Thin Solid Films 517 (2009) 4753–4757

Contents lists available at ScienceDirect

Thin Solid Films

journal homepage: www.elsevier.com/locate/tsf

Characterization of reactively sputtered *c*-axis orientation (Al, B)N films on diamond

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ARTICLE INFO

Available online 24 March 2009

Keywords:
Aluminum nitride
Boron nitride
Diamond

ABSTRACT

In this research, we demonstrated the viability of oriented AlN layer that incorporated BN to enhance the texturing. Wurtzite (Al, B)N films were deposited on a diamond wafer (diamond film on Si wafer) by a co-sputtering technique. The preferred orientation structure is sensitive to sputtering control factors. The relationship between the microstructures and process conditions were examined with XRD, TEM and AFM analysis. The cross-section TEM images showed that amorphous and randomly aligned structures were produced in the initial sputtering period, but the higher *c*-axis orientation structure formed as the sputtering time increased. The thickness of the amorphous and randomly aligned layer decreased with increasing sputtering power, nitrogen concentration, substrate temperature and bias voltage. As the thickness of the amorphous and the randomly aligned layer decreased, an (Al,B)N film with higher film quality than AlN was observed.

1. Introduction

As the power of LED has increased (e.g. >5 W), the thermal degradation of their light intensity and the service life has become worse. Although various heat spreading techniques have been deployed to reduce the die temperature, the effect is limited due to the presence of a thermally insulating ceramic (e.g. AlN) between the LED crystal and packaging material (e.g. PCB). The AlN-on-Diamond architecture is ideal for growing GaN by MOCVD for the manufacture of LED with very high power (e.g. 30 W) [1,2]. Aluminum nitride has excellent thermal conductivity (3.2 W/mK), chemical stability, high hardness, high acoustic velocity, and a wide band gap (6.2 eV) [3–5]. Because of the lower mismatch with GaN layers, *c*-axis AlN is the common buffer layer for GaN LED with sapphire as the major substrate [6]. AlN is relatively easy to form on diamond, e.g. by sputtering. Recent research in to sputtered AlN films mainly focuses on precise control of the (002) *c*-axis textures which are perpendicular to the substrate by altering process parameters such as temperature, N_2 gas ratio and depositing power [7–10]. The crystal quality of the AlN buffer is exceedingly important to the growth of GaN. However, the large difference in interatomic distance between AlN (1.97 Å) and diamond (1.54 Å) will cause defects (dislocations) and a decrease in the of *c*-axis preferential orientation of the AlN layers [11].

Boron doped AlN has a higher thermal conductivity and higher breakdown field than any oxide piezoelectric material [12]. The boron doping can shrink the AlN lattice to make it closer to diamond, and boron doped AlN can be sputtered conveniently onto the surface of a polished diamond film [13–15]. Wurtzite BN and wurtzite AlN are isostructural solid solutions, and by replacing Al for B atoms in the same crystal structure, the lattice of AlN is tightened so that its lattice matching with diamond improves [7]. However, in our previous work [15], the full width at half maximum (FWHM) of the rocking curve of (Al, B)N films was larger than that for AlN, which confound expectation. According to

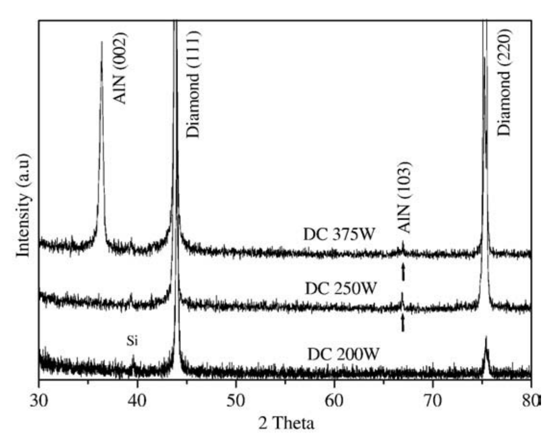

Fig. 1. The θ–2θ X-ray diffraction patterns of the (Al, B)N films on the polycrystalline diamond under various DC powers at 200 W, 250 W and 375 W, respectively.

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doi:10.1016/j.tsf.2009.03.125

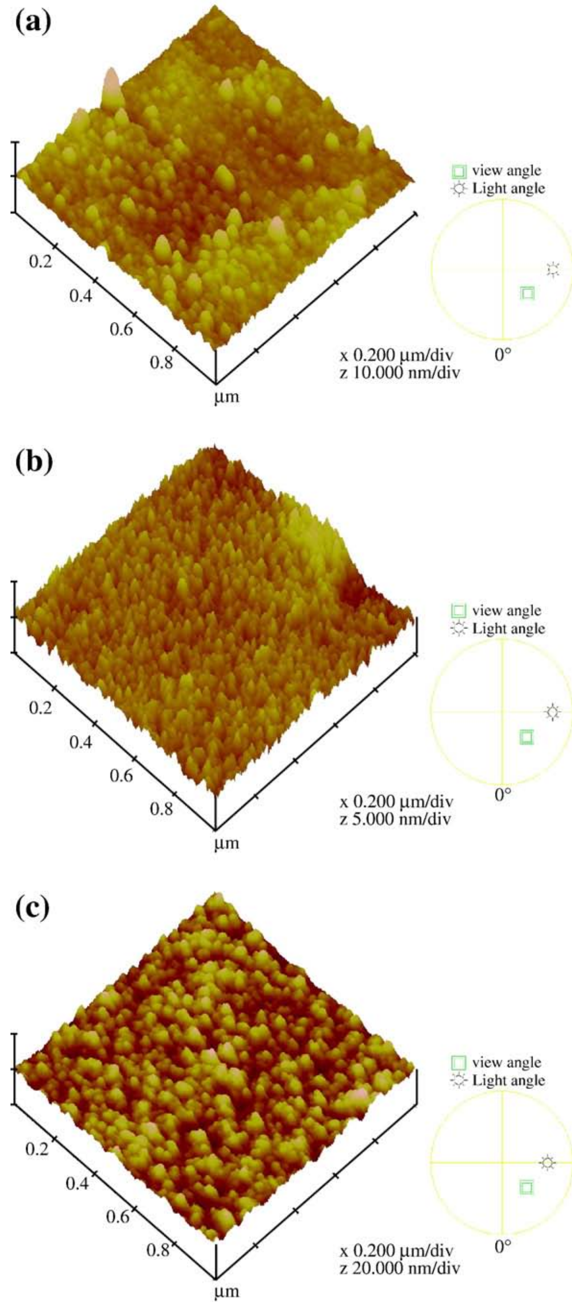

Fig. 2. The AFM images of (Al, B)N films on polycrystalline diamond under various DC powers at (a) 200 W, (b) 250 W, and (c) 375 W. The surface roughness (Ra) of these films was 0.706 nm, 0.468 nm and 1.135 nm, respectively.

Hwang's [16] report, the sputtered AlN growth mechanism appeared to consist of four distinct layers when examined by cross-section TEM. An amorphous and randomly aligned layer was observed at the beginning of the depositing process, and then the crystalline grains started to form and become better aligned. As the amorphous and the randomly aligned layer occurred in the (Al, B)N film, the shrinking of AlN lattice was minor in the case of (Al, B)N films on diamond. Consequently, decreasing thickness of the amorphous and the randomly aligned layer is necessary for (Al, B)N film with good crystallinity, and the film structure was sensitive to sputtering control factors such as sputtering power, substrate temperature, nitrogen concentration and bias voltage. The relationships among the microstructures and these process parameters are investigated by cross-section TEM, XRD and AFM analysis. In addition, the effects of the amorphous and the randomly aligned layer on the film are also examined.

2. Experiment

Polished hot filament CVD diamond on Si wafer was used as the substrate, and the surface roughness was 0.228 nm. The (Al, B)N films were deposited on this substrate by magnetron co-sputtering system with 36 rpm rotation. One target was pure aluminum (99.999%, 7.62 cm in diameter) in DC mode and the other was pure hBN (99.9%, 7.62 cm in diameter) in RF mode. The target–substrate distance was 5 cm. The base chamber pressure was evacuated to less than 5.3×10^{-4} Pa by cryo-pump. The (Al, B)N films were deposited using Ar and N_2 mixture gases under fixed working pressure (4×10^{-1} Pa). The DC power was changed from 200 to 375 W (power density 4.4–8.2 W/cm^2), while all the other

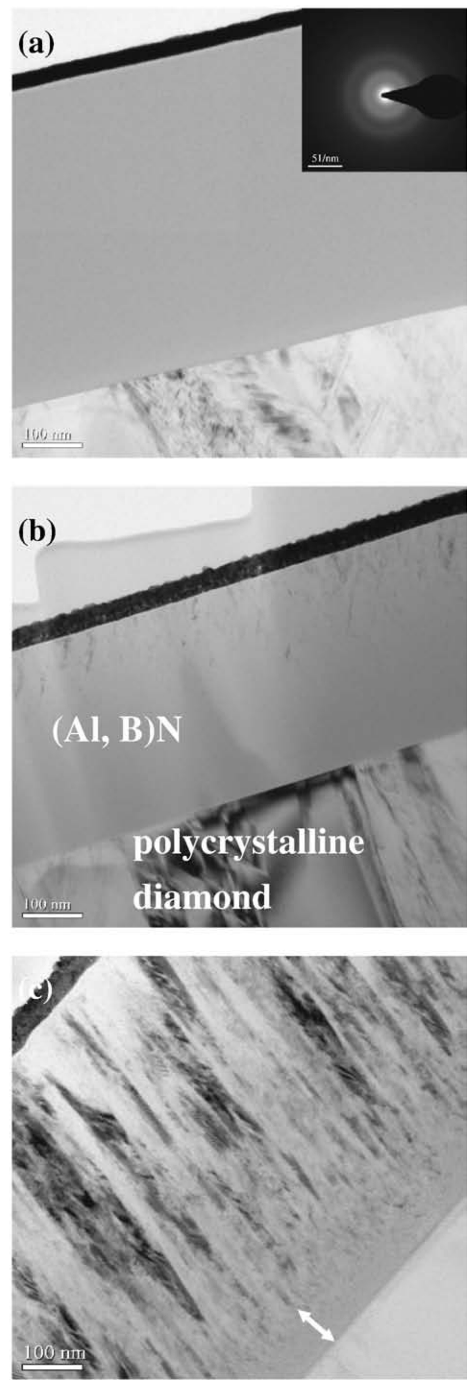

Fig. 3. The (Al, B)N films on polycrystalline diamond cross-section TEM images under various DC powers at (a) 200 W (including the SADP of (Al, B)N films), (b) 250 W, and (c) 375 W.