-eye reflector with reflectivity of 30% keeps the external cavity valid even if the optical components inside cavity are slightly misaligned. The focused light is collimated by the second aspheric lens (CL2). An IF is placed between the CL1 and the L1. The IF consisting of multiple thin layers of dielectric material with super-narrow passband of 0.3 nm and high transmission of 90% serves as laser wavelength selection. The wavelength of the transmitted light is changed by adjusting the filter’s angle. Compared with the Littrow or Littman configuration, the IF and the cat-eye reflector replace the grating to select laser wavelength and form an external cavity. We can easily adjust laser frequency and optimize optical feedback. Furthermore, because the IF and the cat-eye reflector are insensitive to the incident angle\cite{13}, this design has higher mechanical stability than the design of Littrow or Littman configuration.

Fig. 2. Spectra of the beat note signal between two identical ECDLs. The spectrum analyzer (Agilent E4405B) has a resolution bandwidth of 1 kHz and sweep time of 2 s. The inset shows the central sharp peak.
Such narrow linewidth of the ECDL guarantees a high grating external cavity laser of 72 kHz. This result is much better than the result of profile line fitted by Gaussian shape to the linewidth of 112.5 kHz for each individual laser. However, the –3-dB linewidth is determined by the laser has a –3-dB linewidth of 225 kHz, corresponding to the frequency domain of 7.4 MHz, which shows that our ECDL has higher spectral purity than others with the same configuration. A little degraded frequency stability is found at 10–100 s, This is probably due to the fact that the reference Cs cell is not temperature stabilized. To achieve the higher frequency stability, some improvements about the frequency reference, such as temperature stabilization and magnetic field shield of the Cs cell, should further improve laser frequency stability to 10−13 level.

In conclusion, to reduce sensitivity to mechanical vibration of ECDL, a robust ECDL system is built with an interference filter and a cat-eye reflector. The free-running laser has a linewidth of 72 kHz. The high frequency stability of 3×10−12 at 1-s integration time is achieved by homemade servo loop and a typical saturated absorption setup.

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