Synthesis of silicon nanoparticles by picosecond laser ablation in liquid

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ABSTRACT

Silicon-based nanoparticles were produced by irradiating a single crystal silicon target in de-ionized water with Nd:YAG laser at wavelengths of 1064 nm. The main goal of our work presented here was enlight the role of thermal effects on the process of laser ablation of solid target in liquid. The additional heating of the target surface by continuous laser was applied during the experiment. The shift of NPs size distribution caused by applying of additional continuous laser was reported in this work.
Keywords: silicon nanoparticles; laser ablation in liquid; picosecond laser

1 INTRODUCTION

Silicon nanoparticles (NPs) find applications and potential applications in numerous fields, such as engineering, biomedicine etc [1,2]. The silicon particles increase conductivity of conjugated poly(*p*-phenylene vinylene) (PPV) [3,4]. In the field of theoretical studies, silicon NPs play important role in the study of fundamental quantum effects [5,6]. The other silicon-based nanoparticles (NPs) attract attention of authors; silica NPs have possible application for the synthesis of functional materials.

In this regard, a number of methods have been developed for creation of silicon-based nanoparticles, while the one of the most promising method for the producing of silicon-based NPs is the laser ablation of solid target in liquid (LAL), because it's relatively simple, fast and "green". The certain extent of the NPs properties tailoring could be accieved by changing the parameters in the LAL process. Also, LAL provides easy material handling because NPs are produced directly in the liquid. In this paper we investigated the synthesis of silicon-based nanoparticle produced by picosecond laser ablation. Main focus of the work was the analyzing of the role of thermal effect on the LAL process.

2 EXPERIMENTAL METHODS

The silicon targets (square shaped single crystal silicon plates, 15 mm x 15 mm in size) were placed on the bottom of the vessel filled with 3ml of de-ionized water.

The water layer thickness was kept to about 3mm during the experiments and the silicon target was fixed at the position during laser irradiation. The picosecond pulse Nd:YAG laser at wavelengths of 1064 nm was employed. The used laser pulse duration was 150 ps, pulse energy was 70mJ/pulse and the laser exposure time was 10 min. The additional continuous green laser (200mW) was applied during the LAL process and for 5 minutes immediately prior to application of pulse laser. The both laser spots, continual and pulsed, were placed at a fixed position in the centre of the silicon target.

The solution obtained by the LAL was dropped onto the silicon substrates and allowed to dry under atmospheric pressure at room temperature. The dried substrates were inspected using a JEOL 840A instrument equipped with an INCA Penta FETx3 EDX microanalyzer (SEM). For EDX analysis the aluminum substrate was used. All SEM/EDX images were recorded within the 24 hours after the laser irradiation of the targets.

3 RESULTS AND DISCUSSION

The main goal of our work presented here was to enlight the role of thermal effects, such as warming of the target, on the LAL process. To acchieve this goal, we provide additional heating of the target surface by applying the additional continuous laser during the experiment. In attempt to minimize the heating of the water layer, we used the green laser.

The use of picosecond pulse duration in our experiment provides that the nonthermal photon-based ablation could be neglected [7].

Figure 1 shows the SEM micrograph image of silicon nanoparticles prepared by the picosecond laser ablation in de-ionized water (a) with and (b) without applying the additional continuous laser. The large irregularly shaped objects present on the Figure 1a,b are impurities (confirmed by EDX measurements) and are not considered in the further analysis.

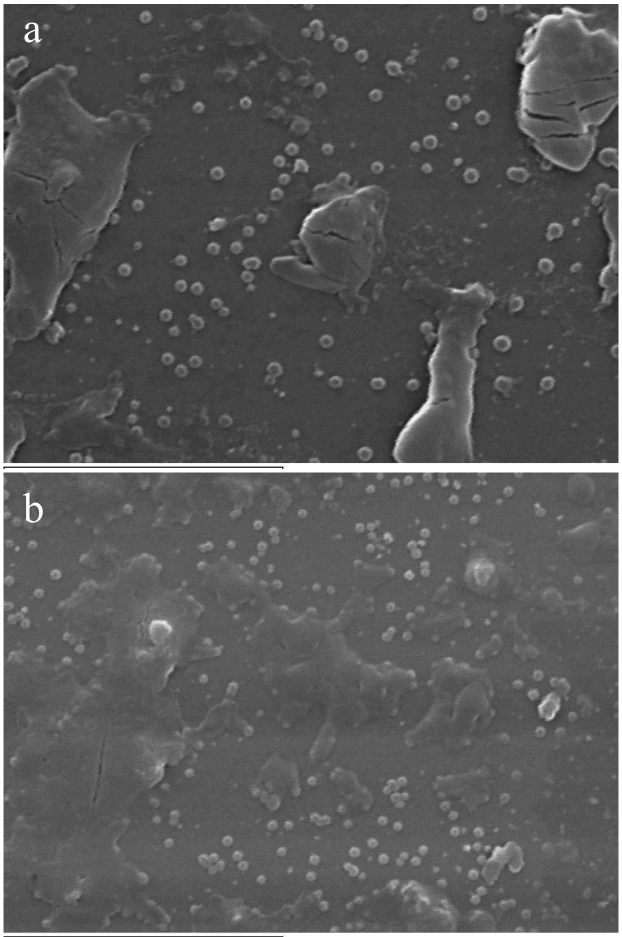

Figure 1: SEM micrograph image of silicon nanoparticles prepared by the picosecond laser ablation in de-ionized water (a) with and (b) without applying the additional continuous laser (bars denote 5 μm).

The size distribution of produced particles obtained by counting approximately 250 particles in SEM image, are shown in Fig. 2a and 2b, respectively. We considered only particles in the 50nm–250nm size range to achieve a size distribution due to the fact that larger ones were uncommon. All particles taken into consideration have a spherical or a nearly spherical shape. It could be noticed from Fig. 2 that applying the continual laser immediately prior and during LAL process changes the NPs size distribution. In the case of applying this laser the region under 100 nm was more populated than in the case when the laser was not applied. Also, the application of the continual laser caused that NPs size distribution was less asymmetric.

Because of plasma plume appears over the laser spot on the target surface the chemical composition of the produced nanoparticles will be of silicon oxide. This was confirmed by EDX measurements of produced nanoparticles, but no precise conclusion regards stoichiometry of silicon oxide could be reached.

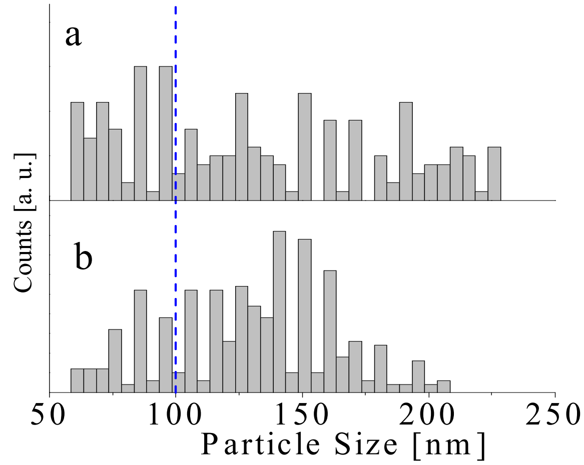

Figure 2: Size distributions of silicon nanoparticles prepared by the picosecond laser ablation in de-ionized water (a) with and (b) without applying the additional continuous laser (vertical lines at 100 nm should facilitate comparison).

4 CONCLUSION

In this paper, we studied the production of silicon-based nanoparticles by irradiating the single crystal silicon target in de-ionized water with Nd:YAG laser at wavelengths of 1064 nm and pulse power of 70 mJ/pulse. To provide additional heating of the target surface the additional continual green laser was applied during and immediately prior the ablation process. The shift of NPs size distribution caused by applying of additional continuous laser was reported. An analysis of correlation between heating of the LAL target and the NPs size distribution could be used for partially controlling the LAL process.

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