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Synthesis of FeCo Nanoparticles by Pulsed Laser Deposition

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Abstract

The paper reports the synthesis of FeCo nanoparticle by pulsed laser deposition (PLD) in inert gas atmosphere. FeCo nanoparticles were deposited by pulsed laser deposition in 0.5 - 7.5 kPa Argon atmospheres at a distance of 4 cm from the FeCo target using 1.064 μm Nd:YAG laser. The SEM micrographs show nanoparticles with diameter ranging from 5 – 10 nm at 0.5 and 2.5 kPa pressures. These nanoparticles, however, form island like cluster with average cluster sizes of 125 nm for 0.5 kPa and 60 nm for 2.5 kPa. As pressure increases to 4.5 kPa, the morphology changes to a network of nanoparticle clusters with particle size ranging from 10 - 15 nm. At 7.5 kPa, only large clusters of nanoparticles with average particles size of 20 nm were observed. The EDX result shows the nanoparticles are reasonably stoichiometric.

Introduction

Nanoparticles are usually referred to as condensed phase particles in the size range of 1–100 nm in diameter. Nanoparticles of a wide range of materials have been prepared by both chemical and physical methods. Among those available methods, pulsed laser deposition has appeared to be one of powerful techniques. It also has capability to produce oxide nanoparticle [1] by incorporating oxygen gas during the deposition. Yet, the formation of nanoparticle during the pulsed laser ablation process is not fully understood, therefore, it is important to understand the effect of various deposition parameters on the size and morphology of the nanoparticles with an aim to achieve narrow particle-size distribution. In present paper, we report the influence of filling gas pressure on the morphology and size of deposited nanoparticles.

Experimental details

The laser ablation was performed in a chamber maintained at different pressures of Ar at room temperature, using Nd:YAG laser (Continuum Surelite) with wavelength of 1064 nm. The typical laser pulse duration was about 11 ns, repetition rate was set at 10 Hz and the

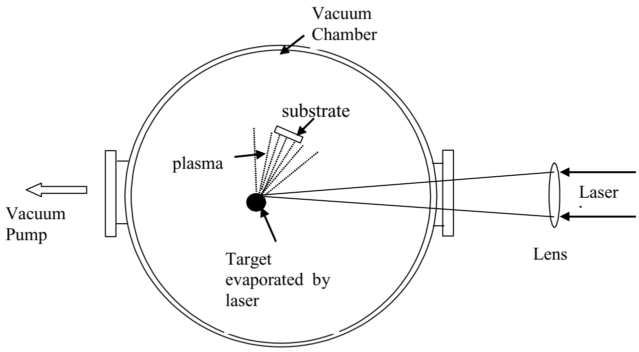

Fig.1: Schematic of experimental setup.

laser pulse energy was kept 145 mJ/pulse. The FeCo (50:50 by atomic percentage) target rod with 99.99% purity was used for nanoparticle synthesis. The one inch dia and 100 mm long target rod was continuously rotated and moved linearly (to and fro) using rotary and linear stages in order to obtain the uniform ablation of the target material. The laser was focused on target rod to a focal spot size of 50 μm diameter. The schematic of the experimental setup is shown in figure 1. A combination of a rotary and a turbomolecular pump was used to create the base pressure of 10^{-4} Pa.

Nanoparticles were deposited on Si substrate, which were cleaned using acetone, alcohol, and deionized water in ultrasonic bath for about 10 minutes each, respectively. The deposition was done at on-axis configuration (along the surface normal of the target rod) at target-to-substrate distance of 4.0 cm. The background gas used was argon and the pressure varied from 0.5 to 7.5 kPa and the target was irradiated with 25000 pulses for every set of experiment. The synthesized samples were characterized using Field Emission Scanning Electron Microscopy, JSM-6700F JEOL, and Energy Dispersive X-Ray Spectroscopy (EDX), attached to FE-SEM machine.

Results and Discussion

Few investigations have been done on pressure effect on nanoparticle formation by PLD, but with contradictory results [2,3]. SEM micrographs in figure 2 show an interesting morphology dependence of deposited nanoparticles to the variation of chamber pressure (0.5 to 7.5 kPa). Firstly, at argon pressure of 2.5 kPa and below, island-like cluster formation took place, which had fractal “snowflake” structure. The size of island-like cluster decreased from 120 nm in 0.5 kPa to 65 nm in 2.5 kPa. This morphology changed to network of small clusters at pressure of 4.5 kPa and large aggregates with small clusters scattered surrounding large aggregates at pressure of 7.5 kPa. Note that few aggregates were also present at pressure of 0.5 – 4.5 kPa. The presence of these aggregates could be attributed to the collisions among the condensed nanoparticles during the transport in the gas phase [4]. Nevertheless, there is still some fraction of nanoparticles, which during the

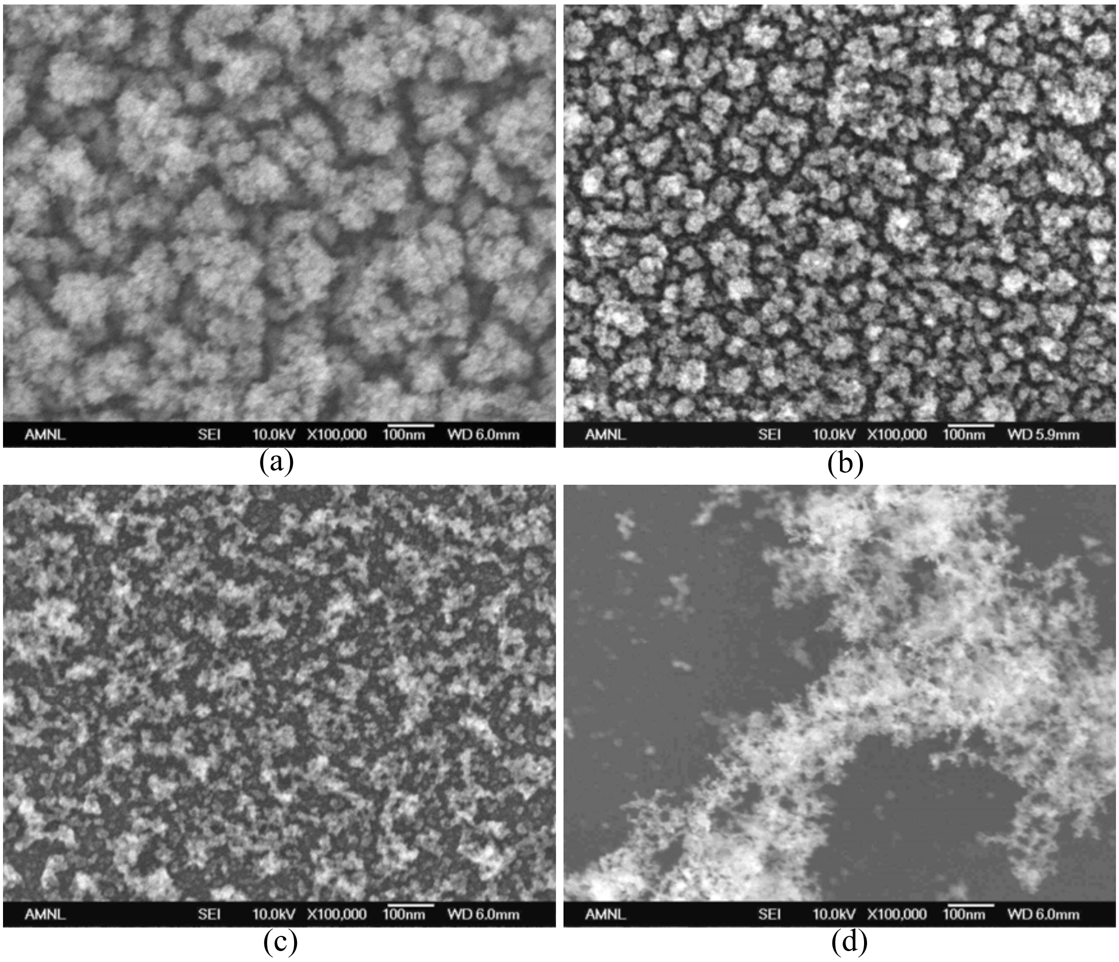

Fig.2: Morphology of FeCo deposited nanoparticles at different argon ambient pressures of (a) 0.5 kPa (b) 2.5 kPa (c) 4.5 kPa and (d) 7.5 kPa.

transport might form clusters which are much smaller in size than these aggregates. These smaller clusters upon deposition will form the background morphology, for example like island-like cluster formation at argon pressures of 0.5 and 2.5 kPa. The morphology changes could be related to the transport of nanoparticles in the gas phase and surface mobility of individual nanoparticles on the substrate.

Surface mobility of nanoparticles in our system is provided by the excess kinetic and thermal energy of nanoparticle upon arriving on the substrate. The larger the surface mobility of deposited nanoparticles, the larger will be the size of the clusters on the substrate since by forming larger clusters the total surface energy of the system is reduced. The surface mobility of arriving nanoparticles was reduced with increasing argon pressure, since the collision cooling between nanoparticles and ambient gas during the transport was increased with increasing pressure, which in turn reduced the kinetic and thermal energy of deposited nanoparticle. Therefore, this explanation accounts for reduction in background cluster size with increasing argon pressure.

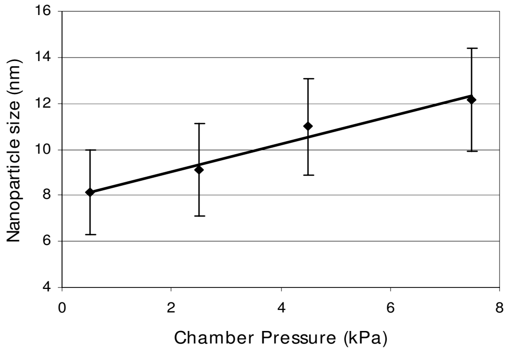

Fig.3: Variation of nanoparticles size with the ambient argon pressure.

The size distribution of the synthesized nanoparticles at different pressures is presented at figure 3. The average particle size is observed to increase from 8 nm at 0.5 kPa to about 12 nm at argon pressure of 7.5 kPa. This trend could be associated to the probability of collisions among the ablated atoms and/or ions in the confinement region, which is growth region just behind the plume boundary with the ambient gas. An increase of ambient gas pressure leads to a decrease in the expansion volume, causing the probability of collision to increase in the confinement region. In such situation, the ablated species still have high kinetic energy to form metallic bonding, which allows the growth of nanoparticles. As a result, at this pressure range, the size distribution increases with the increasing ambient gas pressure.

The EDX analysis of deposited nanoparticles show that they reasonably stochiometric (average Fe:Co is 1:(0.94±0.012) by atomic percentage). This is possible since focused high intense laser beam is focused on small area, therefore it can vaporize small volume of any target irrespective of its boiling temperature.

Conclusions

These results show the feasibility of PLD to synthesize FeCo nanoparticles and also demonstrate that the pressure of ambient gas plays a significant role on the morphology of the synthesized nanoparticles.

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