Electronic Supplementary Material (ESI) for Journal of Materials Chemistry C.

Supporting Information

High-performance light engineering using with hierarchical GaN *m*-plane nano-prism light extractors

*M. Siva Pratap Reddy, Herie Park, Se-Min Kim, Seon-Ho Jang, and Ja-Soon Jang**

Department of Electronic Engineering, LED-IT Fusion Technology and Research Center (LIFTRC), Yeungnam University, Gyeongbuk 712-749, Republic of Korea

* E-mail: jsjang@ynu.ac.kr

Carrier transport mechanisms for the TLM-patterned *p*-GaN of whole LED epitaxail layers (grown on sapphire substrate) before and after the TMAH crystallographic etching

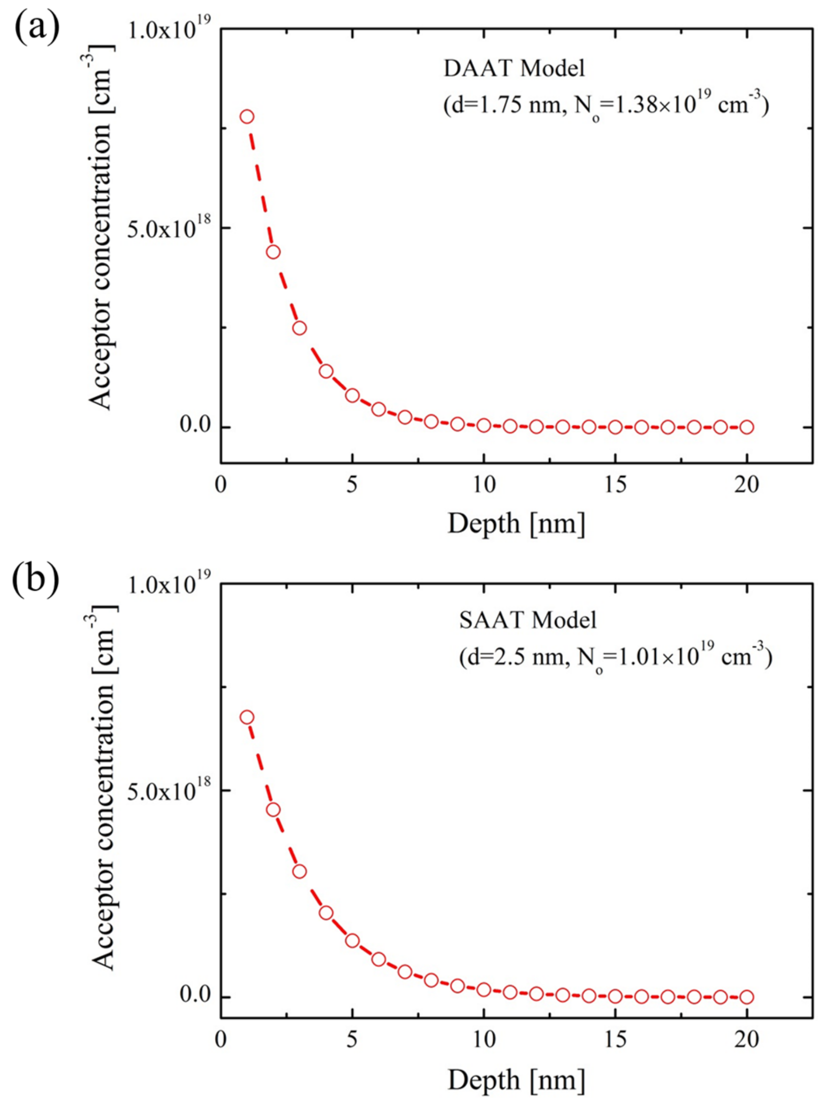

Fig. S1 Plots of acceptor carrier concentration characteristics as a function of the depth for (a) the deep-acceptor-assisted tunneling (DAAT) and (b) shallow-acceptor-assisted tunneling (SAAT) model.

In order to investigate the feasible carrier transport mechanism and Schottky barrier characteristics at the interface between ITO and p^+-GaN/*p*-GaN layer of TMAH etched LED, the specific contact resistance-temperature characteristics have been measured. The carrier distribution in p^+-GaN is assumed to be $N_a(x) = N_o e^{(-x/d)}$. The carrier distributio in p-GaN is given by[1]

$$N_{total} = \frac{\int_0^d N_a(x)dx + \int_d^D N^* dx}{Total\ thickness(D_t)} (cm^{-3}) \tag{S1}$$

where d is the effective thickness of p^+-GaN, N^* the carrier concentration of p-GaN (from d to D_t). For simulation, we assumed that the hole transport is mainly due to either deep-acceptor-assisted tunneling (DAAT) or shallow-acceptor-assisted tunneling (SAAT) in the p^+-GaN region. According to Seghier and Gislason,[2] the energy difference (E_F-E_V=0.17 eV) was used [Fig. S1(a)] for the calculation of DAAT model where as for the SAAT model, the energy difference [E_F-E_V=$kTln(N_c/N_a)$] was used [Fig. S1(b)]. The tunneling parameter (E_{00}) can be defind as $E_{00} = qh/4\pi \sqrt{N_{total}/m_h\varepsilon_s}$ from Equation (S2).

$$R_{sc} = \frac{\sqrt{\coth(E_{00}/kT)}\cosh(E_{00}/kT)}{qA^{**}/k^2\sqrt{\pi E_{00}q(\phi_b + V_n)}} \times \exp\left[\frac{q(\phi_b - V_n)}{E_{00}\coth(E_{00}/kT)} + \frac{qV_n}{kT}\right] \tag{S2}$$

for thermionic field emission (TFE) , where (E_{00}/kT >1),

$$\rho_c = \frac{k}{qA^{**}}\exp\left(\frac{q\phi_b}{E_{00}}\right)\left[\frac{\pi t}{\sin(\pi kTC)} - \frac{\exp(-qV_pC)}{kC}\right]^{-1} \tag{S3}$$

for field emission (FE), where (E_{00}/kT »1),,

and

$C=ln[4\phi_b/V_p]/(2E_{00})$,

where V_p=E_F-E_V. A^{**} is Richardson constant, k is Boltzmann constant, h is Planck's constant, m^* is the effective mass of the semiconductor, and T is temperature. In this simulation (assuming an In composition of 15%), m_h of 0.84m_e, ε_s of 10.8ε_0, and A^{**} of 120α Acm^{-2}K^{-2} were used.[3] The α, an empirical factor can be experimentally obtained using the thermionic emission model based on the current-voltage-temperature relation.[4] The calculated E_{00} values for beofore and after TMAH etching were 53 and 79 meV, respectively.

Surface morphological AFM images for *p*-GaN before and after the TMAH crystallographic etching

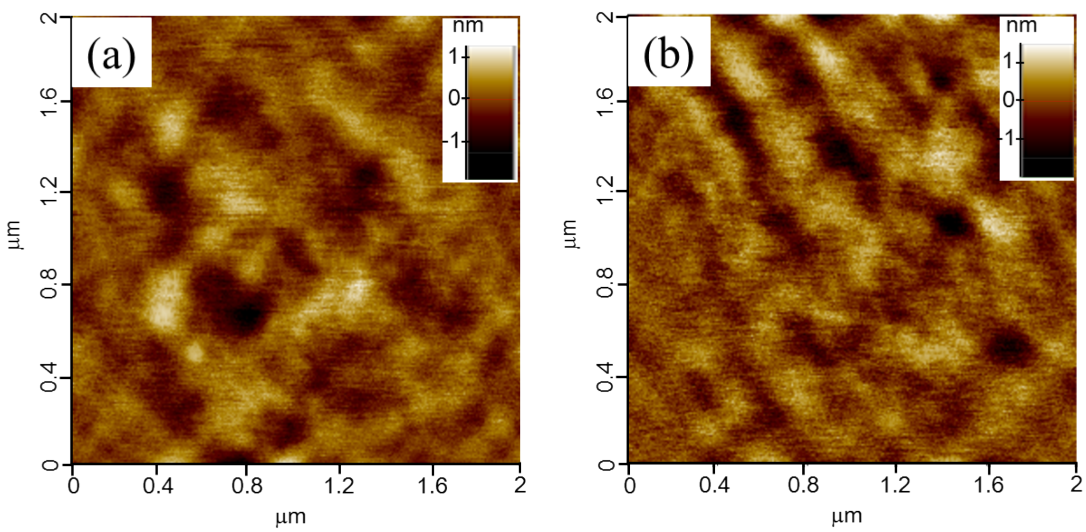

Fig. S2 AFM micrographs of the *p*-GaN surfaces of whole LED epitaxial layers (a) before and (b) after TMAH etching. The measured area is 2 × 2 μm^2. The root-mean-square (RMS) was determined to be 0.95 nm and 1.12 nm for the samples before and after the etching, indicating that TMAH etching does not cause any surface defects and structural deformation.

References

1 J.-S. Jang, T.-Y. Seong and S.-R. Jeon, *J. Appl. Phys.* 2006, **100**, 046106.

2 D. Seghier and H.P. Gislason, *J. Appl. Phys.* 2000, **88**, 6483.

3 J. Wu, *J. Appl. Phys.* 2009, **106**, 011101.

4 J.-S. Jang and T.-Y. Seong, *Appl. Phys. Lett.* 2000**, 76**, 2743.