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Boron Nitride Thin Films Grown on (0001) Sapphire Substrates by Molecular Beam Epitaxy

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Abstract

Boron nitride (BN) thin films were grown on (0001) sapphire substrates by plasma-assisted molecular beam epitaxy. The thickness (11 nm) of the BN was evaluated by X-ray reflectance and atomic force microscopy showed that the BN thin films had flat surfaces. Absorption spectra in the ultraviolet-visible wavelength range showed an absorption peak at 225 nm. Fourier transform infrared spectroscopy revealed that sp^2-bonded BN thin films were formed.

1. Introduction

Hexagonal boron nitride (h-BN) has a graphite-like honeycomb structure. Boron and nitrogen bond with sp^2 hybridization in plane and the planes bond with van der Waals forces to each other. We demonstrated that a h-BN layer inserted between a sapphire substrate and GaN-based device structures grown on the substrate works as a release layer that enables the mechanical transfer of the GaN-based device structure onto foreign substrates [1]. The h-BN epitaxial growth has been achieved by metalorganic vapor phase epitaxy (MOVPE) [2]. In contrast to MOVPE, molecular beam epitaxy (MBE) has several advantages, e.g., low-temperature growth, in-situ reflection high energy electron diffraction surface analysis, and precise thickness control with atomic scale. In addition, strong parasitic reactions between triethylboron and ammonia in BN epitaxial growth using MOVPE can be avoided. However, until now, very limited effort has been dedicated to MBE growth of BN [3].

The h-BN epitaxial growth on Ni (111) substrate has been achieved by MBE with a radio-frequency (RF) nitrogen plasma source and electron-beam (EB) gun for B evaporation [4]. Therefore, MBE growth using the RF nitrogen plasma source and EB gun is potential for growth of h-BN thin film on (0001) sapphire substrates. In this paper, we report on BN growth on (0001) sapphire substrates using MBE and investigate the structural and optical properties of BN thin films on sapphire substrates.

2. Experiments

BN films were grown on single-crystal double-side polished (0001) sapphire substrates by plasma-assisted MBE. Sapphire substrates were degreased and rinsed in conventional solvents, mounted onto a Mo sample holder, and introduced into the MBE system. The growth temperature of the BN thin film was 950°C, measured with a thermocouple. Reactive nitrogen was supplied by flowing high-purity N_2 gas (99.99995%) through the RF plasma source operating at 400 W with an N_2 flow rate of 0.8 sccm. High-purity B (99.9999%) was evaporated with an EB gun as the group-III source. The growth time of the BN films was 30 min.

The BN film thickness was characterized by X-ray reflectance using an X-ray diffractometer (Rigaku SmartLab) with a wavelength of 1.541 Å for a copper target. The surface morphologies of the BN films were analyzed by atomic force microscopy (AFM) using an SII NanoTechnology NanoNavi E-sweep. Optical absorption spectra were obtained using a JASCO V-650 UV/visible double-beam spectrophotometer in the wavelength range of 190-900 nm. We carried out Fourier transform infrared (FTIR) measurements using a JASCO FTIR-6100 spectrometer.

2. Results and discussions

Figure 1 shows the X-ray reflectance curve for BN thin film grown by MBE. The reflectivity clearly oscillated five times, indicating that the surface of the BN thin film was

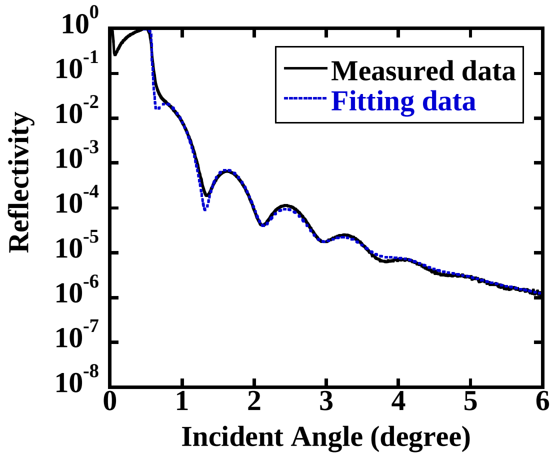

Fig. 1 X-ray reflectance curves of BN film grown by MBE. Solid and dotted curves correspond to measured X-ray reflectivity and simulated reflectivity, respectively.

relatively flat. The amplitude of the oscillation depends on the density difference between the BN thin film and sapphire substrate. Figure 1 also plots a simulated X-ray reflectance curve obtained by fitting to the measured reflectance using a layered model with BN and sapphire densities of 2.30 and 3.98 g/cm^3, respectively. The fitting curve is in good agreement with the measured one, and the thickness of the BN films was estimated to 10.6 nm. The BN density of 2.30 g/cm^3 is close to the theoretical density of h-BN films [5]. X-ray diffraction in a 2θ/ω configuration for the BN films exhibits no BN-related diffraction peak because the 11-nm-thick BN thin film does not have a sufficient signal to enable the observation of lattice diffraction.

In Fig. 2, an AFM image for the BN with 5×5 μm^2 scan area shows a root mean square (RMS) roughness value of 0.08 nm. The small RMS value of the 5×5 μm^2 scan suggests that the BN surface was smooth.

To investigate the optical properties of BN thin films, we carried out UV-Visible absorption measurements. The absorption spectrum is shown in Fig. 3. The absorption increased drastically for wavelengths shorter than 300 nm, and an absorption peak at 225 nm was clearly observed. The absorption peak has been attributed to the quasi-donor-acceptor pair transition or bound exciton transition in h-BN [6].

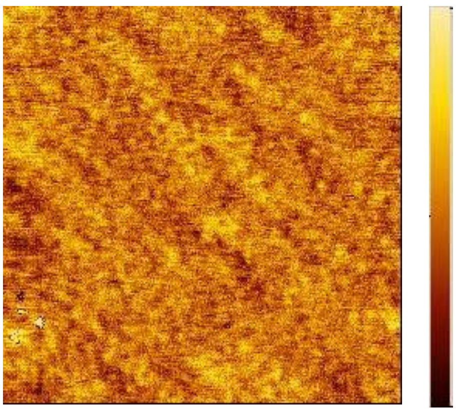

Fig. 2 AFM image showing morphology of BN film with scan area of 5×5 μm^2.

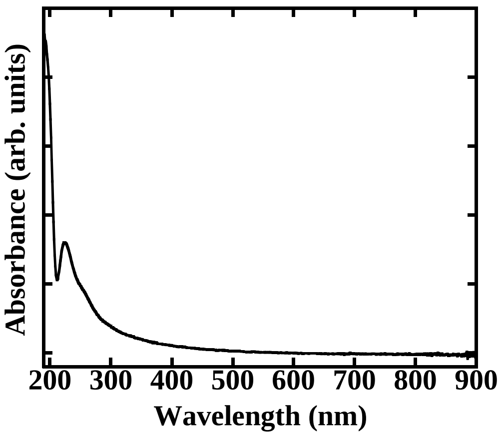

Fig. 3 Absorption spectrum of BN thin film grown on (0001) sapphire substrate by MBE.

Figure 4 shows the FTIR spectrum of BN thin film grown on (0001) sapphire substrate by MBE. The BN thin film had two absorptions at 1375 and 1330 cm^{-1}. The absorption peak at 1375 cm^{-1} is ascribed to the in-plane stretching of sp^2-bonded B-N bonds [7]. An absorption peak at 800 cm^{-1}, which is ascribed to out-of-plane bending of sp^2-bonded B-N-B bonds, was not observed due to strong absorption of the sapphire substrate. The absorption peak at 1330 cm^{-1} may be related to B-N bonds, such as disordered ones. The FTIR spectrum indicates that sp^2-bonded BN thin films can be grown on the sapphire substrates by MBE.

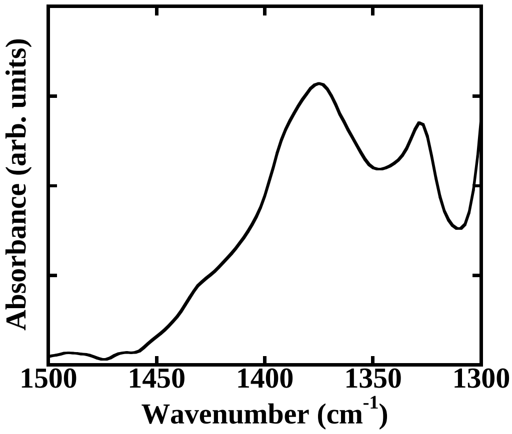

Fig. 4 FTIR spectrum of BN thin film grown on (0001) sapphire substrate by MBE.

3. Conclusions

We grew BN thin films on (0001) sapphire substrates using plasma-assisted MBE. X-ray reflectance and AFM image indicate that the 11-nm-thick BN thin film has a smooth surface. The FTIR spectrum suggests that sp^2-bonded BN thin films can be grown on sapphire substrates by MBE.

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