Quantum dots desorption via high-power Nd:YAG laser pulses

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***Abstract* — In the present work, we investigated the mechanism behind the desorption of quantum dots (QDs) CdSe/ZnS (core/shell) aggregates via Q-switched Nd:YAG pulsed laser. After desorption, we trapped the aggregates in a linear quadrupole Paul trap and analyzed their dynamics using machine vision methods. We found that the number of desorbed aggregates is proportional to the laser radiation energy. The injection efficiency was 13.6% for all values of the laser pulse energy greater than 200 mJ. However, even though the desorption process was also observed at lower values (<200 mJ), we did not register particles trapping in this case. This effect might be caused by the different nature of desorption at low powers (LIAD) and at high powers (desorption as a result of substrate ablation)**

Keywords* — *ion traps, quantum dots, laser desorption, laser-induced acoustic desorption, machine vision

I. Introduction

In the last few years, the number of studies involving nano- and microparticles trapping has become more prominent [1 - 4]. Thus, new experimental challenges and questions, such as methods for microparticles desorption and injection into ion traps, have risen. One of the desorption techniques - laser-induced acoustic desorption (LIAD) [5] - has been shown to be effective for microparticles desorption [3]. The desorption methods might be especially useful for conducting experimental studies with quantum dots (QDs) aggregates and single quantum dots trapped in electrodynamic traps, However, LIAD for quantum dots desorption has yet to be demonstrated. In this work, we experimentally studied the desorption of quantum dots aggregates from the metal foil surface using Q-switched Nd:YAG pulsed laser. We calculated the efficiency of aggregates desorption and injection based on experimental data.

II. Experimental setup

To desorb and trap the particles, we built an experimental setup shown in Fig. 1. The setup consists of (1) Nd:YAG pulsed laser with the first harmonic wavelength 1064 nm, (2) linear trap electrical power supply, (3) optical filters to vary the pulsed laser energy, (4) metal foil with quantum dots aggregates, (5) a linear quadrupole Paul trap with end-cap electrodes, (6) an observation window, (7) a camera to record the dynamics of particles, (8) a laser to illuminate the particles inside the trap, and (9) PC to collect data from camera (7). The pulse duration of a Q-switched Nd:YAG laser was 10 ns; the energy of a single pulse varied from 126 mJ to 276 mJ. Injection of particles into the trap was performed with the following parameters: DC applied to end-cap electrodes was 150 V, amplitude and frequency of AC applied to linear electrodes was 5.8 kV and 50 Hz, respectively; temperature and pressure of the environment was 300 K and 10^5 Pa, respectively.

For this experiment, we prepared metal foil samples (thickness 11 μm) with quantum dots aggregates on the surface. We used a highly concentrated solution of CdSe/ZnS (core/shell) quantum dots in toluene. The samples were prepared using a drop casting method with the full evaporation of the solvent.

The experiment was performed as follows: we focused a laser beam of Q-switched Nd:YAG laser into a spot with an area 1.15 mm^2. As a result of exposure to a single laser pulse, particles were desorbed from the surface of the metal foil, and then injected and trapped. We recorded the particles dynamics with a camera for the further analysis via machine vision methods.

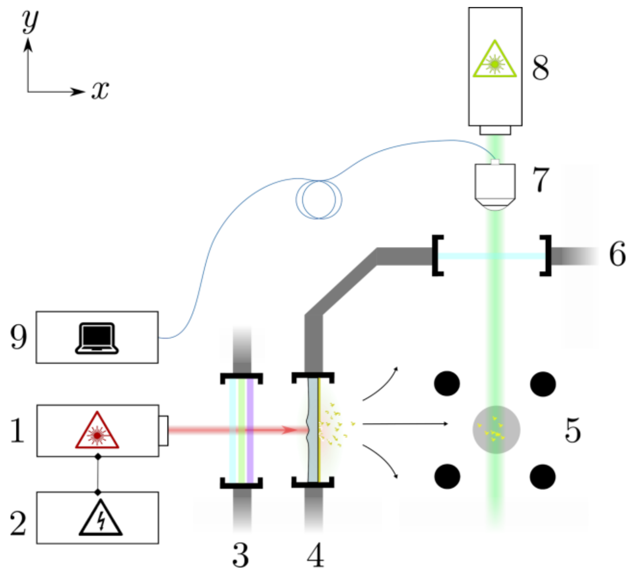

Fig. 1. Experimental setup scheme: (1) Q-switched Nd:YAG pulsed laser, (2) trap electrical power supply, (3) optical filters, (4) metal foil with quantum dot aggregates, (5) linear quadrupole trap, (6) observation window, (7) camera, (8) illumination laser, (9) PC connected to the camera (7)

III. Analysis and results

To analyze the desorption efficiency, we made an algorithm for automatic particles detection using machine vision methods. The automatic detection was performed as follows: firstly, we separated the detection regions of desorbed (or trapped) aggregates of CdSe/ZnS quantum dots from the background by masking. Secondly, we applied high-pass filter to compensate an overexposure of camera matrix. Then we performed frame-by-frame binarization and detection of connected areas with pixels of objects and background. The binarization threshold was chosen as to minimize the number of trajectory breaks. Finally, we defined the contours of unbroken trajectories using the Shen-Castan method [6]. The proposed algorithm allows to estimate the number of desorbed (and trapped) QDs aggregates, and to obtain a velocity distribution that depends on the systems parameters (laser radiation is the foremost influence) as well.

Fig. 2 shows the dependence of the desorbed particles number on the laser pulse energy. As can be seen, the number of the desorbed particles increases with the increase of laser pulse energy. Analytical approximation of the number of desorbed CdSe/ZnS aggregates (N) on the pulse energy (E_p) dependence was made using the Levenberg-Marquardt algorithm in the form

$$N(E_p) = \exp\left[-8.2 + 0.05\, E_p\right]. \qquad (1)$$

Then we evaluated the "injection efficiency" value ξ that equals to a ratio of the trapped particles number to the desorbed particles number. Fig. 3 shows the dependence of the injection efficiency on the laser pulse energy. We observed the desorption for all energy values; however, we did not register particles trapping at lower energy values (<200 mJ). For energy values higher than 200 V, the injection efficiency ξ=0.136±0.018. Moreover, ξ was the same for all values of the pulse energy in a range >200 mJ.

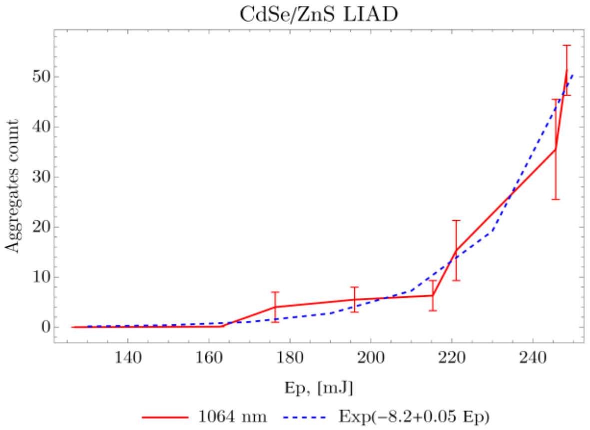

Fig. 2. The dependence of the desorbed particles number on the laser pulse energy: experimental data (red solid line), analytical approximation by Levenberg-Marquardt algorithm (blue dashed line)

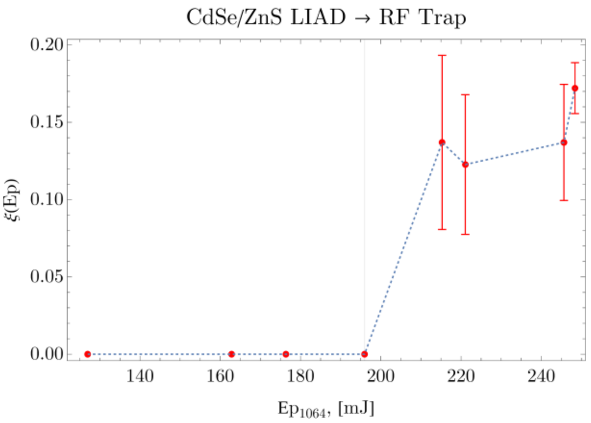

Fig. 3. The dependence of the injection efficiency ξ on the laser pulse energy

IV. Conclusion

In the present work, we experimentally investigated how the injection efficiency of desorbed particles depends on the laser pulse energy. We found that the number of desorbed aggregates is proportional to the laser radiation energy. The injection efficiency was 13.6±1.8% for all values of the laser pulse energy greater than 200 mJ. However, even though the desorption process was also observed at lower values (< 200 mJ), we did not register particles trapping in this case. This effect might be caused by different nature of desorption at low powers (LIAD) and at high powers (desorption as a result of substrate ablation).

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