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Room temperature synthesis of boron nitride thin films by dual-ion beam sputtering deposition

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Abstract

Boron nitride (BN) films are prepared by dual-ion beam sputtering deposition at room temperature (~25 °C). An assisting argon/nitrogen ion beam (ion energy E_i=0–300 eV) directly bombards the substrate surface to modify the properties of the BN films. The effects of assisting ion beam energy on the characteristics of BN films were investigated by Fourier transform infrared spectroscopy, X-ray photoelectron spectroscopy, Raman spectra, atomic force microscopy, and optical transmittance. The density of the B–N bond in the film increased with the increase in assisting ion beam energy. The highest transmittance of more than 95% in the visible region was obtained under the assisting ion beam energy of 300 eV. The band gap of BN films increased from 5.54 eV to 6.13 eV when the assisted ion-beam energy increased from 0 eV to 300 eV.

Keywords: C. Optical properties; Boron nitride; Ion beam deposition; Microstructure

1. Introduction

Boron nitride (BN) is a well-known wide band gap semiconductor with interesting physicochemical properties and potential applications in different fields, such as optoelectronics [1–3], high-temperature electronics [4–6], and tribomechanics [7]. Hexagonal BN (h-BN) and graphite share similar layered crystal structures. However, the electrical properties of h-BN and graphite are markedly different; h-BN is an insulator, whereas graphite is a semimetal.

The synthesis of BN in thin film form can be conducted using chemical vapor deposition methods. Subsequently, h-BN crystals with high quality were prepared by atmospheric pressure liquid phase deposition using a nickel–molybdenum solvent as the catalyst at a temperature of up to 1500 °C [8], representing an important progress in synthesizing h-BN materials. However, using these methods for device application is difficult because of the rigorous synthesizing conditions (1500–1750 °C, 4.0–5.5 GPa). Presently, the demand for lower substrate temperature (T_s) is rapidly growing in device and product manufacturing, such as polymer-based flexible devices, which generally require T_s below 400 °C [9]. Recently, BN films can be formed using several different methods at lower T_s, such as magnetron sputtering [10], electron-assisted or photon-assisted chemical reactions [11], and pulsed laser-induced liquid/solid interfacial reaction [12]. The consensus is that energetic particle bombardment during film growth is necessary to synthesize BN films at lower T_s. At this point, the dual-ion beam sputtering deposition (DIBSD) method, that is, vacuum deposition of boron combined with concurrent nitrogen ion irradiation, is effective for the formation of BN films [13]. However, the influence of assisted ion-beam energy on the chemical bonding structure, surface roughness, and optical properties of the BN films deposited by DIBSD at room temperature have not yet been investigated systematically. Thus, this study aims to analyze the influences

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of assisting ion beam energy on the chemical bonding structure, surface roughness, and optical properties of BN films at room temperature. The optimum deposition parameters for BN films with excellent optical properties were outlined.

2. Experiments

BN films were deposited on quartz substrates at room temperature using DIBSD, which consists of a focused Kaufman ion source (main ion source) and a broad Kaufman ion source (assisted ion source). The main ion source with 10 cm diameter and 45° incident angle served as a sputtering ion source. The composite target of sintered high-purity BN was used as the sputtering target. The sputtering chamber was evacuated to a pressure of 1×10^{-4} Pa before work gas was introduced through a mass flow controller. The main and assisted ion sources were operated at a process pressure of 2.5×10^{-2} Pa using pure argon and an argon/nitrogen mixture of 1:1, respectively. Before deposition, the substrates were cleaned by an argon ion beam for 15 min using the assisted ion-beam source of 10 cm diameter from an incident angle of 60°, energy of 300 eV, and current of 20 mA. During deposition, the ion-beam energy and current of the main ion-beam source sputtering the target were 800 eV and 50 mA, respectively. The beam current of the assisted ion-beam source that bombarded the substrate was 20 mA and the ion-beam energy was a variable parameter in the range of 0–300 eV. The substrate was cooled to room temperature during deposition using a cooling water system. All of the thicknesses of the films were approximately 50 nm, which were measured by using the ET350 surface profilometer (Kosaka Laboratory Ltd.).

The bonding configurations and microstructure were measured by Fourier transform infrared spectroscopy (FTIR) (Nicolet AVATAR 360), Raman spectra (JY-H800 with an argon ion laser at a wavelength of 514 nm) and ESCALAB 250Xi X-ray photoelectron spectroscopy (XPS) system equipped with a monochromatic Al Kα ($h\upsilon = 1486.6$ eV) X-ray source. Prior to XPS measurement, the film surface was etched for 60 s by Ar^+ ion beam (energy of 1 keV and beam current density of 100 μA/mm^2). The binding energy values have been calibrated by using the carbon C 1*s* peak (284.8 eV) as reference. The surface roughness was evaluated by atomic force microscopy (AFM; dimension icon). Finally, optical properties were measured by using the JASCO V-570 spectrophotometer in the wavelength range of 190–800 nm.

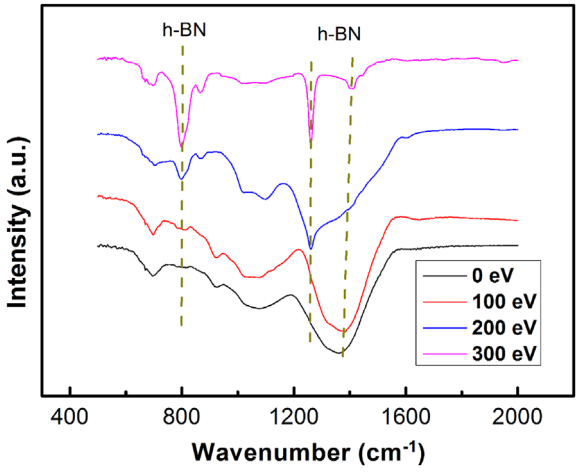

Fig. 1. FTIR spectra of (a) without assisted ion-beam bombardment, (b) with 100 eV assisted ion-beam bombardment, (c) with 200 eV assisted ion-beam bombardment, and (d) with 300 eV assisted ion-beam bombardment.

3. Results and discussion

Fig. 1 shows the FTIR absorption spectra of BN films deposited by bombardment of different assisting ion beam energies (0, 100, 200, and 300 eV). As shown in Fig. 1, five absorption peaks at

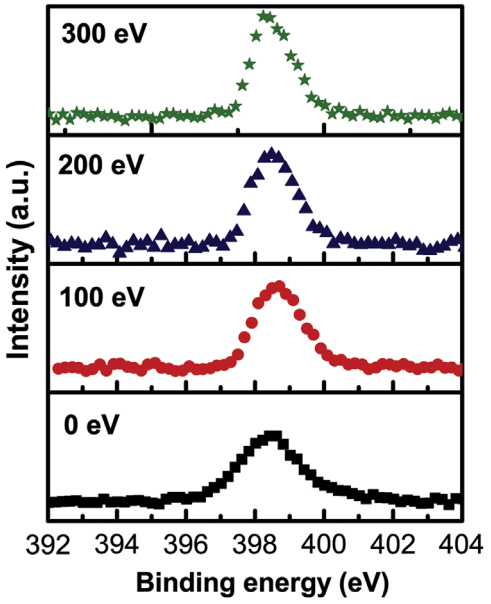

Fig. 2. The XPS spectra of N 1*s* on the surface of the BN films with different assisted ion-beam energy bombardments.

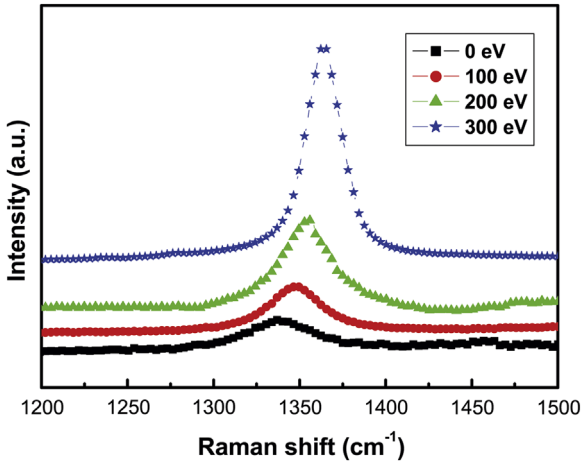

Fig. 3. Raman spectra of the BN films (a) without assisted ion-beam bombardment, (b) with 100 eV assisted ion-beam bombardment, (c) with 200 eV assisted ion-beam bombardment, and (d) with 300 eV assisted ion-beam bombardment.