MRS Internet Journal of Nitride Semiconductor Research

Volume 2, Article 13

Studies of Mg-GaN grown by MBE on GaAs(111)B substrates

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This article was received on June 3, 1997 and accepted on July 22, 1997.

Abstract

This paper discusses the growth of Mg-doped GaN samples using a modified Molecular Beam Epitaxy (MBE) method. Our results suggest that the dopant is incorporated from a surface population maintained by the incident Mg flux by a rapid diffusion mechanism. It follows that the chemical concentration will increase with time of growth and that the p-doping level will also increase progressively with film thickness for a given Mg flux. Increasing the Mg flux to the surface results at first in a higher doping density, but this saturates when the Mg surface concentration reaches a finite value.

1. Introduction

Mg-doping has been used successfully to produce a variety of group III-Nitride LED and LD structures [1] [2] [3] [4]. The key to this improved technology being the efficient p-doping of the GaN and (AlGa)N films. In growth by MOVPE, post growth annealing in a nitrogen atmosphere is needed to activate the dopant, but in MBE due to the absence of atomic hydrogen no post growth treatment is necessary. However, in MBE grown films, various authors report widely different behaviour for the Mg-doped films [5] [6] [7]. In the work of Lin et al [5] the SIMS data shows a very non uniform Mg profile in the layer with the concentration rising strongly towards the surface. Wang et al [6] do discuss the uniformity of the doping, but they comment that no effect of substrate type is observed. Brandt et al [7] present SIMS data for a film which shows a dip in the Mg concentration close to the substrate epilayer interface with a decreasing concentration towards the surface. They also discuss the effects of hydrogen passivation. The purpose of this paper is try to understand the origin of this variability in the reported behaviour of Mg.

2. Experimental Methods

We have grown a series of Mg-doped GaN grown by Molecular Beam Epitaxy. Active nitrogen is produced by an Oxford Applied Research CARS25 plasma source. Further details of the methods used to grow the films have been presented elsewhere [8]. Growth rates are typically 0.3μm/hour. Before growth, to remove the oxide, the GaAs substrates were heated to 620^{o}C. They were then exposed to the nitrogen plasma whilst heating to the growth temperature of approximately 700^{o}C.

We have investigated the structural properties of the films using a Philips Xpert diffractometer employing both θ-2θ and w scans. Hall effect measurements have been used to study the electrical properties. It is important to use a true van der Pauw geometry in order to get reliable electrical data. SIMS measurements have been used to obtain the relevant chemical concentrations and dopant profiles. We have implanted known concentrations of Mg into nominally undoped GaN wafers to obtain quantitative values for the Mg doping level. The optical properties have been investigated by photoluminescence at both 300K and low-temperature (8K), using a He-Cd laser for excitation.

3. Results and Discussions

In the first series of films, a constant Mg cell temperature was used to grow films of increasing thickness to 2µm. The thinnest sample shows n or p type behaviour with relatively high mobility, two thicker layers are definitely p-type in character with low mobilities of 10 $cm^2 V^{-1} s^{-1}$, typical of GaN p-type material. For films of constant thickness, increasing Mg cell temperature results in an increase in both the chemical and electrical concentrations to values of $3 \times 10^{19} cm^{-3}$ and $5 \times 10^{17} cm^{-3}$ respectively. The results of this study are summarized in Table 1.

Figure 1a shows the SIMS profile for the most lightly doped sample MG521. At this low concentration we see a dip in the Mg concentration close to the substrate epilayer interface , but overall the profile is reasonably flat. By contrast for the more heavily doped samples, we see possible evidence for a very small dip at the interface with a uniform concentration with depth as shown in Figure 1b for MG526. All the other SIMS profiles are similar to this second profile. Our results can only really be understood in the context of the likely behaviour of Mg doping in MBE. The vapour pressure of Mg at the substrate temperature (700^oC) is very high, approximately 1 Torr [9]. It is therefore highly likely that the lifetime of the Mg atom on the GaN surface will be finite and that the sticking probability will be less than unity. It follows that doping is really from a finite surface concentration which will depend strongly on substrate temperature, which we are currently investigating. Mg is also known to diffuse very rapidly through III-V compounds and it is therefore possible that the doping level will increase progressively with film thickness as we observe. The diffusion rate and surface concentration will both depend strongly on substrate temperature and III-V ratio. This variation may be the origin of the very different behaviour reported by the various groups [5] [6] [7]. At present, estimating the true temperature of growth for GaN films is difficult due to the transparent nature of the materials and to understand the differences in behaviour observed by different groups requires a precise knowledge of both temperature and III-V ratio.

The optical properties of the above films have been studied using PL. A striking feature of PL from many of the thicker films is the presence of strong thickness related oscillations in the relatively weak deep emission indicating that both the substrate-layer and epilayer-air interfaces are very smooth as shown in Figure 2.

4. Conclusions

Mg-doping of films by MBE probably results from rapid diffusion of a finite surface concentration maintained by the Mg flux to the surface. It follows that the doping level achieve will increase with growth time and hence film thickness and that to achieve efficient p-doping it is necessary to grow films several microns thick. Mg-doped films grown by MBE have smooth substrate-layer and epilayer-air interfaces on an optical length scale.

Acknowledgments

This work was funded under the ESPRIT project LAQUANI 20968.

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Table 1

Electrical properties for the Mg-doped samples grown on GaAs(111)B substrates

Sample No.	**Cell Temp °C**	**Hall p , 10^{17}cm^{-3}**	**Mobility cm^{2}V^{-1}s^{-1}**	**Resistivity Ω-cm**	**Type n/p**	**Thickness mm**	**SIMS [Mg] 10^{18}cm^{-3}**	**[Mg]/p**
MG521	388	1.5	90	0.46	n?	0.65	1.5	-
MG537	388	0.16	5.5	72	p	1.3	3.5	219
MG527	388	0.73	8.1	10.6	p	2.1	7	96
MG525	440	4.6	10.5	1.3	p	2.1	30	65
MG526	507	4.8	10.7	1.2	p	2.1	20	42

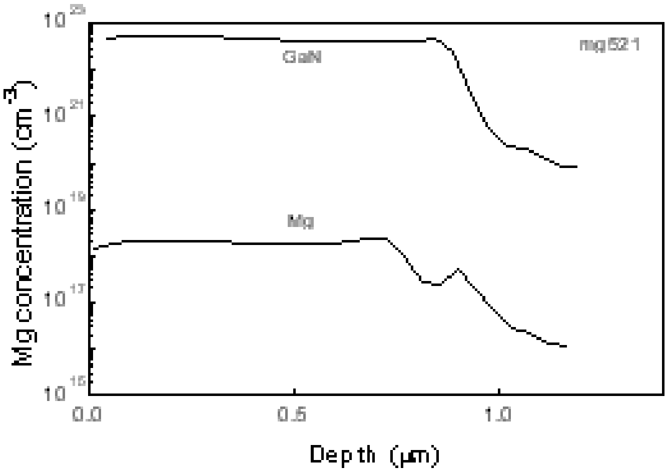

Figure 1a. SIMS profile for the lightly doped sample

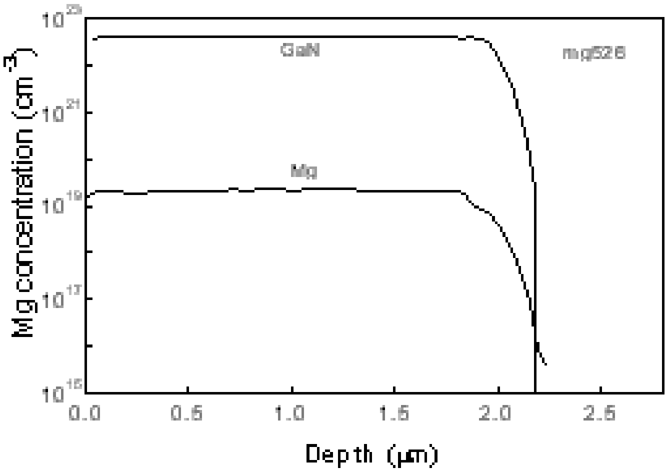

Figure 1b. SIMS profile for the high doped sample

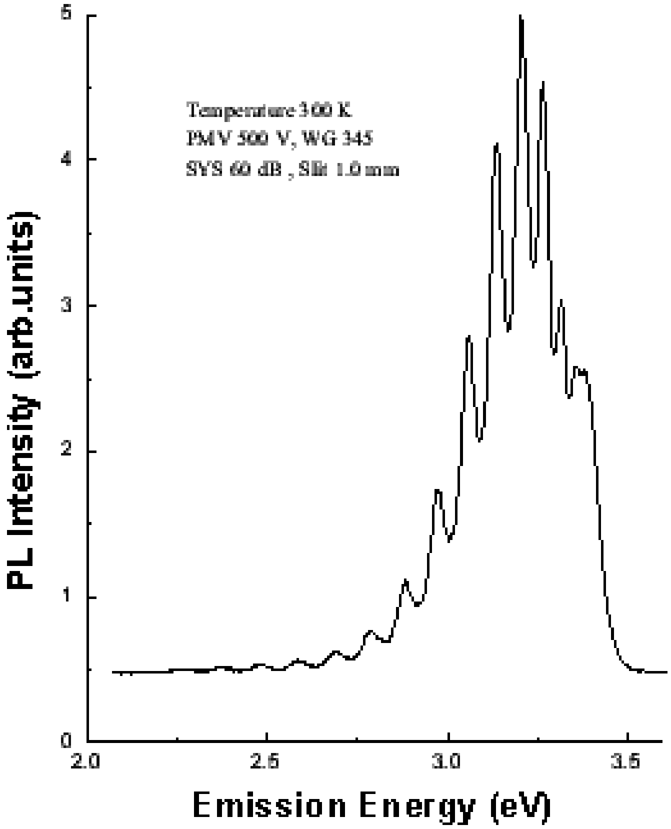

Figure 2. shows a typical PL spectrum for MG526