The development and future of the Faraday laser

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External cavity diode lasers (ECDLs) are very important in a lot of areas. Specifically, the ECDLs that can correspond to the atomic transition lines are extremely significant in many applications. Traditionally, the main frequency selective methods for ECDLs are gratings, Fabry-Pérot etalons and interference filters. The ECDLs based on those methods always have excellent performance in tunability, output wavelength stability, and these methods are commonly used in commercial products. However, the output wavelength of those ECDLs mentioned above cannot automatically correspond to the atomic lines, and is easily affected by fluctuations in the temperature and current of the laser diode. The ECDLs using the Faraday anomalous dispersion optical filter (FADOF) as the frequency selectivity element, which was first named as “Faraday laser” by Peking University [1], have extremely good performance. The Faraday lasers have immunity to the fluctuations of laser diodes’ temperature and current [1,2], and its output wavelength directly correspond to the vicinity of the atomic transition lines immediately as soon as it is turned on. The basic principle of the FADOF's frequency selection is that, the Faraday anomalous dispersion effect only occurs when the frequency of the incident light is near the resonant transition frequency of the atoms. As a result, the FADOF can limit the laser frequency to the atomic Doppler-broadened line, and leads to the fantastic phenomena.

Moreover, we have proposed some methods to solve the mode hopping problem caused by the inner mode of laser diode. In 2011, based on the first creative use of the anti-reflection coated laser diode [2], Peking University achieved an ECDL with rubidium FADOF operating at 780 nm that is immune to the fluctuations of current and temperature of the laser diode. In the past dozen years, we have made a lot of great efforts. The excited-state rubidium FADOF at 775.9 nm without any additional frequency-stabilized pump laser, the ultranarrow-bandwidth FADOF at 455 nm based on the combination of Faraday effect and saturation effect, the high transmittance FADOF with single peak or working at side wings, the cold atom FADOF with the narrowest transmission bandwidth as well as high figure of merit, and a great deal of other breakthroughs have been achieved to optimize the Faraday laser. Besides, the excited-state Faraday laser based on the electrodeless discharge vapor lamp, the free running 852 nm Faraday laser, the frequency stabilization of the Faraday laser to atomic lines have been achieved step by step. We always focus on improving the Faraday laser and try to create a new generation for ECDLs through quantum technologies. After the realization of frequency locking of Faraday laser, the fractional frequency Allan deviation of the residual error signal is down to $5.8 \times 10^{-15}/\sqrt{\tau}$ [3], and it can be further improved.

In addition, we also achieved the Voigt laser, whose wavelength fluctuation is less than ±0.5 pm when the diode current is changed between 73 mA and 150 mA. We believe the Voigt laser is also a promising type of laser for future applications in quantum technology. We also use a corner-cube reflector as the cavity mirror to improve the environmental adaptability of Faraday laser. Furthermore, the Faraday lasers are applied to the optically-pumped cesium atomic clock and the cesium fountain clock to improve the performance of atomic clocks, and they can also be applied to atomic magnetometers, atomic gravimeters, and other quantum precision measurements in the future.

References

[1] Z Tao, Y Hong, B Luo, J Chen, H Guo, “Diode laser operating on an atomic transition limited by an isotope ^{87}Rb Faraday filter at 780 nm,” Opt. Lett. 40(18), 4348-4351, 2015.

[2] X Miao, L Yin, W Zhuang, B Luo, A Dang, J Chen, H Guo. “Note: Demonstration of an external-cavity diode laser system immune to current and temperature fluctuations,” Rev. Sci. Instrum. 82(8): 086106, 2011.

[3] H Shi, P Chang, Z Wang, Z Liu, T Shi, J Chen. “Frequency Stabilization of a Cesium Faraday Laser With a Double-Layer Vapor Cell as Frequency Reference,” IEEE Photonics J. 14(6): 1-6, 2022.