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Optical characterization of antirelaxation coatings

S Tsvetkov[1], S Gateva[1,4], S Cartaleva[1], E Mariotti[2] and K Nasyrov[3]

[1]E. Djakov Institute of Electronics, Bulgarian Academy of Sciences,
 72 Tzarigradsko Chaussee, 1784 Sofia, Bulgaria
[2]Department of Physical, Geological and Environmental Sciences,
 University of Siena and CNISM, via Roma 56, 53100 Siena, Italy
[3]Institute of Automation and Electrometry, SB RAS, Novosibirsk, Russia

E-mail: sgateva@ie.bas.bg

Abstract. Antirelaxation coatings (ARC) are used in optical cells containing alkali metal vapor to reduce the depolarization of alkali atoms after collisions with the cell walls. The long-lived ground state polarization is a basis for development of atomic clocks, magnetometers, quantum memory, slow light experiments, precision measurements of fundamental symmetries etc. In this work, a simple method for measuring the number of collisions of the alkali atoms with the cell walls without atomic spin randomization (Nasyrov et.al., Proc. SPIE (2015)) was applied to characterize the AR properties of two PDMS coatings prepared from different solutions in ether (PDMS 2% and PDMS 5%). We observed influence of the light-induced atomic desorption (LIAD) on the AR properties of coatings.

1. Introduction

Antirelaxation coatings (ARC) are used in optical cells containing alkali metal vapor to reduce the alkali atoms' depolarization after collisions with the cell walls [1]. Characterization of the coating quality is important for the interpretation of the experimental results and development of optical sensors. The long-lived ground-state polarization is the basis for development of atomic clocks, magnetometers, quantum memory, slow light experiments, precision measurements of fundamental symmetries etc. [2,3].

Light-induced atomic desorption (LIAD) is a non-thermal process in which atoms adsorbed at a surface (coated or uncoated) are released upon illumination [4]. It is applied mostly for realization of optical atomic dispensers in the cases when high atomic density at low temperature and/or fast density control is needed – for example, for loading atomic devices as atomic magnetometers, atomic clocks, magneto-optical traps and their miniaturization.

The purpose of this work was to study experimentally the influence of LIAD on the AR properties of coated cells on the example of two PDMS coatings prepared with different solutions in ether (PDMS 2% and PDMS 5%). We showed that the dependence of the number of LIAD collisions is different in the two cells and that this dependence can be used to characterize the process of cell ripening.

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[4] To whom any correspondence should be addressed.

2. Experimental setup

The experimental setup is given in figure 1. It is described in detail in [5-7]. A 780 nm free-running diode laser (DL) was used. To reduce the optical pumping and saturation, all measurements were conducted on the ^{85}Rb set of absorption lines from the F_g=3 set of transitions. PD1 registered the transmitted 780 nm diode laser light, while PD2, the fluorescence at 780 nm [8].
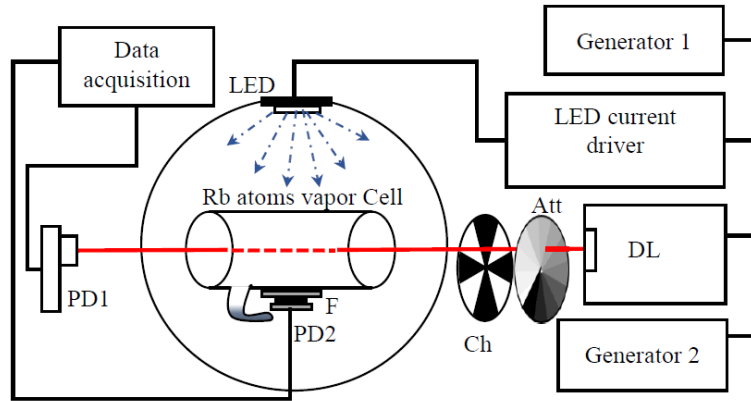

Figure 1. Experimental setup: Att, attenuator; Ch, chopper; DL, 780-nm diode laser; LED, 460-nm light emitting diode; F, filter; PD1 and PD2, photodetectors.

A special sphere with a diffusely reflecting inner surface was used to improve the efficiency of the blue-light illumination by the 460-nm LED [5].

For an optically-thin medium, the change of the Rb density due to the LIAD effect is measured by the absorption coefficient κ_ω of Rb vapor. According to Beer's law, the transmission $T(\omega) = T_\omega$ is:

$$T_\omega = I/I_0 = \exp(-\kappa_\omega L) = \exp(-\sigma_\omega N L), \qquad (1)$$

where I_0 is the 780-nm laser power entering the vapor sample; I, the transmitted power; κ_ω, the frequency-dependent absorption coefficient; σ_ω, the non-saturated, frequency-dependent absorption cross-section; N, the atomic density and L, the cell length.

We applied a simple method for measuring the number of collisions without atom spin randomization $N_c = 1/\varepsilon$ (ε being the probability for atom spin relaxation after one collision with the coating) to characterize the ARCs quality [6]. The method is based on registering the temporal dependence of the fluorescence intensity resulting from alkali atoms irradiated by pulsed light at resonance. The theoretical considerations assuming a cylindrical optical cell with a length larger than the cell radius show that in order to find the number of atom-wall collisions without spin randomization N_c, it is sufficient to know the value of the fluorescence decay rate β and the ratio between the intensities of the fluorescence at the beginning I_i and at the end of the decay I_f, as well as the time between atom collisions with the cell's walls $\tau_c = R_c/2v_T$, where v_T is the atom's thermal velocity.

$$1/N_c = \beta \tau_c I_f/I_i \qquad (2)$$

Table 1 summarizes some parameters of the PDMS-coated cells prepared with two different solutions in ether (PDMS 2% and PDMS 5%).

Table 1. Parameters of the Rb cells: length, diameter, volume, surface, mean distance between two collisions with the cell walls.

Cell coating	Length [cm]	Diameter [cm]	Volume [cm^3]	Surface [cm^2]	L [cm]
PDMS 5	4.5	2.6	24	47	2.0
PDMS 2	6.0	2.6	32	60	2.1

3. Results and discussion

The dependence of the number of collisions without spin relaxation N_c on the LIAD measured in the PDMS5 cell (figure 2) shows that the number of collisions decreases with LED illumination. There are two different parts in this dependence. As the LED power is increased, the number of collisions decreases to a certain value; at higher powers it does not change significantly. This dependence correlates with the measured Rb atoms density N on LIAD (figure 3). The Rb density rises very fast to its value in an uncoated cell at this temperature; it then rises linearly with a steepness lower by more than an order of magnitude than at low LED currents. This dependence can be explained by the results of previous studies of the processes of atom-coating interactions [9-12], which have shown two different components: a slow component, related to interaction of the atoms with the glass or chemically active impurities, and a fast one, associated with the atoms-coating interaction.
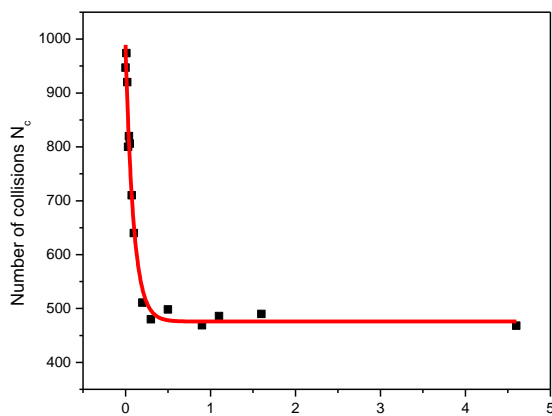

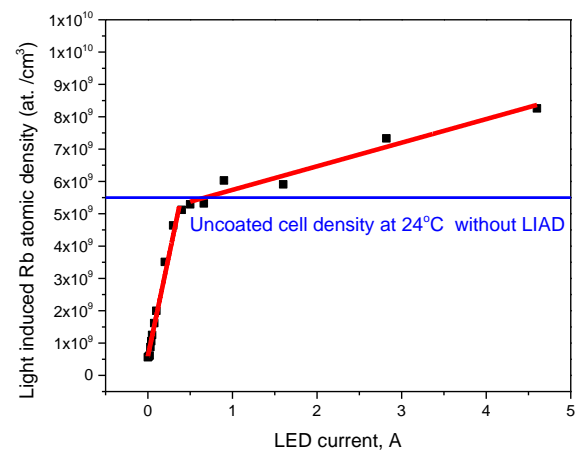**Figure 2.** Number of collisions N_c dependence on LIAD in the PDMS5 coated cell.

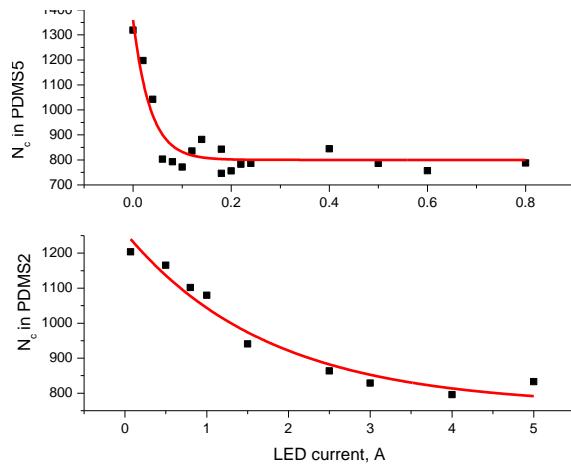**Figure 3.** Rb atoms density dependence on LIAD in the PDMS5 coated cell.

Figure 4. Number of collisions w/o relaxation N_c dependence on LIAD in PDMS5 and PDMS2 coated cells.
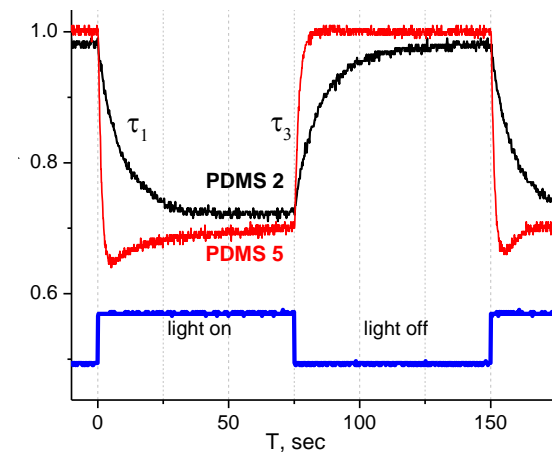

Figure 5. LIAD dynamics in PDMS2 and PDMS5 cells: the normalized transmission measured.

Figure 4 compares the AR properties of two PDMS coatings prepared with different solutions in ether (PDMS 2% and PDMS 5%). As seen, no fast component is present in the AR characteristic of the PDMS2 coated cell. Our previous investigations of LIAD dynamics (figure 5) have shown that the desorption and adsorption rates in a PDMS2-coated cell are about an order of magnitude lower than in

a PDMS5-coated cell, which we explained by the different morphology of the surface, thickness of the coating, and volume density. At equal Rb atoms density, the number of collisions N_c is the same [7].

The study of the relaxation rates of atomic polarization during LIAD in a paraffin-coated Cs cell [9] has shown no significant change in the relaxation rates beyond that expected from the faster rate of spin-exchange collisions due to the increase in the Cs density. The authors use relaxation in the dark registered via optical rotation to characterize the AR properties of the coating at Cs densities higher than 12×10^9 atoms/cm^3, which were higher by an order of magnitude than in our experiment.

4. Conclusions

A system for optical characterization of coated cells was developed, allowing one to measure the atomic density in a cell Rb containing alkali atoms via the absorption and the AR properties of coated cells by means of the simple method, proposed in [6], for measuring the number of collisions without spin randomization.

The system was applied to experimental investigation of LIAD influence on the AR properties of two PDMS coatings prepared with different solutions in ether (PDMS 2% and PDMS 5%). It was shown that in both cells LIAD reduces the number of collisions without spin relaxation, and the dependence of the number of collisions on LIAD is different in the two cells. These results illustrate the influence of the alkali atoms' penetrating from the vapor phase into the AR coating, and can be applied for characterization of the coating and the process of ripening.

The studies performed and its results are of value in gaining further understanding of the light-atom-surface interactions, in view of developing new optical elements for photonics applications, LIAD loaded atomic devices and their miniaturization, and new methods for surface and coating diagnostics and monitoring.

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