AIP Applied Physics Letters

Nanometer sized Ni-dot/Ag/Pt structure for high reflectance of p-type contact metal in InGaN light emitting diodes

Kyu Sang Kim, Myoung Gyun Suh, and S. N. Cho

Citation: Appl. Phys. Lett. **100**, 061113 (2012); doi: 10.1063/1.3685466
View online: http://dx.doi.org/10.1063/1.3685466
View Table of Contents: http://apl.aip.org/resource/1/APPLAB/v100/i6
Published by the American Institute of Physics.

Nanometer sized Ni-dot/Ag/Pt structure for high reflectance of p-type contact metal in InGaN light emitting diodes

Kyu Sang Kim,[1,a)] Myoung Gyun Suh,[2] and S. N. Cho[3]
[1]*Department of Applied Physics & Electronics, Sangji University, Wonju, Gangwon-Do 220-702, Korea*
[2]*Department of Applied Physics, California Institute of Technology, Pasadena, California 91125, USA*
[3]*Micro Devices Group, Micro Systems Laboratory, Samsung Advanced Institute of Technology, Samsung Electronics Co. Ltd., Giheung-Gu, Yongin-Si, Gyeonggi-Do 446-712, Korea*

(Received 13 October 2011; accepted 24 January 2012; published online 9 February 2012)

The Ni-dot/Ag/Pt layer, where Ni-dot layer is formed of nanometer sized Ni dots, has been used to improve the reflectivity from the surface of p-type GaN in a light emitting diode (LED). Comparing with Ni/Ag/Pt layer, where Ni layer is a thin film, the Ni-dot/Ag/Pt structure shows significantly improved reflectivity with stable contact resistivity. The optical output power and external quantum efficiency of InGaN LEDs with Ni-dot/Ag/Pt structure for p-metal have improved by 28% and 29%, respectively, over the results of Ni/Ag/Pt structure. © *2012 American Institute of Physics*. [doi:10.1063/1.3685466]

The optical output power of (Al,In)GaN based light emitting diode (LED) can be significantly improved by enhancing the light extraction efficiency, and such has been extensively investigated by others.[1–4] For instance, in the vertical thin GaN LED structure, a silver coating may be applied to the surface of p-type GaN for high reflectivity.[5–10] This has an effect of improving the light extraction at the surface of n-GaN side, which surface faces the p-type GaN. Unfortunately, such solution faces difficulties arising from fabrication processes. For one, the silver easily agglomerates and oxidizes while annealing, resulting in a "peeling off." In addition, the direct deposition of Ag on the surface of p-GaN results in poor Ohmic contact due to its low work function. As a result, high contact resistance is introduced by silver coating, which is undesirable.[11,12] In an attempt to resolve the peeling off and high contact resistance problems, a Ni layer has been inserted between the p-GaN surface and the Ag coating.[13–16] Although introduction of Ni layer improves the adhesion and decreases the contact resistance, it has a side effect of degrading the overall reflectivity from Ag coated p-GaN surface. We suspect that by using nanometer sized "Ni-dots" instead of Ni thin film layer, the reflectivity from Ag/Ni/p-GaN surface can be significantly improved while maintaining good adhesion and low contact resistance of Ag coating.

In this report, we demonstrate that high reflectance (>90%) is achieved by applying Ni-dot/Ag/Pt layer to a vertical type blue LED. For comparison, the performance of Ni-dot/Ag/Pt structure has been directly compared with the Ni/Ag/Pt counterpart, where the Ni layer is a thin film instead of composing of nanometer sized Ni-dots, by considering the optical output power and external quantum efficiency (EQE) of vertical type blue LEDs.

The LED structure was grown on the c-plane sapphire substrate by metal-organic chemical vapor deposition (MOCVD) method. The emission wavelength of InGaN LEDs has been carefully chosen for the dominant wavelength of 445 nm. The produced device has a chip size of roughly 1×1 mm^2. For the chip produced, the p-contact metal layer composed of Ni/Ag/Pt/Au was deposited on the top of p-GaN layer and the n-contact metal layer composing of Ti/Al/Ti/Au was deposited on the bottom of n-GaN layer immediately following the ICP-RIE etching. The nanometer sized Ni-dots were formed by depositing Ni on p-GaN surface at a rate of 0.3 Å/s for few seconds and then annealing at 450 °C in O_2 ambient for 1 min. This annealing condition corresponds to a minimum Ohmic contact resistance for the deposited Ni-dot/Ag/Pt/Au layer.

Ni-dots produced are categorized according to their diameter size, which critically depends on the Ni evaporation time and temperature. In this work, we were able to produce Ni-dots with diameter less than 10 nm as well as those with diameters ranging anywhere between 20 nm and 90 nm. Larger Ni-dots are formed from agglomeration of smaller dots, and such agglomeration rate increases with evaporation time. Illustrated in Figure 1 are atomic force microscopy (AFM) and scanning electron microscopy (SEM) images of the produced Ni-dots on P-GaN surface. In Figure 1(a), the Ni was evaporated for 5 s and the result shows Ni-dot formations of diameters between 2 nm and 7 nm. We shall denote this sample as type-1 throughout the discussion. Although the majority of Ni-dots formed have diameters less than 10 nm, there are sparsely formed agglomerations of Ni-dots with much larger diameters, i.e., 35 nm to 84 nm. For the sample in Figure 1(a), the density of Ni-dots formed is about 730 dots per square micrometer. Illustrated in Figure 1(b), denoted as type-2, is the sample with evaporation time of 17 s. As discussed, the resulting Ni-dots have much larger diameters, which ranges between 21 nm and 51 nm. For the type-2, the density of Ni-dots formed is about 380 dots per square micrometer.

In this work, we compare four types of p-metal structures on double side polished sapphire wafer for the reflectance. They are (1) Ag/Pt, (2) type-1/Ag/Pt, (3) type-2/Ag/Pt, and (4) Ni/Ag/Pt, where the layer thickness of Ni and Ag layers is 1 nm and 100 nm, respectively.

a)Electronic mail: kyuskim@sj.ac.kr.

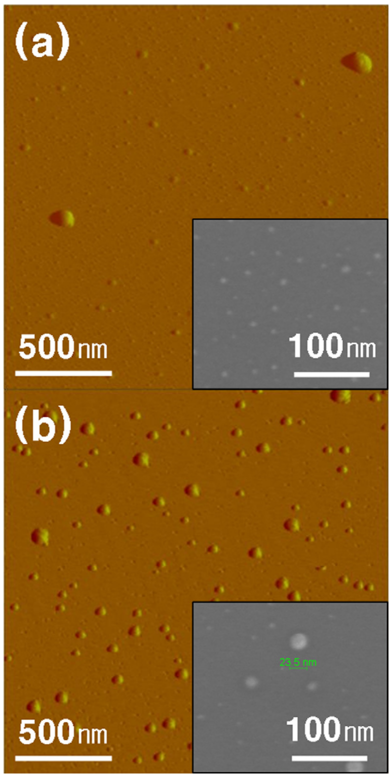

FIG. 1. (Color online) AFM image and SEM image of the evaporated nanometer sized Ni-dots on P-GaN surface with controlling its grain size of (a) 2-7 nm and (b) 20-50 nm, respectively, by evaporation time and temperature.

Illustrated in Figure 2 are the measured reflection spectra of the aforementioned four types. For the wavelength of 445 nm, the sample with type-1/Ag/Pt and sample with type-2/Ag/Pt, respectively, yield reflectivity of 93.7% and 91.8%. This is a remarkable increase in the reflectivity over Ni/Ag/Pt sample, which shows reflectivity of 86.7%. Comparing with the Ag/Pt sample, which has the best reflectivity value among the four, i.e., 95.8%, the sample with type-1/Ag/Pt layer shows reflectance only lower by 2.1%. This result clearly shows that by using Ni-dot instead of Ni thin film layer, the reflectivity in p-metal can be significantly increased.

Illustrated in Figure 3(a) are the measured LED output power and external quantum efficiency versus the operation current for each of the aforementioned four types. At the injection current of 350 mA, the optical output power of blue

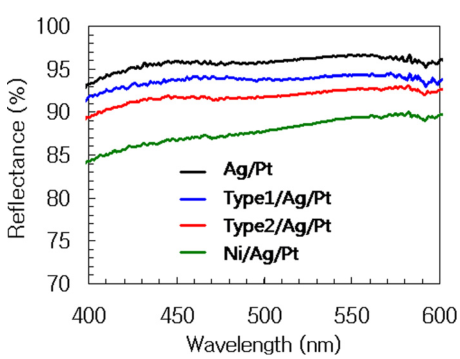

FIG. 2. (Color online) Measured reflection spectra of p-metal layers; Ag(100 nm)/Pt, Ni-dot (type 1)/Ag(100 nm)/Pt, Ni-dot (type 2)/Ag(100 nm)/Pt, and Ni thin film (1 nm)/Ag(100 nm)/Pt, respectively.

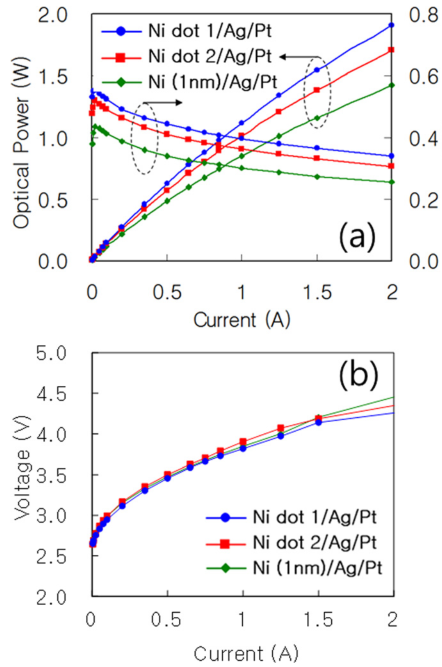

FIG. 3. (Color online) (a) Measured LED output power and external quantum efficiency versus the operation current and (b) measured operating voltage versus the operation current for each LED structure of given reflectivity.

LEDs increased as much as by factor of approximately 1.27 for samples with Ni-dots over the one with Ni thin film layer. The external quantum efficiency has increased by factor of 1.3 for samples with Ni-dots over the one with Ni thin film layer. Interestingly, the enhancement ratio of the optical output power of blue LEDs with increased p-metal reflectivity is about 3.37.

Illustrated in Figure 3(b) is the measured LED voltage versus the operation current for each of the aforementioned four types. The turn-on voltage of blue LEDs is all about the

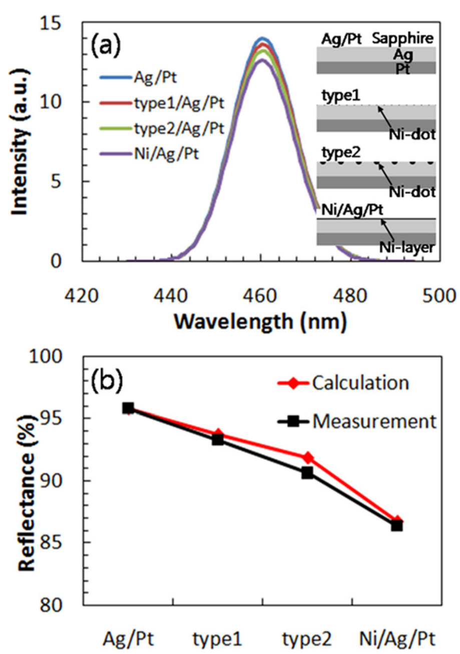

FIG. 4. (Color online) For each of the p-metal structure (inset of figure (a)), (a) calculated reflection spectra by 2-dimensional finite-difference time-domain method and (b) plots of measured and calculated reflectivity.

same, i.e., ~2.66 V. In addition, at the injection current of 350 mA, the operation voltage of blue LEDs is little difference of ~3.3 V. The contact resistivity of Ni-dot/Ag/Pt type p-metal and Ni-layer/Ag/Pt type p-metal are of $2–3 \times 10^{-3}$ Ωcm^2 and $1–4 \times 10^{-3}$ Ωcm^2, respectively. We assume that the low Ohmic contact resistivity of Ni-dot/Ag/Pt metal on p-GaN is attributed to the aforementioned oxidation annealing promoting the out-diffusion of Ga atoms from GaN to the surface to dissolve in the Ag layer, leaving Ga vacancies below the contact.[13]

Finally, we have calculated the reflected light intensity for each of the aforementioned four types using the 2-dimensional finite-difference time-domain method (2D FDTD). The 2D FDTD calculation was done using MEEP and the results are shown in Figure 4(a). Illustrated in Figure 4(b) is the comparison between the calculated and the measured results, which shows a good agreement.

In summary, we have experimentally shown that high reflectivity with stable operating voltage can be achieved from p-type GaN surface by using Ni-dot/Ag/Pt layer instead of Ni/Ag/Pt layer, where in the later, the formation of Ni is a thin film. We have also compared the measured data with 2D FDTD calculation and showed that they are in good agreement.

This research was supported by Sangji University Research Fund, 2011.

[1]C. Huh, K. S. Lee, E. J. Kang, and S. J. Park, J. Appl. Phys. **93**, 9383 (2003).
[2]T. Fujii, Y. Gao, R. Sharma, E. L. Hu, S. P. DenBaars, and S. Nakamura, Appl. Phys. Lett. **84**, 855 (2004).
[3]D. H. Kim, C. O. Cho, Y. G. R. H. Jeon, Y. S. Park, J. Cho, J. S. Im, C. Sone, Y. Park, W. J. Choi, and Q. H. Park, Appl. Phys. Lett. **87**, 203508 (2005).
[4]E. F. Schubert, *Light-Emitting Diodes* (Cambridge University Press, New York, 2006).
[5]D. L. Hibbard, S. P. Jung, C. Wang, D. Ullery, Y. S. Zhao, H. P. Lee, W. So, and H. Liu, Appl. Phys. Lett. **83**, 311 (2003).
[6]J. K. Kim, T. Gessmann, H. Luo, and E. F. Schubert, Appl. Phys. Lett. **84**, 4508 (2004).
[7]J. Y. Kim, S. I. Na, G. Y. Ha, M. K. Kwon, I. K. Park, J. H. Lim, S. J. Park, M. H. Kim, D. Choi, and K. Min, Appl. Phys. Lett. **88**, 043507 (2006).
[8]C. H. Chou, C. L. Lin, C. Chuang, H. Y. Bor, and C. Y. Liu, Appl. Phys. Lett. **90**, 022103 (2007).
[9]J. H. Kim, H. Baik, J. Cho, J. W. Lee, S. Yoon, H. Kim, S. N. Lee, C. Sone, Y. Park, and T. Y. Seong, IEEE Photon. Technol. Lett. **19**, 336 (2007).
[10]J. K. Sheu, I. H. Hung, W. C. Lai, S. C. Shei, and M. L. Lee, Appl. Phys. Lett. **93**, 103507 (2008).
[11]J. O. Song, J. S. Kwak, Y. Park, and T. Y. Seong, Appl. Phys. Lett. **86**, 062104 (2005).
[12]Y. T. Hwang, H. G. Hong, T. Y. Seong, D. S. Leem, T. Lee, K. K. Kim, and J. O. Song, Mater. Sci. Semicond. Process. **10**, 14 (2007).
[13]H. W. Jang and J. L. Lee, Appl. Phys. Lett. **85**, 5920 (2004).
[14]Z. Hassan, Y. C. Lee, F. K. Yam, Z. J. Yap, N. Zainal, H. A. Hassan, and K. Ibrahim, Phys. Status Solidi C **1**, 2528 (2004).
[15]L. B. Chang, C. C. Shiue, and M. J. Jeng, Appl. Surf. Sci. **255**, 6155 (2009).
[16]H. S. Kim and S. N. Lee, J. Vac. Sci. Technol. **29**, 011032 (2011).