2830
doi:10.1017/S1431927622010662
Microsc. Microanal. 28 (Suppl 1), 2022

Growth and Characterization of Boron Nitride/Diamond Heterostructures

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Ultrawide-bandgap (UWBG) semiconductors are attracting much recent attention due to their potential applications in high-power and high-temperature devices. Boron Nitride (BN) is one such UWBG semiconductor that is becoming of particular interest. Cubic BN (c-BN) has a bandgap of 6.4 eV, a breakdown field greater than 15 MV/cm, and thermal conductivity of ~940 W/m.K [1], making it a strong candidate for high-power electronics. However, the synthesis of c-BN using epitaxial growth methods is difficult. Allotropes of BN crystallize in the sp^2-bonded hexagonal (h-BN), rhombohedral (r-BN), and turbostratic (t-BN) phases, and in the sp^3-bonded cubic (c-BN) and wurtzite phases (w-BN) [2]. h-BN is the most stable phase among these polymorphs and usually grows preferentially over c-BN, thus hindering the adoption of c-BN in emerging device technologies. In this study, transmission electron microscopy (TEM) has been used to evaluate the growth of c-BN on polycrystalline (PC) and single-crystal diamond substrates, using the technique of electron cyclotron resonance plasma-enhanced chemical vapor deposition. Samples suitable for cross-sectional TEM observation were prepared by focused-ion beam (FIB) milling using a Thermo-Fisher Helios 5UX dual-beam instrument with initial thinning at 30 keV and further thinning at 5 keV and 2 keV. A Philips-FEI CM-200 FEG TEM operated at 200 kV and an image-corrected FEI Titan 80-300 operated at 300 kV were used for imaging.

Figure 1 (a) shows a very thin, non-uniform c-BN layer grown on a single crystal (111) diamond substrate, and figure 1 (b) shows a c-BN island grown on a (100) diamond substrate. Both samples were synthesized under limited hydrogen gas flow, which yielded the desired cubic growth. However, the BN layers had highly variable thicknesses and were sometimes even discontinuous. Figure 1 (c) shows a 15-nm-thick mixed h- and t-BN layer grown on a (100) diamond substrate with an increased rate of flow of hydrogen carrier gas. The sp^2 bonding characteristics of the BN epilayer have remarkably increased. In another trial, with different precursor gas mixture ratio, high substrate temperature (750°-800° C) and different hydrogen gas flow rate, a 120-nm-thick multi-phase (t-, h- and c-) BN layer was grown on a polycrystalline diamond substrate, as visible in figure 2 (a). Figure 2 (b) shows the same region at higher magnification, revealing the presence of small (~10 to 50 nm) c-BN patches amidst h- and t-BN. Thus, the high flow rate of hydrogen gas has produced a thicker BN epilayer and promoted sp^2 bonding. Further experiments to identify optimal growth parameters to yield significantly larger fractions of the cubic phase are in progress [3].

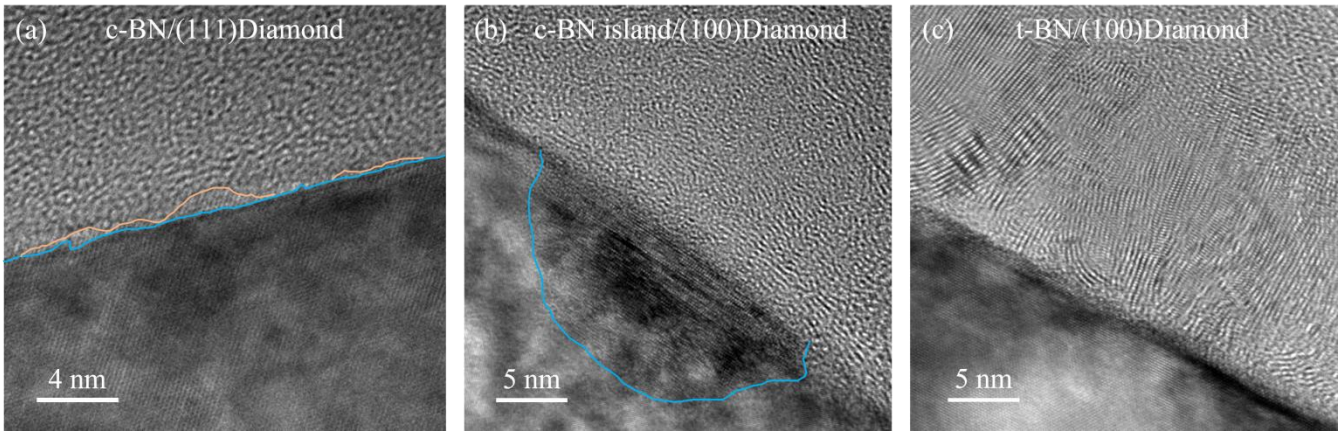

Figure 1. (a) Non-uniform c-BN grown on (111) diamond substrate; (b) c-BN island grown on (100) diamond substrate, and (c) 15-nm-thick t-BN grown on (100) diamond substrate.

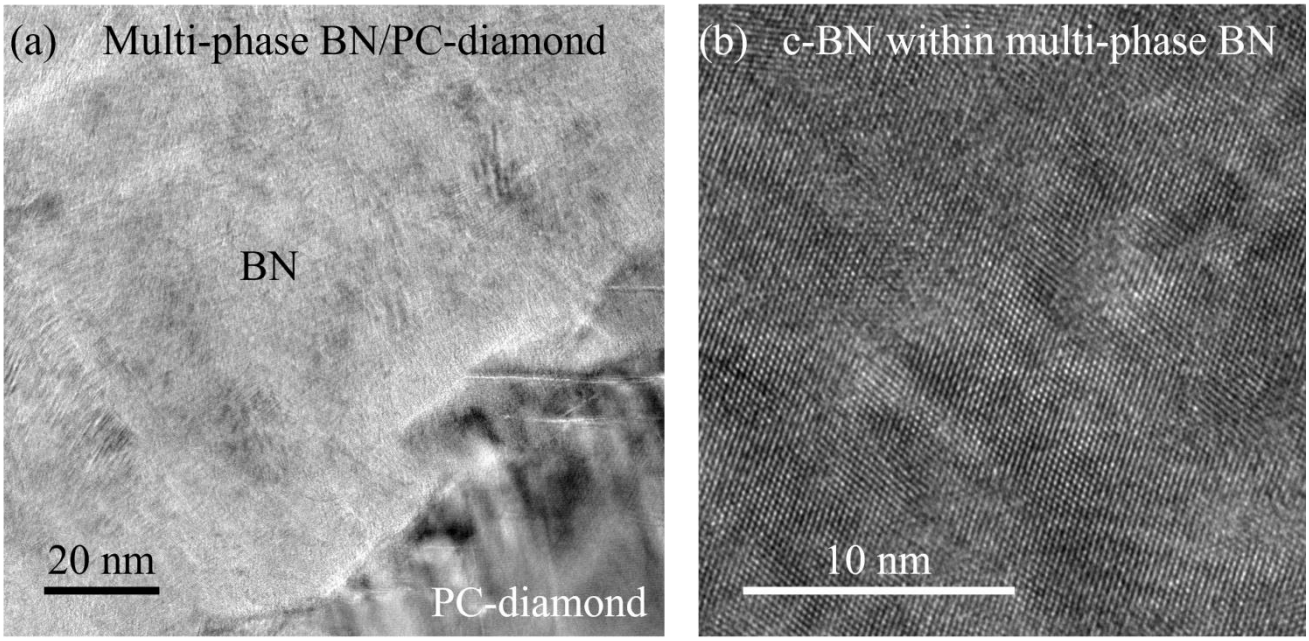

Figure 2. (a) 120-nm multi-phase (t-, h- and c-) BN grown on a polycrystalline diamond substrate, and (b) Highly magnified image showing c-BN patches within the multi-phase BN epilayer.

References:

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[3] This research is supported as part of ULTRA, an Energy Frontier Research Center funded by the U.S. Department of Energy (DOE), Office of Science, Basic Energy Sciences (BES), under Award No. DE-SC0021230. The authors acknowledge the use of facilities within the John M. Cowley Center for High Resolution Electron Microscopy at Arizona State University.

https://doi.org/10.1017/S1431927622010662 Published online by Cambridge University Press