5. p-Type GaN Obtained by Electron Beam Irradiation

5.1 Highly p-Type Mg-Doped GaN Films Grown with GaN Buffer Layers

5.1.1 Introduction

In order to use GaN for blue light emitting diodes (LEDs) and laser diodes (LDs) the long standing problem of high p-type doping had to be solved. Amano et al. [157, 158] grew Mg-doped GaN films using AlN buffer layers on a sapphire substrate. After growth, low-energy electron beam irradiation (LEEBI) treatment was performed on these GaN films and p-type GaN films were obtained. The hole concentration was $10^{17} \text{ cm}^{-3}$ and the lowest resistivity was $12 \Omega\text{cm}$. These values were not sufficient for the fabrication of blue LDs and high-power blue LEDs. It has been explained in Sects. 4.5 and 4.6 that GaN films grown with GaN buffer layers are superior in terms of their electrical characteristics [159] to those with AlN buffer layers. In the present section the characteristics of p-type Mg-doped GaN films grown with GaN buffer layers on sapphire substrates are described.

5.1.2 Experimental Details

The TF-MOCVD system discussed in section 4.2 was used for the Mg-doped GaN growth. Sapphire with (0001) orientation (C-face) was used as a substrate. Trimethylgallium (TMG), ammonia (NH$_3$) and bis-cyclopentadienyl magnesium (Cp$_2$Mg) were used as Ga, N and Mg sources, respectively.

The growth methods are discussed in detail in Chapter 4. Specific growth information for the present section is summarized in Table 5.1 and Table 5.2. The films consisted of 200 Å GaN buffer layers followed by 4 µm Mg-doped GaN layers.

LEEBI treatment was performed under the condition that the accelerating voltage of incident electrons was kept at 5 kV. Hall-effect measurements were performed by the van der Pauw method at room temperature.
5.1.3 Results and Discussion

The 4 μm-thick Mg-doped GaN films with GaN buffer layers were grown with a Cp₂Mg flow rate of 3.6 μmol/min. These as-grown GaN films showed p-type conduction without LEEBI treatment. Their resistivity fluctuated between $3.2 \times 10^2$ Ωcm and $1 \times 10^5$ Ωcm. The reason for the fluctuation of the resistivity between the grown GaN films was not clear. According to the work of Amano et al. [157] and Amano and Akasaki [158], the as-grown Mg-doped GaN films with AlN buffer layers show high resistivity (over $10^8$ Ωcm). Therefore, the as-grown Mg-doped GaN films grown with GaN buffer layers are substantially superior to those grown with AlN buffer layers in terms of their conductivity control. The sample which had the lowest resistivity had a hole concentration of $2 \times 10^{15}$ cm$^{-3}$, the hole mobility was 9 cm$^2$/Vs, and the resistivity was 320 Ωcm at room temperature. This work was the first report of Mg-doped GaN films showing p-type conduction without the LEEBI treatment.