Active Faraday optical frequency standard based on diffuse laser cooling of ^{87}Rb atoms

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Narrow linewidth and highly frequency stabilized diode laser systems are widely used in atomic clocks, laser spectroscopy, quantum precision measurements and other fields. Traditionally, the diode lasers use Fabry-Pérot etalons, gratings, and interference filters to achieve tunable single-mode outputs. However, they are very susceptible to vibration and cannot provide good long-term stability because they do not have an absolute reference. Faraday laser uses the Faraday anomalous dispersion optical filter as the frequency selective element. It has the advantage of output laser frequency directly corresponding to the Doppler broadening line of atomic transition, with frequency being insensitive to temperature and current fluctuations of laser diode. In order to further realize the ultra-stable laser, Faraday laser has been combined with the modulation transfer spectroscopy technology for laser frequency noise suppression, the linewidth can reach the order of kHz, and the short-term frequency stability can reach $5.8\times10^{-15}/\sqrt{\tau}$. But this scheme is an external frequency stabilization scheme, where the laser output is passively locked on the atomic transition line. Moreover, the laser operates at passive mode, where the cavity-mode linewidth is smaller than the gain linewidth, making it susceptible to the cavity-pulling effect.

Active Faraday optical frequency standard[1] can well improve the robustness of Faraday laser to cavity length fluctuations. It operates in the "bad-cavity" regime, where the cavity-mode linewidth is larger than the gain linewidth. The laser directly originates from the stimulated emission of a quantum reference system, with an output linewidth much smaller than the natural linewidth determined by spontaneous emission, and has the advantage of suppressed cavity-pulling effect. To further reduce the influence of thermal atomic collision frequency shift, this work proposes an active cold-atom Faraday optical frequency standard based on diffuse laser cooling. The meter-scale diffuse laser cooling can increase the effective number of atoms, improve laser output power, and compensate for insufficient power caused by excessive cavity loss. Based on cold atoms, ultra-narrowband laser gain close to atomic transition natural linewidth and corresponding hyperfine transition frequency is achieved using velocity-selective optical pumping and Faraday atomic filtering technology. By constructing an external-cavity laser feedback system and controlling cavity loss rate, we enable the laser to operate in "bad-cavity" regime, ultimately achieving a narrow-linewidth active cold-atom Faraday optical frequency standard where the output laser frequency is completely determined by atomic hyperfine transition frequency.

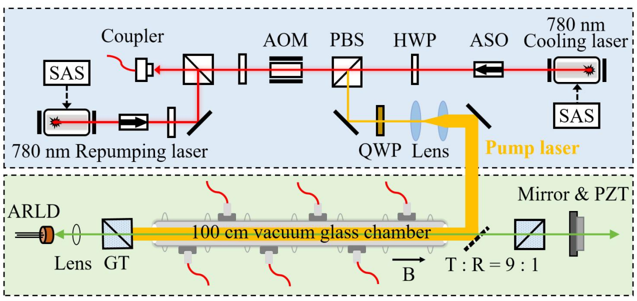

Fig. 1: Schematic of the experimental setup.

[1] W. Zhuang, "Active Faraday optical frequency standard", Opt. Lett., vol. 39, p. 6339-6342, 2014.