The effect of Mg diffusion on the contact resistance of low doped p-GaN

C. C. Chen, J. L. Yen, and Y. J. Yang

Department of Electrical Engineering, National Taiwan University, Taipei, Taiwan
yjyang@cc.ee.ntu.edu.tw

Abstract: Magnesium diffusion was applied to low doped p-GaN ($3 \times 10^{16} \text{ cm}^{-3}$) resulting in a reduction of resistance of the Ni/Au contact to the p-GaN by ~ 1.5 orders of magnitude.

In recent years III-nitride semiconductors have been studied intensively due to its important applications of the short-wavelength optoelectronics and electronics. Although the rapid progresses on this material system already makes the commercial laser diodes (LDs) available [1], still, the critical issue for the device is the lifetime. One of the factors affecting the lifetime is the high p-type contact resistance of the devices, which generates ohmic heating preventing the devices from cw or long-life operation. The obstacles of making a low resistance p-type contact to GaN are mainly in the difficulty to obtain a high in-situ doping level in p-GaN, and the lack of a metal with a large work function to eliminate or reduce the band offset. For the latter issue, various metals and annealing conditions were attempted to reduce the p-type contact and some good results have been achieved [2]. However, for the former issue, the doping levels in p-GaN are mostly limited to the growth systems and techniques used. Besides few reports, the maximum hole concentration in p-GaN is typically $\sim 5 \times 10^{17} \text{ cm}^{-3}$, which is about two orders of magnitude lower than that of the conventional III-V semiconductors such as GaAs for making a good p-type contact. The post-growth diffusion, which is a conventional way to increase the doping level of as-grown materials, has been unavailable for GaN until recently [3]. In this letter we report for the first time that Mg diffusion was applied to low doped GaN ($\sim 3 \times 10^{16} \text{ cm}^{-3}$) using Mg_3N_2 as Mg source to reduce the resistance of contact to p-GaN. The results have consistently showed a reduction of contact resistance by ~ 1.5 orders of magnitude.

A MOCVD grown p-GaN wafer with a hole concentration of $3 \times 10^{16} \text{ cm}^{-3}$ and a thickness of $\sim 2 \mu\text{m}$ was used for this study. To conduct the Mg diffusion into p-GaN, the sample was sealed with Mg_3N_2 powder in a vacuumed quartz ampoule and put into a 950°C for 5 min. Secondary ion mass spectroscopy (SIMS) was used to determine the Mg diffusion profile. Hall measurement was used to characterize the hole concentrations of the sample before and after diffusion. To understand the effect of surface treatment on the contact to p-GaN, the samples were also processed with and without 20 min Aqua regia etching for comparison. A Ni/Au film was deposited on the sample and annealed at 600°C for 1 min to form an ohmic contact. The contact resistance

Fig. 1. Current-voltage curves of the samples processed under four different conditions.

was measured by a transmission line model (TLM) using a linear configuration of $200 \times 80 \mu\text{m}^2$ metal pads with spacing varied from 4 to $40 \mu\text{m}$ linearly in 10 steps.

The measured hole concentration of the p-GaN sample increased from $3 \times 10^{16} \text{ cm}^{-3}$ to $3 \times 10^{17} \text{ cm}^{-3}$ after Mg diffusion. Since the diffusion region with the Mg concentration $> 5 \times 10^{19} \text{ cm}^{-3}$ observed from SIMS was only $\sim 0.2 \mu\text{m}$ thick, based on a $\sim 2 \mu\text{m}$ thick p-GaN layer, the actual hole concentration near the surface of GaN can be estimated to be $> 3 \times 10^{18} \text{ cm}^{-3}$, which was one order higher than the typical maximum hole concentration obtained from the in-situ doping in crystal growth. Fig. 1 shows the current-voltage (I-V) curves of the Ni/Au contacts to p-GaN wafers under four different process

Fig. 2. Contact resistance measured by the transmission line model on the four different samples as same as those used in Fig. 1.

conditions: the as-grown as well as the diffused samples each with and without surface treatment (Aqua regia etching). It clearly indicates that the resistance of the diffused samples was much lower than that of the as-grown samples. There is a turn-on of ~1 V on the I-V curve of the diffused sample without surface etching, indicating the existence of oxide on the GaN surface [4]. With the Aqua regia etching to remove the oxide a linear I-V curve showing an ohmic contact was obtained.

Fig. 2 shows the results of the TLM measurement on the four different wafers same as those used in Fig. 1. The contact resistance was determined to be $2.73 \Omega\text{-cm}^2$ for the as-grown wafer, $6.86 \times 10^{-2} \Omega\text{-cm}^2$ for the as-grown wafer with surface treatment, and $1.93 \times 10^{-3} \Omega\text{-cm}^2$ for the diffused wafer with surface treatment respectively. These results indicate that the contact resistance was reduced by ~1.5 orders of magnitude by the surface etching only [4], and improved by another ~1.5 orders of magnitude by the Mg diffusion. The improvement from the Mg diffusion can be explained as the following model: Since the transport property of the metal-semiconductor contact is dominated by the tunneling mechanism, the contact resistance R_c can be determined from the equation [5]

$$R_c \sim \exp\left(\frac{2\phi_B}{\hbar} \sqrt{\frac{\epsilon_s \cdot m^*}{N_A}}\right)$$

Thus the high acceptor doping level (N_A) of $> 3 \times 10^{18} \text{ cm}^{-3}$ resulted from the Mg diffusion into p-GaN will significantly reduce the contact resistance.

In conclusion, the Mg diffusion into low doped GaN indeed improved the Ni/Au contact to the p-GaN with a resistance reduction of ~ 1.5 orders of magnitude by increasing the doping level near the surface to $> 3 \times 10^{18} \text{ cm}^{-3}$. This new process in conjunction with an optimized metalization will provide a reliable way to make a low resistance contact to p-GaN, which plays an important role of fabrication of high quality and long life GaN based devices.

References:

- [1] S. Nakamura, M. Senih, S. Nagaham, N. Iwasa, T. Yamada, T. Matsushita, Y. Sugimoto, and H. Kiyoku, "Room-temperature continuous-wave operation of InGaN multi-quantum-well-structure laser diodes with a long lifetime," *Appl. Phys. Lett.* **70**, 868-870 (1997).
- [2] J. -S. Jang, S. -J. Park, and T. -Y. Seong, "Metalization scheme for highly low-resistance, transparent, and thermally stable ohmic contacts to p-GaN," *Appl. Phys. Lett.* **76**, 2898-2900 (2000).
- [3] J. L. Yen, K. W. Wen, Y. J. Yang, and C. Y. Lin, "p-type GaN formed by Mg diffusion using Mg_3N_2 as the Mg source", 25th International Conference on the Physics of Semiconductors, (Osaka, Japan, September 2000), p.934.
- [4] J. K. Kim, J. -L. Lee, J. W. Lee, H. E. Shin, Y. J. Park, and T. Kim, "Low resistance Pd/Au ohmic contacts to p-type GaN using surface treatment", *Appl. Phys. Lett.* **73**, 2953-2955 (1998).
- [5] S. M. Sze, *Physics of Semiconductor Devices*, 2nd ed., (Wiley, New York, 1981), p. 304.