Dual-beam electromagnetically-induced absorption resonance in a $^{87}$Rb cell with antirelaxation coating

E Taskova' and E Alipieva

Academician Emil Djakov Institute of Electronics, Bulgarian Academy of Sciences
72 Tsarigradsko Chaussee, 1784 Sofia, Bulgaria

E-mail: taskova@ie.bas.bg

Abstract. Destruction of the laser-induced coherence in the ground state of alkali atoms manifests itself as an ultra-narrow resonance in the atomic spectrum. Depending on the geometry of irradiation and observation, the coherent spectroscopy studies CPT (coherent population trapping), EIT (electromagnetically-induced transparency) or EIA (electromagnetically-induced absorption). In the present work, we investigated EIA on the D$_1$ $^{87}$Rb line by applying a counter-propagating dual-beam scheme. The main advantage of this scheme is the high resonance contrast – an important parameter for many applications. In our previous work performed in a paraffin-coated cell we observed that, unlike the resonance in buffer gas cell detected in the same experimental scheme, the EIA signal has a complex form, because it is formed by two atomic sub-ensembles in the vapor cell with different relaxation rates determined by the laser excitation conditions. We focused on the narrow component, since it has a higher amplitude-width ratio, making it preferable for applications. We investigate the influence of the atomic vapor density and the pump laser intensity on the resonance parameters in order to optimize the amplitude ratio of the wide and narrow components and achieve the highest amplitude-width ratio value for the narrow component of the EIA resonance.

1. Introduction
The EIA is an interference effect, which manifests itself as increased absorption of the resonant medium after interacting with resonant coherent light fields. Like other coherent interference phenomena (CPT [1] and EIT [2]), the electromagnetically-induced absorption experiments are mostly realized on the ground-state hyperfine levels of alkali atoms (Rb, Cs, K) and the resonances stand out with a narrow sub-Doppler width. The EIA resonance was first registered on an optical transition with $F_z = F_{z^*} + 1$ ($F_{z^*} > 0$) in a buffer gas cell [3] and was attributed to a spontaneous transfer of population or Zeeman coherence from the excited state to the ground state [4]. Due to the collisional depolarization of the excited state, the EIA resonance in buffer gas cells has a small amplitude and does not find wide applications. Different experimental geometries and methods to obtain EIA in buffer gas cells have been proposed recently. They have not achieved a narrow width and a high contrast capable of competing with the nonlinear CPT and EIT resonances.

A new scheme based on counter-propagating pump and probe light beams with mutually orthogonal linear polarizations, proposed in [5], allows one to obtain a very high-contrast and a

---

1 To whom any correspondence should be addressed.
narrow-width EIA resonance in a buffer gas cell. The advantages of this scheme were proved recently by experiments in Rb and Cs [6, 7]. In [8], the authors used the dual-beam scheme for a Cs atomic clock. A contrast, defined in [6] as the ratio of the amplitudes of the Doppler background and the EIA resonance, of over 100% was measured in $^{87}$Rb D$_1$ line in a buffer gas cell. In our previous work, we investigated the EIA resonances in the same scheme, but in a coated vacuum cell [9]. We found that in a coated cell, the shape of the EIA resonance has a complex form and the contrast does not have the expected high values. The task of the present work is to investigate the influence of the cell temperature and intensity of the pump laser on the resonance parameters in order to optimize the EIA resonance.

2. Experimental set-up
The experimental setup consists of a single-mode diode laser, two polarization beam splitters (PBS) and a system of mirrors used to form two counter-propagating laser beams with orthogonal polarizations, a paraffin-coated $^{87}$Rb cell enclosed in a 2-layer magnetic shield, and a registration system. It is described in detail in [9] and shown schematically in figure 1. A dc magnetic field $B_{\text{scan}}$, created by a solenoid, is applied collinearly to the laser beams.

![Figure 1. A configuration of the pump and probe beams in the cell. PBS – polarization beam-splitter.](image)

The coated $^{87}$Rb cell has a diameter of 2 cm and is 2.5 cm long. It is placed in a 50-cm long solenoid providing a homogeneous magnetic field along the cell axis. The cell was heated by a bifilar coil.

The beam diameters were 5 mm for the pump beam and 3 mm for the probe one. The absorption of the probe beam was registered in dependence on the dc magnetic field with an amplitude of 40 mG scanned at a frequency 0.33 Hz around zero value. The signal is an EIA resonance centered at zero magnetic field.

The experiment was performed on the $^{5}\Sigma_{3/2} \rightarrow ^{5}\Pi_{1/2}$ transition ($F_g = 2 \rightarrow F_e = 1$) of the $^{87}$Rb D$_1$ line. Figure 2 shows the absorption spectrum of the D$_1$ $^{87}$Rb line. The laser frequency is tuned to the $F_g = 2 \rightarrow F_e = 1$ transition, marked by an arrow in figure 2. The magnetic field scanned around zero destroys the coherent state created by the pump beam and changes the probe-beam transmission through the cell.

3. Experimental results and discussion
The coherence in the ground state is created by the pump beam and its destruction by the magnetic field manifests itself in the magnetic field dependence of the probe beam absorption. An experimental resonance profile obtained using the presented scheme is shown by a black line in figure 3. It has a shape typical for coated cells – a narrower part superimposed on a broader pedestal [9]. The broad pedestal is attributed to the relaxation of atoms interacting only once with the laser beam, while the narrower part is due to the relaxation of atoms with multiple crossing of the beam after spin-preserving collisions with the cell walls. The curve is fitted with two Lorentzian functions shown in red and blue in the figure. The widths and amplitudes of the experimentally obtained resonances are determined in accordance with the fitting results.
The source of our signal – the coherence of the ground state levels, is due to the pumping beam. Therefore, the amplitude and width of the EIA resonance are determined mainly by its parameters – diameter and intensity. The intensity of the probe beam must be much lower in order to minimize its influence on the coherent state created in the ground levels. In our experiment, the probe beam intensity was kept constant, $P_{\text{probe}} = 5 \, \mu\text{W}$ and the pump-to-probe ratio was changed from 10 to 1000.

**Figure 2.** Absorption spectrum of the $^{87}\text{Rb} \, D_1$ line.

**Figure 3.** The EIA signal registered for $P_{\text{pump}} = 5 \, \text{mW}, P_{\text{probe}} = 5 \, \mu\text{W}$ and $T_{\text{cell}} = 50 \, ^\circ\text{C}$.

### 3.1. EIA resonance dependence on the $^{87}\text{Rb}$ vapor density

The width and amplitude of the EIA resonance was measured in dependence on the vacuum cell temperature. The heater was turned off during the measurements to avoid the influence of residual MF created by the heater on the magneto-optical resonance. The maximum temperature used was 55 °C in order to preserve the paraffin coating of the vacuum cell. The results for the wide (triangular points) and narrow (circular points) component of the signal are shown separately. In the following figures, the solid lines are guides for the reader's eye only.

**Figure 4.** Dependence of the width (a) and amplitude-to-width (b) of the wide component of the EIA resonance on the temperature. Parameters: $P_{\text{pump}} = 5 \, \text{mW}, P_{\text{probe}} = 5 \, \mu\text{W}$.

For $^{87}\text{Rb}$ vapor pressure from $4 \times 10^{-7}$ to $3 \times 10^{-6}$ Torr, the width of both resonance components, narrow and wide, does not increase (figure 4 (a) and figure 5 (a)), while their amplitudes increase nonlinearly. The amplitude-to-width ratio of the resonance is an important parameter for many applications. Figure 4 (b) and figure 5 (b) show its dependence on the cell temperature for the wide and the narrow component, respectively. Since the amplitude-to-width parameter does not saturate up to 55 °C, the use of higher temperature coatings would increase the possibility of resonance applications.
Figure 5. Dependence of the width (a) and amplitude-to-width (b) of the narrow component of the EIA resonance on the temperature for $P_\text{pump} = 5 \, \text{mW}$, $P_\text{probe} = 5 \, \mu\text{W}$.

3.2. EIA resonance dependence on the laser pump beam intensity

The EIA resonances were registered for a pump beam power from $P_\text{pump} = 50 \, \mu\text{W}$ to 7 mW and probe beam power $P_\text{probe} = 5 \, \mu\text{W}$. Results for the wide and narrow component of the signal are shown in figure 6 and figure 7.

Figure 6. Dependence of the amplitude (a) and width (b) of the wide component of the EIA resonance on the pump power density for $P_\text{probe} = 5 \, \mu\text{W}$, $T_\text{cell} = 50 \, ^\circ\text{C}$.

Figure 7. Dependence of the amplitude (a) and width (b) of the narrow component of the EIA resonance on the pump power density. Parameters: $P_\text{probe} = 5 \, \mu\text{W}$, $T_\text{cell} = 50 \, ^\circ\text{C}$.
As might be expected, the widths of both components increase nonlinearly in a similar way. The amplitude of the EIA resonance reaches its maximal value around a pump power density of 5 mW/cm². The amplitude-to-width ratio is largest for a pump power density 5 mW/cm², too.

4. Conclusions
In this work, we studied the EIA resonances obtained in a counter-propagating pump and probe light beams configuration using a paraffin-coated optical cell. The widths and amplitudes of the EIA resonances were investigated in dependence on the intensity of the pump beam and cell temperature.

The experimental curves were fitted by two Lorentzian curves. The dependences are drawn according to the fitting results, separately for the wide and narrow resonance component. The widths and amplitudes of the wide and narrow resonances depend on the pump intensity in a similar way - nonlinear increase for the range of intensities used. The influence of the probe beam intensity on these parameters is negligible for the pump-probe beam intensity ratio used in the experiment. The amplitude-width ratio reaches a maximum value at pump power density around 5 mW/cm².

The investigation of the influence of Rb vapor pressure on the resonance parameters showed that in the range of 30 °C ÷ 55 °C, the width of the resonance does not change for both components, while the amplitude increases nonlinearly. The amplitude-width ratio for the narrow component increases more rapidly with the cell temperature than that for the wide one. To improve the parameters of EIA resonance in a vacuum cell, high-temperature coatings and pump-beam intensities around 5 mW/cm² should be used.

Acknowledgments
The work was supported in part by the Bulgarian National Science Fund, Contract No DN 08-19/14.12.2016 "New coherent and cooperative effects in hot alkali atoms".

References
[1] Arimondo E 1996 Coherent population trapping in laser spectroscopy Prog. Opt. 35 257–354
[2] Fleischhauer M, Imamoglu A and Marangos J 2005 Electromagnetically induced transparency Rev. Mod. Phys. 77 633–73
[3] Akulshin A M, Barreiro S and Lezama A 1998 Electromagnetically induced absorption and induced sign change of a sub-natural-width nonlinear resonance JETP Lett. 69 819–24
[4] Goren C, Wilson-Gordon A D, Rosenbluh M and Friedmann H 2003 Electromagnetically induced absorption due to transfer of coherence and to transfer of population Phys. Rev. A 67 033807
[5] Brazhnikov D V, Taichenachev A V, Tumaikin A M and Yudin V I 2014 Electromagnetically-induced-absorption resonance with high contrast and narrow width in the Hanle configuration Laser Phys. Lett. 11 125702
[6] Brazhnikov D V, Ignatovich S M, Vishnyakov V I, Skvortsov M N, Andreeva Ch, Entin V M and Ryabtsev I I 2018 High-quality electromagnetically-induced absorption resonances in a buffer-gas-filled vapour cell Laser Phys. Lett. 15 025701
[7] Brazhnikov D V, Ignatovich S M, Novokreshchenov A S and Skvortsov M N 2019 Ultrahigh-quality electromagnetically induced absorption resonances in a cesium vapor cell J. Phys. B: At. Mol. Opt. Phys. 52 215002
[8] Brazhnikov D, Ignatovich S, Vishnyakov V, Boudot R and Skvortsov M 2019 Electromagnetically induced absorption scheme for vapor-cell atomic clock Optics Express 27 36034–36045
[9] Taskova E, Alipieva E, Andreeva C and Brazhnikov D 2020 Electromagnetically induced absorption resonances in Hanle-configuration prepared in a paraffin coated ⁸⁷Rb cell J. Phys.: Conf. Ser. 1492 012011