Extended Abstracts of the 2020 International Conference on Solid State Devices and Materials, VIRTUAL conference, 2020, pp153-154

Two-Dimensional Characterization of n-GaN Schottky Contacts Printed by Using Ni Nanoink

Kenji Shiojima[1], Yuto Kawasumi[1], Yuto Yasui[1], Yukiyasu Kashiwagi[2], and Toshiyuki Tamai[2]

[1] Univ. of Fukui
3-9-1 Bunkyo, Fukui-shi, Fukui 910-8507, Japan
Phone: +81-776-27-8560 E-mail: shiojima@u-fukui.ac.jp
[2] Osaka Research Institute of Industrial Science and Technology
1-6-50 Morinomiya, Joto-ku, Osaka-shi, Osaka 536-8553, Japan

Abstract

We report on uniformity of Ni Schottky contacts printed by using Ni nanoink on n-GaN epitaxial wafers by scanning internal photoemission microscopy (SIPM) at various annealing temperature (T_a). When T_a was 500 ºC, a better uniformity was obtained than that of 400 ºC. A Schottky barrier height was as high as 1.25 eV, which is close to that of a conventional evaporated Ni contact. When T_a was 600 ºC or higher, rectifying characteristics were degraded. Less uniformity in the SIPM map was observed after 850 ºC annealing. We found that SIPM is a powerful tool for nondestructively visualizing inhomogeneity over printed electrodes.

1. Introduction

A printing method is explored as a direct formation method for electrodes onto semiconductor surfaces under atmospheric pressure, rather than electron beam evaporation. We have demonstrated uniform luminescence of Eu-doped GaN light-emitting diodes with printed ITO and Ag ohmic contacts to p-GaN layers [1,2]. On the other hand, the development of basic processing techniques for printing electrodes on wide-band gap materials is still premature. We proposed that SIPM could be used to map the electrical inhomogeneities of metal-semiconductor interfaces [3]. We have demonstrated to characterize uniformity of printed Ag/n-GaN Schottky contacts [4]. In this study, for the electron-device application, we report on the basic electrical characteristics of printed Ni/n-GaN Schottky contacts in conjunction with T_a of the Ni nanoink electrodes.

2. Sample preparation and characterization

The epitaxial layers were grown by metal organic vapor phase epitaxy on a sapphire substrate, and consisted of a 1-µm-thick n-GaN layer on a 1-µm-thick undoped-GaN and low-temperature-grown AlN buffer layers, as shown in Fig. 1. The GaN surface was submerged in HCl:H_2O (1:5) and subsequently rinsed in deionized water. Drawing the dots of Ni nanoinks was carried out using a needle-type dispenser (Applied Micro Systems Inc.) on the treated substrate. The tip diameter of needle is 100 µm, and the diameter of the annealed Ni dots is about 150 µm. Isochronal annealing at 400, 500, 600, and 850 ºC for 10 min was conducted in an N_2 ambient. Finally, InGa ohmic contacts were deposited on the same surface.

We conducted current-voltage (*I-V*), internal photoemission: photoresponce (PR), and SIPM measurements [3]. SIPM is based on the PR measurement. When a monochromatic light with a photon energy below the energy bandgap and exceling Schottky barrier height ($q\phi_B$) is incident on a metal/semiconductor interface, electrons in the metal can overcome the barrier and generate a photocurrent. In this technique, Y is defined as the photoyield, which is a measurement of the photocurrent per number of incident photons. According to Fowler's equation ($Y^{1/2}$ = (hν - qϕ_B)), $q\phi_B$ can be determined. In the SIPM measurements, the laser beam is focused and scanned over the interface to obtain a 2-dimensional imaging of Y. We used a green laser (λ = 517 nm) as a light source.

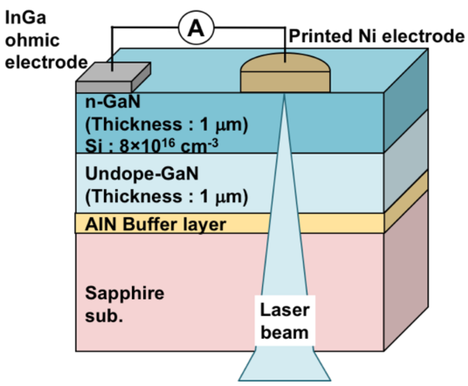


Fig. 1 Printed Ni Schottky contacts formed on the n-GaN epitaxial layer grown on a sapphire substrate by MOCVD.

3. Results and discussion

In the *I-V* characteristics as shown in Fig. 2, the Ni contact annealed at 400 ºC exhibited small forward and reverse currents due to a large series resistance. After annealing at 500 ºC, because the printed Ni nanoink became more conductive, excellent rectifying characteristics with $q\phi_B$= 1.25 eV and n-value= 1.08 were observed. However, when T_a is 600 ºC or higher, the forward and reverse currents significantly increased, because of the interfacial reaction between Ni and GaN. The same trend can be seen for a conventional evaporated Ni contact after annealing around 600 ºC.

In the PR spectra as shown in Fig. 3, as expected from the *I-V* characteristics, a larger Y signal than that at 400 ºC and a straight relationship based on the Fowler's equation can be seen for the contact annealed at 500 ºC. Whereas for the samples annealed at 600, and 850 ºC, the signals became noisy.

We obtained reasonable values of $q\phi_B$ = 1.29 eV, which is close to that of the conventional evaporated Ni contacts.

Figure 4 shows the optical microscope images of the contacts. For the samples annealed at 400 and 500 ºC, center-thick dots typically drawn by a needle-type dispenser were observed. After annealing at 600 ºC, in the periphery of the dot, the surface became rough. Finally, at 850 ºC, the entire dot surface became rough, because of the interfacial reaction.

Figure 5 shows the typical SIPM Y images at λ= 659 nm. For the contact annealed at 400 ºC, the Y signal is small, and significant adhesion at the interface is not obtained. We observed a large Y signal and the better uniformity for the contact annealed at 500 and 600 ºC. When T_a is 850 ºC, decreasing Y and loosing uniformity proceeded from the periphery. Therefore, we confirmed that SIPM is useful to observe inhomogeneity of such a buried interface.

4. Conclusions

Basic electrical characteristics and uniformity of the printed Ni Schottky contacts on n-GaN were characterized. When T_a was 400 ºC, the series resistance was large, and significant adhesion at the interface was not obtained. After annealing at 500 ºC, better I-V characteristics, a large $q\phi_B$ value of 1.25 eV, a small n-value of 1.08 and better uniformity were observed. Finally, when T_a is 600 ºC or higher, the I-V characteristics became leaky, and loosing uniformity proceeded from the periphery because of the interfacial reaction. We confirmed that printing Ni nanoink is a candidate to form Schottky contacts on n-GaN.

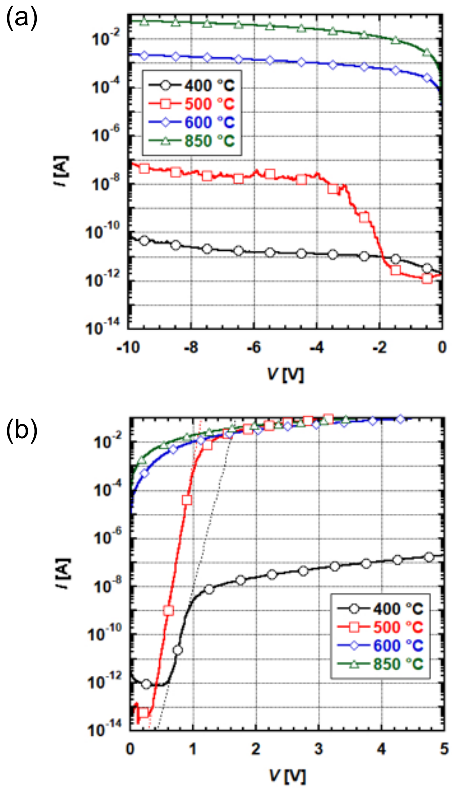
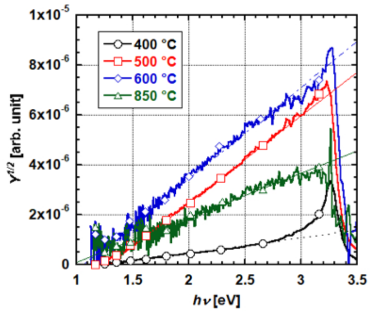


Fig. 2 (a) Reverse and (b) forward I-V characteristics of the printed Ni Schottky contacts with different T_a up to 850 ºC.



Anneling temp. [ºC]	$q\phi_B$ [eV]
400	1.28
500	1.29
600	1.06
850	0.95

Fig. 3 PR spectra of the printed Ni Schottky contacts annealed up to 850 ºC.

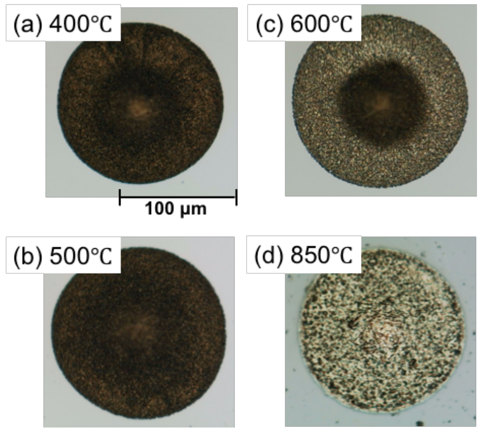


Fig. 4 Optical microscope images of the printed Ni Schottky contacts annealed at (a) 400, (b) 500, (c) 600, and (d) 850 ºC.

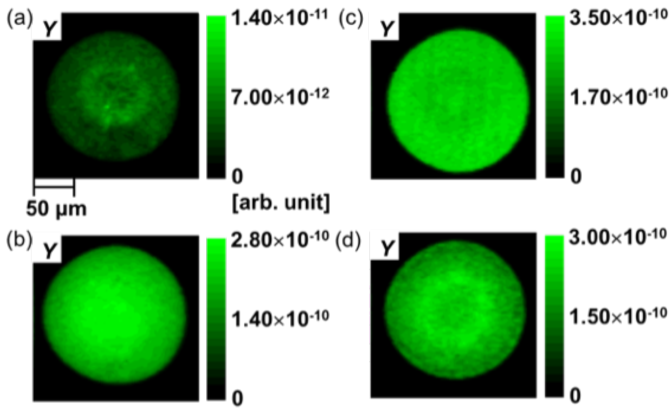


Fig. 5 SIPM Y maps at λ = 517 nm of the Ni Schottky contacts annealed at (a) 400, (b) 500, (c) 600, and (d) 850 ºC.

Acknowledgements

A part of this work was supported by a Grant-in-Aid for Scientific Research C (18K04228) of the Ministry of Education, Culture, Sports, Science and Technology.

References

[1] Y. Kashiwagi et al., Appl. Phys. Lett., **105** (2014) 223509.
[2] Y. Kashiwagi et al., ICEP-IAAC 2016 Proc., (2016) 129.
[3] K. Shiojima et al, APEX, **8** (2015) 046502-1.
[4] K. Shiojima et al, JJAP, **57**, (2018) 07MA01-1.