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Efficient stress relief in GaN heteroepitaxy on Si(111) using various metal buffer

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Abstract

GaN epitaxial layers were grown on Si substrate (111) by metalorganic chemical vapor deposition (MOCVD). We have investigated the effect of the nitridation flow time and various interlayers on the optical property and crystal quality of GaN on Si(111). Buffer layer is used because of large mismatch of lattice constant, thermal expansion coefficient and to prevent melt-back etching. So, we have performed Ti_xSi_y, Cr_xSi_y, Ni_xSi_y and Au_xSi_y as a buffer layer and varied nitridation time (5/10/20/30 min) in the same growth condition. The comparison of different condition of interlayer is evaluated by using scanning electron microscope (SEM), double crystal X-ray diffraction (DCXRD), photoluminescence (PL), atomic force microscope (AFM). Through the SEM analysis, we found that the crystal quality of GaN epilayer increases with the nitridation flow time increase. Finally, we suggested that nitridation time of GaN epitaxial layer was fixed and Ti, Cr, Ni and Au metal interlayer were used for the growth of GaN epilayer. It was expected that high crystal quality and crack-free GaN epilayer. Consequently, we have obtained high quality and crack-free GaN epitaxial layer when we use the Ti, Cr, and Ni metal as an interlayer and 30 min nitridation flow time.

1. Introduction

GaN/Si(111) offers cost-effective technology for the fabrication of GaN based optoelectronic and microelectronic devices[1-2]. GaN/Si(111)[3] has attracted considerable academic and commercial interest because of Si substrates low cost, large available size and the potential for simple device processing and device integration with well-established Si process. In spite of this advantage, however, the large lattice and thermal mismatches between these materials remain a critical problem. A GaN film grown directly on Si using conventional two-step method has a very poor surface morphology and low crystal quality. Therefore, several attempts for growth of GaN/Si(111) substrate such as wafer patterning to induce lateral growth or to confine the growth area and various kinds of buffer or intermediate layers have yielded improved optical/electrical properties and suggest a possibility of high-quality GaN/Si(111). In the past decade, various types of buffer layers such as 3C-SiC, AlN[4-5], GaAs, AlAs, and γ -Al_2O_3 have been used as the intermediate layer between the GaN epilayer and Si substrate. Although some results have been reported on the successful growth of GaN on Si using above the mentioned materials, these methods have not achieved yet perfect crack-free GaN on Si epitaxy compared with growth of GaN on sapphire. So, we have optimized buffer layer with respect to its various metal buffer Ti_xSi_y, Cr_xSi_y, Ni_xSi_y and Au_xSi_y as a buffer layer and varied nitridation time (5/10/20/30 min) in the same growth condition. In this paper, we predict that attributed the decrease of tensile stress with the reduction of the metal buffer layer nitridation time that controlled the duration of metal buffer relaxation.

2. Experiments

A horizontal metalorganic chemical vapor deposition (MOCVD) system with a horizontal quartz reactor was used. Trimethylaluminium (TMA), trimethylgallium (TMG), and ammonia were used as the Al, Ga, and N sources, respectively. H_2 was used as the carrier gas. Phosphorous-doped n-type Si(111) wafers with a cut-off of 4° were used as substrates. The Si(111) plane was chosen because of its trigonal symmetry favoring the epitaxial growth of the GaN (0001) plane. A bare Si(111) substrate was ultrasonically cleaned for 5 minutes in methyl alcohol and acetone baths, respectively. Then, the substrates were degreased by H_2SO_4:H_2O_2:H_2O(3:1:1) solutions for 5 min, and etched with HF (2%) for 5 min to remove the surface oxide layer. After preparations, Si(111) substrate were heated under H_2 ambient at 900°C for 5 min to etch its surface thermally prior to growth. Metal buffer was grown at 1020°C, followed by GaN growth at 1040°C. Microscopy, X-ray diffractometry (XRD) and photoluminescence (PL) measurement were used to characterize the surface morphology, crystallinity, and optical properties of GaN on Si(111).

3. Result and discussion

Fig. 1 shows the optical microscopy images of the surface of GaN on Si(111) epitaxy grown using various nitridation duration. Type of buffer layer is nitridation duration 10 min. for S1, nitridation duration 20 min. for S2, nitridation duration 30 min. for S3, respectively. As shown in fig. 2, the FWHM of DCXRD rocking curves for GaN(0002) grown using the various duration for S1, S2 and S3 were 728, 648 and 541 arcsec, respectively. It means that GaN/Si(111) grown with nitridation duration 30 min has the highest crystal quality. It is believed that the reason for the poorer crystal quality of S1 and S2 compared with S3 was the presence of some cracks. For these results of surface and crystal quality shown in figs. 1 and 2 shows that nitridation duration 30 min. gives rise to a significant improvement in the quality of GaN/Si(111) epitaxy. It was found that nitridation duration 30 min. plays a very important role in improving the quality and eliminating the cracks that formed during the growth of GaN epitaxial films on Si(111).

4. Conclusions

An intermediate layer is normally used to control the tensile stress induced by cooling after growth. Therefore, this study examined the growth of GaN/Si(111) epitaxial layers on metal buffer such as Ti_xSi_y, Cr_xSi_y, Ni_xSi_y and Au_xSi_y Also, Nitridation duaration was varied 5/10/20/30 min. Consequently, we have obtained high quality and crack-free GaN epitaxial layer when we use the Ti, Cr, and Ni metal as an interlayer and 30 min nitridation flow time.

5. References

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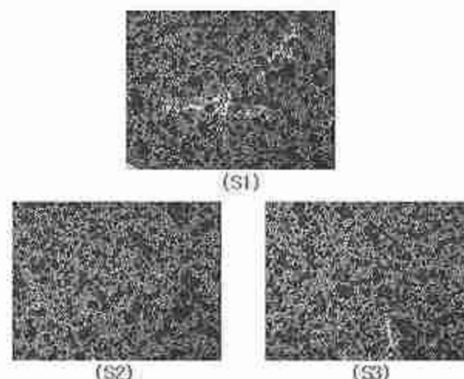

Fig. 1. Optical surface images of GaN/Si(111) epitaxial films for S1 with nitridation duration 10 min. S2 with nitridation duration 20 min. and S3 with nitridation duration 30 min.

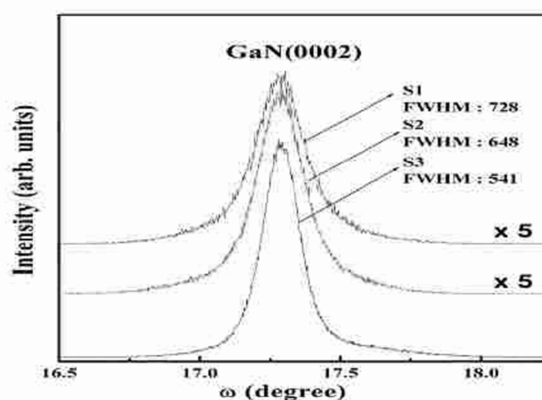

Fig. 2. DCXRD rocking curves for GaN(0002) and its FWHMs of GaN/Si(111) epitaxy grown with various nitridation time.