Effects of Polarization Charge in GaN-based Blue Laser Diodes (LD)

Li-Wen Cheng[1+], Yang Sheng[2], Chang-Sheng Xia[2], Wei Lu[1+], Michel Lestrade[3], Zi-Qiang Li[3] and Zhan-Ming (Simon) Li[3]

[1]National laboratory for Infrared Physics, Shanghai Institute of Technical Physics, Chinese Academy of Science, Shanghai 200083,China
[2]Crosslight Software China, Suite 906,Building JieDi, 2790 Zhongshan Bei Road, Shanghai 200063, China
[3]Crosslight Software Inc., 121-3989 Henning Drive, Burnaby, BC, V5C 6P8, Canada

Abstract—**LASTIP software was applied to simulate a classical GaN-based blue laser diodes (LD) emitting at about 410nm. Considering effects of polarization charge (PC) in this LD, theoretical simulation showed accordant results with that in experiments. On the other hand, without regard to PC, threshold voltage and current are lowered, while laser characteristic temperature is enhanced, which indicates that PC acts as a negative role for laser performance.**

I. INTRODUCTION

As a type of short-wavelength-emitting device, GaN-based blue laser diodes (LDs) have many applications, such as full-color electroluminescent displays and laser printers, etc[1]. Conventionally, GaN-based blue LDs were grown on c-plane GaN buffer, which leads large internal electric fields due to discontinuities in spontaneous and piezoelectric polarization effects which cause charge separation between holes and electrons in quantum wells and limit the radiative recombination efficiency [2]. In the last several years, nonpolar GaN devices (such as in the m-plane [1100] and a-plane [1120][3]) and semipolar GaN devices (such as in the plane of [1011], [1013] or [1122][4]) were developed to reduce or to smooth polarization-related electric fields. Nevertheless, it's hard for nonpolar and semipolar GaN devices to perform with high efficiency and high output power due to high density of threading dislocations which act as non-radiative recombination centers[5]. So it is still a meaningful subject to investigate polarization effects in c-plane GaN devices for sake of optimizing device structures.

In this paper, the blue LD with and without polarization charge (PC) are investigated numerically with the Lastip simulation program, which was developed by the Crosslight Software Inc.[6]. It is delighting that when PC was considered, simulation results are well accordant with that in experimental. Comparing results with and without PC, we found that polarization charge not only improves threshold voltage for current boosting and threshold current for lasing, but also decreases characteristic temperature which describes the thermal stability of LD devices. All the effects of polarization charge indicate a negative function for LD performance.

II. DEVICE STRUCTURE

The structure of GaN-based blue LD under study is shown schematically in Fig.1 [7]. It consisted of a 3-µm-thick layer of n-type GaN standing on sapphire substrate, a 0.1-µm-thick layer of n-type $In_{0.05}Ga_{0.95}$ N, a 0.5-µm-thick layer of n-type $Al_{0.08}Ga_{0.92}N$, a 0.1-µm-thick layer of n-type GaN, an $In_{0.15}Ga_{0.85}N$/ $In_{0.02}Ga_{0.98}N$ MQW structure consisting of four 35-Å-thick $In_{0.15}Ga_{0.85}N$ well layers forming a gain medium separated by 70-Å-thick $In_{0.02}Ga_{0.98}N$ barrier layers, a 200-Å-thick layer of p-type $Al_{0.2}Ga_{0.8}N$, a 0.1-µm-thick layer of p-type GaN, a 0.5-µm-thick layer of p-type $Al_{0.08}Ga_{0.92}N$, and a 0.5-µm-thick layer of p-type GaN. The area of the ridge-geometry LD is 4µm x 550µm.

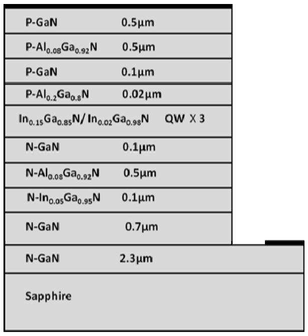

Fig. 1. The schematic structure of GaN-based blue LD under study

III. RESULTS AND DISCUSSIONS

In LASTIP software, ideal density of polarization charge was calculated according to paper [8], including spontaneous and piezoelectric polarization charges. The ideal polarization charge density was scaled down since that in realistic device produced in factory or laboratory, defects will smooth polarization charge more or less. When 22 percents of polarization charge density was considered, we obtained I-V and L-I curves well fitted to experimental results at 20℃, which is shown in Fig.2.

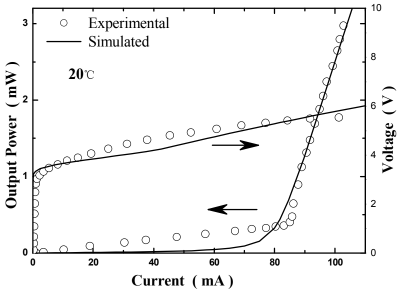

Fig. 2. Simulated and experimental I-V curves and L-I curves for the blue LD at 20℃.

[+] email: lwcheng@crosslight.com.cn

[+] email: luwei@mail.sitp.ac.cn

Besides this, the device was simulated at different environmental temperature from 20℃ to 70℃, which shows good agreement between the experimental data and our simulations[7] (see Fig.3).

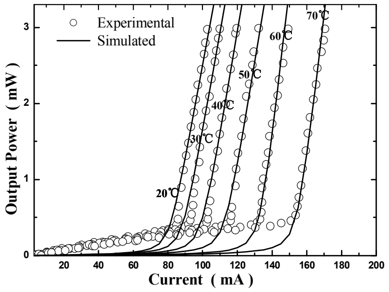

Fig. 3. Simulated and experimental L-I curves at different environment temperature.

Based on the fitting work above, we took away PC in simulations to investigate polarization effects. Fig.4a and Fig.4b show I-V and L-I characteristic curves of the blue LD with and without PC, respectively. We can see that threshold voltage for current boosting and threshold current for lasing are both lowered due to PC. Fig.5 shows that band is tilted when considering PC, which is due to additional electronic field generated by PC. The tilted band not only causes higher applied voltage to offset the additional electronic field so as to turn on current, but also makes quantum well harder to constrain electrons so that the LD needs more injected carrier current to obtain positive gain for lasing.

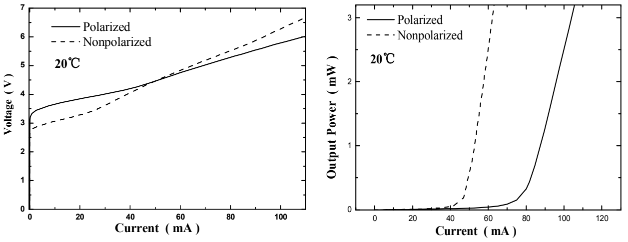

Fig.4. I-V and L-I characteristic curves of the blue LD with (a) and without (b) polarization charge (PC)

It is well known that characteristic temperature (denoted T0) is a widely used figure of merit for describing the sensitivity of threshold current in LDs [9]. The value of T0 is obtained for a specific LD by obtaining a best fit of the defining empirical relation,

$$I_{th}(T_0) = I_0 \exp(T/T_0) \qquad (1)$$

to the measured temperature-dependent threshold current over some temperature range of interest. Here, I0 and T0 are simply empirical fitting parameters . Fig.6 shows 2 groups of I-V curves at different temperature for the blue LD with and without polarization charge. After fitting to Eq.(1), characteristic temperatures are estimated as 76.2k and 87.8k for the blue LD with and without polarization charge, respectively. It is clear that polarization effects increase the sensitivity of threshold current, which is negative for LD devices.

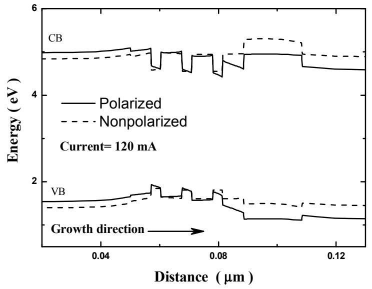

Fig.5. Band diagram of the blue LD with and without polarization charge (PC)

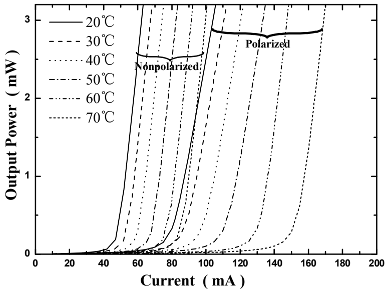

Fig.6. I-V curves at different temperature for the blue LD with and without polarization charge

IV. CONCLUSIONS

We simulated a classical GaN-based blue laser diode grown on c-plane substrate. When polarization charge was considered, simulations show well-fitted I-V and L-I curves like that in experiment. By comparing cases that with and without polarization charge, we found that polarization charge decreased LD performances, whose reason was explained through band diagram variation caused by polarization charge. Results in this work lead to a conclusion that if polarization charge (especially piezoelectronic charge) can be eliminated by experimental technics, laser efficiency of LD on c-plane can be improved greatly.

REFERENCES

[1] Shuji Nakamura, et al， Appl. Phys. Lett. 69 (26), 23 December 1996
[2] F. Bernardini, V. Fiorentini, and D. Vanderbilt,Phys. Rev. B 56 (1997) R10024.
[3] P. Walterweit, et al,Nature 406 (2000) 865.
[4] A. E. Romanov, T. J. Baker, S. Nakamura, and J. S. Speck,J. Appl. Phys. 100 (2006) 023522.
[5] J. S. Speck and S. J. Rosner, Physica B 273 (1999) 24.
[6] LASTIP by Crosslight Software Inc., Burnaby, Canada http://www.crosslight.com_.
[7] Shuji Nakamura, et al，Appl. Phys. Lett. 70 (11), 17 March 1997
[8] Vincenzo Fiorentinia, et al，Appl. Phys. Lett. 80(7), 18 February 2002
[9] J. I. Pankove: IEEE J. Quantum Electron. 4, 119 ~1968