

Investigation on p-contacts in Mg-doped GaN and the effect of various pre-treatments

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Abstract-

P-contacts on MOVPE-grown Mg-doped GaN were investigated as function of various pre-treatments in order to enhance the hole concentration of the starting material. After a Mg-activation at 950°C for 30 s in N₂-ambient the samples show a typical hole concentration of $\sim 10^{17} \text{ cm}^{-3}$. In the investigations a metallisation of Ni-Au (20/100 nm) was mostly used which, after a thermal annealing, shows a slight Schottky behaviour. One of the pre-treatments induces a current increase at constant voltage of about 20%.

Introduction

The potential of GaN-based devices is immense in the optoelectronic domain like LEDs, laser diodes and their use in a multitude of applications like giant displays, lighting and data storage. These devices require good contacts to p-doped GaN, however this material suffers from a low conductivity despite of the high concentration of Mg dopant. Mg-atoms are bonded to a H-atom and hence electrically inactive [1]. Without Mg-activation all metallisations result in Schottky contacts.

In this work we investigated the contact resistance using two different metallisation schemes, Pt and Ni/Au, on MOVPE grown Mg-doped GaN. The circular transmission line method (CTLM) was used with 9 different spacings between the circle and the outer contact (fig.1). CTLM presents the advantage of avoiding one processing step (mesa etch) as compared to linear TLM [2].

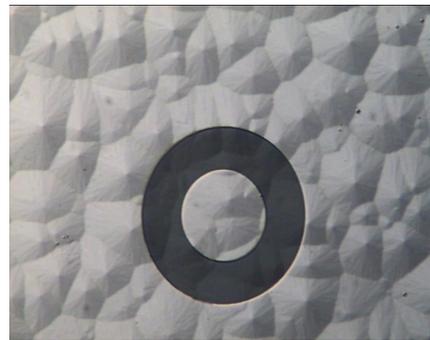


Figure 1- A microscope photograph of the largest spacing used in our CTLM.

Experimental

All samples have been activated in an RTA process at 950°C for 60 s in N₂-ambient. This activation leads to a hole-concentration of $2\text{-}4 \times 10^{17} \text{ cm}^{-3}$ and a hole-mobility around $10 \text{ cm}^2/\text{Vs}$. The samples were cleaned in BHF prior to metallisation. Some of the samples were treated in aqua regia prior to lithography, which is thought to remove native oxides. No real evidence of improvement was found about the role of these two handlings. However we kept using the BHF treatment.

Three metal schemes were investigated: Pt (90 nm thick) because of its high work function, Ni/Au (20/100 nm) mostly used for contacting p-GaN and a thin or semi-transparent Ni/Au (5/5 nm). All contacts were annealed using an RTA process at temperature ranging from 550

to 700°C for various laps of time under N₂ or N₂/O₂ ambient. The latter was used with the semi-transparent Ni/Au stack as nickel oxide formation at the metal-GaN interface has resulted in ohmic behaviour [3].

We have investigated several pre-treatments in order to increase the p-conductivity. Those have been performed either before the Mg-activation or just after and before any processing step. These pre-treatments are:

- exposing the samples to N₂- and N₂O-plasmas before the RTA activation.
- perform a shallow RIE etch in order to expose a fresh GaN surface.
- A 50 nm thick Ti layer was evaporated followed by an RTA step.
- treatment X.

Results

A few experiments were carried out using sputtered 90 nm of Pt preceded by in situ Ar-plasma. This has resulted in a very high sheet resistance (>100 kΩ/sq) making difficult to explain or compare results with and without pre-treatments. This contact was annealed at 600°C for 120 s.

In most of our experiments we have used a Ni/Au metallisation with a thickness 20/100 nm. The samples were annealed in N₂-ambient at various temperatures (550, 650 and 700°C) during 30s. This has resulted in fair contact resistance of $\sim 10^{-3}$ Ωcm². However the contacts present a Schottky-type behaviour which, is caused by the large sheet resistance (about 40 kΩ/sq) of this material that dominates the resistance during the measurements. Therefore it is quite common to compare the contacts by giving measured current at constant voltage for the same contact surface. Typical values of current at 2.5 and 5 V were 0.5 and 1 mA respectively.

The last metallisation scheme we tried was the semi-transparent metallisation Ni/Au (5/5 nm) followed by an annealing in N₂/O₂ (80/20% in volume) at 550°C. A second metallisation was needed to enable us to perform measurements on the sample but unfortunately the semi-transparent metallisation was completely invisible and hence no alignment was possible. In order to carry out this experiment we need a special mask with etched pre-alignment marks that allow an easy alignment for the semi-transparent metallisation as well as for the thicker metallisation.

For the rest of our experiments we used Ni/Au (20/100 nm).

Pre-treatments

The influence on the p-conductivity of two plasma-based exposures and a RIE step was investigated:

N₂-plasmas have been reported to improve the contact resistance on p-GaN [4,5] and it is thought to compensate N₂ vacancies. We have tried three N₂-plasma treatments on already activated samples at 40, 70 and 100 W respectively. All N₂-plasmas were carried out at 500 mTorr during 9 minutes with N₂ flow of 100 sccm at a sample temperature of 400°C. Subsequently an RTA step was performed at 600°C for 30s in N₂ ambient. The samples treated at 40 and 70 W showed similar results to a reference sample (without N₂-plasma) while the sample treated at 100 W showed worse results.

Though an O₂-plasma is known to enhance the donor concentration in GaN, a N₂O-plasma (150 mTorr, 20 sccm N₂O, T=300°C, 150 W, 10 minutes) was applied in which oxygen is supposed to attract the H-atoms responsible of deactivating the Mg atoms. The result was

negative and the contact was more of a Schottky type in comparison to the result without this N₂O-plasma. With both plasma treatments we used a Pt metallisation.

Furthermore, a shallow RIE during 1 min at 70 W using SiCl₄+Ar was performed resulting in an etch depth of about 15 nm. This was done to expose a fresh GaN surface exempt of native oxides. Subsequently a Ni/Au (20/100 nm) metallisation was evaporated and annealed. Current values of 0.2 and 0.6 mA were measured at 2.5 and 5 V respectively, independently whether the Mg-activation took place before or after the RIE process. Apparently the benefit of removing the native oxides was counter-balanced by the introduction of N-vacancies caused by the RIE process and hence making the contacts worse.

One way of increasing the p-conductivity is to break the Mg-H bond by means of attracting the H-atom using an element that presents a large affinity for hydrogen. In the GaAs technology Ti/Pt/Au is commonly used for contacting p-GaAs. This metal stack cannot be annealed in a H₂ ambient as Ti reacts with Hydrogen at low temperature. Therefore we have evaporated a thin layer of Ti (50 nm) on activated p-GaN, followed by an RTA step at various temperatures (375, 450, 525 and 600°C). Afterwards Ti was removed in diluted HF, before contacting the sample using Ni/Au. The result was very bad and we found out that Ti has even larger affinity [6] for nitrogen as compared to its affinity to hydrogen.

Moreover, the last pre-treatment, called hereafter treatment X, has been applied before the RTA activation. The details of this pre-treatment will not be disclosed as further investigation is undergoing to determine its potential for a patent. This pre-treatment improves substantially the contact behaviour though a Schottky type contact was still dominant. At constant voltage (2.5 and 5 V) the measured current was 15-20 % higher to current of the reference sample.

Table 1 shows a summary of most relevant results.

	I (mA) at 2.5 V	I (mA) at 5 V	R _{sh} kΩ/sq	ρ _c (Ωcm ²)
Pt (90 nm)	0.3	0.6	110	9x10 ⁻⁴
Ti-treatment	0.5	1.5	-	5.4x10 ⁻³
Ni/Au (20/100 nm)				
RIE	0.2	0.5	-	-
N ₂ -plasma	0.25	0.5	140	-
Treatment X	0.85	1.9	36	8x10 ⁻⁴
Treatment X	0.9	2	35	6x10 ⁻⁴
Treatment X	0.9	2	34	5.2x10 ⁻⁴

Conclusions

We have investigated ohmic contacts on MOVPE grown p-doped GaN. All our contacts showed a Schottky-type behaviour. We also investigated the effect of several pre-treatments on the contacts and only treatment X increased the current at constant voltage for the same contact surface of about 15-20%. This treatment is at the moment the subject of a complementary study to determine its potential for a patent application.

References

- [1] S.Nakamura and G.Fasol, "The blue laser diode", Springer Verlag, Berlin, 1997.
- [2] M.C.J.C.M.Kramer, "Fabrication and characterization of metal-semiconductor contacts for application in AlGaIn/GaN HEMTs", Masters thesis, October 2000.
- [3] L.C. Chen, J.K. Ho, F.R. Chen, J.J. Kai, L. Chang, C.S. Jong, C.C. Chiu, C.N. Huang and K.K. Shih, *Physica Status Solidi (a)*, 176, p. 773, 1999.
- [4] Zhang A. P., Dang G. T., *J. of Vac. Sc.&Tech.-A*, 18, no4, p.1149.(2000)
- [5] Sang-Woo-Kim, Ji-Myon Lee, *Appl. Phys. Lett.* 76, no21, p.3079.(2000)
- [6] F.R.de Boer, "Cohesion in metals, Transition metal alloys", North Holland, 1988.