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Epitaxial Lateral Overgrowth of Gallium Nitride on Sapphire*

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Abstract: The effect of growth conditions on GaN layer growth in the epitaxial lateral overgrowth (ELO) process by metal organic chemical vapor deposition (MOCVD) was investigated. Sapphire wafer was used as the substrate, which was chemically etched to make pattern on it. Then a GaN buffer layer was deposited at low temperature (LT) as the seeding layer to alleviate the lattice mismatch and difference in thermal conductivity between GaN and the substrate to grow a high quality layer with a low density of screw and mixed threading dislocations. Finally the GaN epilayer was deposited on the seeding layer by ELO. The properties of the GaN layer were then investigated by double-crystal X-ray diffraction, atomic force microscopy, and wet chemical etching.

Key words: GaN; epitaxial lateral overgrowth; MOCVD; *c*-plane (0001) sapphire substrate
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1 Introduction

Wide bandgap semiconductor materials provide specific electrical, optical, and thermal properties that classical semiconductors are unable to achieve. Ⅲ-nitride semiconductors, including InN, GaN, and AlN and their semiconductor alloys, are very popular for wide-bandgap semiconductor device applications. Among these, GaN can emit light at short wavelengths and operate at high temperatures due to its large bandgap, high thermal conductivity and chemical properties, and it has attracted great interest because of the demonstration of applications such as light emitting diodes (LEDs), laser diodes (LDs), and photo detectors (PDs)[1,2]. Owing to the lack of bulk GaN material, it must be deposited on other substrates. Still, the lack of a lattice-matching substrate continues to be a challenge for the growth of GaN, and it is usually grown on sapphire or SiC, not because these substrates are particularly well suited for GaN growth, but because much experience has been gained over the years on how to grow GaN on them. Compared with other substrates, sapphire has the merits of cost effectiveness in device fabrication, ease of rinsing, and high stability at high temperatures. Early on, progress in GaN growth was typically hampered by poor nucleation on sapphire, which resulted in large dislocation densities, high background doping levels, and buried conductive layers near the GaN/sapphire interface[3~5]. The large lattice mismatch (16%) and thermal expansion coefficient mismatch between GaN and sapphire substrate generally cause high-density threading dislocations (TD) in the GaN epilayer. TDs are very harmful to electronic and optoelectronic devices, so TD density is a very critical parameter for GaN films[6~8].

In this study, sapphire wafers were used as substrates, and GaN buffer layer was deposited at low temperatures as the seeding layer to compensate for the lattice mismatch and difference in thermal conductivity between GaN and the substrate, and thus to grow a high quality layer with a low density of screw and mixed threading dislocations. Epitaxial growth techniques such as epitaxial lateral overgrowth (ELO) were also used to produce a high-quality GaN layer. The properties of the GaN layer were investigated by atomic

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force microscopy, double-crystal X-ray diffraction, and wet chemical etching.

2 Experiment

At first, *c*-plane (0001) sapphire substrates with a diameter of 50mm (Fig. 1, one side polished wafer, the pattern was from the unpolished side below) were cleaned with H_3PO_4 solution and boiled in the solution for 45min at 270℃. In this procedure, H_3PO_4 solution also made a pattern (Fig. 2) on the substrates, which was very important for the ELO procedure, and then NaOH solution was used to basify it. A final dip in H_3PO_4 solution was accompanied by an immediate rinse in deionized water, followed by N_2 blow-drying.

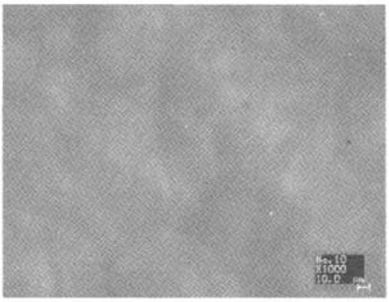

Fig. 1 Sapphire wafer before etching

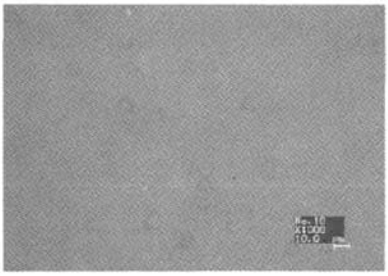

Fig. 2 Sapphire wafer after etching

Then samples were grown by a low-pressure metal-organic chemical vapor deposition system (Thomas Swan vertical flow reactor) on patterned sapphire wafers. A regular two-step growth technique was applied in this experiment. TMGa and NH_3 were used as Ga and N precursors, respectively. After loading, the (0001) substrate was ramped up to 1000℃ under H_2 ambient to remove native oxide on the surface. Then a roughly 20nm-thick LT GaN buffer was deposited at 500℃. Finally, the GaN epilayer was deposited at 1060℃.

3 Results and discussion

The crystal structure and film orientation of the layers were obtained from the analysis of X-ray diffraction spectra and the value of the full-width at half-maximum (FWHM) for the GaN (0002) peak from X-ray rocking curve measurements. The FWHM of the rocking curve for the GaN (0002) peak of the sample is 217.08″, and high intensity was reached.

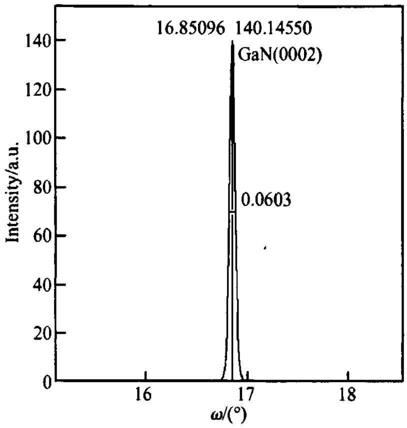

Fig. 3 X-ray rocking curve of the sample

Figure 4 shows an AFM image of the surface of the GaN epilayer. It can be seen very clearly that the epilayer is quite smooth, with a root-mean-square (RMS) roughness of 0.25nm.

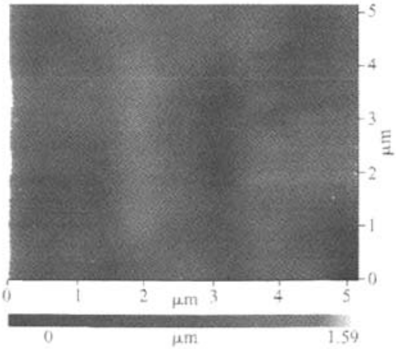

Fig. 4 AFM image of the surface of GaN epilayer

Wet chemical etching is a commonly used technique for surface defect investigation because of its low cost and simple equipment. In this work, the GaN sample was etched in molten potassium hydroxide (KOH) at 180℃ for about 10min. Through examining the surface morphology of the etched GaN sample, the etch pits revealed by the KOH etch, which were mostly hexagonally shaped, were ascribed to threading dislocations (TD) with screw character or mixed character. The etch pit density was quite low.

All the experimental results show that low density of dislocations and high quality crystal were obtained using this procedure. The ELO process improved the morphology of the GaN film. In this growth procedure the patterned sapphire was very important, as it ensured that the GaN epilayer could be grown by the ELO mechanism. The growth steps can be seen in Fig. 5. LT GaN was first deposited on the patterned sapphire substrate as the seeding layer, which was not deposited on the pits of the sapphire. Then the GaN epilayer was deposited on the seeding layer. Because the horizontal growth rate was much faster than the vertical growth rate, the two sides of the GaN joined together and the GaN plate became a whole plate. In addition to this, there were also hollows on the pits, which can release the stress of the material and improve the quality of the epilayer.

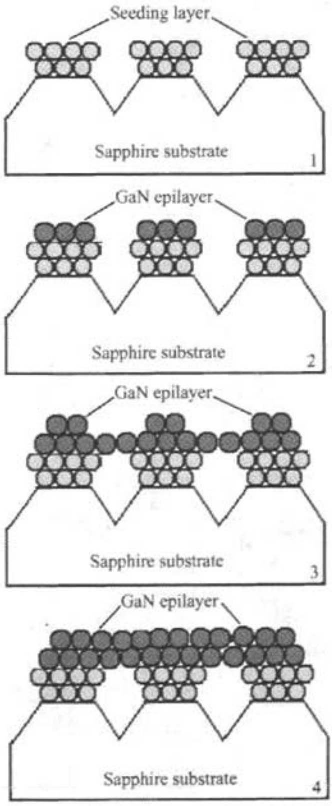

Fig. 5 Growth steps of GaN epilayer

4 Conclusion

From the XRD patterns, the morphology of the surface, and the dislocation density of GaN film, it is found that using the patterned sapphire as the substrate for the ELO process is a low cost and simple way to grow high quality GaN film on sapphire.

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蓝宝石上横向外延GaN薄膜*

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摘要： 在蓝宝石衬底上利用金属有机物气相外延(MOCVD)方法对横向外延(ELO)GaN薄膜的生长条件进行了研究．在蓝宝石衬底上利用化学腐蚀的方法刻饰出图案，再沉积低温GaN缓冲层作为外延层的子晶层，以降低外延层与衬底的晶格失配与热失配，制备出低位错密度的GaN外延层．分别利用X射线衍射、原子力显微镜及湿法腐蚀对外延层进行检测．

关键词： GaN；横向外延；金属有机物气相外延；(0001)蓝宝石衬底
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