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Uniformity Characterization of Printed Schottky Contacts Formed on n-GaN Epitaxial Layers by Using Ag Nanoink

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Abstract

We report on uniformity of Ag Schottky contacts printed on n-GaN epitaxial wafers by using Ag nanoink in conjunction with overlaying times characterized by scanning internal photoemission microscopy (SIPM). When the overlaid time was one, due to strong water-repulsion, the nanoink was isolated in small particles. We found that when the overlaying was more than 4, the samples exhibited better uniformity. 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 red light-emitting diodes (LEDs) with printed ITO ohmic contacts to p-GaN layers [1], and blue LEDs with Ag ohmic contacts to p-GaN layers [2]. On the other hand, the development of basic processing techniques for printing electrodes on wide-band gap materials is still premature. In this study, we report on the basic electrical characteristics of printed Ag/n-GaN Schottky contacts in conjunction with overlaying times (OT) of the Ag nanoink.

2. Sample preparation and characterization

The epitaxial layers were grown by metal organic vapor phase epitaxy on a sapphire substrate, and consisted of a 2-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 Ag 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 sintered Ag dots by up-to-ten times overlay printing is about 180 µm. Finally, InGa ohmic contacts were deposited on the same surface.

We conducted current-voltage (*I-V*) and SIPM measurements [3]. The *I-V* results were analyzed with the thermionic emission model to obtain Schottky barrier height ($q\phi_B$) and the ideality factor (n-value). SIPM is based on internal photoemission measurements. When a monochromatic light with a photon energy below the energy bandgap and exceling $q\phi_B$ 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. In the SIPM measurements, the laser beam is focused and scanned over the interface to obtain a 2-dimensional imaging of Y.

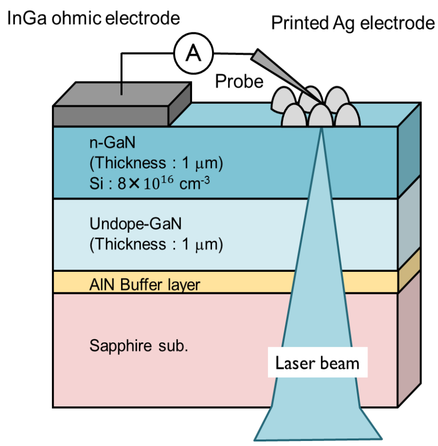

Fig. 1 Printed Ag Schottky contacts formed on the n-GaN epitaxial layer grown on a sapphire substrate by MOCVD.

3. Results and discussion

The printed Ag contacts with OT up to 10 exhibited good exponential forward *I-V* characteristics as shown in Fig. 2. However, when OT is 1, the forward current level is more than two-order-magnitude lower than other samples. When OT > 1, we obtained reasonable values of $q\phi_B$ = 1.3 eV, and n=1.45.

In the optical microscope images of the contacts with OT = 1, 2, and 10 as shown in Fig. 3, the printed nanoink was split into small particles over the dot area, due to the strong water-repulsion of the GaN surface. The observed diameter of the particles ranged 2 to 5 µm. However, OT>1, the particles became connected to each other from the center to the edge of the dot.

In the SIPM images (Fig. 4) at λ= 516 nm for the same samples as shown in Fig. 3, because the most of Ag particles were connected each other by increasing OT, the shape of the effective electrode was imaged. We obtained SIPM signal even at the edge of the dot when OT > 4, and better uniformity was obtained. SIPM is useful to observe inhomogeneity of such a buried interface.

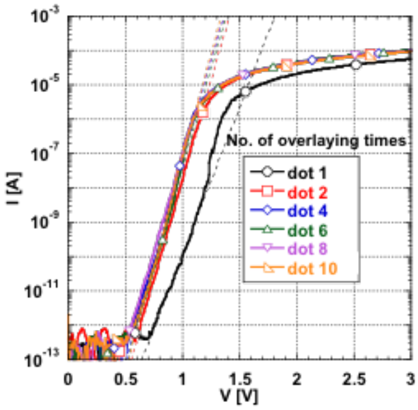

Fig. 2 Forward *I-V* characteristics of the printed Ag Schottky contacts with different overlaying times up to 10.

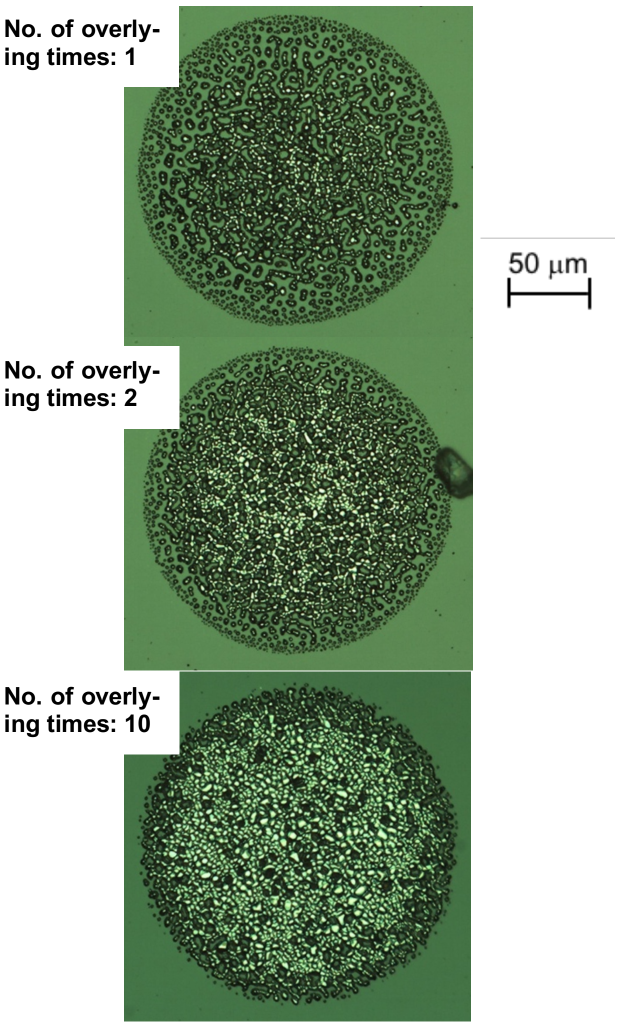

Fig. 3 Optical microscope images of the printed Ag Schottky contacts with overlaying times of 1, 2, and 10.

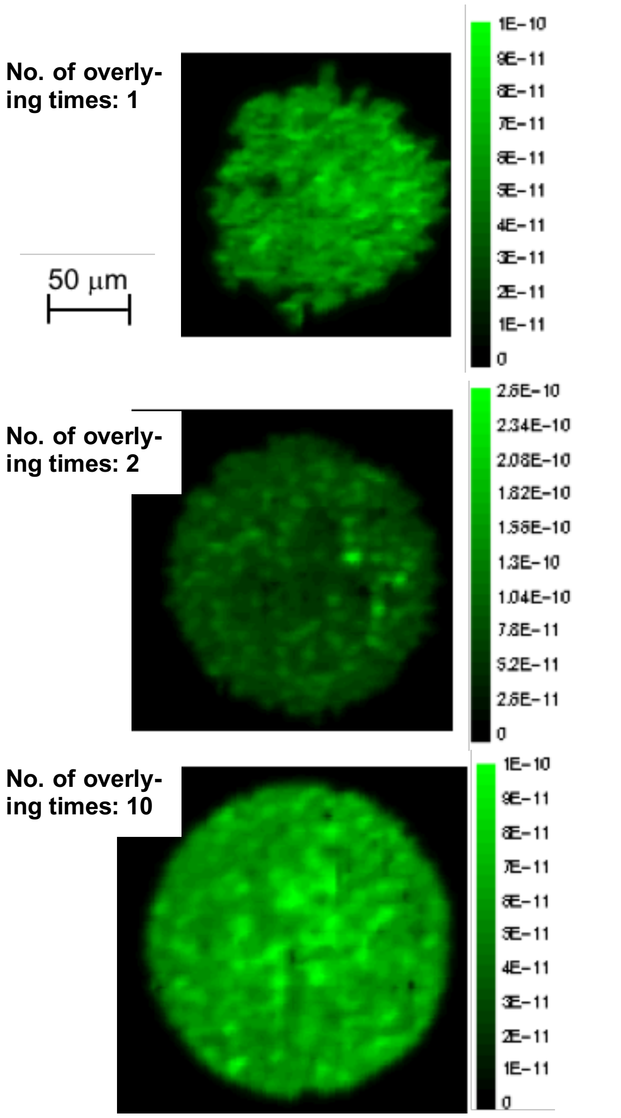

Fig. 4 Y maps at λ = 516 nm of the same Ag Schottky contacts as shown in Fig. 3.

4. Conclusions

Uniformity of the printed Ag Schottky contacts on n-GaN were characterized by SIPM. When TO was one, because the Ag nanoink was spread out into small particles, the current level was small and the SIPM signal was not detected from the entire dot. By increasing TO, the effective area of the electrode became larger, and finally when TO >4, we confirmed good uniformity over the dot. SIPM is useful to observe inhomogeneity of such a buried interface.

Acknowledgements

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