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Growth of AlN Films by Chemical Vapor Deposition

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AlN films were prepared by CVD using aluminum alkyl ($(CH_3)_3Al$) precursor in an horizontal hot-wall type reactor. AlN films of different crystalline quality were obtained at T_{dep}=973-1023 K and P_{tot}=1.99 kPa. 2 μm thick AlN films can be grown highly oriented on amorphous quartz substrates. Thicker AlN films exhibit a polycrystalline nature. The 0.1-0.2 μm thick AlN films were transparent and their refractive indexes were about 1.5-1.9.

1. Introduction

Aluminum nitride (AlN) has received much attention in recent years because of its attractive properties such as chemical stability, high thermal conductivity, electrical isolation, a wide band gap (6.2 eV), and higher acoustic velocity [1-7]. Therefore, AlN films have great potential for microelectronic and optoelectronic devices.

AlN films have been applied not only to surface passivation of semiconductors and insulators, but also to optical devices in the ultraviolet spectral region, acoustic-optic devices and surface acoustic wave devices [8-15]. Various methods have been reported for the growth of AlN films.

They include reactive evaporation, reactive sputtering, atomic layer epitaxy, molecular beam epitaxy, and chemical vapor deposition (CVD) [5-9]. The CVD method has been widely used for the synthesis of group III-V compounds owing to its excellent versatility and suitability for mass production.

CVD growth of group III-nitride films has been achieved at high temperatures, typically above 973 K, which has usually been attributed to the thermal stability of NH_3 or to a formation of relatively stable adducts, e.g. $AlCl_3$-NH_3 [5]. Nitride films can be grown at lower temperatures using metal-organic precursors.

However, these films may contain carbon from the decomposition of the organic radical during pyrolysis. In general, it has been difficult to grow high-quality films, especially with smooth surfaces as desired for electronic applications.

In this work, highly oriented AlN films with smooth surfaces and low carbon content have been prepared on amorphous quartz substrates by CVD using aluminum alkyl ($(CH_3)_3Al$) precursor.

2. Experimental details

The AlN films were prepared in a horizontal hot-wall CVD type reactor, which is depicted in Fig. 1. The CVD apparatus consists of: (1) electrical furnace, (2) quartz tube reactor ［5 cm in diameter and 120 cm in length］, (3) substrate holder (4) precursor, (5) pressure sensor, (6) substrate, (7) thermocouple and (8) vacuum pump.The films were prepared on amorphous quartz substrates. The liquid aluminum precursor, $(CH_3)_3Al$, was diluted and carried by N_2 gas. It was kept at 294-296 K. $(CH_3)_3Al$ and NH_3 were mixed just before being added to the reactor. The films were prepared under N_2 and H_2 atmospheres. The total pressure (P_{tot}) was controlled from 0.066 to 11.33 kPa and the deposition temperature (T_{dep}) was explored from 973 to 1173 K.

The morphology and crystal structure of the films were investigated by scanning electron microscopy (SEM) and x-ray diffraction (XRD) using Cu-Kα radiation. The film refractive index was estimated by ellipsometry. The film electrical resistivity was measured by the Van der Pauw method.

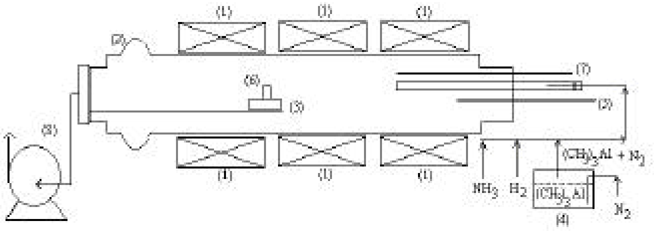

Fig. 1. Schematic diagram of the horizontal hot-wall CVD apparatus.

3. Results and discussion

Figures 2(a) to 2(c) show the effect of thickness of AlN films prepared at T_{dep}=973-1023 K and P_{tot}=1.99 kPa under H_2 atmosphere on the XRD patterns. No films were obtained at any other set of deposition conditions. The XRD pattern of a relative thin film (~1 μm thick) in Fig. 2(a) shows poorly resolved AlN reflections suggesting low crystallinity. In contrast, in the Fig. 2(b) only one AlN (100) reflection is observed.

This indicates that highly oriented AlN films were obtained with the AlN ［210］ direction normal to the surface of the films. AlN films with preferred ［001］ orientation on amorphous quartz substrate have been previously prepared from $AlCl_3$ precursor [3]. The XRD pattern of a thicker AlN film shown in Fig 2(c) exhibits well-defined reflections indicating the polycrystalline nature of the films.

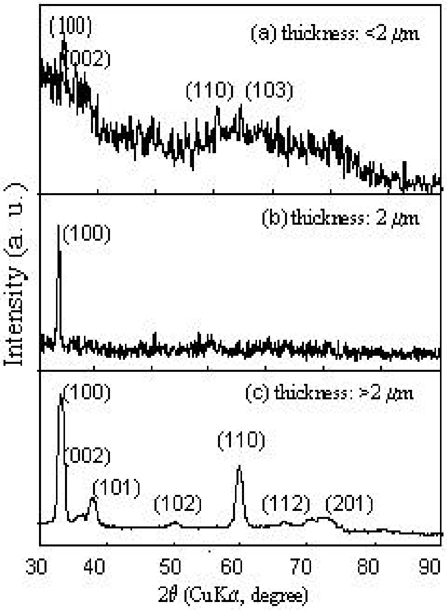

Fig.2 Effect of thinckness of AIN films on the XRD patterns

The variation of crystallinity with thickness may be related to the film growth process in which a particular orientation is usually maintained up to a certain thickness beyond which deposition leads nucleation of new grains and eventually random orientation [17].

Figures 3(a) to 3(b) depict the SEM images of the surface morphology of AlN films grown at different temperatures and P_{tot}=1.99 kPa. The image of Fig. 3(a) shows an irregular morphology of an AlN film grown at T_{dep}=873 K However, as the deposition temperature increases the surface morphology becomes smooth. Figures 3(b) and 3(c) reveal the surface morphology of AlN films grown at T_{dep}=893 K and T_{dep}=1023 K, respectively.

In particular, the SEM image of Fig. 3(c) suggests well-ordered growth features.Figure 4 shows a typical Auger spectra for AlN films prepared at T_{dep}=1023 K.

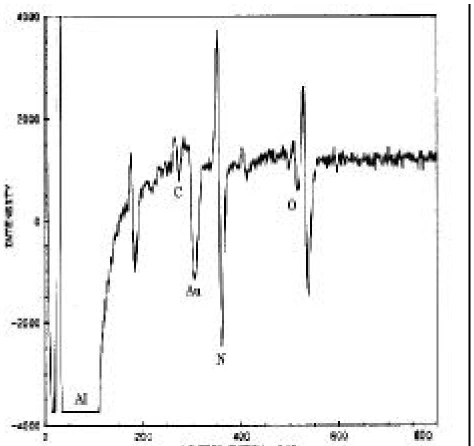

Fig. 4 Auger spectra for AlN films prepared at T_{dep}=1023 K.

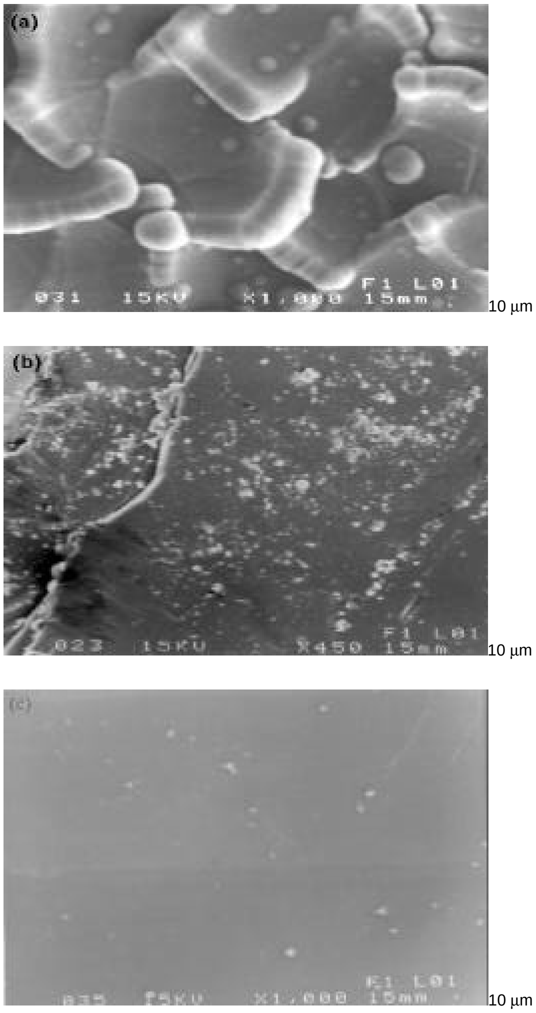

Fig. 3. SEM images of the surface morphology of AlN films grown at different temperatures and P_{tot}=1.99 kPa

Table 1. Refractive index and thickness of AlN films

Deposition temperature (K)	Thickness (nm)	Refractive index
813	101.1	1.543
903	133.3	1.694
923	119.7	1.592
973	93.2	1.62
1023	60.1	1.99

Table 1 summarizes refractive index and thickness of AlN films for various deposition temperatures.

The small signals of carbon and oxygen in the spectra indicate contamination of the film from the decomposition of the metal-organic precursor. In spite of these features, 0.1-0.2 μm thick AlN films were transparent and their refractive indexes at λ= 632.8 nm were about 1.5-1.9. In general, AlN films have shown refractive indexes ranging from 1.99 to 2.25 [3].

4. Conclusions

AlN films were prepared by CVD using $(CH_3)_3Al$ precursor. AlN films of different crystalline quality were obtained at T_{dep}=973-1023 K, P_{tot}=1.99 kPa. Highly oriented (100) AlN films with smooth surfaces can be grown on amorphous quartz substrates.

Acknowledgments

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