Light-induced atomic desorption under different types of illumination

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Abstract We studied the light-induced atomic desorption (LIAD) at different geometries and homogeneities of cell illumination. An original system for homogeneous illumination of the cells was developed and the Rb D2 line absorption spectra in several uncoated and coated cells were compared without illumination, with single-side illumination and with homogeneous illumination. The transmission as a function of the illumination intensity and the tuning direction was measured. The absorption coefficients with and without illumination of the stem were compared. The system developed for homogeneous illumination increases the efficiency of the LIAD, enables the investigation of LIAD without lateral diffusion, prevents cluster formation and reduces the influence of the stem. A good knowledge of the factors influencing the alkali atom spectra will be useful not only for the development of new LIAD-loaded atomic devices and their miniaturization, but also for the study of atom-dielectric surface interactions and the development of new all-optical methods for surface and coating diagnostics.

1. Introduction

Light-induced atomic desorption (LIAD) is a non-thermal process whereby atoms adsorbed at a surface are released under illumination. LIAD has been investigated in a large number of works and has found various applications – vapor density stabilization, magneto-optical trap (MOT) loading, surface nanostructuring etc. Among the parameters affecting the LIAD are the cell dimensions and geometry, the wavelength of the illuminating light, the atom species, the cell’s history, the stem-opening area etc. [1,2 and references therein]. LIAD was reported for the first time by Gozzini et al. [3] and has been subsequently investigated extensively both experimentally and theoretically. There exist several models describing LIAD, which take into account different processes concerning its dynamics [2,4-6]. Reduction of the factors influencing LIAD will help the better understanding of the dynamics of this process. A special model describing the LIAD dynamics in a completely illuminated cell was developed in [7].

The present paper presents a study on LIAD at different geometries and homogeneities of illumination. To this end, a special system for homogeneous illumination of the cell was developed. The Rb D2 line absorption spectra in different uncoated and coated cells were compared without illumination, with single-side illumination and with homogeneous illumination. The transmission as a function of the illumination intensity and the tuning direction was also measured. Further, the
absorption coefficients with and without illumination of the stem were compared. The dynamics of the LIAD in an uncoated cell was measured and analysed. An application is proposed for the results obtained to the analysis of vacuum cells’ quality.

2. Experimental setup
The experimental setup is given in figure 1; in principle, it is the same as the one described in [8]. The frequency of a 780-nm diode laser is tuned by the laser current and the transmitted spectra are registered by a power meter. A special sphere with a diameter of 150 mm provides homogeneous illumination for LIAD activation. The sphere consists of two hemispheres allowing easy mounting of the cells. The high reflection coating on the inner surface ensures a near Lambertian scattering. A 60-W light emitting diode (LED) (Luminus PT120 with a central wavelength of 460 nm and FWHM of 20 nm) is mounted on the sphere. When the sphere is closed, the efficiency of the blue light illumination improves dramatically, with the inhomogeneity of the illumination of the sphere’s surface being less than 10 %. The blue LED current is controlled by means of a laboratory-designed electronic circuit. Two photodetectors are placed on the inner surface of the sphere; one of them providing a negative feedback, the other monitoring the blue light intensity. All measurements are performed at room temperature (25 °C). In order to minimize the influence of the optical pumping, a relatively low 780 nm laser power (3 – 4 µW) is used. Table 1 presents some parameters of the cells used, namely, an uncoated one, a silane-based dry film (SC-77 [9]) coated one, and a porous clay heterostructure (PCHS [10]) coated one.

![Figure 1. Experimental set up.](image)

Table 1. Parameters of the Rb cells: length, diameter, volume, surface.

| Cell coating | Length [cm] | Diameter [cm] | Volume [cm³] | Surface [cm²] | Surf/Vol [cm⁻¹] |
|--------------|-------------|---------------|--------------|--------------|----------------|
| uncoated 1   | 4.8         | 3.2           | 38.34        | 64.31        | 1.68           |
| uncoated 2   | 2.0         | 1.8           | 5.05         | 16.39        | 3.24           |
| uncoated 3   | 4.6         | 2.4           | 20.67        | 43.71        | 2.11           |
| SC-77        | 6.0         | 2.6           | 31.63        | 59.60        | 1.88           |
| PCHS         | 6.0         | 2.6           | 31.64        | 59.60        | 1.88           |
3. LIAD at different illumination

In Figure 2, the transmission spectra at different illumination in an uncoated cell and an SC-77 coated one are shown at 4 μW 780 nm laser power and 1 A blue LED current. The spectrum of the 780 nm (Rb D2) line contains four components. The optical spectrum of each Rb isotope consists of two sets of lines: (i) 87Rb, with two groups of hyperfine transitions starting from F_g = 1 and F_g = 2 ground levels and (ii) 85Rb, with two sets originating from F_g = 2 and F_g = 3. The spectrum is the sum of the Doppler profiles (with FWHM ~500 MHz) of all F_g-Fe hyperfine transitions (see for example [8]).

![Image](a)

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

The absorption coefficients in uncoated cell 1 and the SC-77 coated cell were compared at different illuminations. Without illumination, the absorption coefficients are comparable (slightly smaller in the coated cell). The absorption coefficient is the largest in the case of homogeneous illumination in both cells. As a result of the different ratio of adsorption due to lateral diffusion and the stem influence, the single-side illumination of the uncoated cell 1 is not efficient, while it is efficient for LIAD in the coated cell.

The response of the three different uncoated cells from table 1 to blue-light rectangular pulses is shown in figure 3. The peak-to-peak values of the detected signal are in a ratio of 250/40/1. This difference is the result of the stem geometry and the technology of preparing the vacuum cells [2]. The third cell is the cleanest one, as it was prepared using an oil-free vacuum system and baked for a long time.

![Image](Uncoated cell 1)

**Uncoated cell 1**

![Image](Uncoated cell 2)

**Uncoated cell 2**

![Image](Uncoated cell 3)

**Uncoated cell 3**

**Figure 3.** LIAD dynamics in different uncoated cells (the amplitudes ratio is 250/40/1).

In Figure 4 the dynamic characteristics of the LIAD in uncoated cell 1 are presented. The time constants are smaller than in paraffine-coated cells [1]: τ1=2ms, τ2=260ms, τ3=4ms. Another difference with the results obtained before is that when switching on and off the blue light, the changes in the Rb
densities are comparable and we can define and measure a fourth time constant $\tau_4$ connected to the processes after the blue light is turned off. In our case $\tau_4=370\text{ms}$ and it can be attributed to the recovering of the alkali metal vapor density and the initial Rb atom density on the cell surface defined by the temperature of the cell.

Figure 4. Time constants of LIAD process dynamics.

In the SC-77 coated cells and the PCHS coated one, no modulation of the transmission spectrum (alkali metal density) was detected at these frequencies of modulation of the blue light intensity.

Figure 5 illustrates the tuning of the second and third components of the transmission amplitude when the blue light intensity is increased and decreased in uncoated cell 1. (The component number increases with the tuning frequency [8].) As the light intensity is increased, the typical saturation of the absorption coefficient is registered [6,7]. When the current decreases, the transmission behavior is nonlinear, too, but closer to a linear one.

Figure 5. Transmission as a function of the blue LED illumination intensity and the direction of its tuning at 4 $\mu$W 780 nm laser light and 0.2 Hz in uncoated cell 1.

4. Stem illumination

The measurement of the transmission spectra when the metal film in the stem of a PCHS coated cell was illuminated and not illuminated by a blue light show that the absorption coefficient is higher when the metal was illuminated; for one of the components, the transmission changed by more than 30 %. Additional investigations of this influence and its possible applications for compensation of the losses due to the open stem are planned.
5. Conclusions
A new original system for homogeneous illumination of the alkali metal cells is developed, where the illuminated cell is mounted in a sphere with a high-reflection coating on its inner surface functioning as a Lambertian screen.

The investigation of the LIAD effect at different illumination in uncoated and coated cells shows that in the case homogeneous illumination, which enables investigation of LIAD excluding the lateral diffusion, the alkali metal atom concentration is the highest.

A much faster modulation of the density of alkali metal vapors is obtained in uncoated cells compared with coated cells.

The different amplitude of modulation of LIAD in the uncoated cells investigated can be explained as being the result of the technology of their preparation; this can be used as an indicator of the cell surface cleanness.

The illumination of the stem increases the alkali metal atoms density. Additional investigations are planned in order to understand the origin of this fact.

In conclusion, the proposed system for homogeneous illumination of the cells investigated increases the LIAD efficiency, enables one to study LIAD excluding the lateral diffusion, prevents cluster formation and reduces the influence of the stem. A better knowledge of the factors influencing the LIAD in coated cells will be useful not only for the development of new LIAD-loaded atomic devices, but also for the study of atom-dielectric surface interactions and the development of new all-optical methods for surface and coating diagnostics.

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