A novel scheme of Doppler-free spectroscopy by differential detection

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Abstract—We propose and implement a differential detection scheme of Doppler-free spectroscopy. By setting the proper relative polarization direction between the linearly polarized probe and pump beam, which are spatially counter-propagated and overlapped, simultaneous Lamb-dip and -peak are observed by detecting the parallel and perpendicular polarization components of the transmitted probe beam. The differential signal is also obtained with improved signal-to-noise ratio (SNR), which is desired for compact optical reference, high-resolution spectroscopy and so on.

Keywords—Doppler-free; Lamb-dips and -peaks; differential detection; compact optical reference

I. INTRODUCTION

Doppler-broaden is caused by the inhomogeneous distribution of atomic velocities, and can be eliminated or suppressed by Doppler-free techniques such as saturation absorption spectroscopy (SAS) [1], polarization spectroscopy [2-3], modulation transfer spectroscopy [4], etc. Saturation absorption spectroscopy is widely used because of its simplicity, which measures the absorption of the probe beam saturated by a counterpropagating pump beam and then uses the probe beam minus the reference beam to obtain a Doppler-free signal with reduced absorption (Lamb-dips) or enhanced absorption (Lamb-peaks).

In this paper, we propose a new scheme. With the special pump-probe polarization configuration, simultaneous Lamb-dip and Lamb-peak are observed by detecting the parallel and perpendicular polarization components of the probe beam. Compared with the traditional saturation absorption spectroscopy with Lamb-dip shape signal, Doppler-free signals with simultaneous reduced (Lamb-dips) and enhanced absorption (Lamb-peaks) are obtained in our novel scheme, more importantly, differential signals between them are also observed with higher signal-to-noise ratio (SNR) [5-7].

II. EXPERIMENT RESULTS

The light source is a distributed Bragg reflector (DBR) laser tuned to the ^{87}Rb D$_1$ line at 795 nm. The cell temperature is stabilized at approximately 30 °C. The ^{87}Rb-isotope-enriched cylindrical vapor cell (diameter 20 mm, length 50 mm) is surrounded by two layers of permalloy magnetic shield. No static magnetic field is applied.

After passing through a beam splitter (BS), the linearly polarized light beam (pump beam) interacts with the ^{87}Rb atoms. The diameter of the Gaussian-shape beam incident in the cell is about 1.5 mm. Thanks to a quarter-wave plate and mirror, the probe beam is obtained which spatially counter-propagated and overlapped with the pump beam. The transmitted light of the probe beam is spatially separated by the beam splitter, whose orthogonal components are separated by half-wave plate and polarization beam splitter (PBS), and sent to balanced detectors.

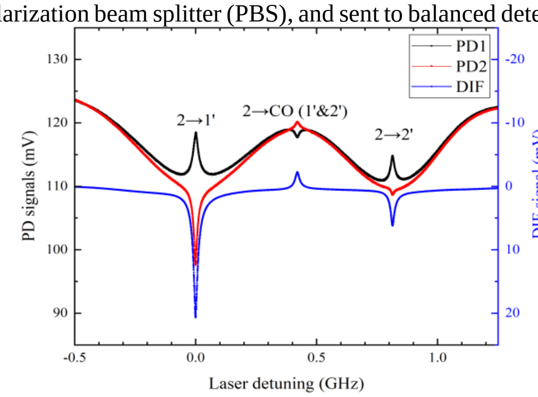

Fig. 1. Experimentally obtained typical Lamb-dips (black), lamb-peaks (red) and differential (blue) spectrum in the D$_1$ line of ^{87}Rb.

Figure 1 demonstrated the observed Lamb-dips (black), Lamb-peaks (red), i.e., the Doppler-free spectroscopy with simultaneous absorption reduced and enhanced signals with ground state $|F=2\rangle$ in the D$_1$ line of ^{87}Rb. Their differential signals (blue) are also plotted. Compared with Lamb-dips or Lamb-peaks signals, the differential signals in our novel scheme are featured with increased amplitude and narrow linewidth, and its Doppler-broaden background is almost completely eliminated, which is desired for high-performance and robust laser frequency locking.

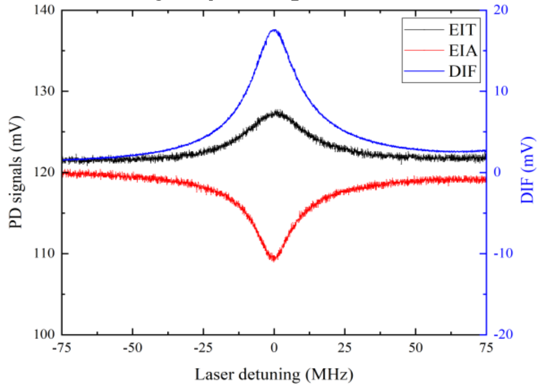

Fig. 2. The zoom-in Lamb-dip, Lamb-peak and differential (reversed) signals of the transition $|F=2\rangle \rightarrow |F'=1\rangle$ in figure 1.

A closer view as shows in Fig. 2, the Lamb-dip, Lamb-peak, and differential signals are obtained with the same conditions as Fig. 1. The SNR improvement of the differential signal is clearly demonstrated, which is about 5 times higher than that of the Lamb-dip or -peak signals.

III. CONCLUSIONS

We propose and demonstrate a novel differential Doppler-free spectroscopy by detected the coexistence of Lamb-dips and -peaks, which can obtain Doppler-free atomic resonant signals with increased SNR. This method can potentially improve the frequency stability of laser frequency locking, thus lead to a compact and high-performance optical reference.

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