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Growth conditions of semi and non-polar GaN on Si with Er_2O_3 buffer layer

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ABSTRACT

The GaN was grown on Si(100) with $Er_2O_3(110)$ buffer by metal organic chemical vapor deposition (MOCVD). The results showed the polycrystalline nature of the layers with dominant non-polar (11–20) and semi-polar (10–13) orientations. GaN was formed in a two step process regime: low temperature growth was followed by high temperature growth regime. At a low temperature GaN tends to crystalize with dominant non-polar (11–20) orientation, while high temperature leads to preferential semi-polar (10–13) orientation growth. Additionally, the effects of parameters such as growth temperature, V/III-ratio and type of carrier gases on structural, morphological and optical properties of GaN was discussed in the current work.

1. Introduction

Due to limited supply of GaN bulk substrates, the feasible way of obtaining cost effective large area GaN based materials is still through heteroepitaxy on foreign substrates [1]. Currently, the most widely used foreign substrates for GaN growth are sapphire, silicon carbide and bare silicon. A large difference in thermal expansion, a mismatch in lattice and chemical reactivity must be solved in order to grow crack free, high quality epitaxial GaN films on Si [2–4]. One possibility to integrate GaN on Si is the heteroepitaxial growth using rare earth oxides particularly Er_2O_3 as a buffer [5,6]. This technology of c-plane GaN on Si(111) has already demonstrated potential for improvement and is in the stage of adoption for mass production [7].

Conventional polar group-III nitrides MQW structures suffer from internal electric fields, which lead to band bending, and a decreased efficiency and spectral instability of optoelectronic devices. The internal electric fields can be reduced or totally avoided with semi-polar or non-polar GaN growth [8]. It was already shown that growth of single domain semi-polar (10–13) GaN can be realized on Si(100) by applying directional sputtering of AlN [9]. Our previous studies revealed, that the same orientation (10–13) semi-polar or (11–20) non-polar GaN domains can be deposited just by introducing Er_2O_3 buffer layer on Si(100) [10]. This work is attributed to the development of semi-polar or non-polar GaN on Si(100) with Er_2O_3 buffer layer growth technology providing with an access to MOCVD parameters for GaN crystallinity improvement.

2. Experimental

The Si wafers used for experiments were 4° off-cutted from the basal (100) plane towards (011). The templates with $Er_2O_3(110)$ buffer layer on Si(100) were grown by molecular beam epitaxy (MBE). Such templates were transferred to a close coupled MOCVD reactor from AIXTRON for GaN deposition. Trimethylgallium and ammonia were used as precursors for gallium and nitrogen sources respectively. An *in situ* interferometer using a semiconductor laser as a light source was employed to monitor the growth rate and surface morphology. Two groups of samples were considered in this study. The low temperature samples (below 750 °C) GaN was grown in nitrogen ambient directly on Si/Er_2O_3 templates. For the second group of samples a nucleation layer at 550 °C was formed

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prior a high temperature (1080–1110 °C) GaN growth either under nitrogen, or hydrogen carrier gas flow.

The crystal orientation analysis and phase identification of GaN structures were carried out by high resolution X-ray diffractometer (Rigaku, SmartLab). The surface morphology was investigated by field emission Appolo 300 scanning electron microscope (SEM). Finally, the luminescence properties of GaN were analysed by photoluminescence spectroscopy (PL). The picosecond pulses from frequency quadrupled mode locked Nd:YAG laser ($\lambda = 266$ nm) were used for optical pumping.

3. Results and discussion

3.1. Investigation of GaN growth at low temperatures

The lattice mismatch between GaN and Er_2O_3 exceeds −14% [10], thus the high temperature, direct epitaxy of gallium nitride on erbium oxide can hinder the pseudomorphic growth leading to poor crystal quality. A number of studies show [11,12], that use of low temperature GaN as a buffer at a very first stage of growth can drastically improve surface morphology and crystal quality. Such a nucleation layer increases a number of nucleation centers and provides with seeds of mono-crystals showing a preferential orientation in one direction after the thermal treatment [12,13]. Therefore, the growth of low temperature gallium nitride was studied, prior high temperature GaN deposition. The evolution of surface morphology of low temperature GaN is shown in Fig. 1. The SEM images reveal that changes in surface texture occurs when growth temperature exceeds 600 °C. Above this temperature a considerable number of crystal grains with sharp interfaces were formed. The majority of those crystallites lie on the surface with the preferred non-polar orientation.

To investigate further the GaN transformation at low temperature the studies on growth kinetics were performed. The growth rates were determined directly from Fabry-Perot oscillations measured by *in situ* interferometer. The Arrhenius plot of growth rate vs. reciprocal temperature is shown in Fig. 2. Two growth regimes can be distinguished in the temperature range between 550 °C and 750 °C. The kinetically limited regime with high activation energy $E_a = 73$ kJ/mol transforms to the reacting species transport limited regime with low E_a (0.8 kJ/mol) at around 600 °C. This growth regime transition point can be associated with crystallization of GaN layer as was already shown by SEM images. It should be mentioned that the extracted activation energy (73 kJ/mol or 17.4 kcal/mol) in the kinetically limited regime is in the same range of the activation energy reported by Kaluza et al. (10.6 for conventional and 18.5 kcal/mol for inverted precursor inlet) for GaN grown on c-plane sapphire substrate [14].

The intense crystallization of GaN above 600 °C was confirmed by XRD measurements (see Fig. 3 a). At growth temperature 550 °C only traces of XRD peaks corresponding to the reflections from polar, non-polar, semi-polar GaN planes can be observed. As shown in Fig. 3 a) the overall crystallinity of GaN gradually improves with increase of temperature and leads to the formation of layer with dominant non-polar (11–20) orientation eventually.

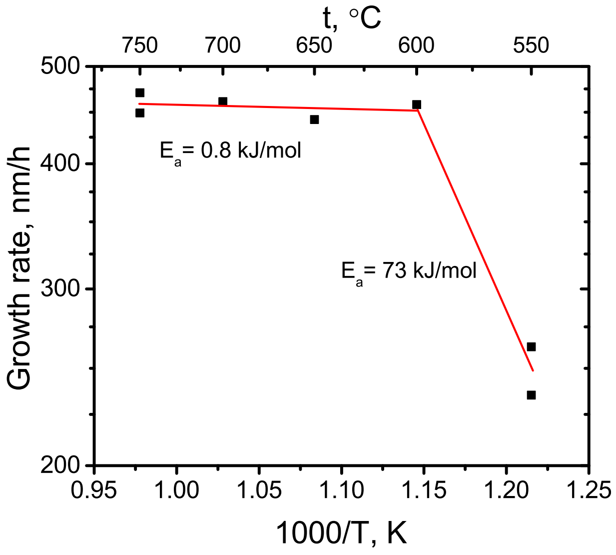

Fig. 2. Growth kinetics of low temperature GaN on Er_2O_3(110).

3.2. Investigation of GaN growth at high temperatures

Fig. 3 b) shows XRD patterns of GaN grown at high temperatures with a low temperature nucleation layer below. In this temperature regime the semi-polar (10–13) orientation of GaN appears and becomes strongly dominant over non-polar at a temperature of 1110 °C.

The ratio of non-polar and semi-polar GaN orientation is sensitive to the MOCVD growth parameters such as V/III ratio at high temperatures. A number of experiments was performed at different ammonia flow, while keeping pressure and temperature constant. Fig. 4 shows XRD patterns of the samples grown at different V/III ratio varying from 484 to 7749. The inset represents the peak intensity ratio of those dominating directions (10–13) and (11–20) vs. V/III ratio. Summarizing V/III effect, it can be concluded that the optimal condition for the semi-polar GaN(10–13) growth on Si(100) with Er_2O_3(110) is low V/III ratio. Increase of ammonia flow results in a higher content of non-polar GaN(11–20) orientation. These experimental results is supported by a majority of studies indicating that lateral growth is enhanced for non-polar a-plane GaN at low V/III [15] and contrary for polar c-plane GaN at high V/III

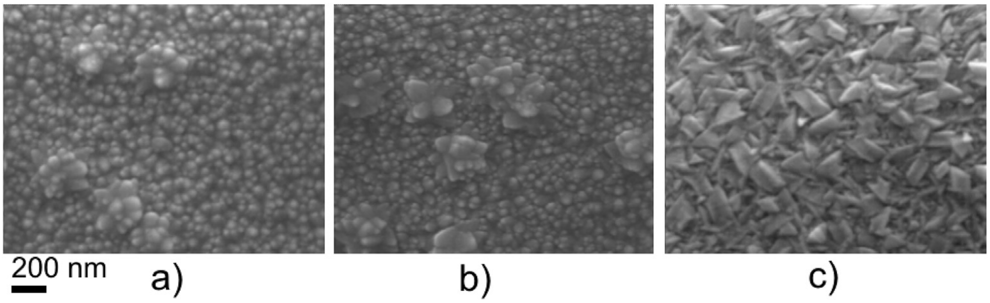

Fig. 1. GaN surface morphology grown at different temperatures: a) 550 °C, b) 600 °C, c) 650 °C.