

Electrical and Optical Characterization of Mg doping in GaN

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Abstract. A possible evidence of Mg related emission in Mg doped GaN material is observed in optical measurement, even without thermal annealing. Meanwhile, the electrical properties of the sample improve when Ni/Au contact layer was annealed up to 400°C, but degrade at further temperature. We propose that such behavior is related to degradation of surface morphology of metal contact at higher temperature.

Introduction

P-type GaN (p-GaN) is one of the critical elements in development of III-V nitride based devices. Traditionally, magnesium (Mg) is used as a dopant for GaN in order to achieve p-type conductivity. However, producing p-GaN with high hole concentration is quite problematic as the activation energy of the Mg is high (135-160 meV) [1-4]. This is due to the strong bonding of Mg-H complexes. For this reason, the evidence of Mg doping in GaN is difficult to be observed in many measurements. On top of that, the strong bonding of the Mg-H complexes leads to low free carrier concentration, causing the difficulty to obtain an excellent Ohmic contact on Mg doped GaN with low resistance.

Here, we investigate the properties of Mg doped GaN using a commercial sample, which was grown by metal-organic chemical vapor deposition (MOCVD). The optical measurement via photoluminescence (PL) allows us to observe the evidence of Mg incorporation in the GaN sample. Further, the ability of the sample to achieve good electrical characteristic will be determined using current-voltage (*I-V*) measurements. The factors that affect the electrical characteristic of the samples are proposed.

Materials and Method

In this work, we used a commercial Mg doped GaN sample grown on sapphire substrate. The doping concentration of the sample is $\sim 10^{17} \text{ cm}^{-3}$. At the first stage, the sample was measured using PL measurement and the results were analyzed so that the evidence of incorporation of Mg in the GaN can be identified. The experiment was conducted at room temperature with the excitation wavelength of 325 nm. Next, Ni-Au metal layers were deposited on the sample using thermal evaporator and annealed at different temperatures (in nitrogen gas ambient) in order to increase the diffusion of the metal contact into the sample. Next, the electrical properties of the sample were measured by *I-V* measurement. In this experiment, a positive bias is applied on the top of the sample, hence allowing electrons to be injected from the bottom contact. Such condition is operated under forward bias. Results from this measurement will identify the electrical contact characteristics of the sample; either it has ohmic or Schottky characteristics. The change of the electrical behavior of the sample with the annealing temperature was discussed.

Result and Discussion

Optical properties. Fig. 1 shows the PL spectrum of the Mg doped GaN sample. Clearly, there is a broad peak around 3.0 to 3.3 eV. We suspect that the transitions from the Mg impurities level may also contribute to this peak. To support this, we had measured PL of an undoped GaN on Si substrate, which typically, has higher density of defects and impurities than most GaN samples on sapphire substrate. The PL for both samples is compared and the result is shown in the insert figure of Fig. 1. It can be seen that the strong peak near band edge emission in GaN/Si sample is broader than that of the Mg doped GaN and it is shifted to lower energy. These indicate that there are high defects and impurities in the GaN/Si sample. In contrast, on the lower energy side, Mg doped GaN sample exhibits a broader emission peak as compared to the GaN/Si sample. This shows that there is possibility that the transition from Mg level also contributes to the emission. In addition to that, such behavior proposes that our sample does not require a thermal annealing process to activate the Mg acceptor, as has been reported in [5]. On another matter, the yellow band emission, which is typically observed at 2.5 eV is almost invisible in the spectrum.

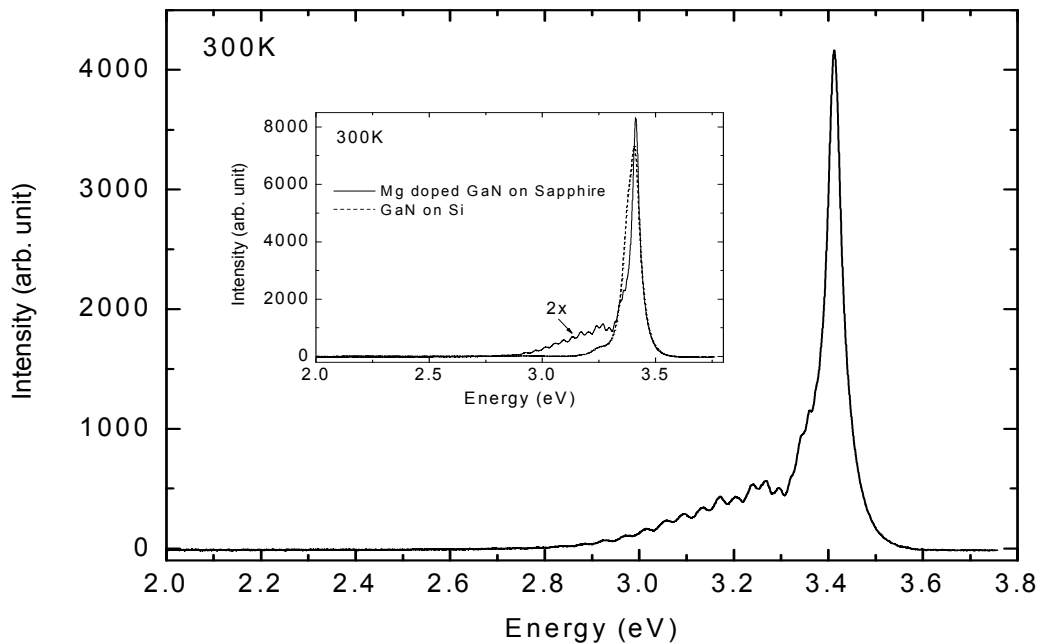


Fig. 1: PL spectrum of the Mg doped GaN sample. Insert figure shows the comparison of PL for the Mg doped sample and the undoped GaN on Si sample.

Next, the electrical properties of the Mg doped GaN samples were investigated via I - V measurement. Prior to this work, Ni ($\sim 0.6\mu\text{m}$)-Au ($\sim 0.3\mu\text{m}$) metal bi-layers were deposited onto the sample using thermal evaporator. The sample was then annealed at different temperature. Changing in temperature results in different I - V characteristic of the sample and this is shown in Fig. 2. Clearly, the sample shows good electrical properties when it was heated up to 400°C . However, further increase in the temperature slightly degrades the electrical properties of the sample. We ambiguously suggest that such behavior relates to the degradation of surface morphology of the metal contact and this will be explained in following discussion.

On the other matter, it is worth to note that the I - V curves do not show Ohmic characteristic at all. This issue may relate to the use of nitrogen gas during the anneal process. Instead, we suggest that oxygen gas would promote good Ohmic characteristic to the sample as the gas will introduce a p-type Ni-oxide layer between Ni and p-GaN [6, 7]. Such layer carries high hole density that makes less resistance to the current to be injected to the sample.

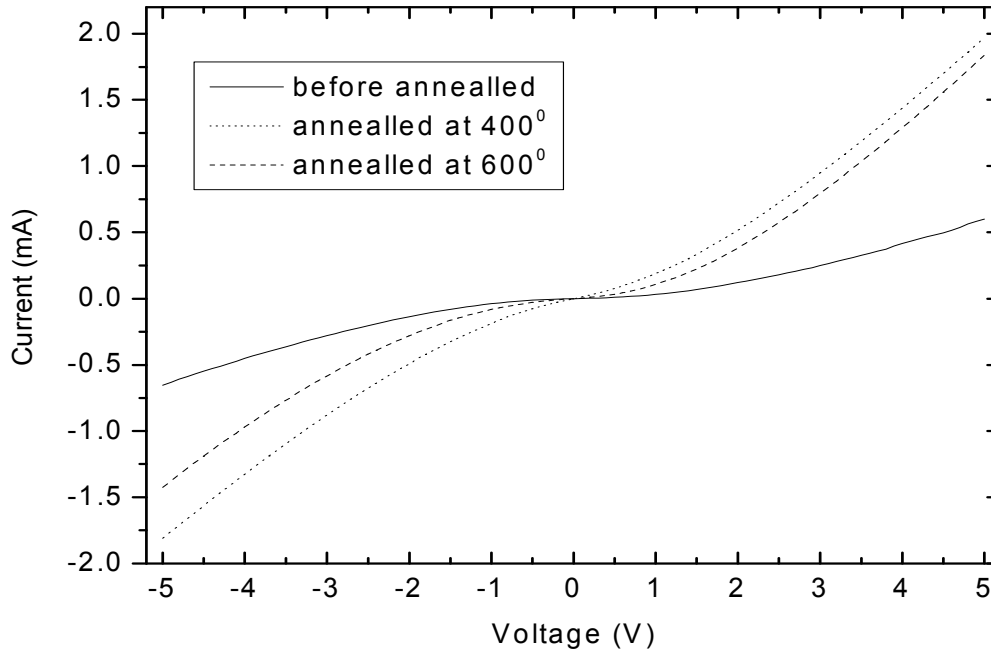


Fig. 2: I - V characteristic of the Mg doped GaN sample annealed at different temperature. Obviously, the electrical properties of the sample behave differently with temperature.

Fig. 3 shows the surface morphology of the metal contact layers on the sample with the variation of annealing temperature. Detailed investigation found that the surface becomes smoother when the sample was annealed up to 400°C. At this temperature, the electrical contact of the sample is improved due to the increase of the metal diffusion into the sample. However, the surface morphology of the metal layers degrades at 600°C, as shows Fig. 3c. This may lead to the fluctuation of the metal layers and surface roughness, and hence reduces the electrical properties of the sample. Degradation of surface morphology of the Ni-Au metal layers on p-GaN samples at higher temperature has been reported across literature, see example [8, 9].

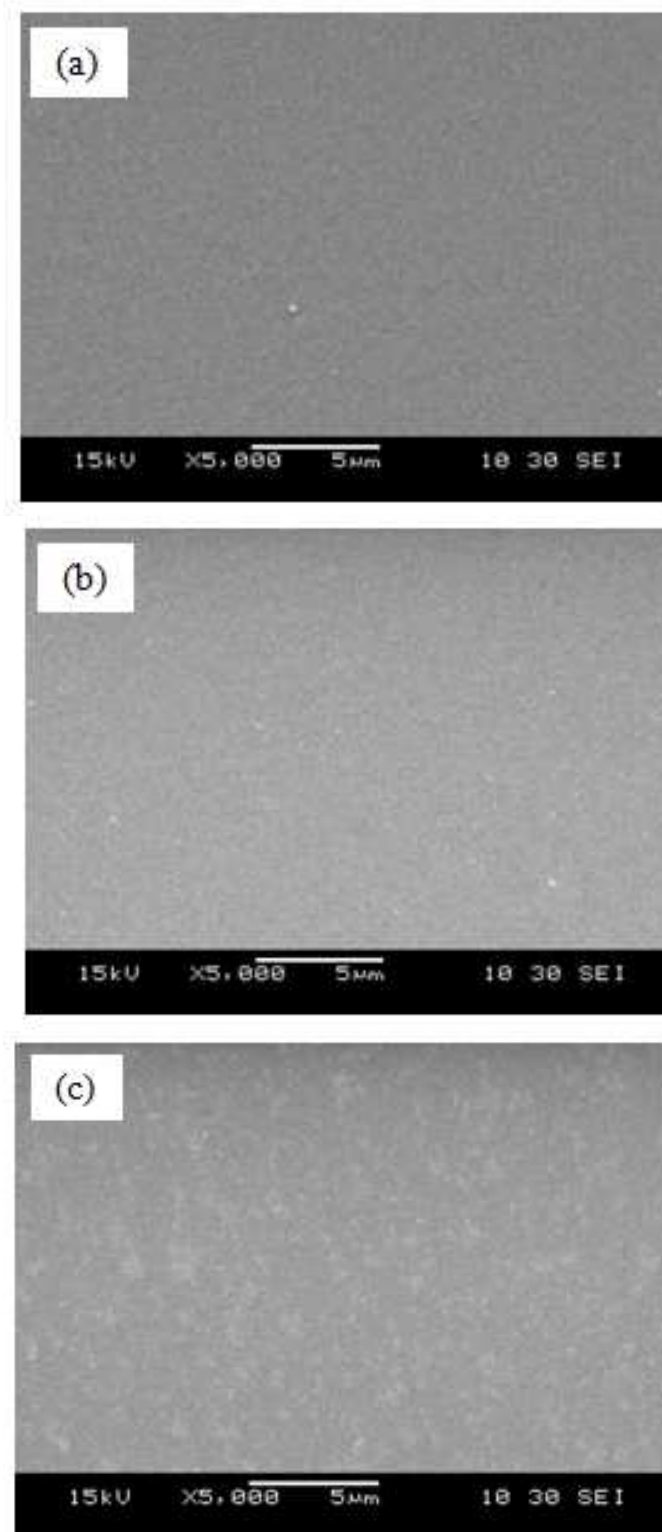


Fig. 3: SEM images of surface morphology of the Ni-Au metal layers on the Mg doped GaN sample at different annealing temperature. (a) before annealed, (b) annealed at 400°C and (c) annealed at 600°C.

Conclusion

The possibility that Mg played a role in the optical transitions in the Mg doped GaN sample was observed in the PL measurement. A Ni-Au layer was deposited onto the sample and its I - V properties degraded as the temperature increased. The degradation of surface morphology might be the factor to this issue.

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