Acceptor activation of Mg-doped GaN by microwave treatment

Shou-Jinn Chang a) and Yan-Kuin Su
Institute of Microelectronics, Department of Electrical Engineering, National Cheng Kung University, Tainan 70101, Taiwan, Republic of China
Tzong-Liang Tsai, Chung-Ying Chang, Chih-Lih Chiang, Chih-Sung Chang, Tzer-Peng Chen, and Kuo-Hsin Huang
Department of Research and Development, United Epitaxy Company, Hsinchu 300, Taiwan, Republic of China

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A microwave treatment method different from thermal annealing and low-energy electron beam irradiation was proposed to activate Mg dopants in p-type GaN epitaxial layer. From photoluminescence spectra and Hall effect measurements, it was shown that microwave treatment is a very effective way to activate the acceptors in Mg-doped p-type GaN layer. The activation of Mg dopant in p-type GaN layer may be explained as the breaking of magnesium–hydrogen bonding due to the microwave energy absorption. © 2001 American Institute of Physics.

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Gallium nitride (GaN) and related group III nitrides are promising materials for manufacturing green, blue, violet, and ultraviolet light emitting devices such as light emitting diodes (LEDs) and laser diodes (LDs). To fabricate such blue LEDs and LDs, it is necessary to achieve high conductive p-type GaN. However, it is difficult to achieve p-GaN with a high hole concentration. Sometimes, it is difficult to even achieve a p-type conductivity. It has been pointed out that hydrogen passivation is the reason to prevent acceptors from activation in p-type GaN. In order to achieve a highly conductive p-type GaN, low-energy electron beam irradiation (LEEBI) and thermal annealing are two popular methods that were used to activate the p-type impurity in GaN.

Akasaki et al. have used LEEBI to convert the compensated Mg-doped GaN into conductive p-type material. However, with acceleration voltage of 5–15 kV, an electron beam can only reach a depth of about 0.5 μm. Therefore, LEEBI is not an effective way to convert a thick high-resistive Mg-doped GaN into a p-type conducting material. Nakamura et al. proposed a method to reduce the resistivity of p-type GaN by thermally annealing the GaN samples in a nitrogen atmosphere at elevated temperatures. In order to effectively activate Mg dopants in GaN, the annealing process should be carried out in the temperature range of 600–1200 °C. At such a high temperature, thermal dissociation of GaN may occur because the dissociation pressure gradually increases when the temperature is higher than 700 °C. In this letter, we report the acceptor activation of Mg-doped GaN layer by microwave treatment, which can be accomplished at a lower temperature and with a shorter cycle time.

The p-type GaN epitaxial layers used in this study were grown on c-face (0001) sapphire substrates by low-pressure metalorganic chemical vapor deposition. Trimethylgallium (TMGa) and ammonia (NH₃) were used as the source material of Ga and N, respectively. Biscyclopentadienylmagnesium (Cp₂Mg) was used as the p-type dopant source. Before epitaxial growth, sapphire substrate was first heated at 1150 °C in a stream of hydrogen to clean the substrate surface. Then, the substrate temperature was cool down to 510 °C so as to deposit a 25 nm GaN buffer layer onto the substrate. During GaN buffer layer growth, the flow rate of TMGa and NH₃ were kept at 1.19×10⁻⁵ and 7.14×10⁻² mol/min, respectively. The temperature was then raised to 1130 °C to grow the 4 μm p-type Mg-doped GaN layer. The acceptor activation of Mg-doped GaN layer was performed by a 2.45 GHz, 560 W microwave treatment with different process time. For comparison, a 730 °C, 20 min furnace annealed Mg-doped GaN sample was also prepared. The activation of acceptors was assessed by photoluminescence and Hall measurement. For Hall effect measurement, Ni/Au layers were deposited onto the surface of the Mg-doped GaN layer as the p-type contact. The resistivity and carrier concentration of Mg-doped GaN samples were then measured by a Polaron Hall effect measurement system. Figure 1 shows the photoluminescence spectra of the p-type Mg-doped GaN (a) with a 5 min microwave treatment, (b)

![Photoluminescence spectra](image)

**FIG. 1.** The photoluminescence spectra of Mg-doped GaN (a) with microwave treatment (b) with thermal annealing (c) as grown without any treatment.
with a 730 °C, 20 min thermal treatment, and (c) as-grown layer without any treatment. It can be seen that Mg-doped GaN layers with microwave treatment and with furnace annealing both showed a strong 437.5 nm blue peak compared with the as-grown sample without any treatment. Figures 2 and 3 show the resistivity and hole concentration of Mg-doped GaN layer with different amount of microwave treatment time. These data were measured by Hall measurement. From these two figures, we can see that the measured resistivity (i.e., 1.1–1.65 Ω cm) and hole concentration (i.e., $9.75 \times 10^{17}$ cm$^{-3}$–$2.15 \times 10^{18}$ cm$^{-3}$) were almost independent of the microwave treatment time. On the other hand, the measured hole concentration at a depth of 1 μm from the surface is lower than that of the surface, it is still much higher than that of the as-grown p-type GaN sample. For the wet chemical etched sample, the carrier concentration at a depth of 1 μm from the surface is almost the same as that at the surface. For the RIE etched sample, we believe the reason why the carrier concentration at a depth of 1 μm from the surface is lower may be due to the damage caused by RIE.

In conclusion, we have shown that microwave treatment is an effective way to activate the acceptors in p-type Mg-doped GaN layer. Using microwave treatment, we can easily convert a high resistivity Mg-doped GaN layer into a conductive p-type GaN layer.

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