APPLICATION NOTE

STATE OF THE ART HIGHLY DOPED GaN LAYERS GROWN BY AMMONIA MBE

Introduction

The problem of p-doping of group-III nitrides dates back to at least the mid last century at which time it was anticipated that wide-band gap semiconducting GaN and its alloys would afford a wide range of applications. However, some time passed before the discovery of an efficient way to obtain p-type GaN layers with appropriate properties at the realisation of efficient optoelectronic devices. The remarkable work of I. Akasaki in the 80-90's, who refused to give up the cause, allowed for the first time the realization of p-type GaN layers, which then evolved into the development and now commercially available of violet-blue-green light emitting diodes (LEDs) and violet-blue edge emitting laser diodes (LDs).

Riber is pleased to report here the studies, in collaboration with the CRHEA-CNRS team of Dr. Jean Massies in Valbonne, on the elaboration of highly p-type Mg-doped GaN layer by molecular beam epitaxy using ammonia as a nitrogen source and solid Mg as the p-dopant source. The growth conditions have been optimised throughout the study of GaN p-n homojunction characteristics in order to achieve state of the art p-doped GaN layers. This work is supported by ANR-PNANO 06 Project "DEMONI".

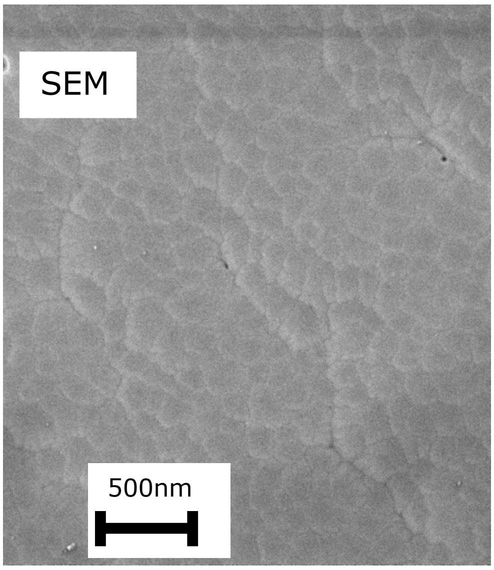

Figure 1 : Plan-view scanning electron microscope image of the p-doped GaN layer surface

Experimental

Growths were carried out in a Riber 32 MBE system using ammonia (NH_3) as a nitrogen source and equipped with solid effusion cells. Gallium and Magnesium were evaporated using a double-filament effusion cell and a single filament cell, respectively. A set of several p-n homojunctions were grown following the same procedure: 2 µm thick n-type GaN (Si doped GaN, n ~ 3.10^{18} cm^{-3}) layer deposited on MOCVD GaN template on sapphire substrate, followed by the growth of 500nm thick p-type GaN layer. We have studied the influence of the Mg flux as well as the growth temperature of the p-type GaN layer on the electric characteristics measured by Hall effect. This work is the continuation of a previous study published by A. Dussaigne *et al.*.[1] We observe that, whatever the growth conditions, growth temperature and Mg flux, ranging from 700 to 800°C and 1.10^{-10} to 4.10^{-10} Torr respectively, the p-doped GaN layer RHEED pattern evolution during the growth reveals a 2 dimensional growth mode. A plan-view scanning electron microscope image (figure 1) underlines the rather smooth surface of the p-doped layer.

Results

Hole concentration ([h]), resistivity (ρ) and mobility (μ) of the p-doped GaN layers have been extracted from room temperature Hall experiments on the P-N homojunctions.

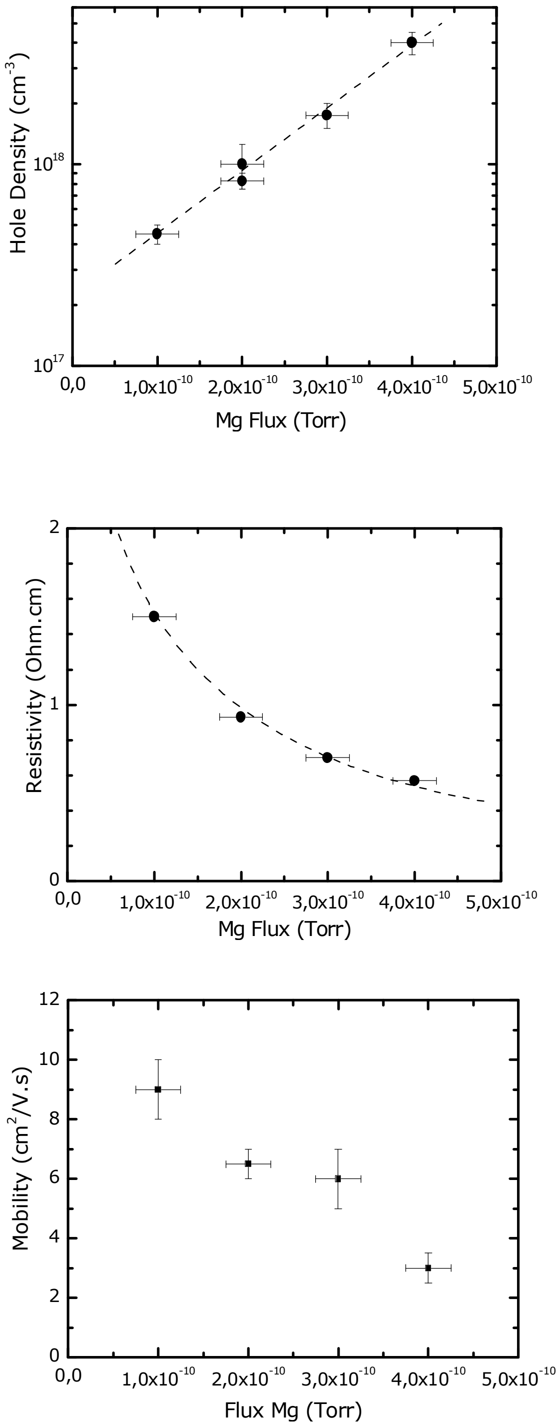

Figure 2: Hole density, resistivity and mobility of p-doped GaN layers as function of magnesium flux

The best results of the set of measurements undertaken on various samples are presented in Figure 2 as a function of the flux of Mg. The graphs underline that a high hole density ([h] = $4.10^{18}/cm^3$), low-resistivity (ρ = 0.57 Ω.cm) and good mobility (μ = 3 cm²/V/s) can be achieved. To our knowledge, this set of values are among the best results ever reported for MBE growth (either N_2 plasma or NH_3 sources). It is also important to emphasize that these values are comparable with the best MOCVD results reported by Nakamura *et al*[2]. ([h] = $3.10^{18}/cm^3$, μ = 9 cm²/V/s, ρ = 0.2 Ω.cm) which allowed the commercial production development of LEDs and LDs. Furthermore, it is important to highlight the excellent reproducibility of these results time after time.

Conclusion

This work has shown that highly p-doped GaN layers with suitable electrical properties can be achieved by molecular beam epitaxy using ammonia as a nitrogen source and solid magnesium as the p-dopant source. These results have a far-reaching impact in the view of the fabrication of high efficient light emitting diodes and laser diodes by molecular beam epitaxy.

About CRHEA (http://www.crhea.cnrs.fr/)

The Centre de Recherche sur l'Héteroepitaxie et ses Applications, CRHEA, is a French laboratory part of the National French Scientific Research academy the CNRS. The activity is actively focussed on epitaxial growth of wide band gap semiconductor: gallium nitride and related alloys, zinc oxide, silicon carbide and small band gap semiconductors InGaAsN. The laboratory is equipped with five Riber MBE reactors. All necessary characterisation tools to support growth are available in the lab and allow material optimisation through a fast and efficient feedback. By focussing the activity upon epitaxial growth, the CRHEA continuously develops a world class expertise in the field of compound semiconductors and has firmly established its place within the community with an international dimension.

About Riber (www.riber.com)

RIBER is a leading supplier of MBE processing equipments and related services. The company offers a wide range of tools, from R&D systems for most compounds to volume production platforms, and provides a global service network with 495 operational systems worldwide (at the end of 2007). RIBER plays a key role in the development of MBE technology via several Process Technology Centers (PTC) providing customer solutions from epitaxial growth through device processing.

References

[1] A. Dussaigne, N. Grandjean, B. Damilano, J. Brault, E. Feltin, and J. Massies, to be published in J. Appl. Phys.

[2] S. Nakamura, M. Senoh, and T. Mukai, J. J. Appl. Phys. **31**, L1708 (1991).