Photo-ejection and transport of alkali atoms embedded in nano-porous silica

A Burchianti, C Marinelli, A Bogi, F Della Valle, E Mariotti, S Veronesi and L Moi
Department of Physics, Siena University, Via Roma 56, 53100 Siena, Italy
E-mail: burchianti@unisi.it

Abstract. Recently we observed non-thermal photoejection of atoms embedded in nano-porous silica samples. Alkali atoms are stored inside porous glass matrices and then they are desorbed by ordinary or laser light. In this paper, we present an experimental investigation of the dependence of photodesorption dynamics on desorbing radiation, showing that light induced effects on alkali nano-particles, dispersed in the glass matrix, are started up upon specific conditions of the incident radiation. On the basis of this study, we find that the light is able both to drive the atomic flux from the glass surface and to modify the optical properties of the glass samples, opening interesting perspectives for applications.

1. Introduction
Photodesorption of alkali atoms from siloxane [1,2] and paraffin [3] films, known in literature as LIAD (Light Induced Atomic Desorption), is characterized by an high efficiency at very low power densities, indicating that a very large number of atoms is stored in the bulk of the organic coating, whereas photodesorption from uncoated sapphire surfaces [4] needs of quite high light intensities in order to see the effect. It follows that uncoated surfaces are not attractive for building up Light Controlled Atom Dispensers (LICADs), unless the adsorbing area is very large. Nevertheless an extremely large surface is not suitable to any experimental set-up. This problem can be overcome by using nano-porous glass, which has an enormous inner surface due to its porosity.

In our previous work [5] we have observed non thermal photo-ejection of rubidium atoms embedded in nano-porous silica. The effect is obtained even with incoherent and weak light (<1mW/cm²), as in the case of LIAD, and its efficiency results close, or even better, than those measured for paraffin and siloxane coatings. Therefore porous silica seems a very attractive material to realize extremely compact photo-atom sources to be integrated with miniaturized devices for trapping and controlling of cold atoms. In respect to this, we emphasize that very recently photo-detachment of rubidium atoms from a Pyrex surface with an helix shape, in order to increase the adsorbing area, has been used to produce a Bose-Einstein condensation in portable atom chip [6]. By other hand solid matrices, in which confine atoms and clusters, are objects extremely interesting. Porous media can supply a tool to study the optical properties of gas and nano-particles, under strong dimensional confinement. A more in-depth understanding of these systems, in presence of resonant and non-resonant radiation, would be useful both in the study of superconfined atoms and in the development of quantum-optic sensors.

In this work, we investigate the dependence of light-induced atomic ejection and diffusion from porous silica on desorbing light wavelength and intensity. A porous silica sample is placed inside a
Pyrex sealed cell containing rubidium and then exposed to laser light. Upon illumination atoms, stored in the glass matrix, are released and diffuse out of the sample. As a consequence, a variation of the atomic density in vapor phase is recorded. Both the maximum relative density variation and the desorbing rate are extrapolated from the data, and their dependence on laser light intensity and wavelength is analyzed. In addition the photodesorption signal and the optical transmission of the sample vs. time are contemporary monitored during several illumination dark cycles for different desorbing light wavelengths.

2. Experiment
The experiments are performed with a porous silica plate (30×15×1mm³) with a pore diameter of about 17nm, free glass volume of about 50%, and inner surface of order of few tens of square meters [7]. The experimental set-up is sketched in figure 1.

![Figure 1. Sketch of the experimental set-up. M: mirror; PG: porous glass sample; IF: interferential filter; PD: photodiode; BE: desorbing beam expander.](image)

The plate is mechanically fixed to a window of a cylindrical Pyrex cell. Then the cell is kept under vacuum for few days at a temperature slowly increasing up to 400K. As last step the alkali metal is distilled in the reservoir and the cell is sealed off. The rubidium density is detected by measuring the transmission of a weak resonant beam sent across the cell. The light is generated by a diode laser, tuned to Rb D₂ (780nm) line. Atomic photo-ejection is produced by illuminating the porous silica sample with different lasers. In all measurements the illumination-dark cycles are controlled by a mechanic shutter, electronically driven. The variation of the optical transmission of the porous silica plate in the red-infrared wave band, under illumination, is detected by measuring the transmission of two weak beams sent across the plate, one delivered by a stabilized helium-neon laser (632.8nm) and the other by an external-cavity Rb diode laser, slightly detuned out of the atomic resonance, in order to avoid the contribution to the absorption of rubidium atoms in vapor phase (see figure 1).

3. Experimental results and discussion
In order to study the dependence of the photo-desorption effect on desorbing radiation a series of measurements has been performed. The maximum relative density variation \( \delta_{\text{max}} \) and the desorbing rate \( R \) have been measured as a function of desorbing laser light intensity \( I_L \) for three different laser wavelengths: 457nm, 590nm, 810nm. The data are shown in figure 2 and in figure 3.
Figure 2. Maximum relative increase of Rb vapor density as a function of laser light intensity for different desorbing light wavelengths.

Figure 3. Desorbing rate of Rb atoms as a function of laser light intensity for different desorbing light wavelengths.

For all tested desorbing light wavelengths, we find that the total number of the desorbed atoms and the desorbing rate increase by increasing the intensity. In particular the desorbing rate, that immediately follows the desorbing light switching on, exhibits a linear dependence on $I_L$, whereas $\delta_{\text{max}}$ shows a saturation behavior due to the atomic diffusion inside the glass. The total efficiency of photo-ejection rises by decreasing the desorbing light wavelength and even the photodesorption dynamics is deeply modified, as shown in figure 4.

Figure 4. Normalized Rb vapor density variation as a function of time for different light wavelengths. The data were taken at the same light intensity $I_L=20\text{mW/cm}^2$. A different dynamic behavior is observed shifting the desorbing laser wavelength from the red to the green-blue side of spectrum.

This features can be attributed to light-assisted effects started up upon specific conditions of the desorbing radiation. We have a direct proof of the increase of atomic mobility with the light by monitoring the changes of the optical transmission in vapor phase and in the glass matrix upon laser light illumination. In figure 5 the time evolution both of the relative Rb vapor density and of the glass optical transmission are shown, when the sample is illuminated twice by consecutive light pulses with green light. A change of the porous silica transmission, triggered by the desorbing light, is visible. By other hand, when the same measurement is performed with red light no changes of the optical transmission are observed, as shown in figure 6. The desorbing light intensity, for the red illumination, has been selected in such way to have about the same number of desorbed atoms of the green illumination. This implies that the variation of the sample transmission is not dependent on the number of rubidium atoms desorbed in vapor phase.
Figure 5. Signal a) variation of the sample transmission at 780nm; signal b) variation of the sample transmission at 632nm; signal c) desorbing light trigger; d) relative Rb vapor density variation. The desorbing light is delivered by an Argon laser at 514nm. $I_L = 5.5\text{mW/cm}^2$.

Figure 6. Signal a) variation of the sample transmission at 780nm; signal b) variation of the sample transmission at 632nm; signal c) desorbing light trigger; d) relative Rb vapor density variation. The desorbing light is delivered by a diode laser at 810nm. $I_L = 18\text{mW/cm}^2$.

We can suppose that the decreasing of the porous silica transmission in the red-infrared wave band, upon illumination, is due to a change of alkali nano-particle size distribution inside the glass matrix. At high desorbing light intensity and frequency this effect can be seen even with naked eye and consists in a transition of the silica plate from transparency to opacity. This hypothesis is also confirmed by the optical absorption spectra of our sample. The optical spectra for porous silica sample, doped with Rb, were measured on a spectrometer over the wavelength range 400-1000nm, before and after UV illumination, and then compared with the spectra of an undoped sample. From these measurements it results that there are rubidium nano-particles dispersed inside the sample. After illumination, the distribution of the alkali clusters in the porous silica is deeply changed, as confirmed from the spectra, nevertheless keeping the “blue” sample in the dark, causes redistribution of the nano-particles inside the matrix and recovers its original conditions.

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