



Effect of dual buffer layer structure on the epitaxial growth of AlN on sapphire

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ABSTRACT

A dual AlN buffer layer structure, including an isolated layer and a nucleation layer, is proposed to improve the growth of AlN films on sapphire substrate by metal organic chemical vapor deposition. This method is aimed to weaken the negative nitridation effect and improve lateral growth condition in the initial growth stage. It is found that suitably increasing the thickness of the nucleation layer is in favor of a better structural quality of the AlN film. An examination of surface morphology by atomic force microscopy suggests that the thicker the dual AlN buffer layer, the rougher the surface, and a higher quality of AlN epilayer is resulted.

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1. Introduction

Group-III nitrides have been investigated for many years due to their extensive applications in optoelectronics and microelectronics. For example, AlGaIn solar-blind ultraviolet photodetectors are able to be used in missile detection, secure space-to-space communication, flame monitoring and so on. Great successes have been achieved in the fabrication of AlGaIn solar-blind ultraviolet photodetectors, including the realization of focal plane arrays and avalanche photodiodes [1–4]. The quality of AlN films plays an important role in determining the performance of back-illuminated AlGaIn ultraviolet photodetectors. However, it is very difficult to grow high quality AlN layers, mainly because the surface mobility of Al atoms is very low. Heteroepitaxial AlN films often exhibit poor crystalline quality or poor surface morphology due to the limited lateral growth. Usually, a special metalorganic chemical vapor deposition (MOCVD) system with an extremely high growth temperature around 1400 °C or with a migration-enhanced growth mode can be employed to promote two-dimensional (2D) grow mode and obtain high quality AlN films [5–7]. On the other hand, the two-step growth method had been widely used to grow nitride materials since it was developed for the growth of GaN epilayer on sapphire substrate by MOCVD [8,9]. The buffer layer is critical in the growth of nitride materials to overcome the problems caused by the large lattice and thermal mismatches with sapphire substrate, and the density of threading dislocations is largely reduced. In fact, both low- and high-temperature AlN buffer layers

have been employed to AlN epitaxial growth [10–12], and the initial process is very important for the growth of high quality AlN epilayers [12,13]. It is known that the nitridation of sapphire substrate is a negative factor which hinders the high quality growth of AlN films since the Al and N faces have different polarities and different growth rates, leading to the formation of inversion domains and a rough surface morphology [13,14]. Therefore, suppressing the nitridation effect of sapphire substrate should also be useful to improve the quality of AlN [15]. In this paper, the dual AlN buffer layer, instead of commonly used single AlN buffer layer (or nucleation layer), is employed during the AlN growth by MOCVD, which is significantly helpful to grow high quality AlN epilayers even when a commercially-available conventional MOCVD system is used. The quality of AlN films could be improved further if the thickness of dual AlN buffer layer is made suitably larger. The additional *in situ* optical reflectance and AFM measurements of such a dual AlN buffer layer show that its surface roughness increases with increasing thickness, and the followed lateral growth of AlN epilayers is thus enhanced.

2. Experimental procedure

All the AlN samples studied in this work are grown on c-plane sapphire substrate by MOCVD. The trimethylaluminum (TMAI) and ammonia (NH₃) are used as Al and N sources, respectively. The H₂ are used as carrier gas. Two kinds of AlN samples are grown by MOCVD in this work, one kind is with dual AlN buffer layer, the other is with single AlN buffer layer, as schematically shown in Fig. 1(a and b), respectively. For the growth of dual AlN buffer layer, a lower growth temperature T_g of 900 °C are used for its first sublayer, while a higher T_g of 1080 °C are used for its second sublayer. For the AlN samples with single AlN buffer layer whose growth condition is the same as that of the above-mentioned second AlN sublayer of the dual buffer layer, i.e., the growth temperature is 1080 °C. The growth

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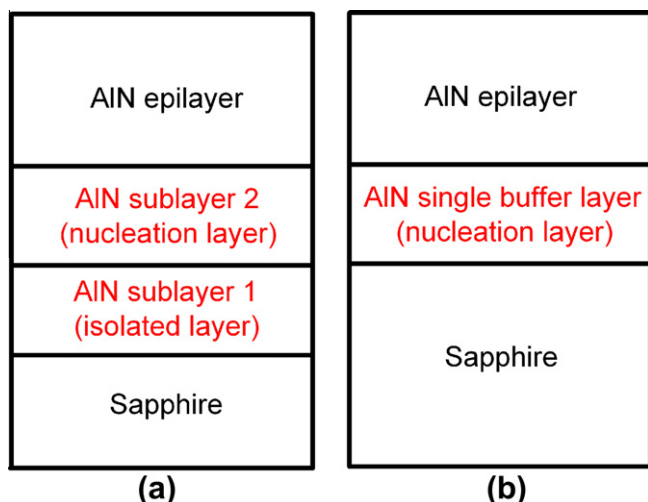


Fig. 1. The schematic diagrams of AlN sample structures: (a) with dual AlN buffer layer, (b) with single AlN buffer layer.

procedure of studied AlN samples is as follows, firstly a dual or single AlN buffer layer is deposited on the sapphire substrate, then the AlN epilayer is grown on the buffer layer at 1100 °C. All growth processes are monitored by the *in situ* optical reflectance, which is used as a powerful tool to study the GaN growth mechanism by MOCVD [16–18]. The quality of AlN films is characterized by the full-width-at-half-maximum (FWHM) of double crystal X-ray ω -scan rocking curves (XRC), *ex situ* performed on a Rigaku SLX-1AL X-ray diffractometer. The surface morphology is examined by the atomic force microscopy (AFM) at room temperature.

3. Results and discussion

Fig. 2(a) shows the *in situ* measured trace of optical reflectance from the surface of sample A which is grown with the dual AlN buffer layer structure by MOCVD. As shown in Fig. 2(a), the trace is divided into three parts as follows, corresponding to the three growth stages of AlN film deposited on the dual AlN buffer layer [16–18]: (I) the growth of AlN “isolated” layer (AlN sublayer 1) at 900 °C which is employed to separate sapphire substrate from nucleation layer and suppress the nitridation effect. The thickness of sublayer 1 is about 75 nm, the corresponding growth rate is about 0.04 nm/s; (II) the growth of AlN “nucleation” layer (AlN sublayer 2) at 1080 °C. The thickness of sublayer 2 is about 375 nm, the corresponding growth rate is about 0.32 nm/s; (III) the growth of thick AlN epilayer at 1100 °C, the corresponding growth rate is about 0.2 nm/s. In order to suppress the nitridation, the conditions of growth temperature, growth rate, and reactor pressure during the growth of isolated AlN layer are carefully adjusted. In Fig. 2(a) the trace in stages I and II corresponds to the grow process of dual AlN buffer layer. During the growth stage III, the reflectance increases gradually, and the growth rate is intentionally reduced to allow a better surface migration of Al atoms. It is noted that during the growth of AlN nucleation layer (in stage II), the intensity of *in situ* optical reflectance decreases gradually, i.e., the surface roughness of material increases. A rough AlN layer may contain a lot of islands which may provide nucleation centers. However, afterwards in stage III the surface of the AlN epilayer gradually turns to be optically smoother, which means that the lateral growth and coalescence of AlN islands emerge. Finally, the quasi 2D growth of the AlN layer occurs. An oscillation of the reflectivity intensity with large and equal amplitude is well observed. In fact, the practical conditions used for the AlN buffer layer growth are very different from those used for the GaN buffer layer growth. For example, the growth temperature of AlN buffer layer must be much higher (up to 900 and 1080 °C as in our case), otherwise the crystalline quality will be very poor

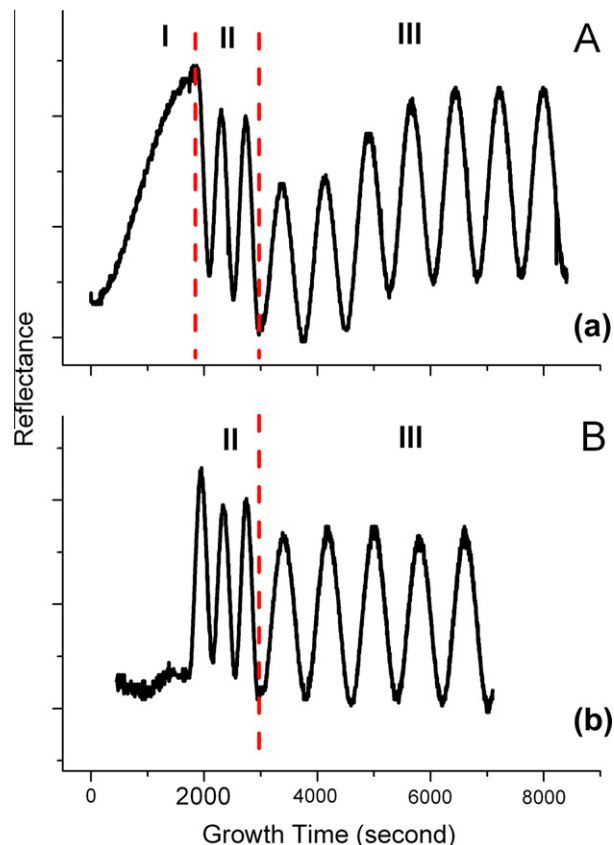


Fig. 2. The three stages of *in situ* optical reflectance traces in the whole growth process of AlN: (a) sample A grown with dual AlN buffer layer including an isolated layer and a nucleation layer. (b) sample B grown with single AlN buffer layer (an AlN nucleation layer).

due to the limited lateral migration of Al atoms, and it will be difficult to form necessary islands and develop enough amount of nucleation centers for further epitaxial growth. However, there is still a basic rule valid for both AlN and GaN growth by MOCVD, i.e., it is very important to better control the processes of nucleation and transition from three-dimensional (3D) to quasi-2D growth mode, as what has been widely reported for the initial growth stage of GaN [16–18]. As a comparison, we have also investigated the growth process of AlN film sample B which employs a single AlN buffer layer (the structure is shown in Fig. 1(b)). As shown by the optical reflectance trace of sample B in Fig. 2(b), in the beginning stage of the growth process, i.e., the temperature ramping process, the reflectance intensity is very low, indicating that the stage of “isolated” AlN layer grown at 900 °C is omitted for this sample, only the growth of the single AlN buffer layer (also named as AlN nucleation layer) is remained and is marked as growth stages II in Fig. 2(b). There is actually a great difference between the *in situ* optical reflectance traces of samples A and B. The average intensity of optical reflectance of sample B in stages II and III almost keeps constant, i.e., there is nearly no any obvious growth mode transformation from 3D to quasi 2D. However, for sample A with the dual AlN buffer layer, there is an extended transformation process from 3D to quasi 2D growth mode, which is very beneficial to the improvement of structural quality of epilayers. The structural quality of AlN samples A and B is checked by the ω -scan XRC. As shown in Table 1, the (002) and (102) plane FWHMs of XRC of sample A are narrow, i.e., 472 and 796 arcsec, respectively, while they are much broader for sample B, i.e., 810 and 966 arcsec, respectively. It is known that the screw and edge dislocation densities could be indirectly represented by the (002)

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