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Direct coating of cubic boron nitride with titanium powder under high pressure and high temperature

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ABSTRACT

In this paper, we propose a facile one-step method for preparing cubic boron nitride (cBN) composite materials. In this method, the pure titanium nitride (TiN) coatings are grown on cBN at 5.0 GPa and 1400–1650 °C during a crystal growth process. We investigate the composition and the microstructure of the coatings. The results indicate that the uniformity of TiN coatings formed on cBN surface can be controlled by the temperature and Ti powder content. The average residual stress of TiN-coated cBN is less than 0.64 GPa. We find that the crystal growth process plays an important role in direct coating of cBN. This one-step method of direct coating of cBN is an effective way to facilitate the preparation of coated cBN composite materials.

1. Introduction

Cubic boron nitride (cBN), a conventional superhard material, has outstanding physical and chemical properties such as high hardness, high thermal conductivity and high chemical inertness. Unlike diamond, cBN is indispensable for tools used in machining ferrous metal materials because of its chemical stability against ferrous alloys at higher temperatures [1–5]. Those fascinating features make it suitable for many applications in microelectronic devices and machine tools [6–8]. To improve the performance (wear resistance, anti-sticking, and anti-frication, etc.) of cBN in practical application further, transition metals or their nitrides (Ni, Ti, or TiN etc.) are usually used as coating materials on cBN surface due to their high chemical activity towards cBN.

In the past decades, the cBN/Ti, cBN/TiN and cBN/TiC composite materials have been extensively studied by the methods of electrostatic spray coating (ESC), chemical vapor infiltration (CVI), and conventional vapor deposition (CVD/PVD) [9–13]. However, the disadvantages of the composite coatings obtained by those methods, such as delamination and non-uniformity, have not been solved. Furthermore, until recently, the preparation of coated cBN composite materials is still a two-step process including cBN growth and coating. It is still a challenge for direct coating of cBN during crystal growth. In our work, a simple method, as a low cost process, is developed for simultaneous synthesis and coating of cBN at 5.0 GPa and 1400–1650 °C.

2. Experimental

The experiments were carried out in a China type SPD 6 × 600 cubic-anvil high-pressure apparatus (CHPA) under the conditions of 5.0 GPa and 1400–1650 °C for 8 min. The detailed experiment set-up has already been described elsewhere [14]. A mixture consisting of Li_3N–hBN (1:9 wt. ratio) and Ti (1–5 wt%) was mechanically mixed in a sealed container for 3 h, and then the mixture was pre-pressed into a cylindrical shape under dry and clean conditions. Then, cBN crystals were obtained after filtrating in hydrochloric acid and molten hydroxides. The morphology and the microstructure of the coating were characterized by using an optical microscope (OM) and scanning electron microscopy (SEM). The material phase was determined by using X-ray diffraction equipment (XRD). The residual stress of coated cBN was calculated based on the results of Raman spectroscopy.

3. Results and discussion

Different morphologies of TiN-coated cBN crystals obtained by introducing 1–5 wt% Ti at 5.0 GPa and 1400–1650 °C are shown in Fig. 1. As shown in Fig. 1a, some regular plate-shape transparent crystals with (111) facet are obtained with 1 wt% Ti, and the shape

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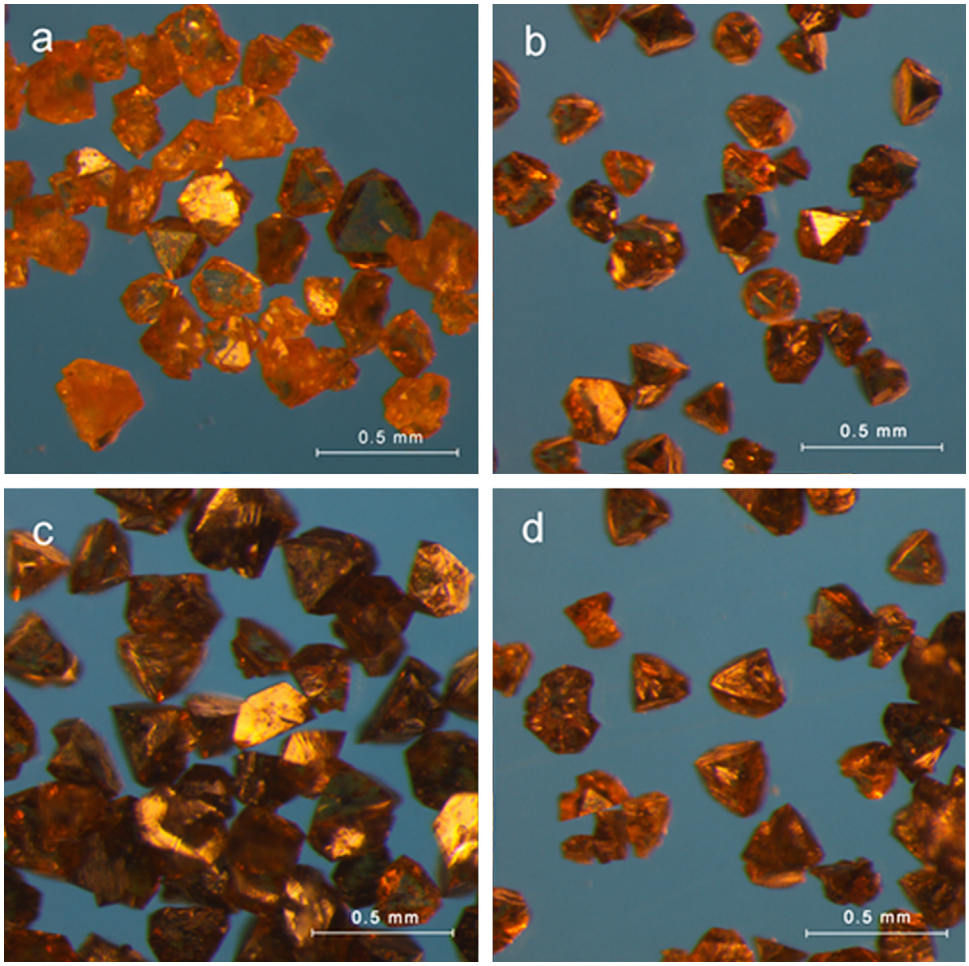

Fig. 1. The OM photographs of TiN coated cBN obtained in Li_3N–Ti–hBN system at 5.0 GPa: (a) 1 wt% Ti, 1460 °C; (b) 2 wt% Ti, 1500 °C; (c) 3 wt% Ti, 1550 °C; (d) 5 wt% Ti, 1650 °C.

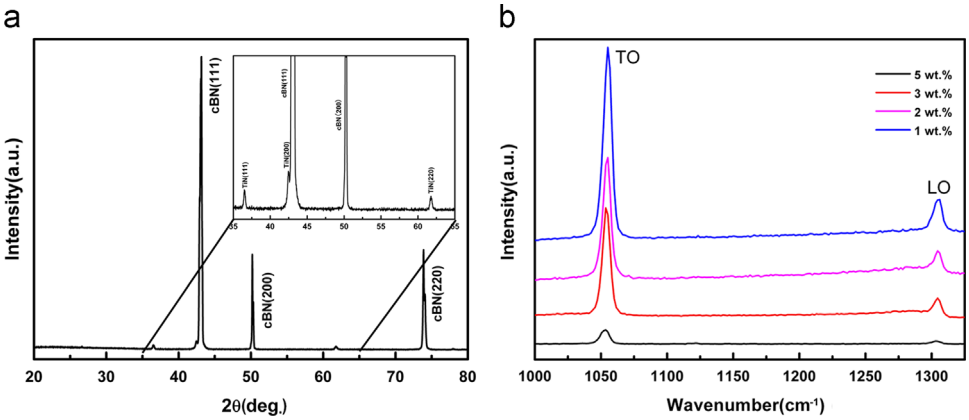

Fig. 2. The X-ray and Raman spectrum pattern of TiN coated cBN crystals: (a) The X-ray pattern of TiN coated obtained at 5.0 GPa and 1650 °C by adding 5 wt% Ti; (b) The Raman spectrum of TiN coated cBN obtained by adding 1–5 wt% Ti. (1) 1 wt%; (2) 2 wt%; (3) 3 wt%; (4) 5 wt%.

of crystals is incongruous, which are similar to what is synthesized in Li_3N–hBN system from our previous works [15]. The plate-shape crystals are decreased while octahedral opaque cBN crystals appear by increasing Ti (Fig. 1b–d). This type of crystal morphology should be formed because ⟨100⟩ facets grow faster than ⟨111⟩ facets and excess boron are appeared on ⟨111⟩ facets. The boron terminated ⟨111⟩ planes are blocked by excess boron atoms leading to a different growth that cBN prone to grow along ⟨100⟩ direction [16]. It can be noticed in Fig. 2a that the X-ray diffraction patterns of cBN crystals have no peak other than those corresponding to cBN and TiN, which indicates that pure TiN is formed during the cBN growth process. Based on those observations, Ti is added to react with cBN during the crystal growth process (Ti+(c)BN→TiN+B) which leads to the existence of the excess B atoms, and then cBN crystals display mainly the octahedral morphology. By increasing Ti, the crystal color becomes darker, and it becomes opaque when 5 wt% Ti is added (Fig. 1d), which indicated that the surface of cBN is completely covered with TiN. The TiN-coated