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Mg concentration profile and its control in the low temperature grown Mg-doped GaN epilayer

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ABSTRACT

In this work, the Cp_2Mg flux and growth pressure influence to Mg doping concentration and depth profiles is studied. From the SIMS measurement we found that a transition layer exists at the bottom region of the layer in which the Mg doping concentration changes gradually. The thickness of transition layer decreases with the increases of Mg doping concentration. Through analysis, we found that this is caused by Ga memory effect which the Ga atoms stay residual in MOCVD system will react with Mg source, leading a transition layer formation and improve the growth rate. And the Ga memory effect can be well suppressed by increasing Mg doping concentration and growth pressure and thus get a steep Mg doping at the bottom region of p type layer.

1. Introduction

In recent years, Gallium Nitride (GaN) and its ternary alloys have attracted a great deal of attention for their material properties which are advantageous for applications in light emitters and detectors devices [1–5]. Nevertheless, the quality of p type GaN sometimes still often acts as a bottle-necks limiting the performance of these devices so far [6]. Up to now, Mg is singly useful element to dope p type GaN, and the Mg atoms doped in the GaN layer often passivated by H (forming a neutral Mg-H complex) as the H is contained in the growth environment of MOCVD system [7,8]. This issue was first treated by Amano et al. through the low-energy electron beam irradiation [9]. Unfortunately, this way has a fatal defect that it only can

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activate several hundred nanometer-thick materials. Subsequently, the thermal annealing reported by Nakamura et al. is well done to solve this Mg passivated problem [7]. Nevertheless, it's often still difficult to get high performance p-GaN. For lower Mg doped samples, the quality of p type GaN is restricted by the lack of acceptor impurities, but for highly Mg doped samples, the quality will be decreased by the strong Mg self-compensation of Mg acceptor. At the same time, the residual carbon impurities, nitrogen vacancy (V_N) and complexes of V_{Ga}-O_N in p-GaN have compensation effect on Mg acceptor [10–12]. With so many problems, it is critical to choose a suitable Mg doping concentration to get high quality p type GaN. At the same time, there always exist some p type layers which thickness is only several decades nanometers in the LD and LED structure, so it critical to getting a steep Mg doping for these layers in order to ensure a good performance of related applications.

In this paper, the relationship between Mg concentration profile and epitaxy growth conditions has been clearly analyzed. The Ga memory effect is found from the SIMS measurement which has an effect on the growth rate, C concentration and Mg doping profile. Meanwhile, we find that the Ga memory effect influence to Mg doping profiles can be well suppressed by increasing Mg doping concentration and growth pressure and then get a steep transition layer at the bottom region of the Mg doping layer.

2. Experiment

A series of 1 μm thick Mg-doped GaN films were grown on a 2 μm thick unintentionally doped GaN layer in Metalorganic Chemical vapor Deposition (MOCVD) system to investigate the growth of Mg doping P type GaN layer. Trimethylgallium (TMG), ammonia (NH_3), and Bis-cyclopentadienyl magnesium (Cp_2Mg) were used as precursors for Ga, N, and Mg, respectively. The detailed message about p-GaN layer samples is shown in Table 1, where samples S1, S2 and S3 were grown with different pressures varying from 150 mbar to 260 mbar and 400 mbar, respectively. As shown in Table 1 these samples may be grown with different CP_2Mg fluxes, but all in a comparatively low growth temperature, because some recent studies found that the high growth temperature and annealing temperature will lead to the In-segregation in InGaN quantum wells (QWs) of the active region for QW laser diode (LD) or light emitting diode (LED), [13–16]. Therefore, relatively low growth and annealing temperatures are needed to avoid the decrease of device performances. In our research, the growth temperature and annealing temperatures are set as 930 °C and 680 °C respectively. After annealing, the Mg and C concentrations of p-GaN films grown with different growth conditions were measured by secondary ion mass spectroscopy (SIMS).

3. Result and discussion

At first, we have studied the p-GaN layer with different growth pressure through SIMS measurement. Fig 1 shown the Mg concentration profiles for samples S1-1, S2-1 and S3-1, which were grown with the same Cp_2Mg flux (135sccm), but different pressure varying from 150 mbar to 260 mbar and 400 mbar. It is obvious that the Mg incorporation efficiency decreases along with the increase of reactor pressure from Fig. 1. Meanwhile, as the growth time for these samples was set the same, from the measured thickness of the epilayers we can find that the growth rate for p-GaN layer decreases with the increase of growth pressure. It is known that there is a boundary gas layer above the substrate in the reaction chamber, and the gas sources need to transfer across this boundary layer at first before they can take part into the growth. However, the gas in the boundary layer moves slowly, as there exists a viscosity force in the substrate surface, and thus the main way to material transport in this layer relies on diffusing. For our low temperature (930 °C) growth of p type GaN, the growth still stays in a mass transport control process which the growth rate is controlled by the rate of organic source across the boundary layer. Increasing the growth pressure means decreasing the gas source flow velocity in the reactor. At the same time, from the well known ideal gas state equation $PV = nRT$, or $P/\rho = RT/M$, where ρ is the gas density and M is the mass of the gas molecule, we can get that the gas density ρ in reactor will be increased by increasing pressure, too, as which will lead the viscosity force and the thickness of boundary gas layer in substrate surface increase. At last, the flux of source which transfers across the boundary to grow decreases and the growth rate decreases. In addition, it is reported that the parasitic reaction will be increased with the increase of reactor pressure as the latter will increase gas density and decrease flow velocity, thereby improve the chance for TMGa and NH_3 to come into contact before reaching the substrate [17,18], which can also make the growth rate decrease with the increase of growth pressure. These reasons can also explain why the Mg incorporation efficiency decreases with increase

Table 1
The growth conditions for p-GaN samples.

Sample	Growth Temp. (°C)	Growth Pres. (mbar)	CP_2Mg flux (sccm)	Mg Con.(cm^{-3})	C Con.(cm^{-3})	Ann. Temp. (°C)
S1-1	930	150	135	1.05×10^{19}	2.58×10^{17}	680
S1-2	930	150	672	8.98×10^{19}	4.05×10^{17}	680
S2-1	930	260	135	7.60×10^{18}	7.75×10^{16}	680
S2-2	930	260	70	3.55×10^{18}	1.13×10^{17}	680
S2-3	930	260	1344	1.18×10^{20}	2.34×10^{17}	680
S3-1	930	400	135	2.78×10^{18}	2.24×10^{16}	680
S3-2	930	400	220	4.75×10^{18}	3.39×10^{16}	680
S3-3	930	400	672	1.02×10^{19}	4.32×10^{16}	680

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