LIGHT-INDUCED ATOMIC DESORPTION (LIAD) FOR ALL-OPTICAL CONTROL OF LIGHT

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1. Introduction

The light-induced atomic desorption (LIAD) is a non-thermal process whereby atoms adsorbed at a surface are released under illumination. LIAD was reported for the first time by Gozzini et al. [1], has been subsequently investigated extensively both experimentally and theoretically and has found various applications – vapor density stabilization, magneto-optical trap (MOT) loading, surface nanostructuring etc. [2-7]. However, there are still several aspects of the LIAD dynamics that remain unexplained and questions that are open – for example, the question on whether there is a common mechanism underlying all LIAD observations [8]. LIAD is influenced by many parameters, among which are the cell dimensions and geometry, the wavelength of the illuminating light, the atomic species, the cell's history, the stem-opening area, etc. The models of LIAD are taking into account different processes for description of the LIAD dynamics [2-7]. Reducing the factors influencing LIAD will assist in gaining a better understanding of these processes and their dynamics.

Under this project, a special system for homogeneous illumination of the cell was developed. The Rb D2 line absorption spectra in uncoated and coated cells were compared without illumination, with one-side illumination and with homogeneous illumination. The transmission was measured as a function of the illumination intensity and the tuning direction. The dynamics of the LIAD in an uncoated cell was analyzed. The results demonstrated the potential of the system for development of new optoelectronic elements, LIAD-loaded atomic devices and their miniaturization, new methods for surface and coating diagnostics, and analysis of the quality of vacuum cells.

2. Experimental setup

The experimental setup is presented in figure 1. The frequency of a 780-nm diode laser was tuned by varying the laser current and the transmission spectra were registered by a power meter. A special sphere with a diameter of 150 mm provided homogeneous illumination for LIAD activation. It consisted of two hemispheres allowing easy mounting of

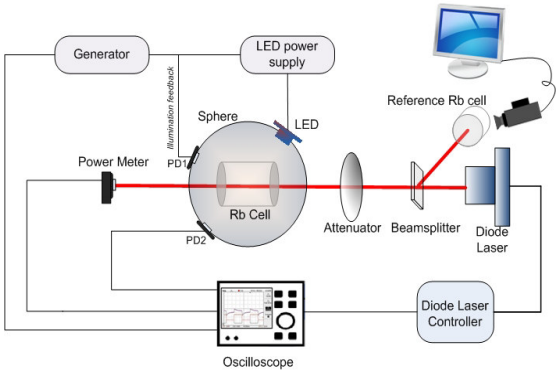

Figure 1. Experimental setup.

the cells. The high-reflection coating on the inner surface ensured near Lambertian scattering. A 60-W light emitting diode (LED) (Luminus PT120 with a central wavelength of 460 nm and a FWHM of 20 nm) was mounted on the sphere. When the sphere was closed, the efficiency of the blue light illumination improved dramatically, with the inhomogeneity of the illumination of the sphere's surface being less than 10 %. The blue LED current was controlled by means of a circuit designed in our laboratory. Two photodetectors were placed on the inner

surface of the sphere, one of them providing negative feedback, the other monitoring the blue light intensity. All measurements were performed at room temperature (25 °C). In order to minimize the influence of the optical pumping, a relatively low laser power (3 – 4 μW) was used at 780 nm. Table 1 presents some parameters of the cells used, namely, an uncoated one and one coated by a silane-based dry film (SC-77 [9]).

Table 1. Parameters of the uncoated and SC-77 coated Rb cells: length L, diameter D, volume V, surface S, and their ratio S/V.

Cell	L [cm]	D [cm]	V [cm^3]	S [cm^2]	S/V [cm^{-1}]
unc.	4.8	3.2	38.3	64.3	1.68
SC77	6.0	2.6	31.6	59.6	1.88

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

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

where I_0 is the 780-nm laser power entering the vapor cell; 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.

In the case of an optically-thick medium, the average absorption coefficient is measured as $\kappa_\omega = (1 - T_\omega)/L$.

3. LIAD at different illuminations

Figure 2 shows the transmission spectra at different illuminationa in an uncoated and and an SC-77 coated cell at 4 μW 780 nm laser power and 1 A blue LED current. The spectrum of the 780 nm (Rb D_2) line has four components. The optical spectrum of each Rb isotope consists of two sets of lines [10]: (i) ^{87}Rb involves two groups of hyperfine transitions starting from $F_g = 1$ and $F_g = 2$ ground levels and (ii) ^{85}Rb with two $F_g = 2$ and $F_g = 3$ sets as well. The spectrum is the sum of the Doppler profiles (with FWHM ~500 MHz) of all F_g–F_e hyperfine transitions.

Figure 2 presents the transmission spectra in an uncoated cell and in an SC-77 coated cell. The comparison of the absorption in the uncoated cell (Fig. 2a) and the SC-77 coated cell (Fig. 2b) at different illumination shows that without illumination (black lines) the absorptions are comparable (somewhat smaller in the coated cell). With homogeneous illumination (pink lines) in both cells, the absorption is the largest. As a result of the different ratio of the desorption to the lateral diffusion [11] and the stem influence, the one-side illumination (blue lines) of the uncoated cell is not efficient, while it is efficient for LIAD in the case of the coated cell.

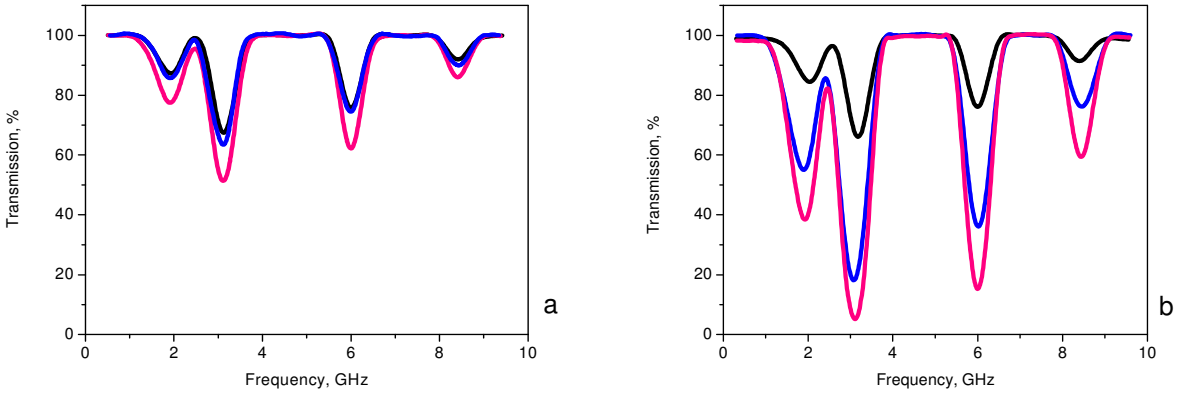

Figure 2. Influence of the illumination geometry in: (a) uncoated cell and (b) SC-77 coated cell without illumination (black), with one-side illumination (blue) and with homogeneous illumination (pink).

4. LIAD dynamics

Figure 3 illustrates the dynamic characteristics of the LIAD in the uncoated cell. There are four time constants characterizing the LIAD process: τ_1 characterizes the exponential growth after the blue light is switched on; τ_2, the density decrease while the desorbing light is still on; τ_3, the density decrease when the light is switched off [3]; τ_4, the processes after the blue light is turned off. The values measured of the first three time constants are: $\tau_1 = 2$ ms, $\tau_2 = 260$ ms, $\tau_3 = 4$ ms.

These constants are about three orders of magnitude smaller than those in a paraffin coated cell [2], which can be used for a faster control of the alkali atom density and its modulation. Another difference with the results obtained before was that when the blue light was switched on and off, the changes in the Rb densities are comparable so that we could define and measure the fourth time constant. In our case, $\tau_4 = 370$ ms, which can be attributed to the stem influence and the recovery of the alkali metal vapor density to the thermodynamic equilibrium value and the initial Rb atom density on the cell surface.

In coated cells (SC-77, PDMS, OTS, PCHS and paraffin coated cells), as a result of the longer time scales of the processes, no modulation of the transmission spectrum (alkali metal density) was detected at these frequencies of modulation of the blue light intensity.

Figure 4 illustrates the tuning of the second and third components of the transmission amplitude when the blue light intensity is increased and decreased in the uncoated cell. (The component's number increases with the tuning frequency [10].) As the light intensity was increased, the typical saturation of the absorption coefficient was registered [3]. When the the current was decreased, the transmission was nonlinear, too, but closer to a linear behavior.

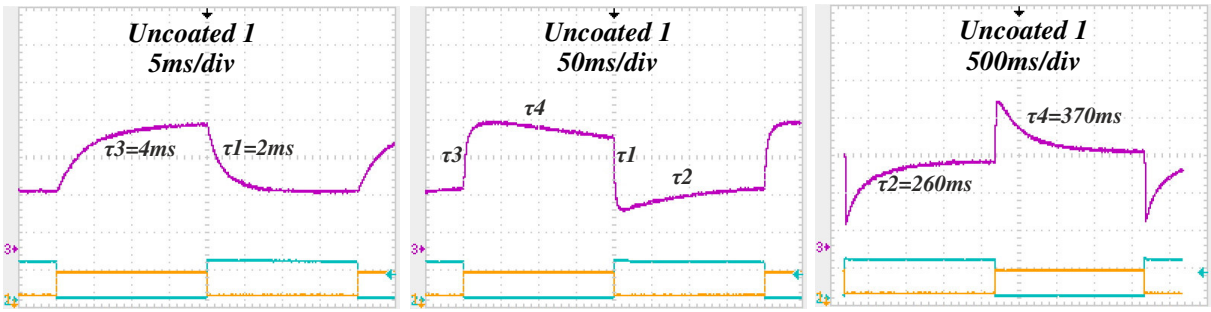

Figure 3. Time constants of the LIAD process dynamics.

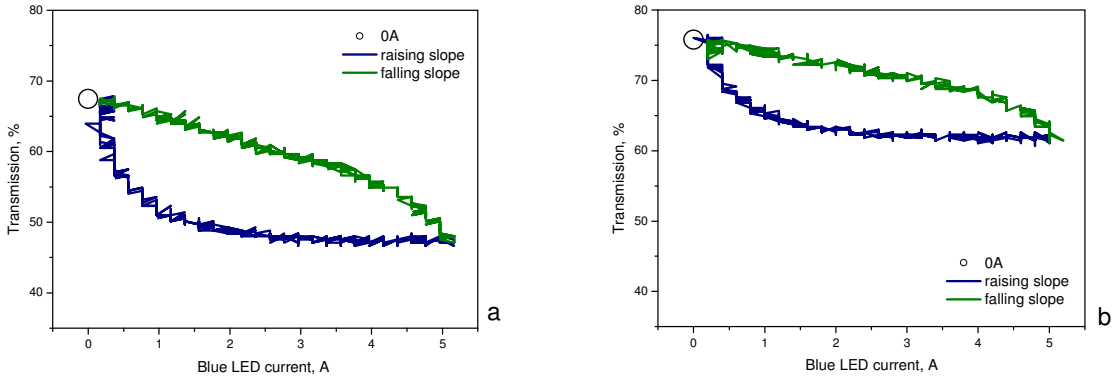

Figure 4. Transmission as a function of the blue LED illumination intensity and the direction of its tuning at 0.2 Hz and 4-μW 780-nm laser light in an uncoated cell.

5. Summary and conclusions

A LED system for homogeneous illumination of alkali metal cells was designed, where the illuminated cell was mounted in a sphere with a high-reflection coating on its inner surface, which functions as a Lambertian screen. A special laboratory electronic circuit for controlling the blue LED current was used.

The system increased the LIAD efficiency, prevented the formation of clusters and enabled us to examine the LIAD without lateral diffusion. The reduction of the number of parameters and processes influencing the LIAD will be useful for a more detailed understanding of the LIAD process.

As a result of the increased efficiency, we were able to register the LIAD dynamics in an uncoated cell. The measured time constants, (about three orders of magnitude smaller than in a coated cells) showed that this system can be applied for optical modulation of the alkali atom density. Moreover, such a cell has the potential for application in experiments where magnetically silent modulation is needed [12].

This work is interesting in view of the development of new optoelectronic elements, LIAD-loaded atomic devices and their miniaturization, and new methods for surface and coating diagnostics.

Acknowledgements

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