Laser system for EIT spectroscopy of cold Rb atoms

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ABSTRACT

A diode laser system for spectroscopy of cold Rb atoms is reported. The apparatus is mainly aimed at studying the electromagnetically induced transparency (EIT) in cold environment. The system is based on a rubidium magneto-optical trap (MOT). Two additional extended cavity diode lasers provide the light beams for experimenting, e.g., a coupling- and probe- beam for EIT. The set-up is equipped with channels for detection of absorption and fluorescence. Some system elements of the ones made in our laboratory, in particular, the electronic system for data acquisition and for control of MOT and experiment, are presented in some detail. Records of probe beam absorption spectra of cold Rb, exhibiting profiles due to EIT in multilevel cascade scheme, registered by the use of this apparatus, are presented as an example of the setup performance.

Keywords: Magneto-optical trap, diode lasers, data acquisition and control system, cold atoms, rubidium, spectroscopy, electromagnetically induced transparency,

1. INTRODUCTION

The essential part of the designed and built at the IP PAS diode laser system for spectroscopy of cold Rb atoms is a standard six-beam rubidium magneto-optical trap (MOT). Two additional extended cavity diode lasers are used for spectral studies. The system is equipped with digital laser frequency tuning-, experiment control- and data acquisition- systems. The apparatus is aimed mainly to study electromagnetically induced transparency (EIT) spectra with a MHz resolution, in different configurations (e.g., for three-level EIT: a usually exploited cascade S-P-D scheme of transitions, or Λ-type S-D-P scheme with two-photon probe transition (Fig. 1)), and with different number of levels and field frequencies involved.

Electromagnetically induced transparency (EIT) is a quantum effect that allows for a destructive interference in absorption, in combination with a constructive interference in the nonlinear susceptibility. The phenomenon of EIT consists in the reduction of the probe beam absorption in the presence of the coupling beam. EIT founds many applications in non-linear optics such as e.g. light amplification without population inversion, enhancement of four-wave mixing, magnetic field cancellation diagnostics, slowing down group velocity of light pulses. EIT can be also applied for spectroscopy of Rydberg states. By using the technique of cooling atoms below mK, peculiar experimental conditions can be established. The role of Doppler and transit broadening is greatly reduced, at the same time low collision rate decreases the coherence decay.

One of our planned MHz resolution studies of EIT spectra in cold Rb involves the nD (n≥5) states. A particular task is to “optimize” the EIT spectral features by controlling the experimental conditions. The goal is to obtain multiple steep jumps of refractive index (accompanying EIT peaks), which would support slowing of probe-light pulses at various nearby frequencies.

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2. DESCRIPTION OF THE SETUP

2.1 Magneto-optical trap

The momentum transfer between a moving atom and a photon, in an act of absorption, constitutes a basis of laser cooling process. In the presence of a quadrupole magnetic field, the velocity-dependent and spatially dependent forces cause both cooling and confinement of atoms, which become trapped at zero field point. In Fig. 2 the hyperfine structure of the states used in cooling the $^{85}\text{Rb}$ atoms is shown, as well as the transitions induced by the beams of two MOT lasers. In order to achieve cooling, the trapping laser is red-detuned against the $5S_{1/2}(F=3) \rightarrow 5P_{3/2}(F'=4)$ resonance. The repumping laser, resonant with the $5S_{1/2}(F=2) \rightarrow 5P_{3/2}(F'=3)$ transition serves to return atoms, which leaked to the $5S_{1/2}(F=2)$ state, back to the trapping cycle. General scheme of the presented MOT is depicted in Fig. 3. While the system can be used for both the $^{85}\text{Rb}$ and $^{87}\text{Rb}$ isotopes, to simplify our presentation we will limit to the more abundant $^{85}\text{Rb}$ isotope.

The MOT cell is made of quartz. It is equipped with a glass vessel with three Rb dispensers (FT-type, SAES Getters, natural abundance of isotopes) serving as a source of Rb atoms. The cell is connected to vacuum system (not shown in Fig. 3) with an ion pump. The vacuum, as determined from the current of continuously working ion pump, is better than $10^{-8}$ Torr. Three pairs of magnetic coils in Helmholtz configuration compensate the Earth and stray magnetic fields at the position of the sample of cold atoms. One pair of coils in anti-Helmholtz configuration produces a necessary field for confinement of atoms (quadrupolar field distribution with gradient up to 40 Gs/cm). Two commercial extended cavity diode lasers (ECDLs) (type DL100, TuOptics-Toptica) (DL1, DL3), and a home made amplifier (DL2) comprise the MOT laser system (1 MHz linewidth). The lasers DL1 and DL2 work in a master-slave injection locking configuration and provide the trapping beam, while DL3 is the repumping laser. Both trapping (40 mW) and repumping (15 mW) beams are combined to co-propagate on the polarising beam splitter, spatially reshaped with anamorphic prism pair, and expanded with telescope to the diameter of 17 mm. Subsequently the beam is split into three mutually perpendicular, retro-reflected beams, of the same intensities and proper circular polarizations intersecting in center of the cell.

In our MOT, a steady state number of cold $^{85}\text{Rb}$ atoms (given by the balance between loading and loss rates), amounts not less than $10^7$ in a cloud of a size usually less than 1 mm at the temperature of ca 100 $\mu$K.

Fig. 2 The levels and transitions involved in the operation of our $^{85}\text{Rb}$ MOT.
The laser frequency stabilization and tuning (Fig. 4) is achieved by applying: (i) the dichroic atomic vapor laser lock (DAVLL) scheme and (ii) the frequency control unit based on the Doppler-free saturated absorption spectrometer. Since DAVLL relies on the Doppler broadened transitions, for experiments with MHz resolution, the use of spectrometer (ii) is necessary to calibrate the laser frequency against Rb hyperfine structure line positions.

In Fig. 5 two fragments of MOT are visualized. In picture a), at the central position, the main part of the trap with the MOT cell can be seen. The view of the cell is partially screened by the small magnetic coils, those creating quadrupolar field for trapping. Some fragments of the big coils for cancellation of the Earth and stray magnetic field are also visible.

Some other details about the MOT can be found in our earlier publication.

Fig. 3 The general scheme of our MOT. Essential blocks are marked with dashed line.

Fig. 4 System for laser frequency stabilization and control.
2.2 The apparatus for spectral studies in cold Rb

The apparatus is aimed at registering laser induced spectra in the cold Rb sample in MOT. In particular, the EIT spectra consisting in reduction of absorption of the probe beam in the presence of the coupling beam are detected (with the use of the PD1 photodiode, see Fig. 6). Examples of level configurations of interest in our EIT experiments are given in Fig. 1. Detection of the accompanying fluorescence (e.g. the blue one of the transition Rb(6P → 5S), from the nearest P state below 5D) is also provided (see the photomultiplier PM in Fig. 6).

In Fig. 7 a block diagram of a specially constructed and programmed DMS2000 system, for data acquisition and for control of MOT and of the experiment, is shown. The control enables to execute a programmed sequence of experimental events including turning ON and OFF the MOT field, advancing laser frequency after the end of the data acquisition period, etc. Due to application of the micro-controller, timing sequence can be precisely established, with µs accuracy, which is usually not available in most of measurement systems based on the Windows platform.
2.3 Examples of the set-up performance

Various absorption spectra have been registered with this apparatus by probing the cold $^{85}$Rb sample with additional laser(s), with MOT lasers constantly ON or switched OFF for the time of data acquisition.

In Fig. 8 an example of EIT spectra in multilevel cascade scheme is shown. The probing (weak) laser was tuned across the $5S_{1/2}(F=3)\rightarrow 5P_{3/2}(F'=2,3,4)$ transitions. The coupling (strong) laser was set to be in resonance with energy distances: either $5P_{3/2}(F'=2)\rightarrow 5D_{5/2}$ (for spectrum (a)) or $5P_{3/2}(F'=3)\rightarrow 5D_{5/2}$ (for (b)). Structured profiles of increased transmission are seen, at the $F'=2$ or $F'=3$ absorption peaks. They are multiple EIT peaks due to hfs of the 5D$_{5/2}$ state, i.e. due to the components $F''=3,2,1$ or $F''=4,3,2$, respectively.

In the course of the measurement MOT lasers were ON. The features at $F'=4$ peak are related to the presence of the trapping light. The repumping MOT laser was tuned to the either $5S_{1/2}(F=2)\rightarrow 5P_{3/2}(F'=3)$ or $5S_{1/2}(F=2)\rightarrow 5P_{3/2}(F'=2)$ resonances, respectively for (a) and (b).

3. CONCLUSIONS AND PERSPECTIVES

In conclusion, we have constructed and checked the experimental arrangement for spectral studies in a cold Rb sample. Many components were designed and built entirely in our lab. Some of them are presented in this paper. We have tested MOT performance on several parameters, like beam intensity and diameter, field gradient, laser detuning. The trap proved to be reliable, and efficient. Also the data acquisition and control system works correctly. At present, efforts are concentrated on further increasing the spectral resolution.

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