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Effect of barrier Mg doping on LED optical power

APPLIED PHYSICS LETTERS **96**, 051113 (2010)

Effect of Mg doping in the barrier of InGaN/GaN multiple quantum well on optical power of light-emitting diodes

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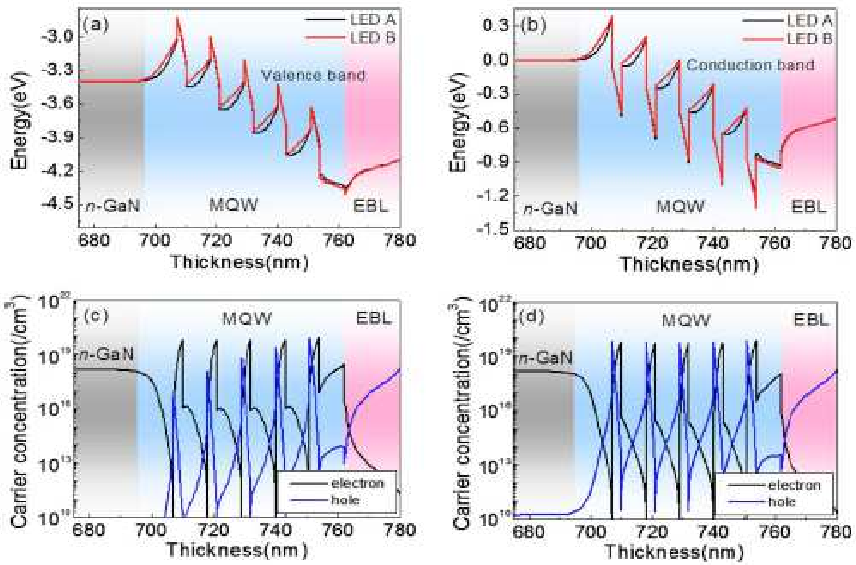
Mg doping in the barriers of MQWs enhances photoluminescence intensity, thermal stability, and internal quantum efficiency of LEDs. The light output power of LEDs with Mg-doped MQW barriers is higher by 19% and 27% at 20 and 200 mA, respectively, than that of LEDs with undoped MQW barriers. The improvement in output power is attributed to the enhanced hole injection to well layers in MQWs with Mg-doped barriers.



Energy band diagrams of well and barrier layer of LED A and LED B at 4 V, (a) valence band and (b) conduction band. Carrier concentration throughout MQW at 4 V, (c) LED A and (d) LED B.

Development of blue LED structures grown by HVPE

Indium-free violet LEDs grown by HVPE

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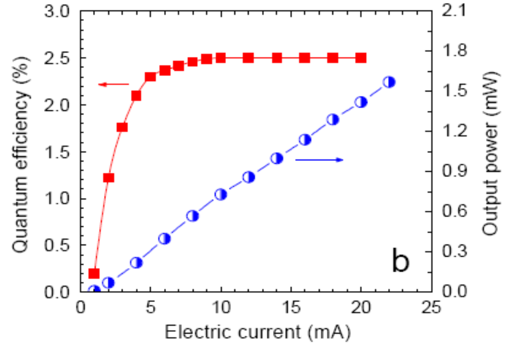
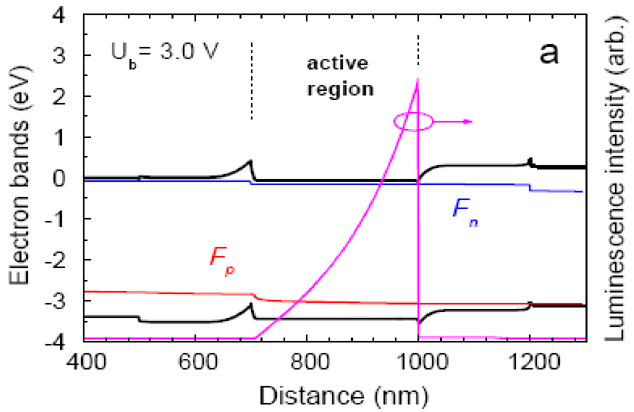
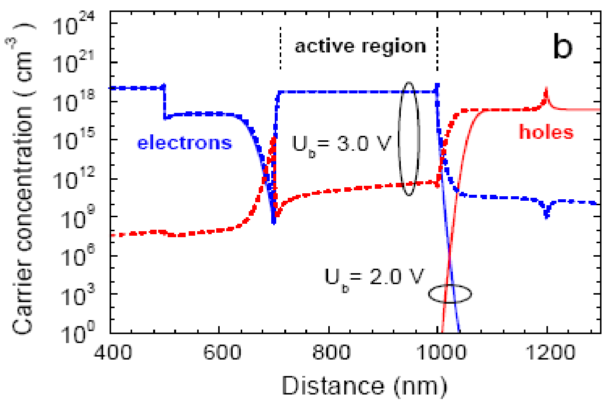
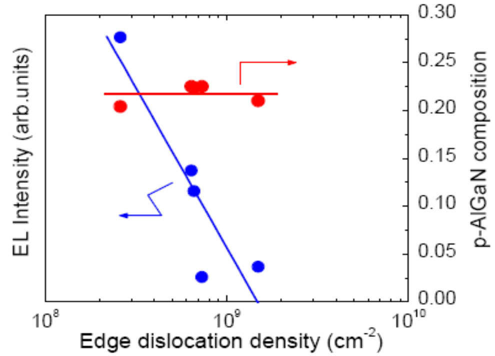
We report on first demonstration of violet light emitting diodes (LED) based on AlGaN/GaN/AlGaN heterostructures grown by hydride vapor phase epitaxy (HVPE). The unique aspects of this technological approach are (i) growth of Al-containing epitaxial material by HVPE and (ii) use of HVPE to fabricate submicron multi-layer epitaxial structures. The LEDs provide light emission at the wavelength of 415-420 nm that did not shift with forward current. External efficiency up to 2.5% is reached at the current of 20 mA. The brightness of LED lamp is as high as 400-500 mcd. This suggests HVPE as an alternative technique for growing AlGaN-based LED structures. Results of the LED modeling and characterization are discussed.

LED structures entirely grown by HVPE have been developed with modeling support and fabricated









Development of ZnO-based hybrid LEDs

Design and simulation of ZnO-based light-emitting diode structures

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Department of Materials Science and Engineering, University of Florida, Gainesville, Florida 32611

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A. Osinsky, J. W. Dong, B. Hertog, and P. P. Chow
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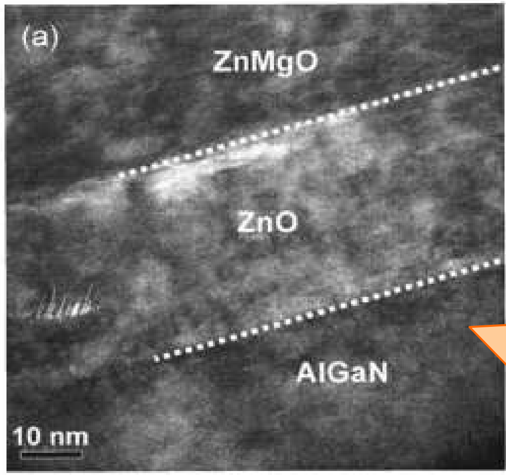
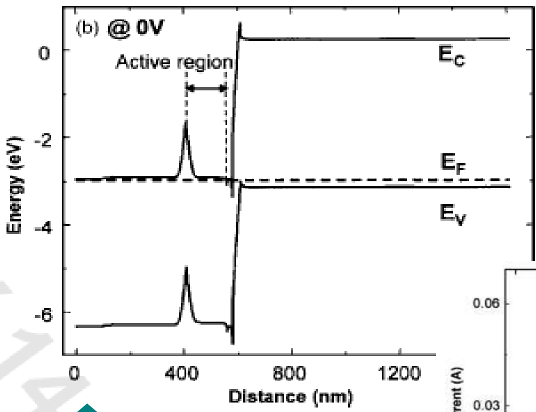
(Received 8 September 2005; accepted 10 October 2005)

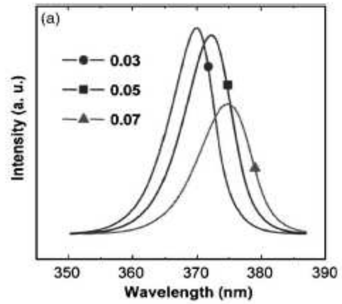
Two different types of ZnO-based light-emitting diode structures have been examined using a one-dimensional (1D) simulator that accounts for specific features of the hexagonal semiconductors—strong piezoeffects, existence of spontaneous electric polarization, low efficiency of acceptor activation, and high threading dislocation density (normally, $\sim 10^7 - 10^9$ cm^{-2}) in the material. A hybrid ZnO/CdZnO/AlGaN/GaN structure grown on sapphire avoids problems in achieving robust *p*-type doping in ZnO. An all-ZnO approach employs a MgZnO/CdZnO/MgZnO double heterostructure grown on a ZnO substrate. Both structures show a strong sensitivity of emission intensity to doping and layer thicknesses within our simulations. © *2005 American Vacuum Society.* [DOI: 10.1116/1.2131869]

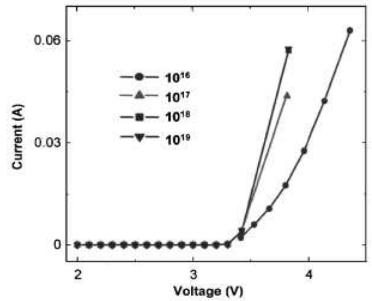


TEM image of hybrid ZnMgO/ZnO/AlGaN LED structure

100 nm ZnO, (Ga) n~ 10^{19} cm^{-3}
300 nm ZnO, (Ga) n~ 10^{18} cm^{-3}
10 nm ZnO n~10^{17} cm^{-3}
150 nm ZnCdO, n~10^{18} cm^{-3}
20 nm ZnO, n~10^{17} cm^{-3}
30 nm $Al_{0.12}Ga_{0.88}N$, (Mg) p~10^{17} cm^{-3}
1000 nm GaN, (Mg) p~10^{17} cm^{-3}
600 nm undoped GaN
30 nm AlN
2" c-plane sapphire







a novel ZnCdO/ZnO/AlGaN LED structure is designed and optimized by using SiLENSe prior its fabrication

Designing of advanced EBLs for III-nitride laser diodes

Theoretical study of current overflow in GaN based light emitters with superlattice cladding layers

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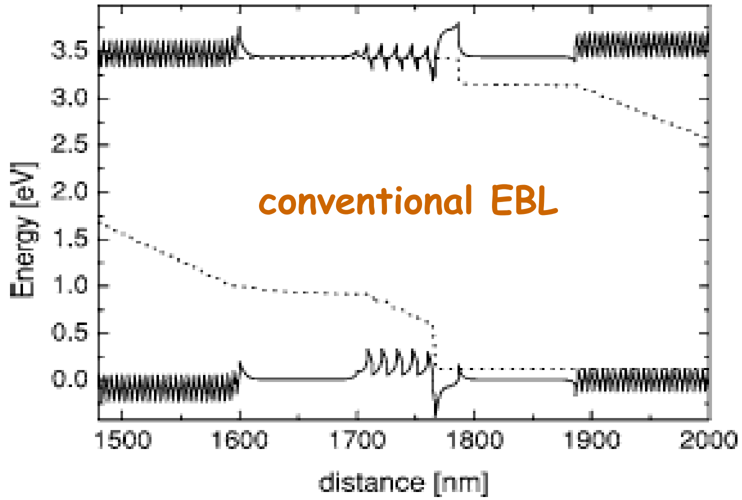
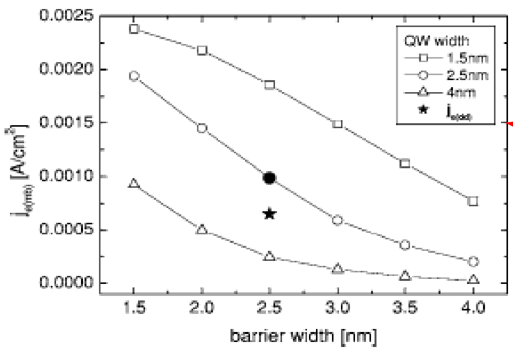
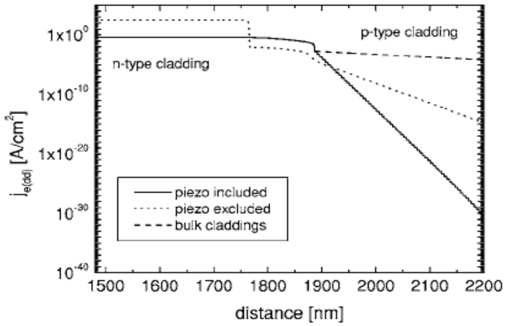
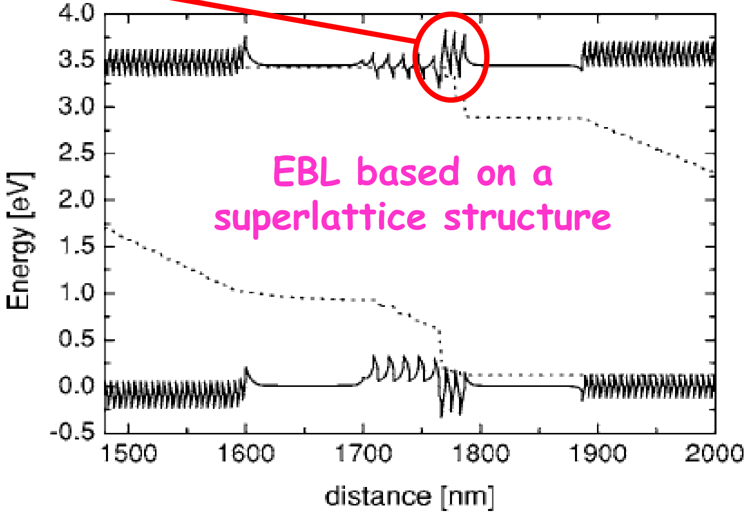
(Received 24 March 2006; accepted 4 May 2006; published online 11 July 2006)

We investigate the effect of the short-period superlattice cladding layer on electron current overflow in nitride light emitters. The classical drift-diffusion current flow and quantum tunneling transport through the miniband are considered. We show that the drift-diffusion electron current in the p-type superlattice cladding layer is drastically reduced by the presence of the intrinsic built-in electric fields. Based on this finding, we propose a design of the electron blocking layer which should considerably lower the electron current overflow in nitride light emitters. © *2006 American Institute of Physics.* [DOI: 10.1063/1.2212127]









a new design of EBL based on superlattice structure has been suggested and optimized by SiLENSe in order to suppress electron leakage in a 405 nm laser diode structure

Optimization of MQW active region in a dual-wavelength LED structure

The effect of silicon doping in the selected barrier on the electroluminescence of InGaN/GaN multiquantum well light emitting diode

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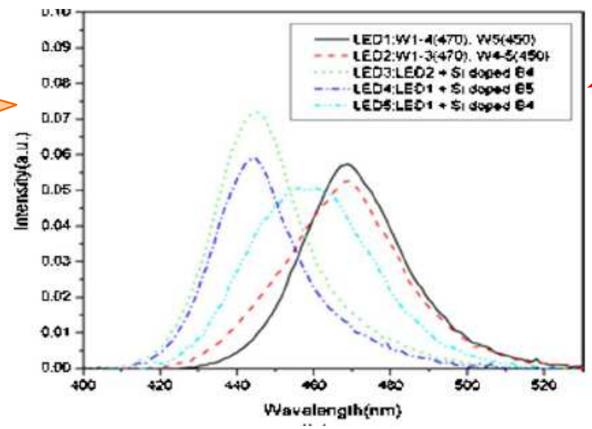
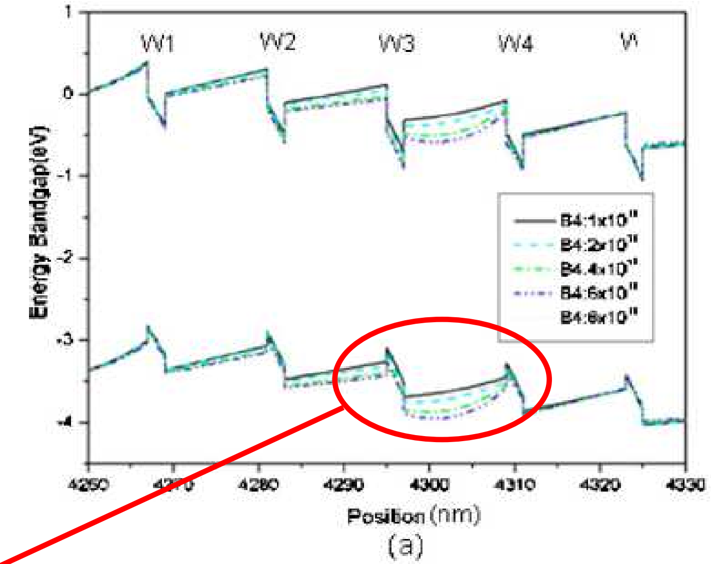
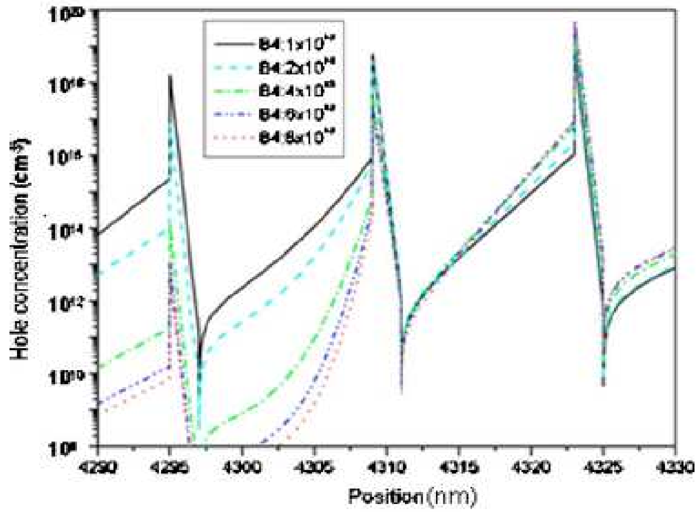
(Received 9 October 2006; accepted 10 December 2006; published online 16 January 2007)

The effect of silicon doping in the selected barrier on the electroluminescence of InGaN/GaN multiquantum well light emitting diode (LED) was studied using dual wavelength LEDs. The result verified that the hole carrier transport is easily blocked by the silicon doped barrier, and the dominant electron and hole recombination occurs at the wells between *p*-GaN and the silicon doped barrier. The electroluminescence spectrum and the wavelength blueshift of the silicon doped LEDs were compared with undoped LEDs. The numerical simulation was done to clearly explain the hole blocking effect by the silicon doped barrier. © *2006 American Institute of Physics.*
[DOI: 10.1063/1.2431717]

control of emission spectra by MQW barrier doping



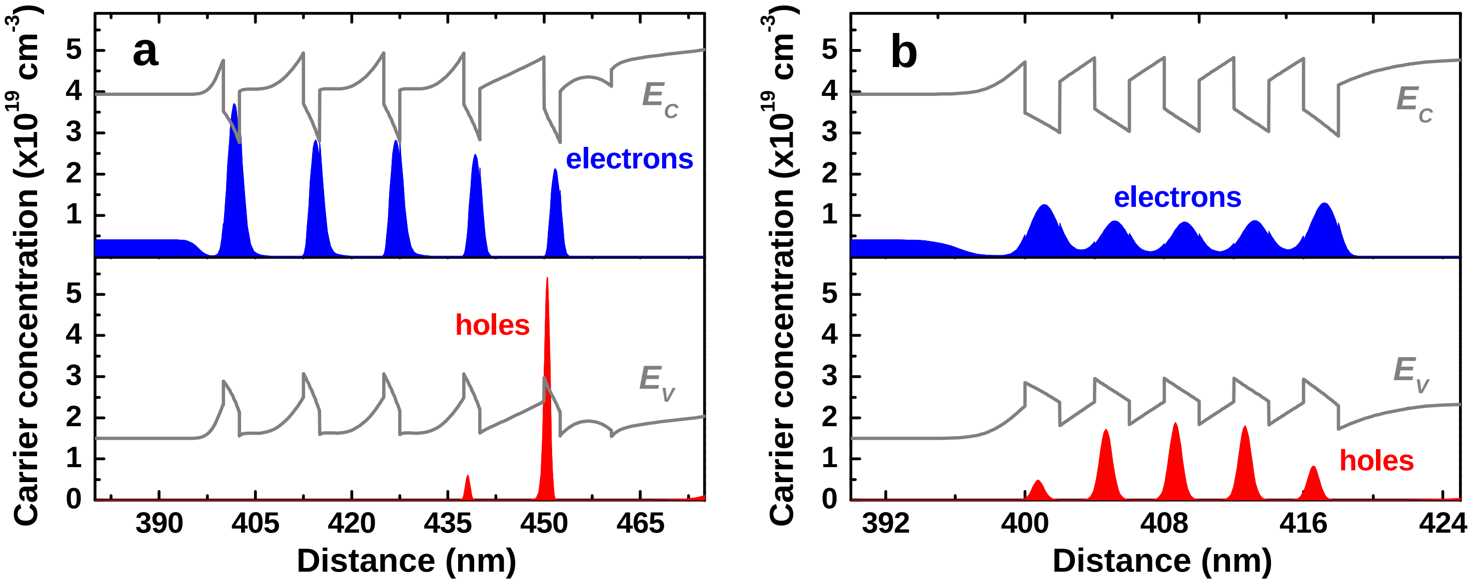




doping of MQW active region has bee optimized to improve the hole injection in all the wells

Use of short-period superlattice for reduction of the efficiency droop

Far more uniform hole distribution is possible with a superlattice active region comprising 2.5 nm-thick wells and barriers. Such a structure is far better at combating droop



A partnership between Ioffe Physico-Technical Institute, Epi-Center and STR-Group has modelled electron and hole distributions in two types of LED: (a) a device with a conventional active region, containing five, 3 nm thick quantum wells sandwiched between 10 nm-thick barriers (b) a device with a short-period superlattice active region comprising 2.5 nm-thick wells and barriers.

Presented at ICNS-9. Glasgow, 2011

http://www.compoundsemiconductor.net/csc/features-details.php?cat=news&id=19734032&name=Droop%20draws%20the%20crowds%20at%20ICNS-9

Development of CdZnO/GaN SQW LEDs

Hybrid CdZnO/GaN quantum-well light emitting diodes

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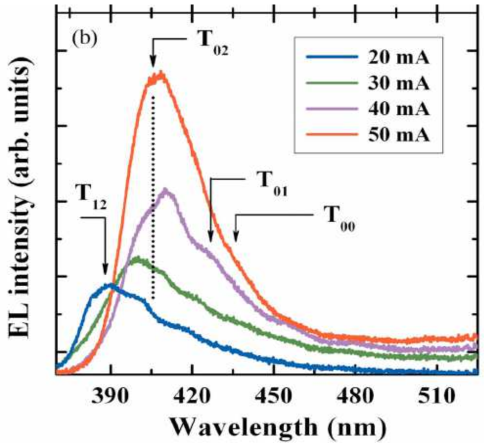
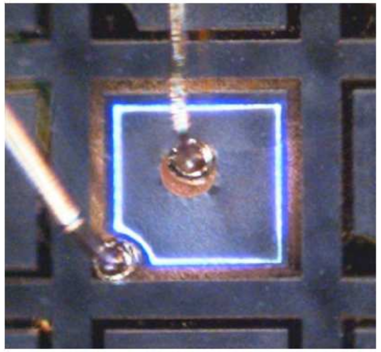
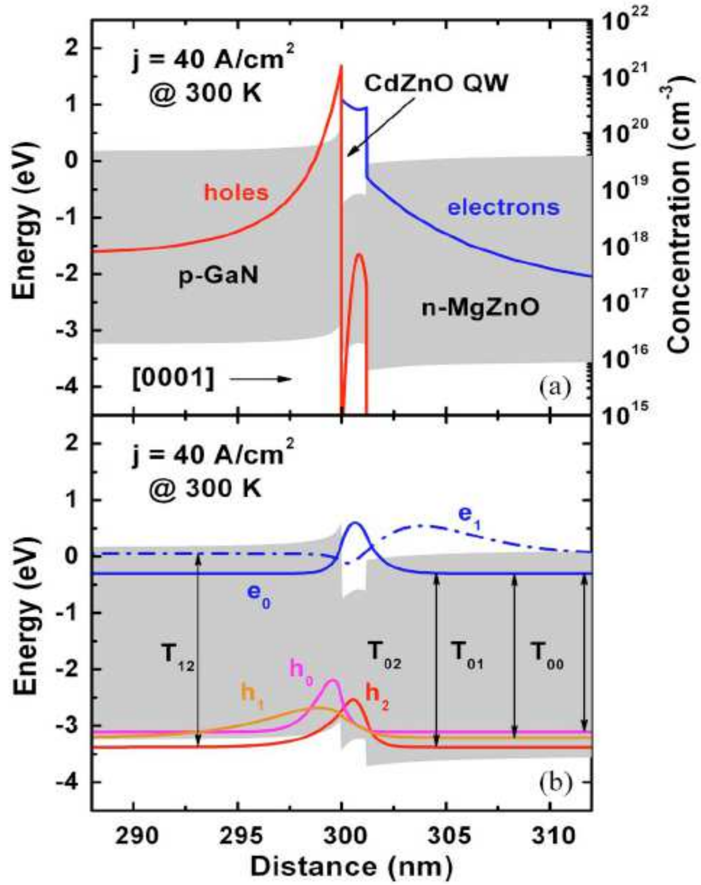
(Received 11 March 2008; accepted 24 September 2008; published online 10 November 2008)

We report on the demonstration of light emission from hybrid CdZnO quantum-well light emitting diodes. A one-dimensional drift-diffusion method was used to model the expected band structure and carrier injection in the device, demonstrating the potential for 90% internal quantum efficiency when a CdZnO quantum well is used. Fabricated devices produced visible electroluminescence that was found to redshift from 3.32 to 3.15 eV as the forward current was increased from 20 to 40 mA. A further increase in the forward current to 50 mA resulted in a saturation of the redshift.
 [DOI: 10.1063/1.3013446]







using modeling support, hybrid CdZnO/GaN LEDs were developed and fabricated for the first time

Semipolar MQW green LEDs

APPLIED PHYSICS LETTERS **99**, 141114 (2011)

Influence of Mg-doped barriers on semipolar $(20\bar{2}1)$ multiple-quantum-well green light-emitting diodes

Chia-Yen Huang,[1,a)] Qimin Yan,[1] Yuji Zhao,[2] Kenji Fujito,[3] Daniel Feezell,[1]
Chris G. Van de Walle,[1] James S. Speck,[1] Steven P. DenBaars,[1,2] and Shuji Nakamura[1,2]
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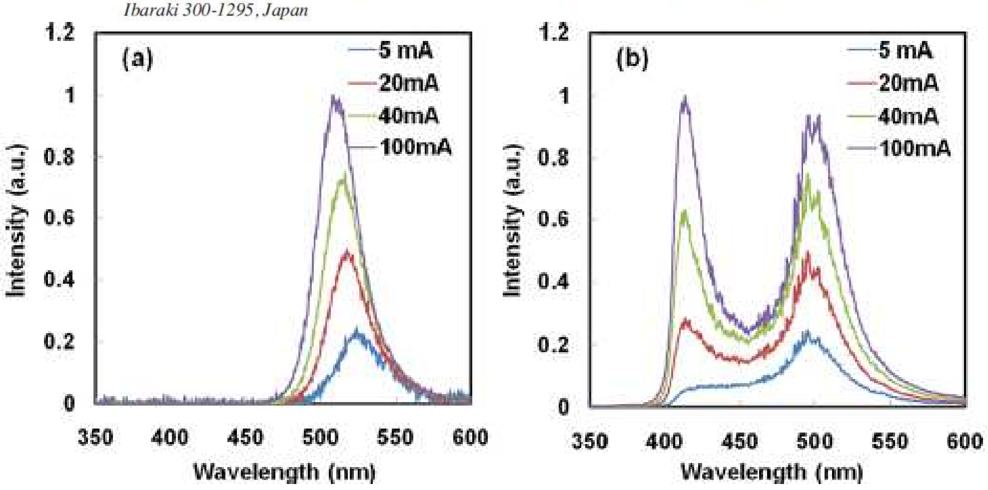

The EL spectra of dichromatic DQW LEDs with (a) undoped barriers and (b) Mg-doped barriers under various injection levels.

Authors report the effects of Mg doping in the barriers of semipolar (20-21) multiple-quantum-well light-emitting diodes (LEDs) with long emission wavelengths (>500 nm). With moderate Mg doping concentrations in the barriers, the output power was enhanced compared to those with undoped barriers, which suggests that hole transport in the active region is a limiting factor for device performance. Improved hole injection due to Mg doping in the barriers is demonstrated by dichromatic LED experiments and band diagram simulations.

Results indicate that improving hole injection efficiency is a key objective for enhancing the performance of (20-21) MQW green LEDs.

Near UV LED grown by atmospheric pressure MOVPE

The letter reports a theoretical and experimental study on the device performance of near UV LEDs with quaternary AlInGaN QB. The indium mole fraction of AlInGaN QB could be enhanced as the TMGa flow rate was increased. It was found the AlInGaN/InGaN LEDs can reduce forward voltage and improve light output power, compared with conventional GaN QB.

APPLIED PHYSICS LETTERS 98, 121115 (2011)

The effect of trimethylgallium flows in the AlInGaN barrier on optoelectronic characteristics of near ultraviolet light-emitting diodes grown by atmospheric pressure metalorganic vapor phase epitaxy

Yi-Keng Fu,[1,a)] Ren-Hao Jiang,[1,2] Yu-Hsuan Lu,[1,3] Bo-Chun Chen,[1] Rong Xuan,[1,4] Yen-Hsiang Fang,[1] Chia-Feng Lin,[2] Yan-Kuin Su,[3] and Jenn-Fang Chen[4]
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[4]*Department of Electrophysics, National Chiao Tung University, Hsinchu 30010, Taiwan*

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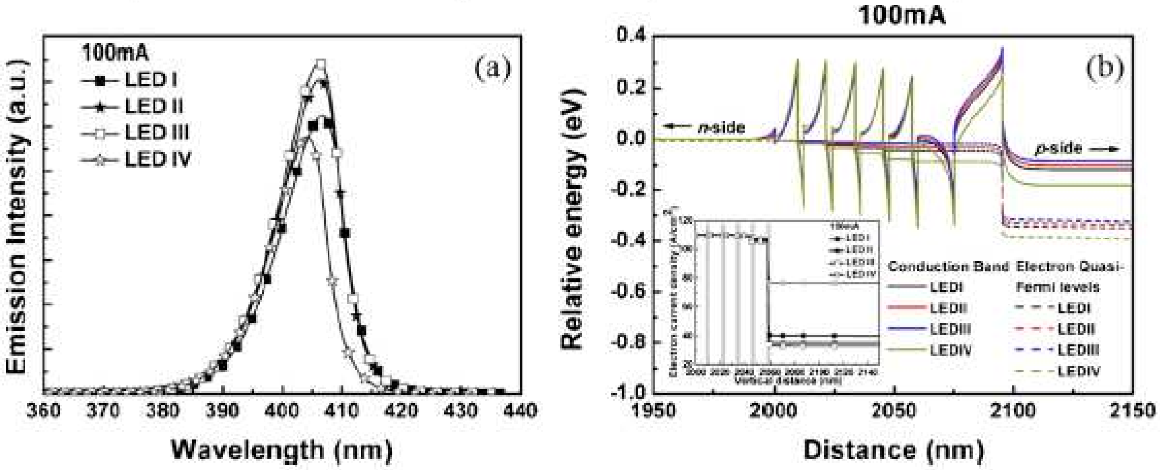

(a) The calculated EL spectra and (b) conduction band diagram of these four LEDs at 100 mA current injection. The inset of (b) shows the vertical electron current density profiles near the active regions

Under 100 mA current injection, the LED output power with $Al_{0.089}In_{0.035}Ga_{0.876}N$ QB can be enhanced by 15.9%, compared with LED with GaN QB

C-V measurements with additional laser illumination

Well-to-well non-uniformity in InGaN/GaN multiple quantum wells characterized by capacitance-voltage measurement with additional laser illumination

Tae-Soo Kim,[1] Byung-Jun Ahn,[1] Yanqun Dong,[1] Ki-Nam Park,[1] Jin-Gyu Lee,[1] Youngboo Moon,[2] Hwan-Kuk Yuh,[2] Sung-Chul Choi,[2] Jae-Hak Lee,[2] Soon-Ku Hong,[3] and Jung-Hoon Song[1,a)]
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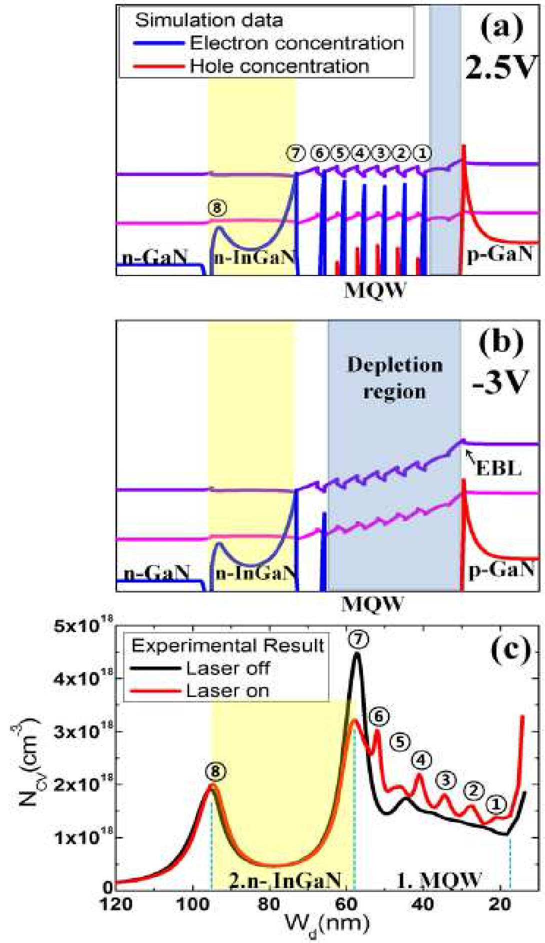
The accumulated carrier distributions in the active region of InGaN/GaN LEDs were investigated experimentally by C-V measurements with additional layer illumination both at RT and 80K. By varying the illuminating powers of the resonant excitation, well-to-well non-uniformity through the MQWs was clearly revealed.



Simulation data of band diagram and carrier concentrations at (a) V=2.5 V, (b) V=-3 V, and (c) experimental C-V depth profile with and without laser illumination

The developed approach can be an effective method to determine the carrier distributions and the degree of well-to-well nonuniformity in InGaN/GaN MQW structures.

Suppression of efficiency droop in blue MQW LED structures

Effect of electron blocking layer on efficiency droop in InGaN/GaN multiple quantum well light-emitting diodes

Sang-Heon Han,[1,2] Dong-Yul Lee,[2] Sang-Jun Lee,[1] Chu-Young Cho,[1] Min-Ki Kwon,[1] S. P. Lee,[1] D. Y. Noh,[1] Dong-Joon Kim,[2] Yong Chun Kim,[2] and Seong-Ju Park[1,a)]

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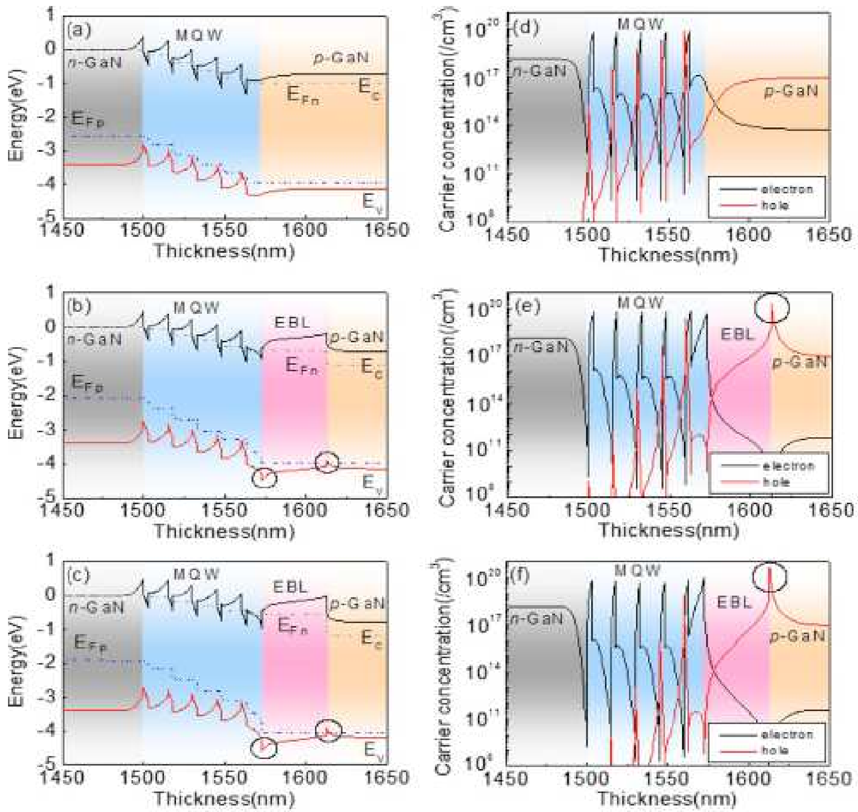
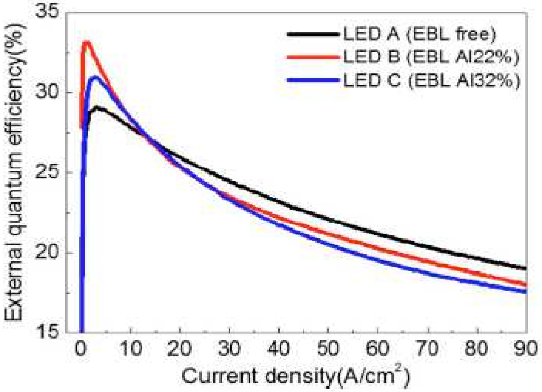
(Received 4 December 2008; accepted 22 May 2009; published online 12 June 2009)

The effect of an electron blocking layer (EBL) on the efficiency droop in InGaN/GaN multiple quantum well light-emitting diodes (LEDs) is investigated. At low current density, the LEDs with a *p*-AlGaN EBL show a higher external quantum efficiency (EQE) than LEDs without an EBL. However, the EQE of LEDs without an EBL is higher than LEDs with an EBL as injection current density is increased. The improved EQE of LEDs without an EBL at high current density is attributed to the increased hole injection efficiency. © *2009 American Institute of Physics.*
[DOI: 10.1063/1.3153508]

simulations



experimental data



an LED structure free of AlGaN EBL has been suggested on the basis of simulations, providing a smaller efficiency droop

LEDs with trapezoidal wells

IOP PUBLISHING JOURNAL OF PHYSICS D: APPLIED PHYSICS
J. Phys. D: Appl. Phys. **43** (2010) 354004 (5pp) doi:10.1088/0022-3727/43/35/354004

Improvement of efficiency droop in InGaN/GaN multiple quantum well light-emitting diodes with trapezoidal wells

Sang-Heon Han[1,2], Dong-Yul Lee[2], Hyun-Wook Shim[2], Gwon-Chul Kim[2], Young Sun Kim[2], Sung-Tae Kim[2], Sang-Jun Lee[1], Chu-Young Cho[1] and Seong-Ju Park[1,3,4]

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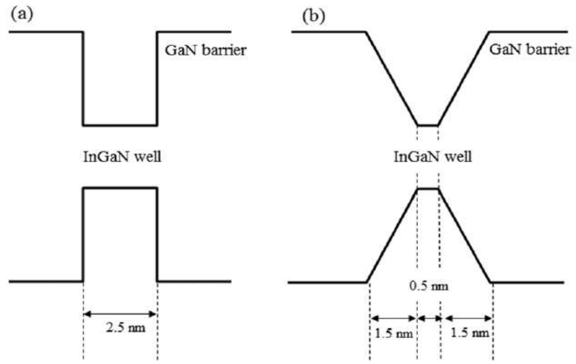

Schematic band diagrams of MQWs of (a) LED with rectangular-shaped well and (b) LED with trapezoidal-shape well

Simulations show that separation of electron and hole wave functions in the wells was reduced in LED B. Overlaps of electron and heavy wave functions in the well adjacent to p-GaN in LED A and LED B are 37.2 and 41.6, respectively.

MQW LED with trapezoidal wells was suggested allowing improvement of efficiency droop at high current densities.

N-polar LEDs

Japanese Journal of Applied Physics 51 (2012) 100201 RAPID COMMUNICATION
http://dx.doi.org/10.1143/JJAP.51.100201

Effect of Internal Electric Field in Well Layer of InGaN/GaN Multiple Quantum Well Light-Emitting Diodes on Efficiency Droop

Sang-Heon Han[1,2], Dong-Yul Lee[2], Jin-Young Lim[2], Jeong Wook Lee[2], Dong-Joon Kim[2], Young Sun Kim[2], Sung-Tae Kim[2], and Seong-Ju Park[1*]

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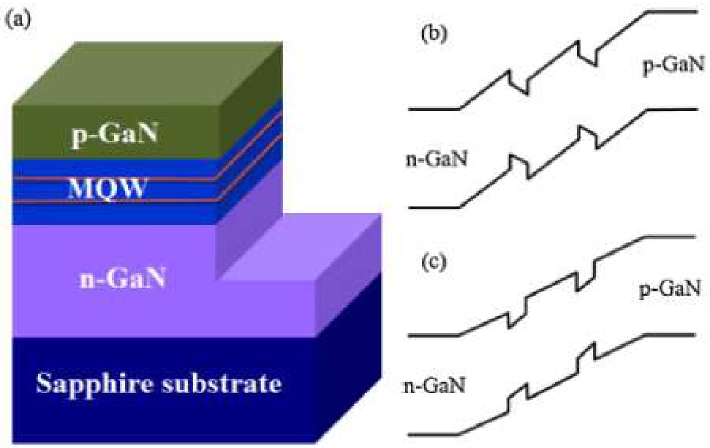
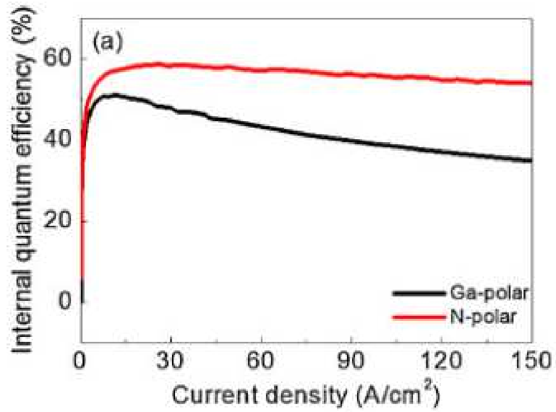
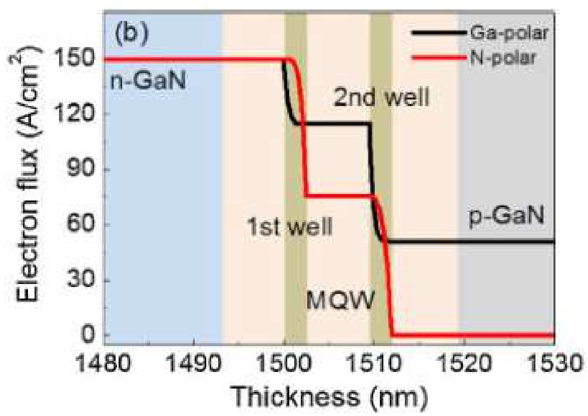


(a) Schematic structure of InGaN/GaN MQW LEDs used in the simulation. (b) Schematic band diagrams of Ga-polar MQW LEDs. (c) Schematic band diagrams of N-polar MQW LEDs.

(a) The calculated internal quantum efficiency of Ga- and N-polar InGaN/GaN MQW LEDs as a function of current density. (b) The calculated electron flux in p-GaN region of Ga- and N-polar InGaN/GaN MQW LEDs at a current density of 150 A/cm^2.





The improvement of efficiency droop in N-polar LEDs is attributed to a decrease of an internal electric field in InGaN well layer with increasing forward bias voltage which enhances the electron and hole wave function overlap and to a decrease of the electron overflow at high current density.

InGaN Green LEDs with Gradual QWs

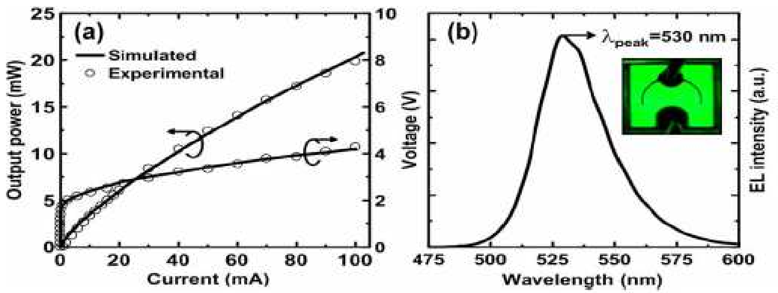


Fig. 1. (a) Experimental (open dots) and simulated (solid lines) L–I and I–V curves of conventional LED. (b) EL spectrum of conventional LED at I = 20 mA with peak wavelength of λ_{peak} = 530 nm. Insert: Photograph of the conventional green LED obtained at I = 20 mA.

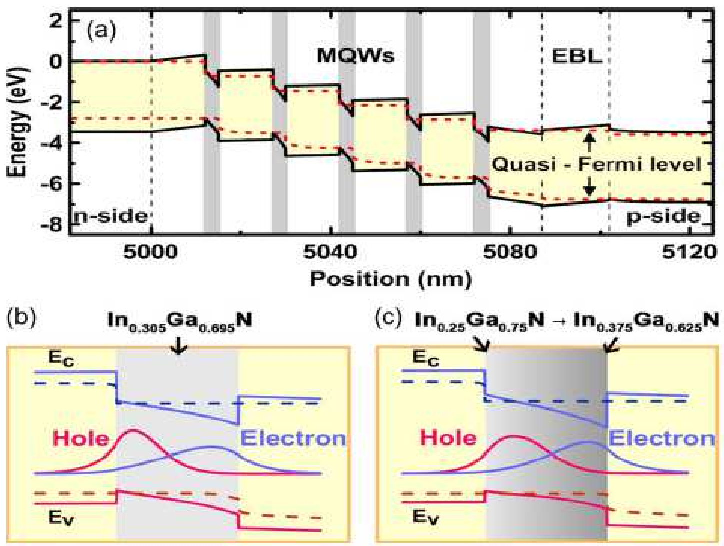
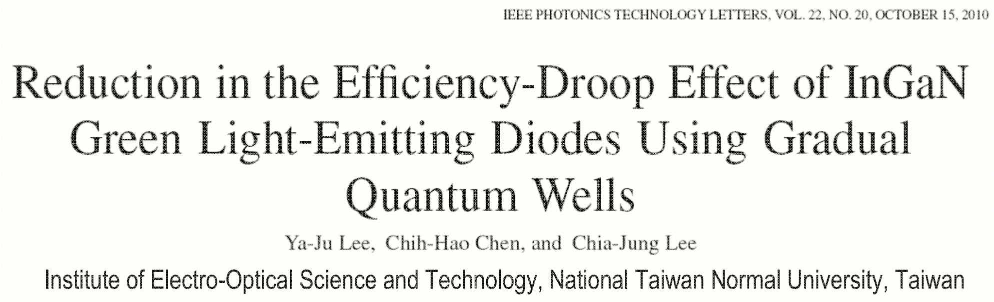


Fig. 2. (a) Energy band diagram of the conventional LED at injection current density of J = 200 A/cm^2. Enlarged images of energy band diagram of QW in (b) conventional and (c) gradual InGaN QW LEDs.


IEEE PHOTONICS TECHNOLOGY LETTERS, VOL. 22, NO. 20, OCTOBER 15, 2010

Reduction in the Efficiency-Droop Effect of InGaN Green Light-Emitting Diodes Using Gradual Quantum Wells

Ya-Ju Lee, Chih-Hao Chen, and Chia-Jung Lee

Institute of Electro-Optical Science and Technology, National Taiwan Normal University, Taiwan

A conventional InGaN QW's structure was replaced by a gradual InGaN QW's structure.

The transport efficiency of injected holes was increased, because band bending in the valence band was alleviated, increasing the overlap of electron and hole wave functions as well as the rate of radiative recombination.

Most importantly, the leakage of injected electrons to the p-type region is correspondingly decreased, suppressing the efficiency droop of the LEDs.

InGaN/p-InGaN as an insertion layer between the EBL and the last barrier

APPLIED PHYSICS LETTERS **101**, 081120 (2012)

Inserting a p-InGaN layer before the p-AlGaN electron blocking layer suppresses efficiency droop in InGaN-based light-emitting diodes

Ray-Ming Lin,[1,a)] Sheng-Fu Yu,[2] Shoou-Jinn Chang,[2] Tsung-Hsun Chiang,[2] Sheng-Po Chang,[2] and Chang-Ho Chen[3]
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[2]*Institute of Microelectronics and Department of Electrical Engineering, Advanced Optoelectronic Technology Center, Center for Micro/Nano Science and Technology, National Cheng Kung University, Tainan 70101, Taiwan*
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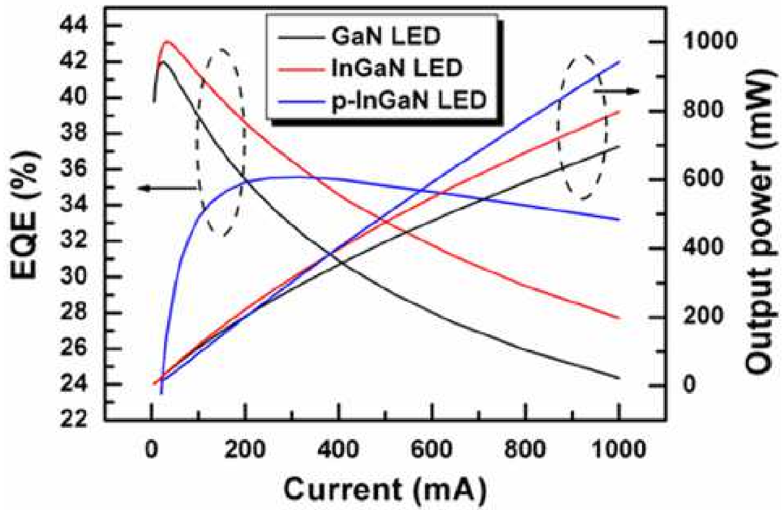
(Received 19 June 2012; accepted 9 August 2012; published online 24 August 2012)

In this study, we observed a dramatic decrease in the efficiency droop of InGaN/GaN light-emitting diodes after positioning a p-InGaN insertion layer before the p-AlGaN electron-blocking layer. The saturated external quantum efficiency of this device extended to 316 mA, with an efficiency droop of only 7% upon increasing the operating current to 1 A; in contrast, the corresponding conventional light-emitting diode suffered a severe efficiency droop of 42%. We suspect that the asymmetric carrier distribution was effectively mitigated as a result of an improvement in the hole injection rate and a suppression of electron overflow.
[http://dx.doi.org/10.1063/1.4747802]



EQEs and output powers of GaN, InGaN, and p-InGaN LEDs versus forward current

Introduction of a p-InGaN insertion layer between the p-AlGaN layer and the last barrier is effective for increase of hole injection and suppression of electron overflow to the p-side. The efficiency droop of only 7% was reached at operating current of 1 A

www.compoundsemiconductor.net October 2012

Hybrid approach for simulation of LED operation is accepted by Philips and OSRAM

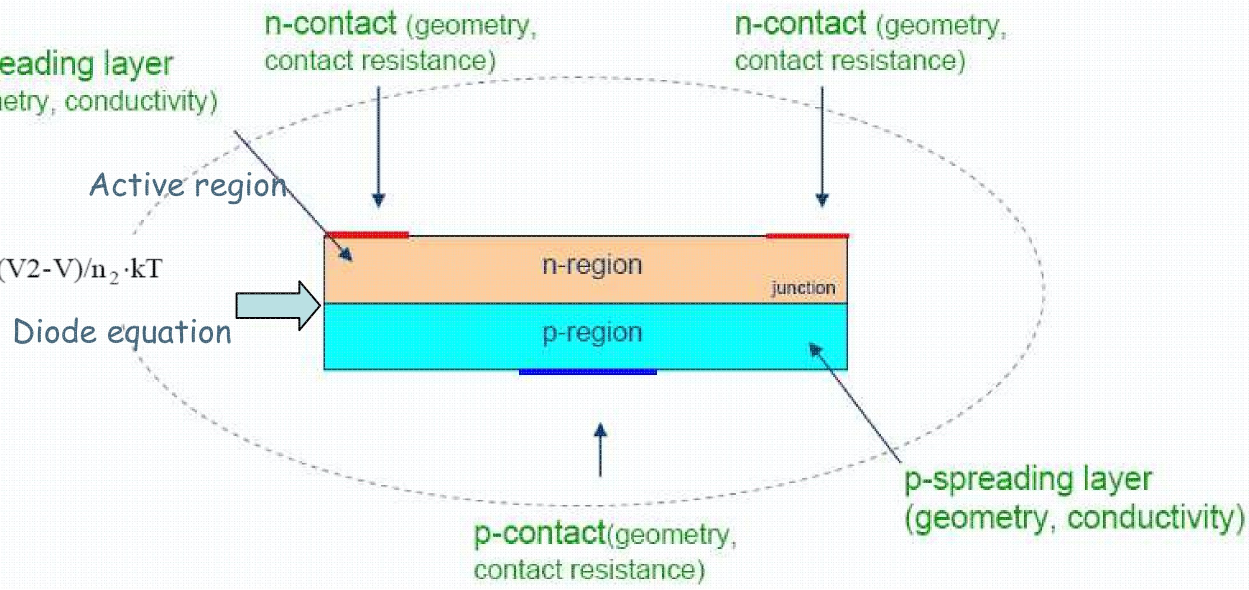
About simulation of current flowing in a LED chip

The model implementation may be dramatically simplified by assuming that lateral current spreading only occurs in the n-layer. The model can be reduced a scheme, where the active region is presented as a contact resistance boundary between two semiconductor layers.

Excerpt from T. Lopez and T. Margalith, 2008 Philips Research & Philips Lumileds Lighting Company

By E. Baur, OSRAM Optosemiconductors GmbH, 2007

$$J = J_{01} \cdot e^{e\cdot(V2\text{-}V)/n_1\cdot kT} + J_{02} \cdot e^{e\cdot(V2\text{-}V)/n_2\cdot kT}$$



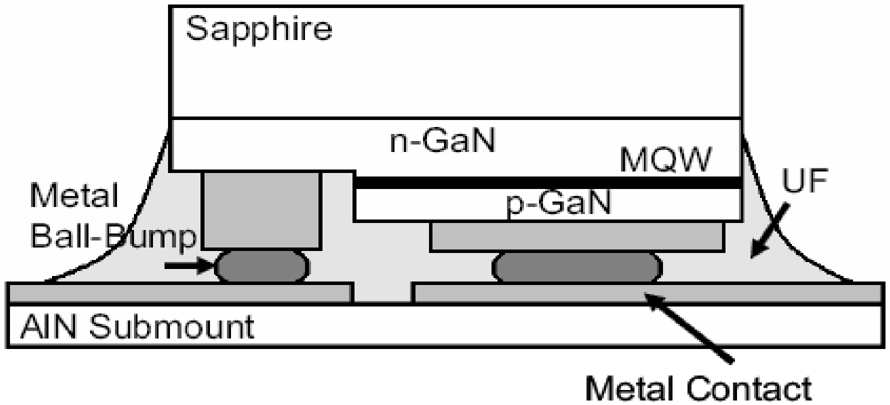
Optimization of electrode configuration to suppress current crowding

Optimization of electrode configuration in large GaInN light-emitting diodes

Wataru Ochiai[*,1], Ryosuke Kawai[1], Atsushi Suzuki[2], Motoaki Iwaya[1], Hiroshi Amano[1], Satoshi Kamiyama[1,2], and Isamu Akasaki[1]

[1] Faculty of Science & Technology, Meijo University, 1-501 Shiogamaguchi, Tempaku-ku, Nagoya 468-8502, Japan
[2] EL-SEED Corporation, Nagoya University Akasaki Institute 3F, Furo-cho, Chikusa-ku, Nagoya 464-8601, Japan

Received 12 September 2008, revised 19 November 2008, accepted 25 November 2008
Published online 30 March 2009



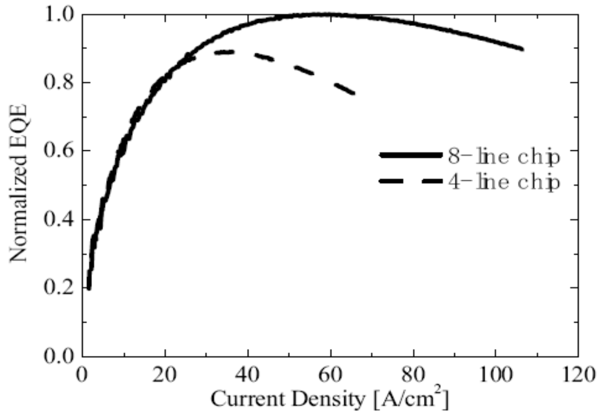
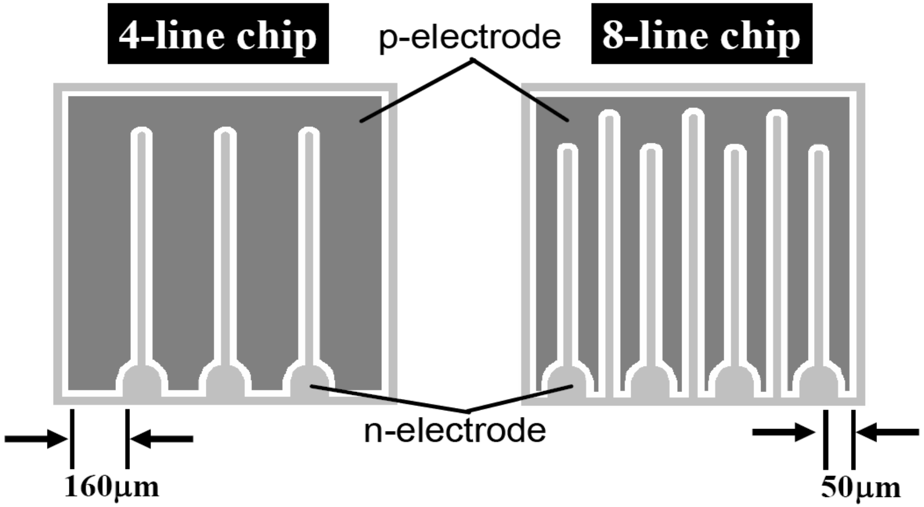
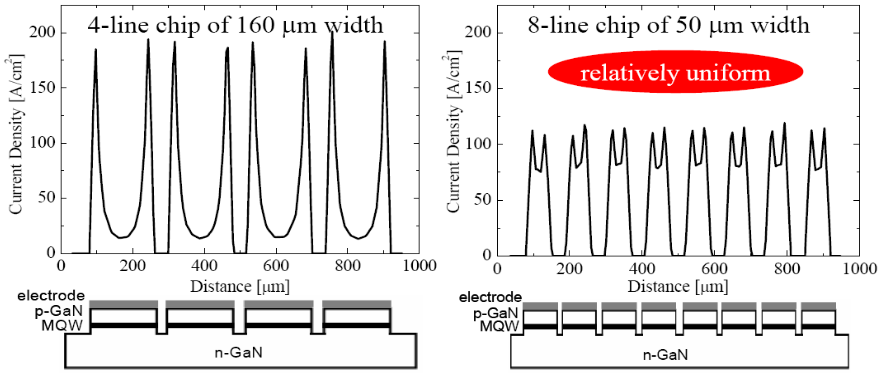


Figure 5 Normalized EQE versus current density of actual devices.

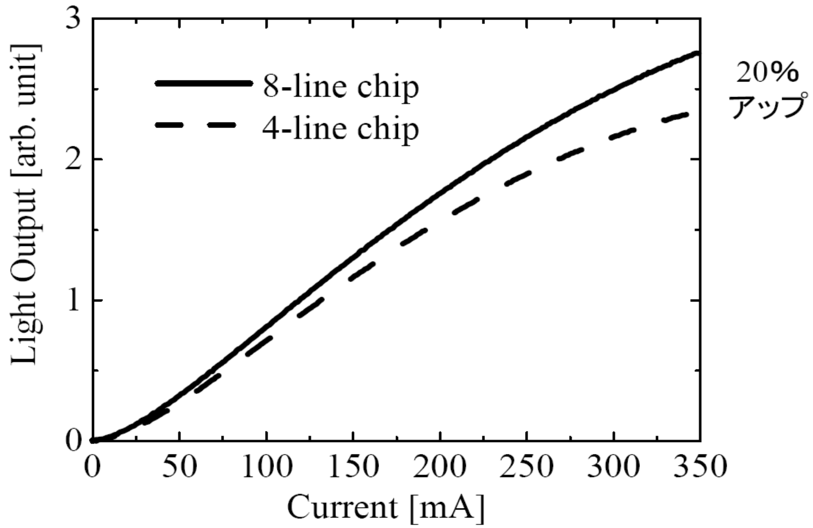
Simulations allowed authors to design electrode configuration for a uniform current injection in a large GaInN LED chip and demonstrated a increase in output power in an optimized device.

Optimization of electrode configuration to suppress current crowding





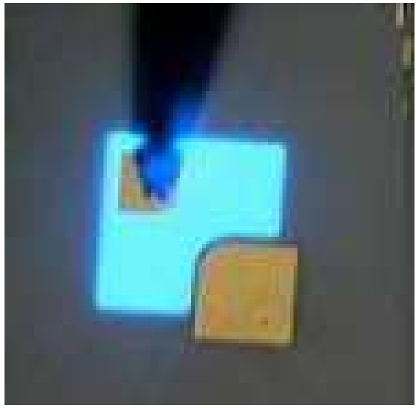
シミュレーションでは，350mA時10%アップ



Improvement of LED performance due to appropriate chip design

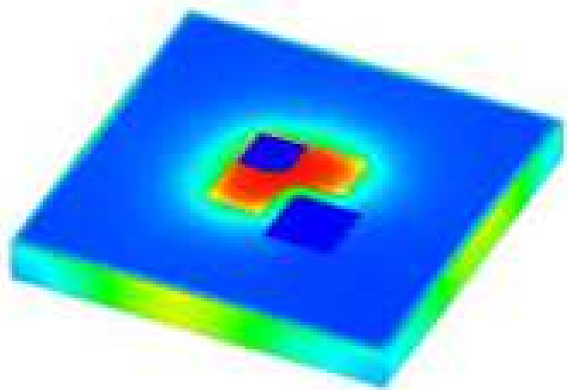
Sharp Laboratories of Europe Limited

http://www.sle.sharp.co.uk/research/advanced_optoelectronics/blue_leds.php



Electroluminesence from blue LED chip

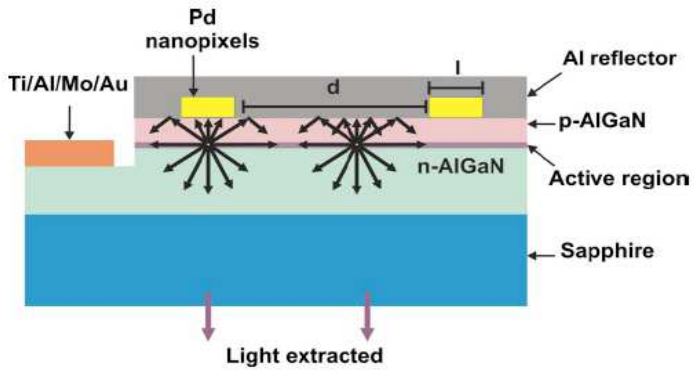
Modeling software such as SpeCLED is used to optimize the LED chip design in order to improve operating voltage, light extraction efficiency and junction temperature.
Other tools such as SiLENSe are also available to model band diagrams and to understand fundamental theoretical work, such as the piezoelectric effect in nitride-based devices.



LED chip design using SpecLED

Enhancement of light extraction in UV LEDs

Schematic cross-sectional view of nitride-based nanopixel UV LED with Pd contacts and Al reflector layer

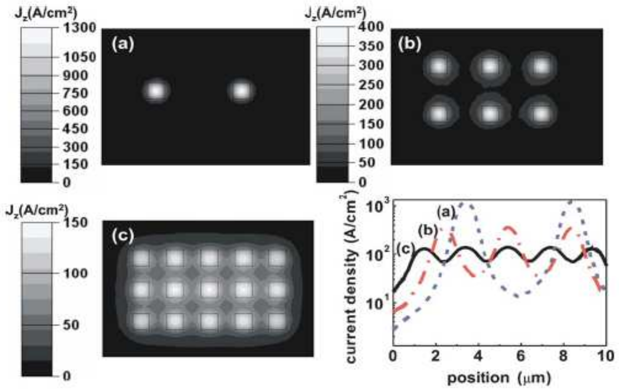


Enhancement of light extraction in ultraviolet light-emitting diodes using nanopixel contact design with Al reflector

N. Lobo,[1,a)] H. Rodriguez,[2] A. Knauer,[2] M. Hoppe,[2] S. Einfeldt,[2] P. Vogt,[1] M. Weyers,[2] and M. Kneissl[1,2]
[1]*Institute of Solid State Physics, Technische Universität Berlin, Hardenbergstr. 36, 10623 Berlin, Germany*
[2]*Ferdinand-Braun-Institute, Leibniz-Institut für Höchstfrequenztechnik, Gustav-Kirchhoff-Straße 4, 12489 Berlin, Germany*

(Received 5 January 2010; accepted 4 February 2010; published online 25 February 2010)

We report on a nanopixel contact design for nitride-based ultraviolet light-emitting diodes to enhance light extraction. The structure consists of arrays of Pd ohmic contact pixels and an overlying Al reflector layer. Based on this design a twofold increase in the light output, compared to large area Pd square contacts is demonstrated. Theoretical calculations and experiments reveal that a nanopixel spacing of 1 μm or less is required to enable current overlap in the region between the nanopixels due to current spreading in the p-GaN layer and to ensure current injection into the entire active region. Light emitted in the region between the nanopixels will be reflected by the Al layer enhancing the light output. The dependence of the light extraction on the nanopixel size and spacing is investigated. © 2010 *American Institute of Physics*. [doi:10.1063/1.3334721]

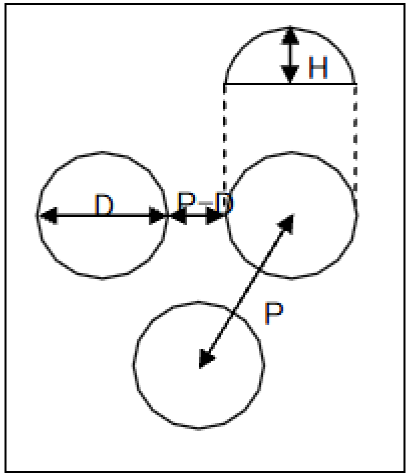


Simulation of the current injection in the active region for nanopixel AlInGaN LEDs with nanopixel size 1x1 μm2 and nanopixel spacing (a) 4 μm, (b) 2 μm, and (c) 1 μm. The total current is constant. In the graph the injection current density as a function of the position along a line through the center of the nanopixels is shown for the different structures.

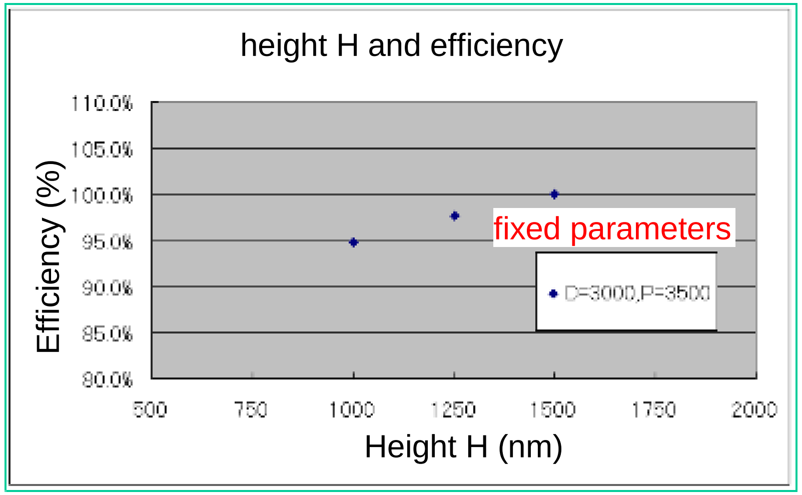
A nanopixel LED design with an Al reflector was developed resulting in enhanced light extraction in UV LEDs

Efficiency improvement by substrate processing

RATRO simulation result

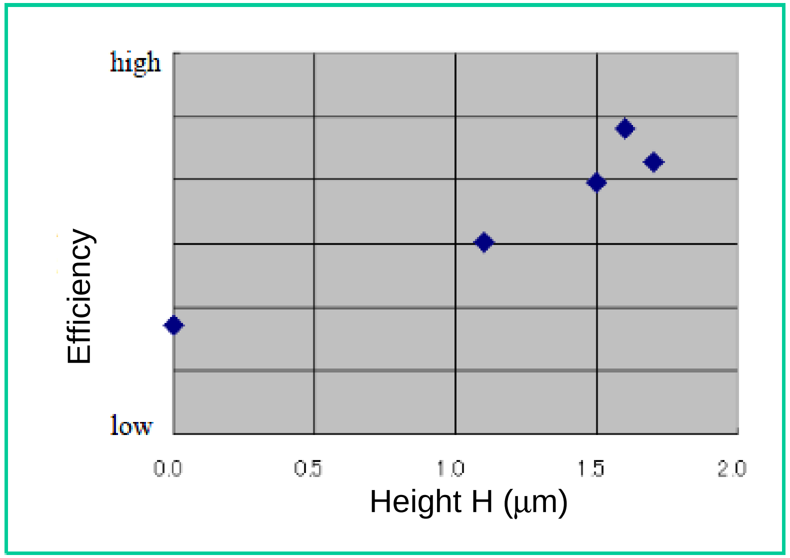


PSS pattern diagram



Relation between height H and efficiency

Actual device



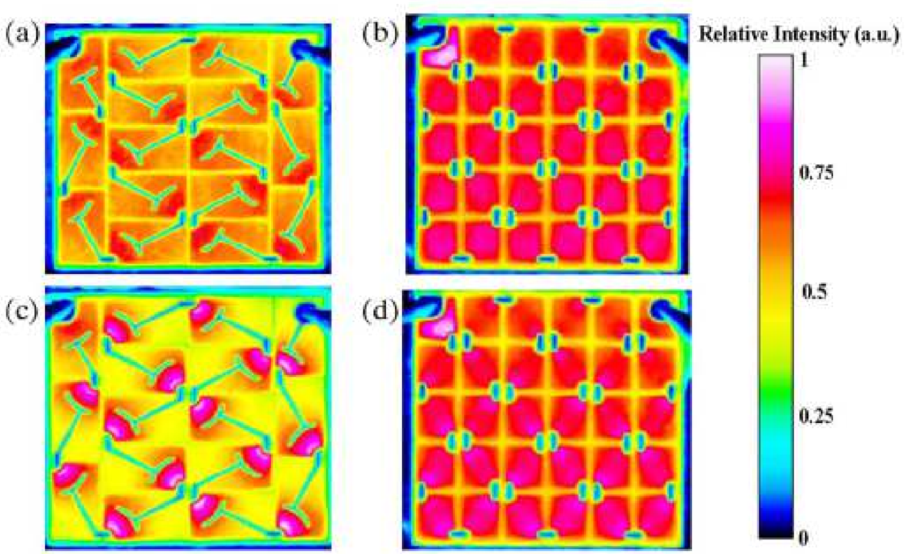
On substrate processing, patterns with high density and high height have the largest radiation efficiency

Efficiency and electrical characteristics of high-voltage LEDs

IEEE ELECTRON DEVICE LETTERS, VOL. 32, NO. 8, AUGUST 2011

Efficiency and Droop Improvement in GaN-Based High-Voltage Light-Emitting Diodes

C. H. Wang, D. W. Lin, C. Y. Lee, M. A. Tsai, G. L. Chen, H. T. Kuo, W. H. Hsu, H. C. Kuo, *Senior Member, IEEE*, T. C. Lu, *Member, IEEE*, S. C. Wang, *Life Member, IEEE*, and G. C. Chi



Measured spatial distribution of light output under 0.1-W operation for (a) 50- and (b) 100-V HV-LEDs and under 1-W operation for (c) 50- and (d) 100-V HV-LEDs

The spatial distribution of light output and simulation results showed that 100-V HV-LED with smaller microchips had superior current spreading.

As a result, under 1-W operation, the luminous efficiency of 100-V HV-LED with smaller microchips was enhanced by 7.8% compared to that of 50-V HV-LED, while the efficiency droop behaviors were reduced from 28% in 50-V HV-LED to 25.8% in 100-V HV-LED.

Smaller microchips exhibited lower series resistance and forward voltage, leading to higher wall-plug efficiency.

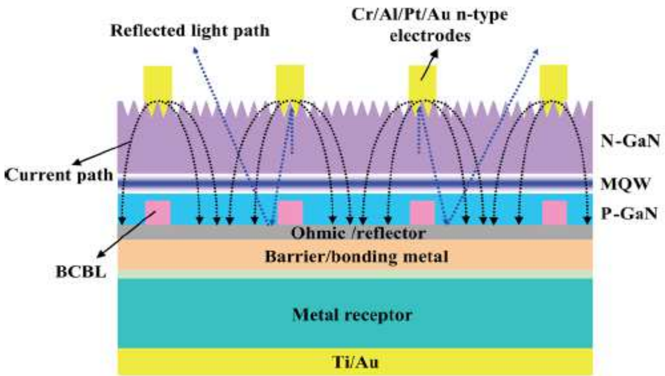
High-Performance VLED

Journal of The Electrochemical Society, **158** (9) H908-H911 (2011)
0013-4651/2011/158(9)/H908/4/$28.00 © The Electrochemical Society

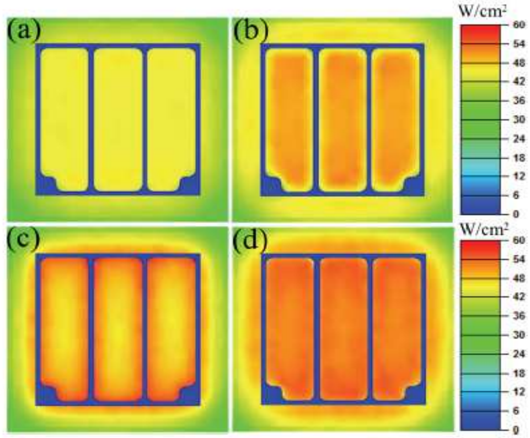
High-Performance Vertical Light-Emitting Diodes with Buried Current Blocking Layer and Non-Alloyed Reflective Cr/Al/Pt/Au n-type Electrodes

Tak Jeong,[a,b] Seung Whan Kim,[a] Sang Hern Lee,[a] Jin Woo Ju,[a] Seung Jae Lee,[a,*] Jong Hyeob Baek,[a] and June Key Lee[b,**,z]

[a] *Korea Photonics Technology Institute, Gwangju 500-460, Korea*
[b] *Department of Materials Science & Engineering, Chonnam National University, Gwanju 500-757, Korea*



Schematic cross sectional view of the VLEDs with the BCBL and highly reflective n-type Cr/Al/Pt/Au electrodes



Calculated light intensity distribution in near-field region of (a) VLED-I, (b) VLED-II, (c) VLED-III, and (d) VLED-IV

A GaN-based vertical light-emitting diode (VLED) with a novel structure, consisting of a buried current blocking layer (BCBL) inserted in p-type GaN and non-alloyed reflective n-type electrodes (Cr/Al/Pt/Au) on N-face n-GaN, is proposed and its enhanced light extraction efficiency is demonstrated.

Design of novel light-emitting devices and IP generation

IP generation based on results of modeling by SimuLED package

Patent of Russian Federation No 2262155 issued by October 10, 2005	*for UV LEDs*
Patent of Russian Federation No 2262156 issued by October 10, 2005	*for UV LEDs*
Patent of Russian Federation No 2277736 issued by June 10, 2006	*for blue LEDs*
Patent of Russian Federation No 2304952 issued by October 27, 2007	*for 808 nm high-power laser diode*
Patent of Russian Federation No 2309501 issued by October 27, 2007	*for 808 nm high-power laser diode*

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- Department of Electronic Sci. & Engin., Kyoto University, Group of Prof. Kawakami
- College of Optics and Photonics, University of Central Florida, FL, USA
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