

Polycrystalline GaN/AlN super-lattice on Si (001) substrate grown by RF-MBE

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Abstract

We have investigated the structural and optical properties of polycrystalline GaN/AlN super-lattice (p-SL) formed on the Si (001) substrates by plasma assisted molecular beam epitaxy. The transmission electron microscopy (TEM), and X-ray diffraction (XRD) measurements revealed formation of a GaN/AlN p-SL made of C-axis oriented columnar wurtzite (wz) crystals. The photo luminescence (PL) measurements indicated clear luminescence from the p-SL nearby the GaN/Si interface at room temperature.

1. Introduction

Nitride semiconductors well known to blue or white LED and laser diode, have attracted many interests of researchers for high power and high frequency device, because of unique properties of GaN; high electron drift velocity, relatively high thermal conductivity, high thermal stabilities, chemical stabilities. In recent years, growth of GaN on Si substrate has been intensively researched¹⁾. Si substrates enable economical mass production of LED²⁾ and large area devices of nitride semiconductor. It also utilizes the highly developed silicon technologies. Higher thermal conductance of Si substrates shows preferable candidate for GaN high power high frequency devices³⁾.

In order to produce high quality GaN single crystal on Si substrate, it is necessary to grow a buffer layer containing GaN/AlN/superlattice and having a thickness of several μm , due to different unit cell symmetry and large lattice mismatch, thus morphology of GaN drastically changes according to the growth conditions, substrates orientations. Thus there are reports of formation of GaN variety in form from nano rods, nanowires⁴⁾, poly crystal⁵⁾, wz single crystal⁶⁾, zinc blende (zb) single crystal⁷⁾ to porous film⁸⁾. Many of these reports are concerned with the growth layer above the buffer layer of 1 μm or more and the growth layer above 1 μm using an intermediate layer such as $\gamma\text{-Al}_2\text{O}_3$ or SiC. There are many unclear points about the structure and characteristics of the crystal nearby the Si interface. However, the characteristics of the buffer layer containing GaN/AlN/SL have not been fully evaluated and its characteristics are not clear.

In this study, we have studied the structural and optical properties of the crystal nearby GaN/Si interface by TEM, XRD and PL measurements.

2. General Instructions

The GaN/AlN SL growths on (001) Si substrates were done by the radio frequency molecular beam epitaxy (RF-MBE) based on VG-V80, the pumping of which was enhanced by cryo pump⁹⁾. The native oxide layers of silicon substrates were removed by dipping into buffered HF just before loading into the RF-MBE machine and exposing atomic hydrogen beam in the growth chamber of the RF-MBE. The nitrogen gas flow was 4 sccm. The RF power was 400W. The growth temperatures were about 600 degree C measured by pyro meter. In growth chamber of the RF-MBE, after raising substrate temperature to growth temperature, atomic hydrogen generated by RF plasma of 30 sccm H_2 gas was applied to Si surface, to ensure the removal of the Si oxidation film. Ga and Al cell temperatures were 1050°C and 1150°C, respectively.

3. Results and Conclusions

The cross sectional structures of GaN/AlN p-SL layer and GaN / Si interface were studied by TEM. XRD θ -2 θ scan measurements and 2-dimesional reciprocal space mapping measurements. Optical property was examined by room temperature PL measurements by UVQ-SW Laser.

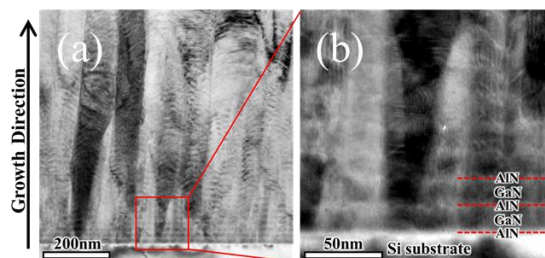


Fig. 1(a) shows a TEM cross sectional image of the GaN/AlN SL on Si (001) substrate. (b) is a close-up of the SL nearby Si substrate.

Figure 1(a) shows a TEM cross sectional image of the GaN /AlN SL on Si (001) substrate. The TEM image shows that

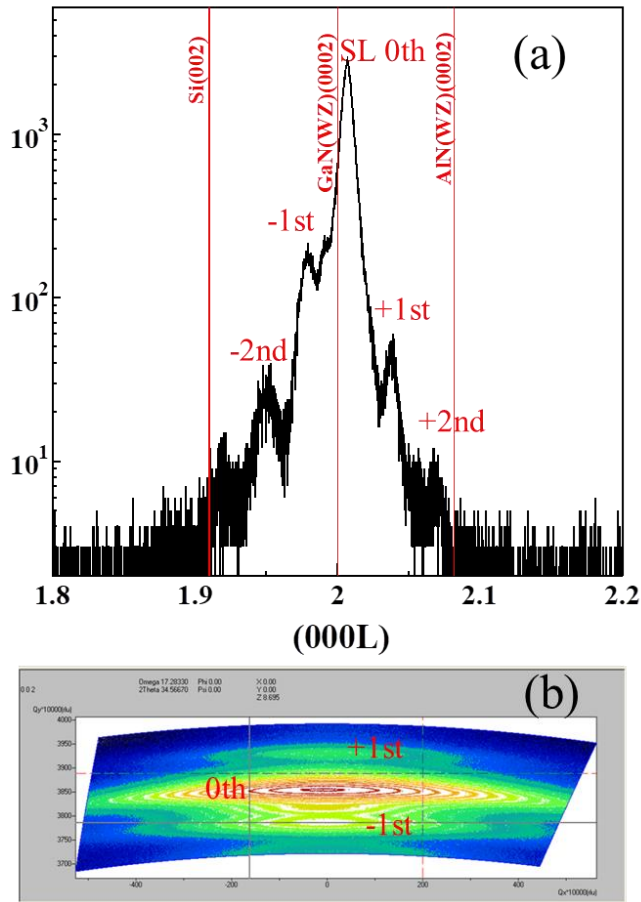


Figure 2(a) shows a XRD θ - 2θ scan of the GaN/AlN polycrystalline SL, where satellite peaks were clearly observed. (b) shows a 2-dimensional reciprocal space image of the SL peaks

the SL is polycrystalline and its columnar crystal is very close each other. From the microscopic image, it can be seen that the interface between GaN and AlN is flat near the Si substrate, and unevenness gradually occurs as the stacking progresses. In addition, it can be seen that each crystal gradually approaches a single crystal by partially increasing the size and decreasing the size of the others. Since the increase in the unevenness of the GaN/AlN interface and the change in the crystal grain size are not observed in the case of GaN produced under the same conditions, it is considered that the lattice strain of AlN and GaN is related. In our GaN growth, Ga beam was applied just after ignition of nitrogen plasma, Ga droplets seemed not to be formed, the GaN growth resulted in formation of poly crystal, not in formation of nano-columns.

In fig. 2(a), the 0th, ± 1 , and ± 2 satellite peaks of the p-SL are clearly observed by x-ray diffraction, which shows the periodicity of the array of elements. Figure 2(b) shows 2-dimensional mapping of p-SL peaks. The FWHM of the 0th peak was more than 5° and much bigger than that estimated from Scherrer's equation using the width of GaN crystal ($\sim 30\text{nm}$) observed in the TEM image as shown in fig.1(b). The two-dimensional image of the 0th peak shows a

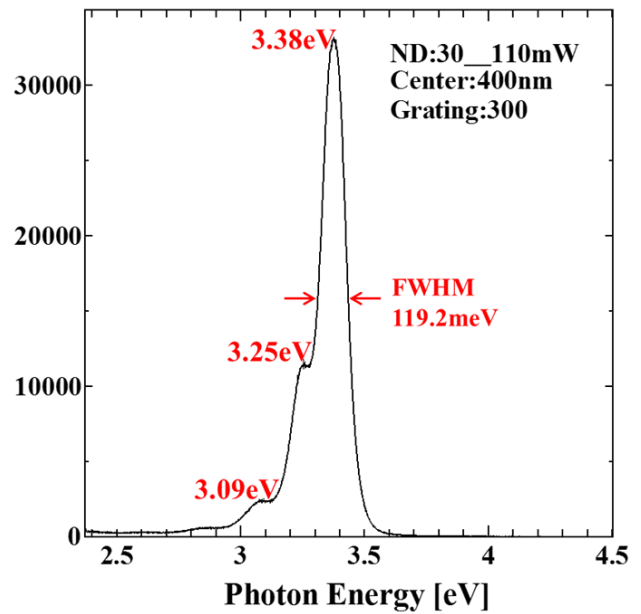


Fig. 3 shows PL spectrum of GaN/AlN polycrystalline super-lattice at room temperature.

crescent like shape, that indicates the c-axis of wz crystals of the p-SL have fluctuation of a few degree in the direction from perpendicular to the Si substrate.

For the PL measurements, the excitation power was 72 mW, the wave length of excitation was 266nm. The center wave length of the spectrum measurement was set to 400nm with the grating of 300. Fig. 3 shows PL spectrum of GaN/AlN p-SL at 300K which indicates clear luminescence. Though, a relatively broad peak with FWHM exceeding 100 meV suggests the effects of lattice mismatch, grain boundaries, or the GaN/AlN interface, the luminescence spectrum is comparable to that from a 1.3-micron-thick GaN single crystal fabricated using a $\gamma\text{-Al}_2\text{O}_3$ intermediate layer on a silicon substrate⁶⁾. Clear luminescence from this SL poly crystal means the grain boundaries are not full of non-radiative sites, and depression width of the GaN crystal from the GaN/Si interface smaller than GaN layer thickness of 300nm. GaN/AlN p-SL structures near the Si substrate can be studied including device applications, because sufficient luminescence emission is observed at room temperature despite many defects and strains due to differences in crystal symmetry and lattice constants.

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