Anomalous Level-crossing Resonances in Rb Vapor Cells with Buffer Gas

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***Summary*—The ground-state level-crossing resonance, or Hanle resonance, in atomic vapors are widely used for atomic magnetometry. In this paper, we report observations of anomalous level-crossing resonances for Rb vapor in a buffer-gas cell. By optically pumping alkali atoms with a ring-shaped laser beam and detecting the spin polarization in the hole of the pumping light with an off-resonance light, we observe a polarization reversion when scanning the transverse magnetic field around zero. Both experiments and simulations are demonstrated.**

Keywords—Magnetometer; Hanle resonance; atomic diffusions; buffer gas

I. INTRODUCTION

The zero-field level-crossing resonance, or zero-field Hane resonance, was discovered by Dupont-Roc *et al.* [1], where a narrow resonant variation of the absorbed light is observed by scanning the magnetic field of which the direction is perpendicular to that of the pumping light, around zero. Based on this resonance, many high-sensitivity atomic magnetometers working around zero fields have been developed [2]. For such atomic magnetometers, the atomic response to the transverse magnetic field is usually a Lorentzian curve centered at zero fields. However, by optically pumping the atoms with a ring-

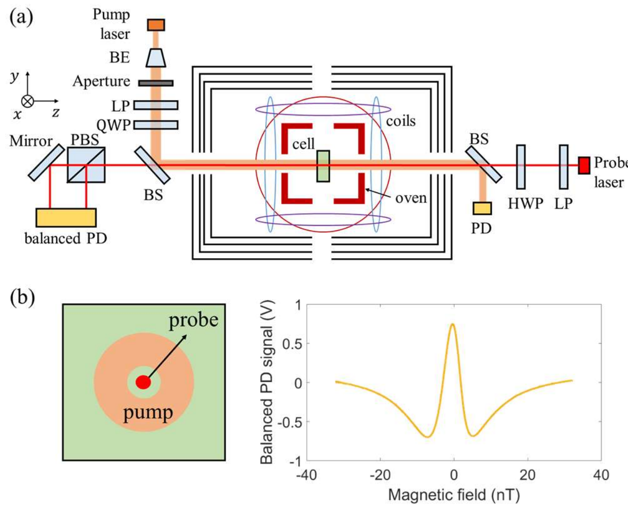

Fig. 1 (a) Schematic of the experiment setup. BE, beam expander; LP, linear polarizer; QWP, quarter-wave plate; HWP, half-wave plate; BS: beam splitter; PBS, polarized beam splitter; PD, photodetector. (b) The anomalous level-crossing resonance observed in experiments.

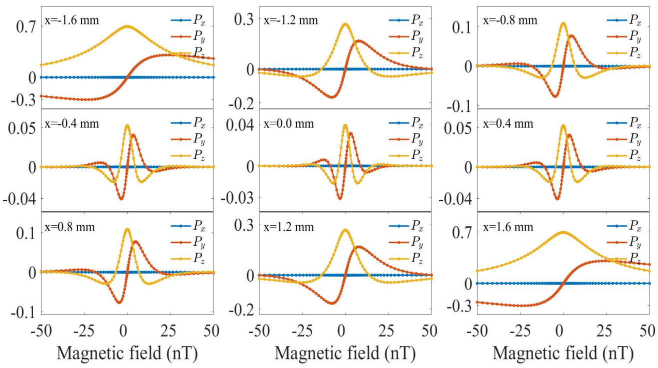

Fig. 2 The simulation results are based on Bloch equations. The results show the atomic response to the transverse field (x-axis) in different locations, ranging from −1.6 mm to 1.6 mm away from the center of the pump light.

shaped laser beam, the response of atoms in the hole of the pump beam is different from the typical level-crossing resonance. In the hole of the ring-shaped pump light, the spin polarization generated by the continuous pump light can be reversed when scanning the transverse fields.

The overall dynamical evolution of the spin polarization **P** can be described by Bloch-Torrey equation

$$\frac{\mathrm{d}}{dt}\mathbf{P} = \gamma\mathbf{P}\times\mathbf{B} + R_{\mathrm{OP}}(\mathbf{s}-\mathbf{P}) - \Gamma_0\mathbf{P} + D\nabla^2\mathbf{P}, \qquad (1)$$

where γ is the gyromagnetic ratio of atoms, R_{OP} is the optical pumping rate, $\mathbf{s} = s\hat{z}$ is the optical pumping vector, Γ_0 is the phenomenological spin relaxation rate, and D is the diffusion constant of atoms within the buffer gas.

II. METHODS/RESULTS

The experimental setup is shown in Fig. 1(a). A 795 nm laser propagating along z direction is performed as pump light to polarize atoms. The diameter of the circularly polarized pump light is expanded to ~8 mm, and the frequency of the light is tuned to the center of the pressure-broadened ^{87}Rb D1 line. A linearly polarized probe light propagating along z-axis with an opposite direction relative to the pump light is used to detect the spin polarization generated by the pump light. The diameter of the probe light is ∼1 mm, and the frequency is detuned about 55 GHz from the center of ^{87}Rb D1 line. A $30\times30\times10\ \mathrm{mm}^3$

cell, filled with ^{87}Rb and 600 Torr N_2, is heated to 155 °C and placed inside a cylindrical magnetic shield.

Figure 1(b) shows the anomalous level-crossing resonance recorded with the balanced photodetector, where a clear spin polarization reversion can be observed. To explain the anomalous phenomenon, we numerically solve the Bloch-Torrey equation and the simulations show a similar atomic response to the transverse field, as shown in Fig. 2. For simplicity, the attenuation of pump light propagating in z-axis is neglected and only the atomic diffusion in x-y plane is considered.

III. DISCUSSION/INTERPRETATION

According to the simulation results, the anomalous level-crossing resonances may be explained by atomic diffusions. When the polarized atoms leave the region of pump light and travel to the center of the pump light, the polarized atoms will precess around the transverse field without pump light. So, the polarized atoms we detected in the center of pump light are those that have evolved freely for a period of time, which obviously can have a different orientation relative to the atoms within the region of pump light. With such an experiment scheme, we can obtain an ensemble of polarized atoms continuously. Furthermore, the atoms are nearly free of the light-shift effect or the power broadening effect caused by the pump light, which can be helpful for achieving higher performance and less systematic error in atom-based quantum sensors.

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