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Letter

Low-temperature growth of high c-orientated crystalline GaN films on amorphous Ni/glass substrates with ECR-PEMOCVD

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ABSTRACT

A low temperature growth method based on electron cyclotron resonance plasma-enhanced metal organic chemical vapor deposition system (ECR-PEMOCVD) was proposed for the growth of GaN films on ordinary soda-lime glass substrates with Ni as intermediate layer. With this method, high c-orientated crystalline GaN films with atomically smooth surface were achieved on amorphous Ni/glass substrate at an extremely low temperature of ~480 °C. This GaN/Ni/glass structures have great potential for dramatically improve the scalability and cost of solid-state lighting, since the adverse effects with high temperature process for glass substrates can be effectively suppressed by this technique.

1. Introduction

By virtue of its wide band gap (3.39 eV) and some other excellent properties, gallium nitride (GaN) is probably the most important semiconductor since silicon [1,2]. Especially, conventional light sources are currently being replaced by GaN-based solid-state lighting due to its advantages of higher reliability, longer lifetime and lower power consumption [3–5]. At present, GaN are deposited mainly by high temperature metal organic chemical vapor deposition (MOCVD), mostly on a single-crystal sapphire or silicon carbon substrate, to ensure high crystal quality [5–8]. Although the defect density is still very high due to the remaining lattice mismatch between GaN and the substrates, fortunately, GaN-based solid-state devices exhibit a peculiar capacity to emit light efficiently in the presence of high defect density- an ability that has been ascribed to carrier localization occurring in InGaN quantum wells [9]. Given the present performance of GaN-based solid-state LEDs have surpassed other popular light sources in terms of efficiency and lifetime, it may seem strange that these devices have not been widely adopted for general illumination. This is due to several reasons, the most significant being the high cost of manufacturing. Significant research effort around the globe is now being devoted to reducing production costs while maintaining the brightness and efficiency of these devices. Since the first demonstration of GaN-based LEDs on fused-silica glass substrates by high temperature MOCVD in 2011, the development of GaN-based material on glass substrates have been regarded as perfect solution for significant cost reductions of GaN-based solid-state [10]. However, the high deposition temperature that is necessary for decomposition of ammonia may cause adverse effects for ordinary soda-lime glass substrates and thus severely degrade the performance of devices on glass. There has been little research on preparing GaN films on ordinary soda-lime glass substrate by low temperature electron cyclotron resonance plasma enhanced MOCVD (ECR-PEMOCVD) with N_2 as N precursor due to its relatively chemical inertness. In our previous studies, ECR has been successfully proved to be a feasible method to remarkably activate reactive energy of N_2 and hence GaN film can be grown by ECR-MOCVD at an extremely low temperature [11,12].

In this Letter, dense and uniformed GaN films with highly c-orientation are achieved on ordinary soda-lime glass substrates with nickel (Ni) as intermediate layer using ECR-PEMOCVD at an extremely low temperature of ~480 °C. Ni is chosen as intermediate layer for its hexagonal structure and relatively low lattice mismatch with GaN. In addition, Ni is thermally and mechanically stable and high electrical conductive, these features are absolutely favorable for the subsequent GaN-based optoelectronic devices. The GaN/Ni/glass structures reported here have great potential for dramatically improve the scalability and cost of solid-state lighting.

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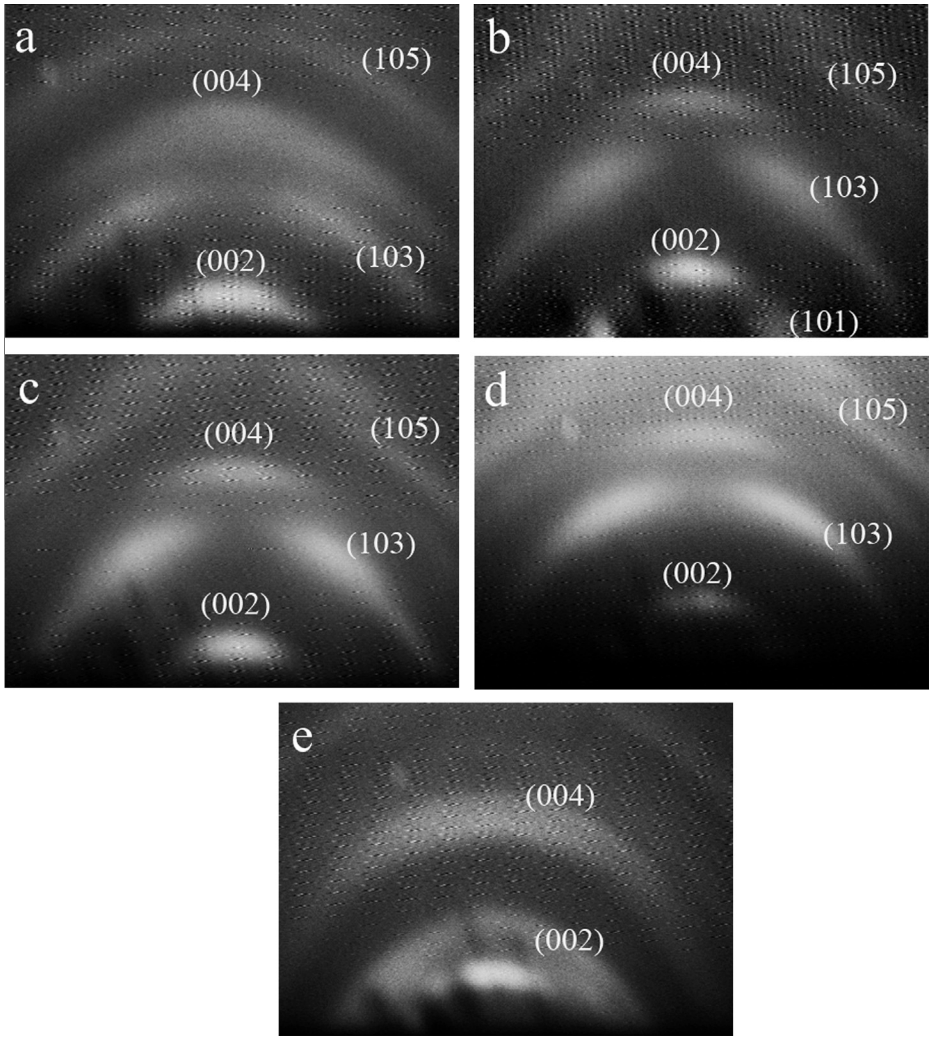

Fig. 1. In-situ RHEED patterns of the GaN films deposited on Ni/glass substrates at different deposition temperatures: (a) 380 °C; (b) 430 °C; (c) 480 °C; (d) 530 °C; and (e) 580 °C.

2. Experiments

GaN films were deposited on Ni/glass substrates using ECR-PEMOCVD system. Ni coated glass were used as substrates, which were obtained using sputtering deposition with Ar as a working gas. In this process, trimethylgallium (TMGa) and nitrogen (N_2) were employed as source of Ga and N, respectively. The N_2 reactivity can be remarkably enhanced by ECR process, i.e., there are much more particles of reactive nitrogen over the substrate as a result of ECR enhancement, which was necessary for the formation of GaN films under the low temperature. The Ni/glass substrates were first sputtered with hydrogen plasma for 3 min to eliminate surface oxidized thin layer. A buffer layer was first deposited on the substrate at the room temperature for 30 min with the TMGa flux of 0.5 sccm and N_2 flux of 80 sccm. Then the GaN films were grown for 180 min with the flow rate of TMGa and N_2 controlled to be 1.2 sccm and 100 sccm, respectively. The higher N_2 flux was used to provide an N-rich atmosphere. To investigate the effect of deposition temperature on the as-grown film, the deposition temperature varied in the range of 380–480 °C.

The crystalline quality and orientation of the samples were determined by in situ reflection high-energy electron diffraction (RHEED) at 19 kV, and X-ray diffraction (XRD) using a D/Max-2400 (Cu Kα1: 0.154056 nm). The morphologies of GaN films were analyzed by atomic force microscopy (AFM) equipment. Photoluminescence (PL) measurements were performed at room temperature by a Jobin Yvon HR320 spectrometer using a He-Cd laser (30 mW) with an excitation wavelength of 325 nm.

3. Results and discussion

3.1. Structural properties

Fig. 1 is the real-time in-situ RHEED patterns observed for the GaN films under different deposition temperatures. The disconnected rings in RHEED patterns indicate that polycrystalline GaN films are obtained on ordinary amorphous glass substrates. In addition, the brighter and more distinct rings in Fig. 1(c) suggested that the GaN films with better crystalline and highly preferred orientation have been obtained at the optimized temperature of

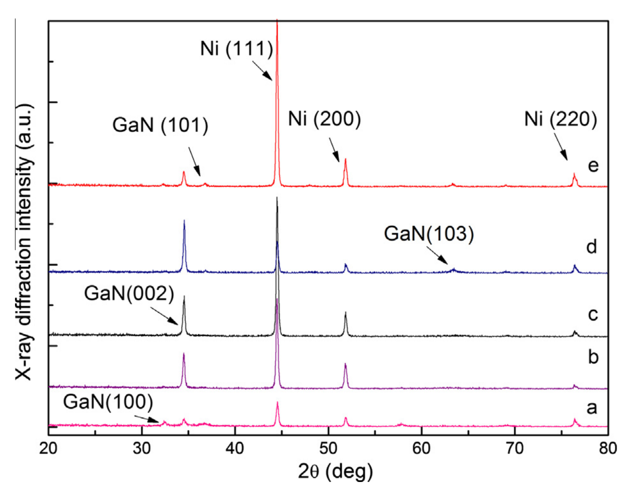

Fig. 2. XRD patterns of the GaN films deposited on Ni/glass substrates at different temperatures: (a) 380 °C; (b) 430 °C; (c) 480 °C; (d) 530 °C; and (e) 580 °C.