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Effect of liquid level and laser power on the formation of spherical alumina nanoparticles by nanosecond laser ablation of alumina target

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ABSTRACT

Alumina nanoparticles (NPs) were synthesized by laser ablation of a bulk α-alumina (corundum) target immersed in distilled water using nanosecond laser pulses of 1064-nm wavelength. We investigated the effect of laser power and water column above the target. Synthesized particles were analyzed regarding particle shape and size distributions with scanning electron and transmission electron microscopy. Ablated NPs were spherical in shape and the average particle size ranged from 12 to 18 nm at varied laser power and water levels, although a very small number of melted droplets of submicron spheroids and irregular-shaped cracked particles were observed. X-ray diffraction analysis was conducted, which shows mainly the peaks of α-Al_2O_3 and minor peaks of γ-Al_2O_3. Phase identification of NPs, using high-resolution transmission electron micrograph lattice images and fast Fourier transform exhibits both metastable γ-Al_2O_3 and stable α-Al_2O_3 phases.

1. Introduction

Aluminum oxide nanoparticles (NPs) are prepared for a variety of applications due to their large surface area, which gives improved characteristics including catalytic activity compared with bulk alumina. Recent studies have shown that nanofluids (aluminum oxide NPs in water) have significantly greater transport properties of thermal and electrical conductivity and viscosity compared to their base fluids due to large surface area to volume ratio and certain effects of Brownian motion of the NPs [1]. Unlike bulk materials, the principal parameters of NPs are their shape, size, and morphological substructure of the substance, which primarily define the physical and chemical properties.

Laser ablation in liquid has been one of the most popular methods for NP synthesis. Although Al_2O_3 NPs can be generated by a variety of techniques, such as the chemical method [2,3], plasma or flame synthesis [4,5], ball milling [6], electric spark discharge and sono-hydrolysis [7], contamination by constituting reactants is often inevitable. It has recently been reported that laser ablation in liquid initiates a higher ablation rate than that in a gas phase [8], which can be better explained by confined plasma with higher pressure [9] than that in ambient air. Because the induced shock wave lasts three times longer in liquid than that in air, mechanical responses of substrates tend to be enhanced. The liquid level and laser power could also be optimized to control the ablation rate and particle size distributions [10].

The synthesis of alumina NPs by using the liquid phase laser ablation method has been reported. Khan et al. [11] synthesized γ-Al_2O_3 using continuous wave laser ablation in liquid with the average size ranging from 17 to 29 nm. Sajti et al. [12,13] achieved high NP productivity of 1.3 g/h at 18.5 W of focused laser power at a 4-kHz repetition rate by aiding the liquid flow and scanning the target, but the average size was comparatively large, around 30 nm. Liu et al. [14] synthesized γ-Al_2O_3 and its derivative θ-type structure by irradiating an Al metal target in the liquid phase. Musaev et al. [15] irradiated a bulk corundum (α-Al_2O_3) target with UV radiation (337 nm) but unfortunately, most of the ablated particles were submicron and micron-sized. In this work, spherical Al_2O_3 nanocondensates (12–18 nm) were synthesized by irradiating a bulk corundum target with an infrared pulsed laser (1064 nm) immersed in water.

We varied the ablation rate and size distributions by controlling laser power and liquid layer thickness in nanosecond laser ablation of the alumina target. We also investigated the crystal phase of the ablated NPs.

2. Experimental details

Ablation experiments were carried out with a Q-switched Nd:YAG (Quantel Brilliant b; Les Ulis, France) pulsed laser source, which provides 6-ns-pulse 1064-nm wavelength with a repetition rate of 10 Hz. Fig. 1 is a schematic of the experimental setup with a laser source

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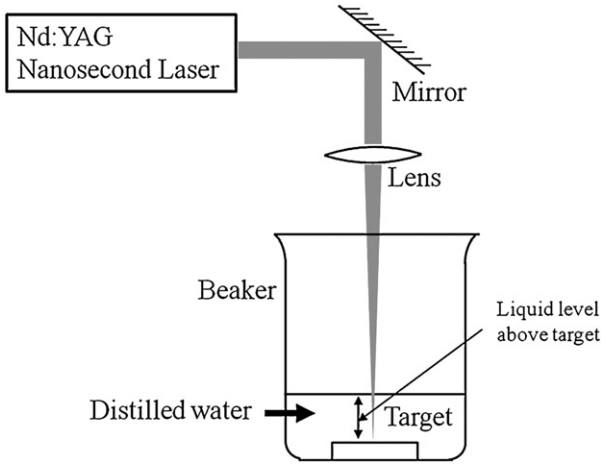

Fig. 1. Schematic of the experimental setup.

along with laser guiding and focusing mirrors and lens system. The laser beam, which was in the TEM_{00} mode, was focused onto a laser spot of approximately 250 μm. The size of the laser spot was measured by irradiating a specially made burn paper placed along the target surface.

The irradiated corundum target was a $10\times10\times4$ mm sintered body with 99.9% purity and a relative density above 99%. All ablation experiments were conducted at room temperature in atmospheric pressure in a distilled water environment.

The target crystal was immersed in water contained in a small 20-ml beaker which was mounted on a motor-driven rotator (0–100 rpm). The purpose of rotation was to ensure uniform irradiation on the target and the movement of water to enhance the diffusion of the ablated particles. The rotation speed was set at 40 rpm. The laser beam entered the solution from above at a normal incident angle to the target. The thickness of the distilled water layer above the target (Fig. 1) was varied to investigate the effect on the ablation rate and particle size. The beam irradiated the target for 1–2 h. Laser power was also varied and the effect of laser fluence on the ablation rate, size, and morphology of the synthesized NPs was observed. Laser power was measured with a low-power thermal sensor (Ophir; Model 7Z01560; Tokyo, Japan).

Laser-generated particle size, and the distribution and morphology of water-dispersed ceramic NPs were determined using scanning electron microscopy (SEM; JEOL JSM-5310, 15 kV; Tokyo, Japan) and transmission electron microscopy (TEM; JEOL JEM2100F, 200 kV; Tokyo, Japan). Crystal phase was also analyzed with an X-ray diffractometer

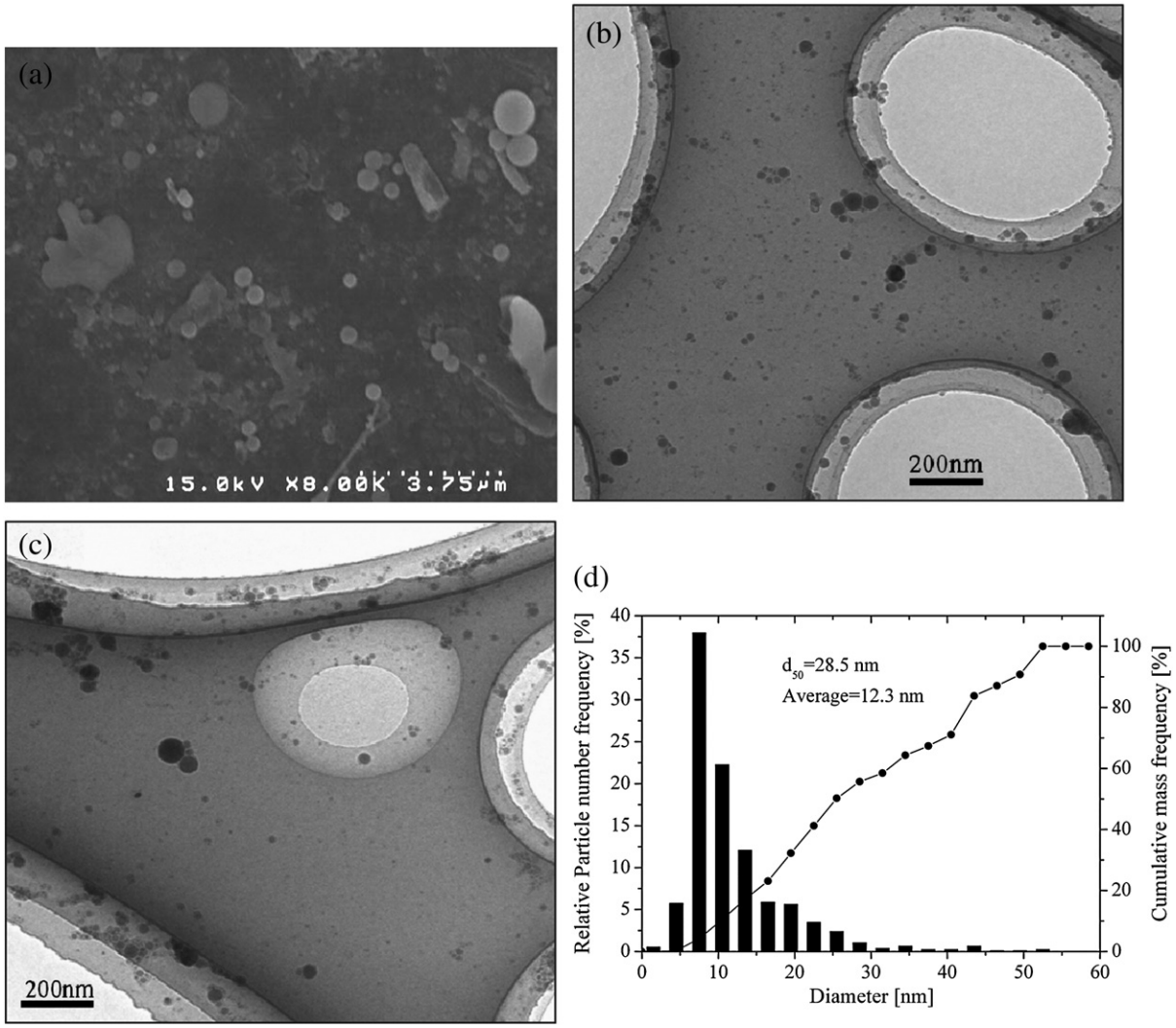

Fig. 2. (a) SEM micrograph at a water level of 2 mm, (b) and (c) TEM images at a water level of 4 and 6 mm, respectively; (d) histogram showing NP size distributions at 6 mm; laser power was set to 80 mW [fluence; 20 J/cm^2].