Al nanoparticles generation and characterization by Nd:YAG laser ablation in deionized water

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In this work, Al nanoparticles were generated using second harmonic of pulsed Nd:YAG laser (532 nm) ablation in water confined plasma at 5 min exposure time. Nanoparticles were characterized by transmission electron microscopy (TEM), selected area electron diffraction (SAED) and the dynamic light scattering (DLS). Nanoparticles had spherical shape and they were in the crystalline form as bulk Al. Obviously, the chemical composition of the nanoparticle’s surface must be Al2O3 because of the water medium.

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1. Introduction

According to utilize of laser ablation of a solid target in liquid medium, the expectation is an advantageous in the generation of nanoparticles (especially, metastable phases). The Laser ablation in liquid includes mechanisms in nucleation, phase transition and growth of the nanoparticles during laser ablation in liquid which those mechanisms are not well understood. Laser ablation of solid target in the liquid medium for nanoparticle fabricating was done for metals [1–4], alloy [5–7] and ceramics [8,9]. Al nanoparticle generation using short laser pulses in liquid medium was reported [10–12].

Good heat releasing in the exothermal oxidation of Al nanoparticles makes them as a probable fuel candidate in the new energetic materials [13–15]. Moreover, Al nanoparticles were considered as hydrogen storage material with high capacity [16–18]. Optoelectronic applications are other capability of Al nanoparticles. For example they were utilized in surface enhanced Raman scattering [19]. In this work, we have fabricated Al nanoparticles in deionized water medium using fundamental and second harmonics of Nd:YAG laser for different exposure times. Then, characterization and investigation of structural and morphological properties of the nanoparticles were done so that it complete the mentioned reports in [10–12].

2. Experiment

Q-switched Nd:YAG laser (VmTim, 532 nm–40mj/pulse, 12 ns, 5 Hz) was used as coherent beam source. Spot sizes on the target was ~500 nm. Laser beams were expanded by two lenses with 20 and 10 cm focal distances and focused at 2 mm distance from target using a 15 cm focal distance concave mirror. Al target supplied by Fluka with 99.9%, was cut in 2 cm × 2 cm square with 2 mm thickness. It was situated at the bottom of glass beaker filled with 10 ml distilled water so that 10 mm of water height was above the target at room temperature. The exposure times were performed on 5 min. After laser irradiation, drops of suspension were placed on a plate of glass using pipet. Then after water evaporation, we have collected remained materials.

TEM and SAED were used for morphology and structural characterization of the nanoparticles. It was done by a Philips CM 30 equipment. DLS was done by a Malvern ZEN3600 equipment.

3. Results and discussion

For the formation of the nanoparticles via laser ablation in liquids several factors such as laser parameters and the liquid have a significant affect the generation and properties of the nanoparticles. It was shown the laser properties such as fluence, wavelength, pulse width and repetition frequency could affect the fabrication of the nanoparticles in liquids. In fact, these effects could be described based on the nanoparticle growth dynamic mechanisms. The fluence of the laser irradiation has a significant portion on the shape of the generated nanoparticles [20].
TEM measurement was done to determine size and shape of nanoparticles. Fig. 1(a) shows the TEM image of the fabricated nanoparticles using 532 nm wavelength and 5 min exposure times and Fig. 1(b) depicts the corresponding nanoparticle size distribution. The nanoparticles have nearly spherical shape and mean size \( \sim 10 \text{ nm} \).

Fig. 2(a–c) shows the Al nanoparticles DLS size distribution characterization with respect intensity, volume and number, respectively. Fig. 2(a–c) shows the most strength scattering intensity belong to nanoparticles with diameter \( \sim 79 \text{ nm} \). The difference between TEM size distribution and DLS ones is due to rapid aggregation of the nanoparticles (TEM image was taken just after nanoparticle generation and DLS was done an hour after TEM imaging).

Typically, the most common products prepared via the laser ablation in liquid (LAL) method are metal nanoparticles or nanoparticles of metal compounds formed via the reaction of ablated metal with liquid media. LAL of metal targets like Al, fabricates compound nanoparticles due to the reaction of created plasma and the liquid [21]. However, if plasma creation rate is drastically greater than rate of clustering of the plasma fragments, the reaction between plasma fragments occurs more than the reaction between fragments and liquid medium. Under such condition, metal nanoparticles are fabricated. Compare the described method, there is an approach includes the reactions between ablated fragments and the liquid. Thus, the generated nanoparticles by this approach belong different chemical composition from that of the target.

Fig. 3 shows the selected area electron diffraction (SAED) patterns of the nanoparticles for the nanoparticles generated by various. The measured ring’s diameters of the patterns give the crystallographic surface of Al. For calculating the lattice spacing corresponding each crystallographic surface we have used below equation:

\[
Rd = \lambda L
\]

where \( d \), \( \lambda \), \( L \) and \( R \) are the lattice spacing, wavelength of accelerating voltage, camera length and ring radius, respectively. Using the equation denotes the crystalline structure of the bulk Al would be unchanged after nanoparticle generation by laser irradiation on the bulk target at the liquid medium.

4. Conclusion

Laser ablation of the Al target in deionized water leads to fabrication core–shell type Al nanoparticles due to partial oxidation in the water medium. The second harmonic of Nd:YAG laser was utilized to perform the experiments. Results showed the nanoparticles were spherical in shape and their mean size was \( \sim 10 \text{ nm} \) for 5 min exposure time. The generated nanoparticles were aggregated rapidly after one hour so that their mean size became \( \sim 79 \text{ nm} \). The crystallographic structure of Al nanoparticles was similar to the bulk one. Produced Al nanoparticles were highly desirable properties for advanced energetic applications.
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