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Laser Phase and Frequency Stabilization Using Atomic Coherence

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Abstract: We present a simple method of stabilizing the laser phase and frequency by polarization spectroscopy of an atomic vapor. In analogy to the Pound-Drever-Hall method, which uses a cavity as a memory of the laser phase, this method uses atomic coherence as a phase memory of the transmitting laser field. A preliminary experiment using a distributed feedback laser diode and a rubidium vapor cell demonstrates a shot-noise-limited laser linewidth reduction (from 2 MHz to 20 kHz).

1. Introduction

The Pound-Drever-Hall (PDH) method has become the standard method for laser linewidth reduction. The key feature of the PDH method is its use of the cavity not only as a frequency reference but also as a *time-averaged phase memory* of the incident laser field, which leads to a fast response to the laser phase fluctuations on a time scale shorter than the cavity response time, enabling efficient laser linewidth reduction. Recently, we have shown that *atomic coherence* (dipole oscillations) works as a phase memory for the transmitting laser field [1]. Indeed, the frequency discriminator using polarization spectroscopy of an atomic vapor possesses exactly the same transfer function as that of the PDH method. We performed a preliminary experiment using a DFB laser and a rubidium vapor to demonstrate laser linewidth reduction by polarization spectroscopy.

2. Experiments

Experimental setup is shown in Fig. 1. We used a Doppler-free polarization rotation signal as an error signal for phase and frequency stabilization of the DFB laser. Bias-T fast current feedback was implemented to suppress fast phase fluctuations of the DFB laser. The laser linewidth was measured by a multi-pass delayed self-homodyne technique (1.5 km total fiber delay). We observed a significant linewidth reduction from 2 MHz to a shot-noise-limited linewidth of 20 kHz.

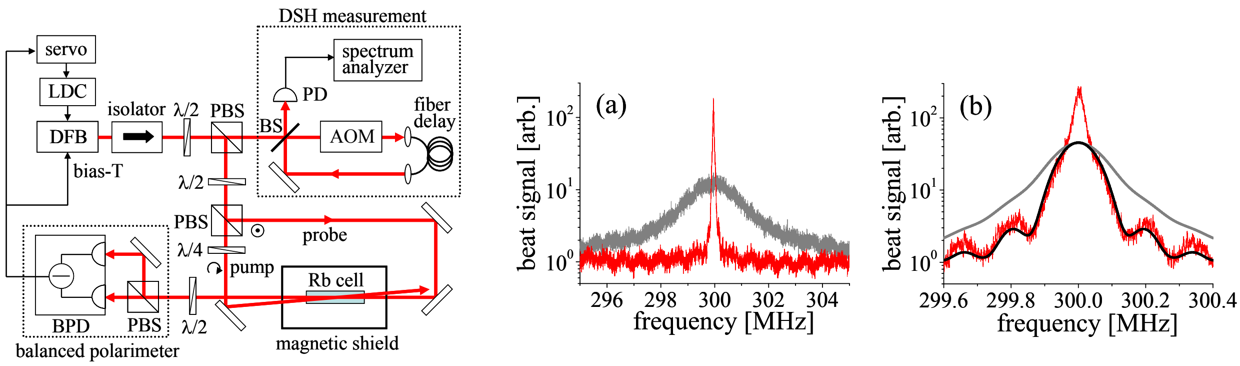

Fig. 1. (Left) Experimental setup. (Right) (a) Power spectra of the beat signals in a delayed self-homodyne measurement using a 780-nm DFB laser. (b) A detailed scan of the central part of the spectrum. The black and gray lines represent the calculations for laser linewidths of 20 kHz and 80 kHz, respectively

3. Conclusion

We have demonstrated a novel laser phase and frequency stabilization which uses atomic coherence and thereby is immune to mechanical noise and thermal drift. This method would drastically simplify the experiments which have relied on the PDH method using an ultralow heat expansion (ULE) cavity for laser linewidth reduction. The laser phase and frequency stabilization demonstrated here can be viewed as the suppression of laser frequency (FM) noise to amplitude (AM) noise conversion, or FM noise to optical rotation (OR) noise conversion in a resonant medium. Our method is readily applicable to improve the performance of gas-cell-based optical atomic clocks or magnetometers, which have been suffering from this type of laser-induced noise.

[1] Yoshio Torii, Hideyasu Tashiro, Nozomi Ohtsubo, and Takatoshi Aoki, Phys. Rev. A **86**, 033805 (2012).