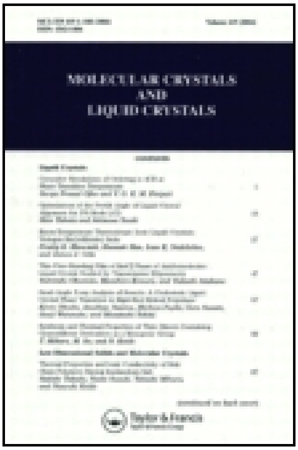

Molecular Crystals and Liquid Crystals Science and Technology. Section A. Molecular Crystals and Liquid Crystals

Publication details, including instructions for authors and subscription information:
http://www.tandfonline.com/loi/gmcl19

Formation and Properties of Boron Nitride Nanocapsules with Metals and Semiconductor Nanoparticles

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Version of record first published: 24 Sep 2006

Mol. Cryst. and Liq. Cryst., 2000, Vol. 340, pp. 787-792
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Formation and Properties of Boron Nitride Nanocapsules with Metals and Semiconductor Nanoparticles

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(Received May 30, 1999; In final form July 1, 1999)

Boron nitride nanocapsules with gold, iron oxide and germanium nanoparticles were produced. High-resolution electron microscopy and electron energy-loss spectroscopy showed the gold, iron oxide and germanium nanoparticles were encapsulated in the boron nitide sheets. Weak peaks of photoluminescence spectrum were observed from the nanocapsules with germanium nanoparticles. The present work indicates that the boron nitide nanocapsules with conducting, magnetic and semiconductor nanoparticles can be produced by arc melting method, and models for the formation mechanism and nano-structures of the boron nitide nanocapsule were proposed.

Keywords: BN nanocapsules; gold; iron oxide; germanium

INTRODUCTION

Nanoclusters encapsulated in carbon hollow-cage structures are intriguing for both scientific research and future device applications[1-4]. However, the graphite sheets are conductive, and insulating sheets such as boron nitride (BN) are needed for the control of electrons in future nanoscale devices.

A few works on BN nanocapsules (BNNC) have been reported as by-products of BN nanotubes, recently[5,6]. Recently, we have succeeded in producing BNNC[7]. However, detailed studies of the BNNC have not been done.The purpose of the present work is to investigate the structural study of the nanocapsules and to obtain photoluminescence (PL) spectrum. These studies will give us a guideline for the design and synthesis of BNNC, which is expected as future nanoscale devices.

EXPERIMENTAL

Boron particles (99 %, 40 μm) were mixed with gold (99.5 %, 0.5 μm), iron oxide (10 nm,) and germanium particles (10μm). The mixture powder was pressed into pellets. The green compacts were set in an arc furnace. After introducing a mixed gas of Ar (0.06 MPa) and N_2 (0.06 MPa) arc melting was applied to the samples at an accelerating voltage of 60 V and arc current of 200 A for a few minutes. After the arc melting, a white or gray powder was obtained around the pellets.

The high resolution electron microscopy (HREM) observation was performed with 300 kV and 200 kV electron microscopes (JEM-3000F and JEM-2010). To detect light elements, the electron energy-loss spectroscopy (EELS) analysis was performed. PL spectra were obtained by spectrometer (LS50B, Perkin Elmer).

RESULTS AND DISCUSSION

A transmission electron microscope (TEM) image of BNNC with gold nanoparticles is shown in Fig. 1. The particle size is in the range of 10~30 nm. Lattice fringes with distances of 0.23 nm and 0.20 nm, which correspond to distances of {111} and {200} planes of Au, are observed.

A TEM image of BNNC with iron compound nanoparticles is shown in Fig. 2 (a). Fe_3O_4, B, Fe_2B, Fe_3B were detected by diffraction analysis as shown in Fig 2 (b). Figure 2 (c) is an EELS spectrum of BNNC shown in Fig. 2 (a). Two distinct absorption features are observed, which correspond to boron (B) and nitrogen (N) K-edge onsets, respectively. The fine structure of B in the EELS spectrum shows the hexagonal bonding between B and N, and spherical structure of BN. A B:N ratio was determined to be 1 ± 0.2.

An enlarged TEM image of a BNNC with a Fe_3O_4 nanoparticle is shown in Fig. 3 (a). Lattice fringes, which correspond to the {111}, {222} and {400} planes of Fe_3O_4, are observed at distances of 0.47 nm, 0.23nm and 0.20nm. An enlarged image of BN sheets is shown in Fig. 3 (b).

A HREM image of a BNNC with a boron nanoparticle is shown in Fig. 3 (c). Lattice fringes with a distance of 0.51 nm, which corresponds to the distance of the {104} plane of boron, is observed. An enlarged image of BN sheets is shown in Fig. 3 (d).

A HREM image of a BNNC with germanium nanoparticles is shown in Fig. 4 (a). Lattice fringes with a distance of 0.33 nm which corresponds to the distance of the {111} plane of germanium, are observed. PL spectrum of BNNC with germanium nanoparticles is shown in Fig. 4 (b). The luminescence was observed at 343 nm. The mechanism of PL is considered to originate in interband transition by impurity of carbon and hydrogen [11].

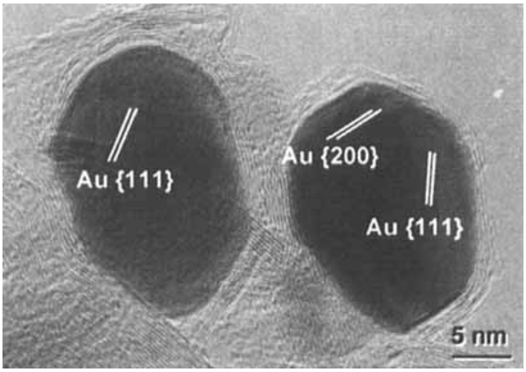

FIG. 1. (a) HREM image of BNNC with gold nanoparticles.

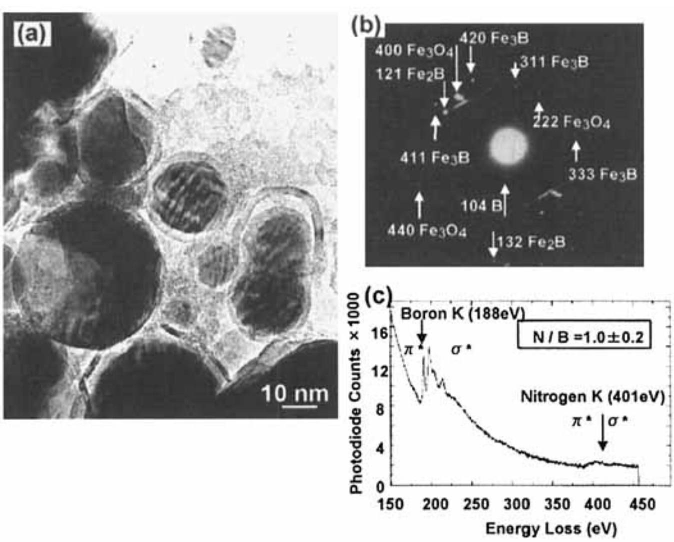

FIG. 2. (a) HREM image of BNNC with iron compound nanoparticles. (b) Diffraction pattern of Fig 2 (a). (c) EELS spectrum of BNNC.

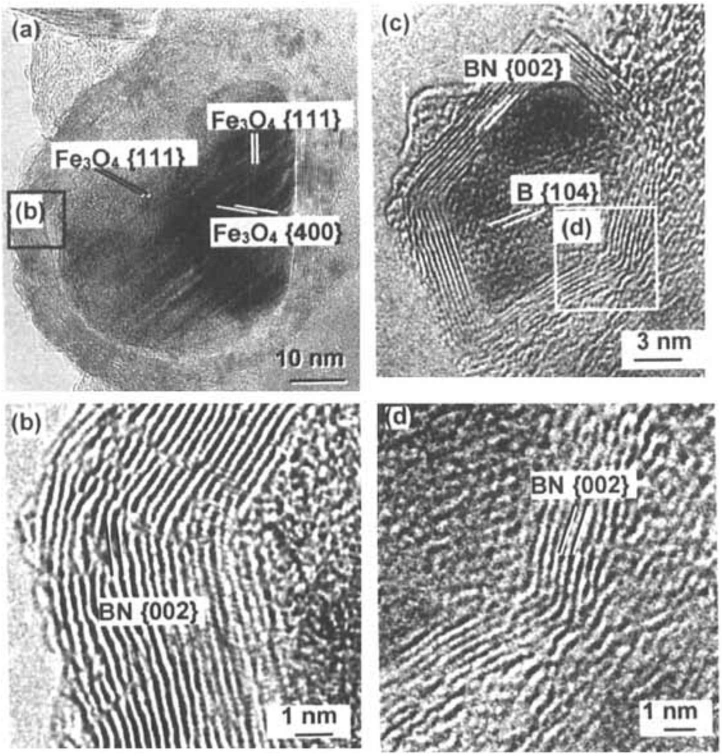

FIG. 3. (a) HREM image of BNNC with Fe_3O_4 nanoparticle.
(b) Enlarged image of the interface of the nanoparticle.
(c) HREM image of BNNC with boron nanoparticle.
(d) Enlarged image of the interface of the nanoparticle.

BNNC have been observed in previous studies[5-7]. In these works, included metals and compounds had never been confirmed by phase identification and structure analysis.

For the BNNC with boron nanoparticles, BN sheets form vertices and flat planes with 4- and 6-membered rings as shown in Fig. 2 (b), which would be due to the restriction of the nanoparticles shapes during BN growth[7]. For the BNNC with iron oxide nanoparticles, BN sheets form spherical surface with many plane defects as shown in Fig. 2 (d). Since the iron oxide nanoparticles do not melt during the BNNC formation, BN sheets grow along the nanoparticles[7], and are restricted by the shape of the nanoparticles.

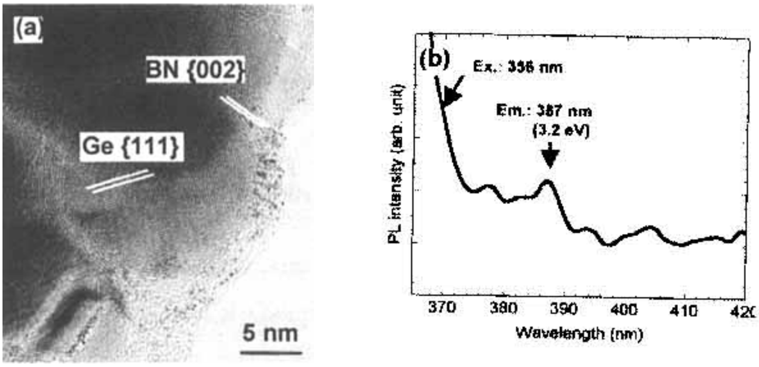

FIG. 4. (a)HREM image of BNNC with Ge nanoparticles.
(b) PL spectrum of BNNC with Ge nanoparticles

BNNC are expected to have various properties. It is expected that gold nanoparticles encapsulated in BN nanocapsules enable to control a single electron through the insulator sheets, and they can be applied to single electron transistors [8,9]. If BN sheets with a thickness of less than 3 nm divide the iron oxide nanoparticles, superparamagnetism is expected, and they can be applied to magnetic refrigeration[10]. In the present work, nanostructure of nanoscale insulated and non-magnetic BN layers around nanoparticles was discussed in detail, and the guidelines for preparation of the future nanoscale devices were provided.

CONCLUSION

BNNC with metals and semiconductor nanoparticles were produced. EELS analysis showed the K-edge onsets of boron and nitrogen. The nanostructures of BNNC change for each formation processes. The present work indicates that the conducting, magnetic and semiconductor nanoparticles surrounded by insulating and non-magnetic BN sheets can be produced by the arc-melting method, and the nano-structures of these nanocapsules strongly depend on the included metals.

Acknowledgements
The authors would like to acknowledge Profs. Y. Hirotsu T. Ohkubo, B. Bian

and K. Murakami, for allowing us to use the electron microscopes and the arcmelting furnace. This work is supported by The Iketani Foundation, the Sasagawa Scientific Research Grant and The Grant-in-aid for Scientific Research, Ministry of Education, Science, Sports and Culture, Japan.

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