ACHIEVEMENTS AND CHARACTERIZATIONS OF GaN WITH Ga-POLARITY IN RADIO-FREQUENCY PLASMA-ASSISTED MOLECULAR BEAM EPITAXY

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ABSTRACT

Lattice polarities and film qualities of GaN grown by rf-MBE were investigated concentrating on the use of different buffer layer processes at the initial stage. Direct clarifying by coaxial impact collision ion scattering spectra technique, together with RHEED and chemical wet etching, were applied to identify the lattice polarity of GaN films. XRD rocking curve and photoluminescence results showed that the qualities of GaN films with Ga-polarity were dramatic improved compared to those with N-polarity. Hall effect measurement results indicated that the mobility of the Ga-face film was increased to one order higher (568 cm²/Vs in maximum at room temperature) than that of N-face one.

INTRODUCTION

Wide band-gap GaN and related III-nitride materials have attracted a great deal of attention due to their potential usefulness in optical and electronic devices. Recently, lattice polarity in III-nitride films becomes a hot topic due to its great influence on the optical and electrical properties of the films. Several techniques were applied to characterize the film polarity, such as convergent beam electron diffraction (CBED) [1], hemi-spherically scanned x-ray photoelectron diffraction (HSXPD)[2], Rutherford backscattering ion channeling[3], chemical wet etching and surface reconstruction by reflection high-energy electron diffraction (RHEED) [4], etc. Based on the results, Ga-polarity films are believed to be usually obtained by metalorganic chemical vapor deposition (MOCVD), which is known to be the most suitable technique for III-nitride growth at present. Contrary to the case of MOCVD, the lattice orientation of conventional molecular beam epitaxy (MBE)-grown sample is assumed to be mainly N-polarity [5]. In III-nitride materials, MBE-grown films usually show poor qualities compared with MOCVD-grown ones, especially concerning electrical properties. Recently, we pointed out that the growth should be done under the Ga-face mode to get high...
film qualities in MBE [6]. Therefore, characterization and comparison of GaN films with Ga- and N-polarity are becoming interesting and important subjects.

In this study, we characterized lattice polarities and film qualities of GaN grown by rf-MBE concentrating on the use of different buffer layer processes at the initial stage. Direct clarifying by coaxial impact collision ion scattering spectra (CAICISS) technique, together with RHEED and chemical wet etching, were applied to identify the lattice polarity of GaN films. XRD, PL and Hall-effect measurements were carried out to characterize the qualities of GaN films.

EXPERIMENTAL

The GaN films were grown on sapphire (0001) substrates by rf-MBE. Low temperature (LT=500°C), high-temperature (HT=700°C) GaN and AlN buffer layers were deposited at the initial growth stage, respectively. The thickness of LT buffer layer was about 20 nm as a conventional way, and the thickness of HT AlN buffer layer was changed from 20 to 300 nm before the GaN growth. Despite using different buffer layers processes, other growth conditions were the same for the GaN growth. The main growth processes and conditions are as follows. Before depositing buffer layers, the substrate was exposed to a N$_2$-plasma flux for nitridation at 700°C for 5 min with the power being 350 W and flow rate being 2.0 sccm. After that, different buffer layer growth as described above were carried out. Then, an GaN film was grown on the buffer layer. During the growth of GaN films, the N$_2$-plasma power was 350 W and N$_2$ flow rate was from 3.5~5 sccm. The growth temperature was fixed at 700°C and the growth rate was 0.6 $\mu$m/hr. The total thickness of the GaN film was from 1.2 to 2.4 $\mu$m. CAICISS technique was used to clarify the lattice polarity directly. In CAICISS measurements, a He$^+$ ion beam was employed as an incident beam.

EXPERIMENTAL RESULTS AND DISCUSSIONS

Clarification of Lattice-Polarity of GaN

To clarify the lattice-polarity of GaN, RHEED reconstruction and wet chemical etching are often used[6]. However, these characterization methods are expedient measurements and more direct way to characterize the lattice-polarity is required. Recently, CAICISS technique has been proved to be a direct way to characterize the lattice polarity of GaN films [7, 8]. We applied this technique to our GaN films to directly characterize the lattice-polarity.
Figure 1 gives the CAICISS results of two kinds of GaN samples with HT AlN and GaN buffer layers. The figure shows the polar angle (beam incident angle of He\(^+\) with respect to the normal to the (0001) surface) dependence of Ga signal intensity. It is clear that two large peaks around 20° and 40° were observed from the film with HT AlN buffer (upper curve). On the contrary, the polar angle dependence for the sample with HT GaN buffer (lower curve) illustrates peaks around 14° and 54°, and a dip between 38~52°. According to our simulation results [8] based on a three-dimensional two-atom triple-scattering model, these incident angle dependence features are specified for Ga-polarity and N-polarity films, respectively. Based on the above results, it is concluded that the polarity of GaN films with an AlN HT buffer process is Ga-face, while that of films with the other kinds of buffer layer processes is N-face. In-situ RHEED reconstruction observations and wet chemical etching experiments [4, 5] also show good agreements to the above lattice-polarity assignments. This is the first approval to the correlation among the CAICISS technique, in-situ RHEED and wet chemical etching to clarify the lattice-polarity of GaN films [9].

Figure 1. Polar angle (beam incident angle of He\(^+\) with respect to the normal to the (0001) surface) dependence of Ga signal intensity \(s\) of GaN films grown using a HT AlN buffer layer (upper curve) and a HT GaN buffer layer (lower curve), by CAICISS measurements.

**Optical Properties of GaN Films with Ga or N-Polarity**

GaN films with Ga or N lattice-polarity were characterized by XRD (rocking curve scan). It was found that the FWHM of GaN (0002) peak of Ga-polarity film decreased to half of that
of N-polarity one, indicating that the structural quality was greatly improved for Ga-polarity films [6]. PL measurements (He-Cd laser as an exciting source) at 4.2K were carried out to characterize the optical properties of GaN films with different lattice-polarity. Figure 2 (a) and (b) show the PL results of two GaN samples with N- and Ga-polarity, respectively. Both of samples show good optical property with sharp band-edge-related peaks and almost no yellow-band emissions. However, there are two remarkable differences between them. One is that the FWHM values of band-edge-related peak for both samples are different. The value is 15 meV for N-polarity sample, while it decreases to 8 meV for the Ga-polarity one (see insets in figure 2). Another important difference is the peak energy position for the two samples. PL peaks of N-and Ga-polarity films dominate at 3.477 eV and 3.483 eV, which is thought to be related to I2 and free-exciton (A-exciton) recombination, respectively [10]. From the above results, it is clear that GaN films with Ga-polarity show better optical quality than that with N-polarity.

![PL spectra of GaN films at 4.2K](image)

Figure 2. PL spectra of GaN films at 4.2K. (a) N-polarity film, showing I2 emission dominant, (b) Ga-polarity film, showing free-exciton (A-exciton) recombination.

**Electrical Properties of GaN Films with Ga or N-Polarity**

Electrical property of GaN films is an important reference to the film quality. In case of N-polarity GaN films, we got the electron mobility typically to be a few 10 cm²/Vs at room temperature (RT). On the other hand, Ga-polarity GaN films always show much higher mobility. Table 1 lists the data of mobility and carrier concentration for both lattice-polarity films. From the table, it can be clear that the Ga-polarity film show better electrical property that N-polarity one. The highest mobility we got is 568 cm²/Vs at RT with carrier
concentration being $1.1 \times 10^{17}$ cm$^{-3}$. The dependence of electron mobility on measuring temperature of the film is shown in Figure 3. It is clear that the mobility firstly increases with the decrease of temperature. Then, the mobility decreases with the decrease of temperature. The peak temperature is about 150 K with the mobility value being 780 cm$^2$/Vs. This is a typical bulk behavior of mobility on temperature.

**Table 1. Electrical properties for N- and Ga-polarity GaN films**

<table>
<thead>
<tr>
<th>Sample name</th>
<th>Lattice-polarity</th>
<th>Mobility (cm$^2$/Vs)</th>
<th>Carrier concentration (cm$^{-3}$)</th>
</tr>
</thead>
<tbody>
<tr>
<td>A1</td>
<td>N</td>
<td>18</td>
<td>$1.8 \times 10^{17}$</td>
</tr>
<tr>
<td>A2</td>
<td>Ga</td>
<td>366</td>
<td>$1.2 \times 10^{17}$</td>
</tr>
<tr>
<td>A3</td>
<td>Ga</td>
<td>568</td>
<td>$1.1 \times 10^{17}$</td>
</tr>
</tbody>
</table>

Figure 3. The dependence of electron mobility of a Ga-polarity GaN film on temperatures by the Hall-effect measurement.

**Discussions**

As described above, GaN films with Ga-polarity show better qualities (optical and electrical) than N-polarity ones. This can be understood by considering the growth behaviors under the two different lattice-polarities. In N-polarity case, the surface shows domain features consisting of many boundaries. These boundaries give high mosaicity which increase the scattering for electron transport resulting in low mobility. On the other hand, Ga-polarity films give the smooth and uniform surface [5]. The great reduction of the mosaicity results in a dramatic increase of mobility. XRD and electrical characterization results give a proof of this consideration. Therefore, controlling the lattice-polarity during
the MBE growth is an important condition for getting high-quality GaN film.

SUMMARY

As a summary, we succeeded in realizing GaN films with Ga-face lattice polarity by using AlN high temperature (HT=700 °C) buffer layer in rf-MBE, while other kinds of buffer layer result in N-polarity films. XRD rocking curve showed that the FWHM of GaN film with Ga-polarity was decreased to half of that with N-polarity. Both optical and electrical properties of Ga-polarity GaN films were dramatically improved, compared to those of N-polarity ones. The highest electron mobility obtained in this study was 568 cm²/Vs at RT with carrier concentration being 1.1×10¹⁷ cm⁻³. This promising technique is expected to give a breakthrough for getting high quality III-nitride films by MBE for device applications.

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REFERENCES