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# Light-induced atomic desorption in cells with different PDMS coatings

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**Abstract.** Light-induced atomic desorption (LIAD) is a non-thermal process in which atoms adsorbed at a surface are released under illumination. It is applied mostly to implementing optical dispensers in the cases when high atomic density at low temperature is needed – for example, for loading atomic devices as atomic magnetometers, atomic clocks, magneto-optical traps and their miniaturization. However, as the desorption depends on the atom-surface interaction, it can also be used for optical characterization and manipulation of alkali metal nanoparticles. The paper describes an experimental investigation of the shape of the transmission spectra and their dependence on the illuminating blue-light power in PDMS coated cells prepared with two different concentrations of PDMS in ether. A comparison is conducted with the LIAD effect in SC-77 coated and in uncoated cells. All measurements are performed on the Rb D2 line in vacuum. The potential is discussed for application of these dependences to analyzing the quality of the coating surface and its optimization.

## 1. Introduction

Light-induced atomic desorption (LIAD) is a non-thermal process whereby atoms adsorbed on a surface are released under illumination. It is applied mostly to implementing optical atomic dispensers in the cases when high atomic density at low temperature is needed – for example, for loading atomic devices as atomic magnetometers, atomic clocks, magneto-optical traps and their miniaturization [1,2 and references therein]. However, as the desorption depends on the atom-surface interaction, it can be applied to the optical characterization and manipulation of alkali metal nanoparticles [3]. LIAD was reported for the first time in a polydimethylsiloxane (PDMS) coated cell with Na vapor [4]. Since then, LIAD in PDMS has been observed with Rb, Cs and K alkali atoms as well.

Polydimethylsiloxane ( $\text{CH}_3[\text{Si}(\text{CH}_3)_2\text{O}]_n\text{Si}(\text{CH}_3)_3$ ) is a polymer with a chemical behavior intermediate between organic and inorganic materials and a good stability after dehydration. It has been used as an antirelaxation coating (to reduce the spin relaxation resulting from atom-wall collisions). The PDMS molecules are highly flexible and PDMS is amorphous. The glass transition temperature is 144 K, with the melting temperature being 232 K. In our experiments, the temperature was kept above these values, so that PDMS was in a rubbery state. On the one hand, the structure of

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PDMS is suitable for alkali metal atoms adsorption. On the other hand, it causes problems, such as bubble formation and sample evaporation. The AFM measurement of the roughness values for various concentrations of PDMS in ether reported in [5] showed that the surface roughness increases as the PDMS concentration is raised, namely, from 20 nm to 50 nm for an increase from 2 % to 5 %. The thickness of the PDMS film also increases with the concentration.

This paper presents an experimental investigation of the shape of the transmission spectra and their dependence on the illuminating blue-light power in PDMS coated cells prepared with two different concentrations of PDMS in ether. A comparison is carried out with the LIAD effect in SC-77 coated and in uncoated cells. All measurements were conducted on the Rb D2 line in vacuum cells with similar dimensions and geometry.

## 2. Experimental setup

The experimental setup for measuring the influence of the LIAD on the transmission spectra in a Rb vacuum cell is described in detail in [6,7]. The frequency of a 780-nm diode laser was tuned by varying the current through it (using a waveform generator) and the transmitted spectra were registered by a photodiode. To activate LIAD, a special sphere with a diffusely-reflecting inner surface was made and an 18-W light emitting diode (LED) (Luminus PT120 with a central frequency of 460 nm and FWHM of 20 nm) was mounted on it. The optical power was regulated and measured, after a proper calibration, by varying the current supplied to the LED. All measurements were performed at a temperature of 27 °C. A continuous wave (cw) illumination was performed, which provided the possibility to examine the absorption spectrum profile. Moreover, the cw approach is suitable for various practical applications. The measurements were performed in four different Pyrex cells. Table 1 summarizes some parameters of the cells (length, diameter, volume, surface, surface-to-volume ratio). The LIAD effect in the PDMS cells was compared with that in SC-77 cells, because the SC-77 coating (a silane-based dry film coating) ensures a very low equilibrium desorption rate coefficient, which maintains the best vacuum level in the cell and it has been widely used for magneto-optical trap loading [8].

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

Cell coating	Length [cm]	Diameter [cm]	Volume [cm <sup>3</sup> ]	Surface [cm <sup>2</sup> ]	Surf/Vol [cm <sup>-1</sup> ]
PDMS 5	4.7	2.6	25	49	1.98
PDMS 2	6.0	2.6	32	60	1.88
SC-77	6.0	2.6	32	60	1.88
uncoated	4.8	3.2	38	64	1.68

The transmission spectra were measured at a relatively low 780-nm light intensity (3 – 4 μW) in order to minimize the optical pumping so that the absorption characteristics could be deduced.

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

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

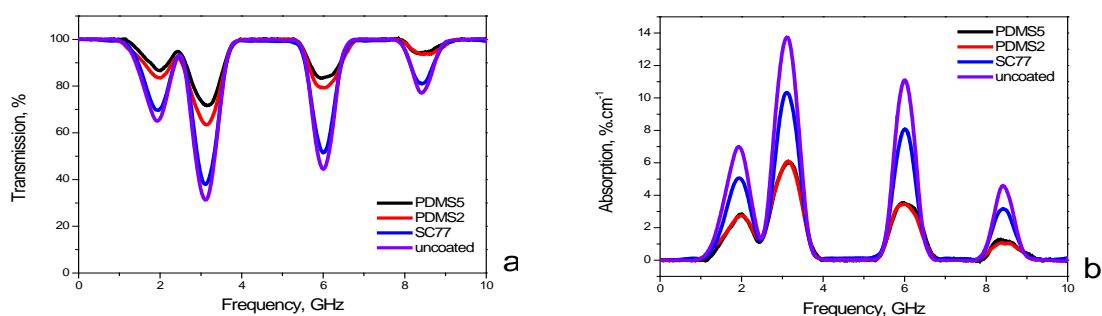
where  $I_0$  is the 780-nm laser power entering the vapor sample;  $I$ , the transmitted power;  $\kappa_\omega$ , the frequency-dependent absorption coefficient;  $\sigma_\omega$ , the non-saturated, frequency-dependent absorption cross-section;  $N$ , the atomic density and  $L$ , the cell length.

In the case of an optically-thick medium, the 780-nm light intensity is reduced along the optical cell. Thus, one measures the average absorption coefficient  $\kappa_\omega = (1 - T_\omega)/L$ .

The absorption coefficients were measured in order to compare the LIAD effect in cells with different length.

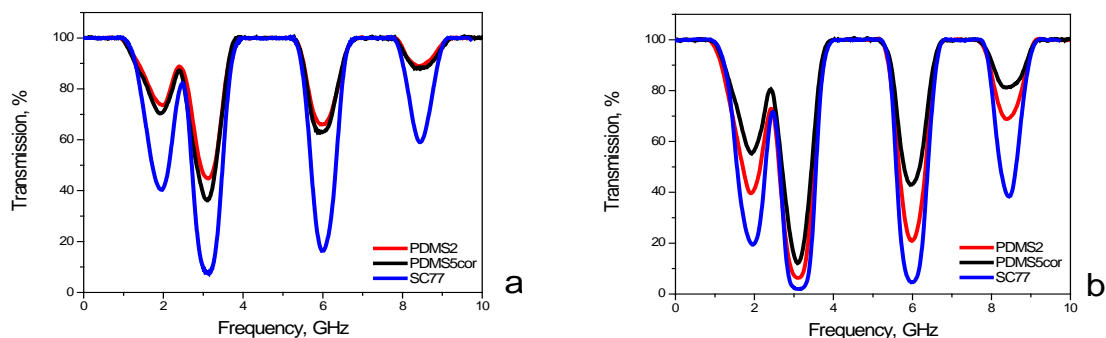
### 3. Transmission spectra

Figure 1 provides a comparison of the transmission spectra of the Rb D2 line in two PDMS coated cells prepared with 2 % and 5 % concentrations in ether, an SC-77 coated cell and an uncoated cell without illumination at 3  $\mu$ W 780-nm laser power. The spectrum of the 780 nm (Rb D<sub>2</sub>) line contains four components. The optical spectrum of each Rb isotope consists of two sets of lines: (i) <sup>87</sup>Rb involves two groups of hyperfine transitions starting from  $F_g = 1$  and  $F_g = 2$  ground levels and (ii) two sets of <sup>85</sup>Rb transitions originating from  $F_g = 2$  and  $F_g = 3$ . The spectrum is the sum of the Doppler profiles (with FWHM  $\sim$ 560 MHz) of all  $F_g \rightarrow F_e$  hyperfine transitions (see for example [6]). The spectra of all cells are similar to that of the uncoated cell, but the absorption coefficient is smaller as a result of the optical pumping and depends on the coating. The absorption coefficients of the two PDMS cells are equal within the experimental error (5 %). The absorption coefficient of the SC-77 coated cell is higher by a factor of about two.



**Figure 1.** Transmission and absorption spectra of the Rb D2 line in different coated cells without illumination at 3- $\mu$ W 780-nm laser power.

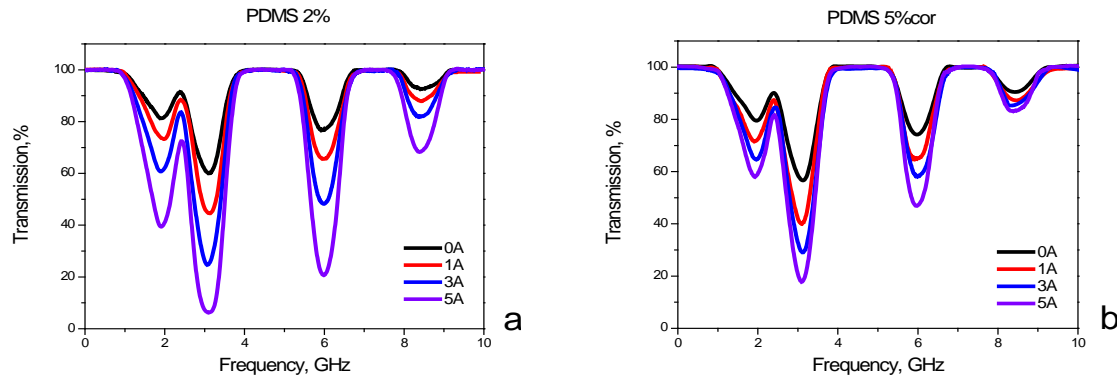
Figure 2 displays the transmission spectra with blue-light illumination at 1-A and 5-A LED current. The comparison of the shape and amplitude of the spectra from the three coated cells (PDMS2, PDMS5 and SC-77) shows that the Rb density depends on the coating and that the spectra have different behavior depending on the blue-light intensity. The maximum density was observed in the SC-77 coated cell. The Rb D2 line components widths and amplitudes for the case of LIAD in SC-77 coated cells were investigated in [6].



**Figure 2.** Transmission spectra of the Rb D2 line with 1 A (a) and 5 A (b) blue LED illumination.

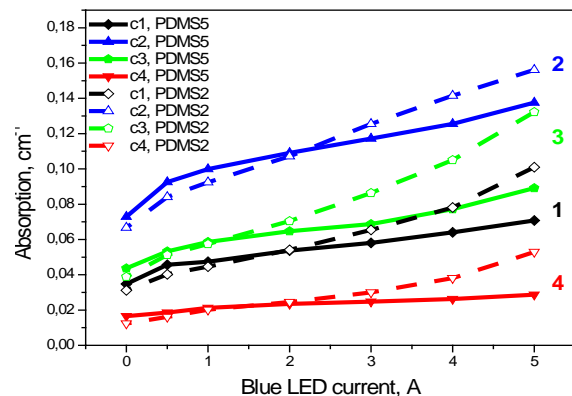
Figure 3 presents the transmission spectra of the PDMS coated cells prepared with PDMS concentrations in ether of 2 % (figure 3a) and 5 % (figure 3b). The measurements were registered as the LED current was increased after illumination time of three minutes. In figure 3b, as the cell is shorter, the transmission is corrected in such a way as to have a quantity proportional to the absorption coefficient. The component number increases with the tuning frequency. The width of the second and

third component does not change within the experimental error limit. Only the second component of the SC-77 coated cell at 5 A is broader, which can be explained by atomic emission re-absorption [6].



**Figure 3.** LIAD spectra in coated cells with PDMS concentrations in ether 2% (a) and 5% (b).

Figure 4 compares the absorption coefficients of the four components in PDMS coated cells with PDMS concentrations in ether 5% (solid line) and 2% (dashed line). At a LED current of less than 2 A, the absorption coefficient is slightly higher in the 5-% PDMS coated cell, while the dependence of the amplitude on the illumination power has the typical saturation shape. At powers exceeding that at a LED current of 2 A, the absorption coefficient is higher in the 2-% PDMS coated cell, while the dependence of the amplitude on the illumination power does not saturate in the range of blue-light powers investigated.



**Figure 4.** Absorption coefficients of the four components in PDMS coated cells with PDMS concentrations in ether 5% (solid line) and 2% (dashed line).

#### 4. Summary and conclusions

The experimental study performed of the shape of the Rb D2 line transmission spectra under homogeneous blue-light illumination and their dependence on the illuminating power in PDMS coated cells prepared with two different concentrations of PDMS in ether (5% and 2%) showed that without illumination and at low blue-light powers (at LED currents of less than 2 A), the absorption coefficient is higher in the 5-% PDMS coated cell within the experimental error limit; the dependence of the amplitude on the illumination power has the typical saturation shape [9]. At powers higher than that achieved at a LED current of 3 A, the absorption coefficient is higher in the 2-% PDMS coated cell, while the dependence of the amplitude on the illumination power does not show a tendency to saturation up to 5-A LED current. A possible explanation of this increase is the different probability for alkali atoms to find adsorption sites on substrates with a different volume density. On the other hand, the widths of the components do not change with the illumination power, except for the second component at 5 A, which can be explained with atomic emission re-absorption [6]. As is known, increasing the PDMS concentration causes an increase in the surface roughness and the film thickness [5]. Additional studies are necessary to find the best roughness needed for preparation of an anti-relaxation coating and to understand the influence of the film thickness. Knowing the influence of the coating roughness on the absorption spectra will enable one to use the absorption spectra for analysis of the quality of the coating surface and its optimization.

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