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Fabrication of Ultrananocrystalline Diamond Powder by Using A Coaxial Arc Plasma Gun

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Abstract

A new method that enable us to synthesize ultrananocrystalline diamond (UNCD) in powder compactly, briefly, and flexibly is proposed. Highly energetic carbon species such as C^+ ions ejected from a graphite cathode of a coaxial arc plasma gun (CAPG) are provided on a quartz plate in a high density by repeated arc discharge in a compact vacuum chamber, and resultant films automatically peeled from the plate are aggregated and powdered. The existence of a huge number of diamond grains with diameters of less than 10 nm was confirmed by transmission electron microscopy (TEM) and powder X-ray diffraction (XRD). In addition, it was found that the grain size is easily controllable from 2.4 to 15 nm with increasing arc discharge energy from 1.8 to 144 J/pulse. It was experimentally demonstrated that this is a new promising method that makes possible the synthesis of powdered ultrananocrystalline diamond (PUNCD) easily and controllably.

1. Introduction

Diamond possesses several superior physical properties including high hardness, wide bandgap, and chemical inertness. Furthermore, it is possible to impart functionalities by doping and surface modification. Nano-sized diamond, so-called nanodiamond, has received much attention in recent years, since nanodiamond possesses unique properties, which are partially different from those of bulk diamond and other nanocarbon such as carbon nanotube and fullerene. Nanodiamond has mainly been produced by detonation so far [1-5]. High-purity nanodiamond powder has been difficult to be fabricated by detonation. Moreover, the functionalization of nanodiamond is generally made after the growth, because the process control including doping is impossible during detonation. We has proposed a new novel method that employs a coaxial arc plasma gun, which enables us to fabricate nanodiamond crystallites [6-7]. The specifics to this method are as follows: i) the growth is made using a simple apparatus equipped with CAPG, ii) high-purity nanodiamond can be fabricated in principle, iii) doping can be easily made by using hetero-atom blended targets, and iv) the grain size is expected to be changed by controlling the discharge condition of CAPG.

In this work, we suggest a new fabrication method for producing nanodiamond in powder. Fabricated powders are experimentally structurally investigated by powder XRD and TEM and the density was analyzed using a sink-float method.

2. Experimental

Nanodiamond powder was fabricated using CAPG (ULVAC, APG-1000) equipped with a graphite target. The inside of the chamber fitted with CAPG was evacuated to < 10^{-4} Pa and hydrogen was introduced at 5 sccm. The head of the arc plasma gun was pointed at quartz plate heated at

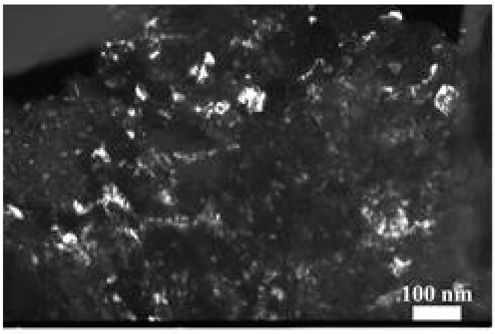

Figure 1. Dark-field TEM image of nanodiamond powder.

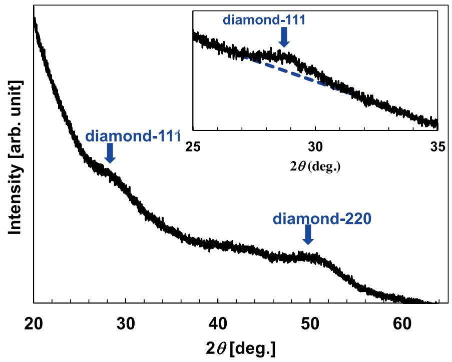

Figure 2. XRD pattern of nanodiamond powder.

550°C. The powder that quickly and automatically exfoliated from the quartz plate was gathered in the collection cell located under the quartz plate. In order to confirm the formation of diamond, the films were structurally investigated by TEM and powder XRD using synchrotron radiation at beamline 15 of the SAGA-LS. The density was measured by sink-float meathod using bromoform and ethanol as a heavvy liquid.

3. Results and discussion

A nanodiamond powder exhibited diamond-111 and 220 diffraction rings in the electron diffraction patterns. The existence of diamond grains was confirmed from the dark-field TEM image as shown in Fig. 1.

Figure 2 shows the XRD pattern of a nanodiamond powder fabricated using discharge energy of 3.6 J/pulse, which was transformed from a Debye-Scherer ring on an imaging plate.

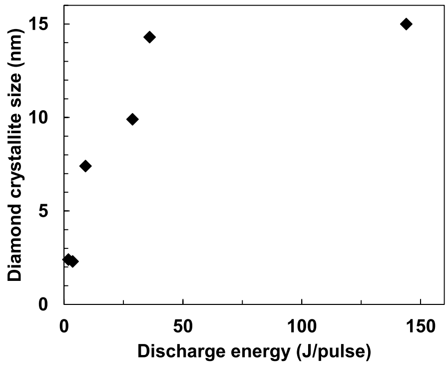

Figure 3. Diamond crystallite sizes against discharge energy.

Diffraction peaks due to diamond-111 and diamond-220 are observed. Their diffraction peaks were observed for the other samples prepared at different discharge energies.

The diamond crystallite size was calculated from the diamond-111 peaks using Scherrer's equation. Figure 3 shows the dependence of the diamond crystallite size on the discharge energy. The grain size was increased from 2.4 to 15.0 nm with increasing electric power applied to an arc plasma gun from 1.8 to 144.0 J/pulse.

From sink-float density measurements, the density of the powder was estimated to be approximately 1.77 g/cm^3. This value is smaller than that of diamond (3.52 g/cm^3), which indicates that the powder contains non-diamond phase which should predominantly be amorphous carbon. The fraction of diamond in the powder was estimated to be approximately 35% on the assumption that the densities of diamond and amorphous carbon are 3.52 and 1.40 g/cm^3, respectively.

4. Conclusion

It was demonstrated that a new method employing a coaxial arc plasma gun is a potential method for forming single-digit nanometer diamond particles easily. It was demonstrated that the diamond crystallite size is controllable by the discharge energy of the coaxial arc plasma gun. The powder contains a large amount of amorphous carbon that cogenerates during the growth process of nanodiamond.

Acknowledgments

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