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A comparative study of the structural and electrical properties of n-type InGaN epilayer grown by MBE and commercially

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ABSTRACT

This work reports the growth of n-$In_{0.27}Ga_{0.73}N$/GaN/AlN epitaxial layer on Si(111) substrate by using plasma-assisted molecular beam epitaxy (MBE) and commercially obtained n-$In_{0.08}Ga_{0.92}N$/AlN. As-grown and commercial thin films were characterized by using field emission scanning electron microscopy, atomic force microscopy, and high-resolution X-ray diffraction. A high work function metal (Pt) was deposited as metal contact on the thin films, and the electrical characteristics of the films pre- and post-annealed at 500 °C were studied under 3 V. Results show that the electrical characteristics of post-annealed thin films are better than those of pre-annealed thin films.

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1. Introduction

Ternary alloy systems, particularly InGaN, have attracted much interest because of the ability to tune their direct band gap from infrared to ultraviolet (0.7–3.4 eV) [1] by controlling their In/Ga ratio. This property of InGaN makes it one of the most promising materials for various future optoelectronics and energy applications [2]. However, group-III elements undergo phase separation when growing

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high-quality InGaN with intermediate composition [3,4]. Phase separation is caused by the dissociation of InN at high temperature and by the low miscibility of InN in GaN. Low-temperature InGaN growth is needed to prevent InN dissociation. Nevertheless, high-temperature InGaN growth is still necessary for high films [5]. Molecular beam epitaxy is an ideal technique of growing GaN-based optoelectronic devices [6], which are relatively lagging because of the unavailability of suitable sources of active nitrogen species. The large difference of the interatomic spacing of InN and GaN, which results in solid phase miscibility gap, is another challenge to consider [7]. This problem can be solved by using a low-temperature AlN buffer layer or interlayer [8,9]. The structural properties of the InGaN epilayers play an important role in determining the performance of light-emitting devices [10]. The structural properties of InGaN are affected by the formation of stress-induced defects in the InGaN active layer, which are commonly ascribed to the lattice and thermal expansion coefficients mismatch between InGaN and GaN epilayers [11]. Crystalline microstructure quality is closely related to growth parameters, thereby significantly influencing film quality. Currently, most studies focus on the optical and structural characteristics of InGaN. The electrical properties of this material are less investigated because of the low carrier mobility of InGaN and because of the presence of large amount of surface defects in InGaN layers. Jang et al. [12] studied the electrical characteristics of Pt/InGaN Schottky contacts by *I–V* measurements. They found that there is a difference in the SBHs obtained by the TE and TFE modes. Cheng et al. [13] used Ni/Ir/Au multilayer as a contact on AlInGaN to fabricate MIS ultraviolet detector. They reported that the dark current of photodetector reduced and enhance the device performance after inserting (Ir) metal. Lin et al. [14] fabricated Ni/InGaN Schottky barrier solar cell with different indium contents. They found that the high crystal quality is an important factor to obtain high-performance InGaN-based Schottky barrier solar cells. Recently, Padma et al. [2] studied the effect of annealing temperature of the Ir/Ru Schottky contact on n-type InGaN by *I–V* and C–V measurements. They reported that 300 °C was the optimum annealing temperature for Ir/Ru Schottky contact on n-InGaN. A good Schottky contact induces large barrier height, which can lead to better device characteristics, such as small leakage current and high breakdown voltage [2]. Therefore, this work aims to fabricate and characterize the Pt contact on n-type InGaN.

2. Experimental details

The samples used in this study can be divided into two kinds; the first is that InGaN(110 nm) epitaxy layers were grown on Si(1 1 1) substrate using plasma-assisted molecular beam epitaxy (PA-MBE) system (Veeco Gen II) with GaN(125 nm) and AlN(85 nm) as buffer layers. High purity sources, such as gallium (7 N), aluminum (6N5), and indium (7 N), were installed at the Knudsen cells. Reactive nitrogen species were generated by channeling high purity nitrogen to the radio frequency (RF) source. The resultant nitrogen plasma was formed at nitrogen pressure of 1.5×10^{-5} Torr under 300 W rated discharge power. Before loading the substrate to the PA-MBE system, the Si(1 1 1) wafer (3 in) was cleaned by using the Radio Corporation of America method. After loading the substrate into the PA-MBE system, the substrate was outgassed in the load-lock and buffer chamber systems and was then transferred to the growth chamber. Surface treatment was conducted on the substrate to ensure that SiO_2 is removed and that only the clean Si substrate remains. Surface treatment was performed by depositing a few monolayer of Ga on the substrate at 750 °C, which resulted in the formation of Ga_2O_3. The clean Si surface was further confirmed by the presence of prominent Kikuchi lines shown by reflection high-energy diffraction (RHEED). Prior to the growth of nitride layers, few monolayers of Al were deposited on the Si surface to inhibit Si_xN_y formation, which is detrimental to the growth of the subsequent epitaxy layers. The AlN buffer layer was deposited by setting Al and N shutters to open simultaneously for 15 min. Afterward, the GaN layer was deposited on the buffer layer with a substrate temperature of 800 °C for 25 min. Finally, the substrate temperature was reduced to 700 °C, and the In and Ga effusion cells were, respectively, heated to 930 °C and 935 °C to initiate InGaN growth for 30 min.

The second kind is commercial $In_{0.08}Ga_{0.92}N$(1000 nm) grown on low resistivity p-type Si(1 1 1) substrate using plasma-assisted molecular beam epitaxy (PA-MBE) technique with 100 nm AlN as a buffer layer.

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