K-2-6

Extended Abstracts of the 2013 International Conference on Solid State Devices and Materials, Fukuoka, 2013, pp1000-1001

Trap Analysis of InGaN-based Blue Light Emitting Diodes using Current-Transient Methodology

Garam Kim[1], Euyhwan Park[1], Jang Hyun Kim[1], Jong-Ho Bae[1], Dong Hoon Kang[2] and Byung-Gook Park[1]

[1] Inter-university Semiconductor Research Center and Department of Electrical Engineering, Seoul National University, 599 Gwanak-ro, Gwanak-gu, Seoul 151-742, Republic of Korea
Tel.: +82-2-880-7279, E-mail: garami21@hanmail.net
[2] Samsung Electronics, Co. Ltd., San 24, Nongseo-dong, Giheung-gu, Yongin, Gyeonggi 446-711, Republic of Korea

Abstract

A Recoverable increase in current of InGaN-based blue LEDs is observed when constant forward voltage is applied. These characteristics are assumed to be a result of a trapping process and a trap activation energy of 0.30 eV is extracted. Through a numerical simulation, it is confirmed that barrier height of MQW is reduced by hole trapping process and current is increased by the lowering of this barrier.

1. Introduction

InGaN-based blue light emitting diodes (LEDs) are used in various applications such as the back lighting units of LCDs and as general lighting sources. Although the market size has increased and the efficiency of LEDs has improved rapidly [1,2], the general level of understanding on the physics of the LEDs remain insufficient.

In this paper, we found a temporal increase in the current of the LEDs and extracted the activation energy of the trap causing this abnormal behavior. The process involved in the current increase caused by the trapping was also analyzed in a numerical simulation.

2. Results and discussions

InGaN-based LED samples for the experiment were grown on c-plane sapphire substrates. Five pairs InGaN/GaN MQWs were grown, emitting light with a wavelength of 450 nm. The area of the active region was approximately 500×1000 μm^2.

The as-prepared LED samples show abnormal electrical characteristics as shown in Fig. 1. When a constant voltage level is applied to the anode, current increases slowly and becomes saturated after a few seconds. When high voltage (3.5 V) is applied and a high level of current flows, as shown in Fig. 1(a), the junction temperature increases and influences the current. Therefore, it is difficult to obtain repeatable current-transient characteristics. In order to eliminate the influence of the junction temperature and guarantee the repeatability of the experiments, a much lower voltage (2.4 V) is applied and the current measurements are repeated five times without an interval. As shown in Fig. 1(b), the measurement results are nearly identical. To find the origin of the abnormality, the interval time between repeated measurements is changed and the results are compared. The measurement results in Fig. 2 show that the increased current according to the measurement completely recovers during the five-minute interval. Given this result, we can assume that this abnormal process is recoverable, like the trapping and de-trapping process.

Based on the assumption that the abnormality originates from the trapping process, we analyzed the current-transient characteristics by fitting them with equation (1), which models the increased current as the sum of pure single exponential terms [3].

$$I_{fitted} = \sum_{i=1}^{n} a_i\, exp(t/\tau_i) + I_\infty \qquad (1)$$

The current-transient characteristics shown in Fig. 2 are fitted with equation (1), Fig. 3 shows the time constant (τ_i) of trap and change of its amplitude as the interval becomes longer. From this result, we can extract a time constant of trapping of 0.1 seconds which causes the increase in current. In order to calculate the activation energy of the trap, the current-transient characteristics are measured under different temperature conditions (Fig. 4). These time constants at different temperatures are plotted as an Arrhenius plot and the estimated activation energy of the trap is 0.30 eV (Fig. 5). This result is consistent with the cathodoluminescence (CL) spectra of LED samples [4]. Fig. 7 shows the CL spectra of 'region A' (low trap density) and 'region B' (high trap density) in Fig. 6. The CL spectrum of region B shows a luminescence peak of 2.3~2.4 eV, which is 0.3~0.4 eV smaller than the bandgap of the MQW.

To find the relationship between the trapping process and the increase in current, a simulation of InGaN-based LEDs is conducted [5]. The physical parameters of nitride-based materials are based on Ref [6]. Negatively charged trap situated at 0.3 eV above the valence band of InGaN is defined as Ga vacancy considered the origin of the yellow luminescence [7]. Trapped hole concentration and conduction band are shown in Fig. 8, and Fig. 9 shows increase in current obtained by numerical simulation. Barrier height of the MQW is reduced by hole trapping process and the current is increased by this barrier lowering.

3. Conclusions

We analyzed an abnormal increase in the current of InGaN-based LEDs and extracted a trap activation energy level of 0.30 eV. We confirmed that this activation energy is consistent with the peak energy of the CL spectrum. In addition, the relationship between the current increase and the trapping process is analyzed by a numerical simulation.

Acknowledgements

This work was supported by Samsung Electronics and the Center for Integrated Smart Sensors funded by the Ministry of Education, Science and Technology as Global Frontier Project (CISS-2012M3A6A6054186).

References

[1] H. Jia *et al*: Adv. Mater. **21** (45) (2009) 4641.
[2] N. Gardner *et al*: Appl. Phys. Lett. **91** (24) (2007) 243506.
[3] J. Joh *et al*: IEEE Trans. on Elec. Dev. **58** (1) (2011) 132.
[4] E. Park *et al*: presented at *2012 12th IEEE Conference on Nanotechnology*, 2012.
[5] Atlas user's manual: SILVACO International, (2008).
[6] I. Vurgaftman *et al*: J. of Appl. Phys. **94** (6) (2003) 3675.
[7] M. A. Reshchikov *et al*: J. of Appl. Phys. **97** (6) (2005) 061301.

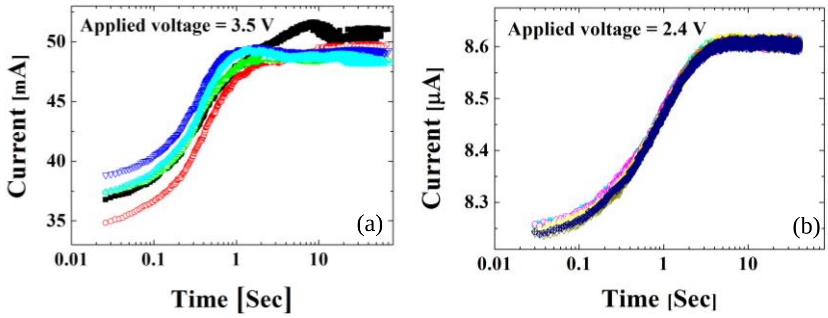

Fig. 1 Current-transient characteristics when a constant voltage level (3.5 V (a) and 2.4 V (b)) is applied. The same measurements are repeated five times without an interval.

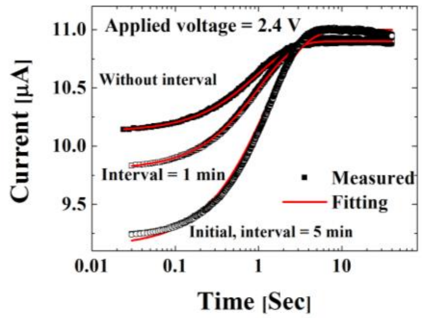

Fig. 2 Current-transient characteristics with different measurement intervals.

.

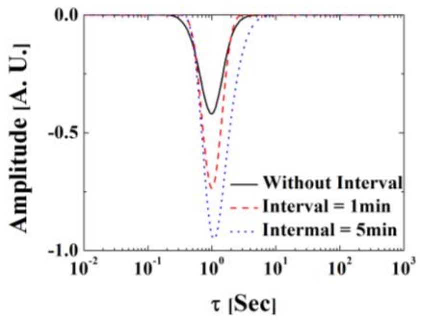

Fig. 3 Time constant spectrum with different measurement intervals.

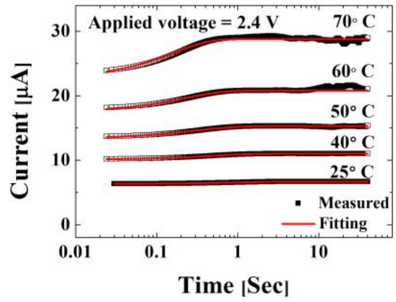

Fig. 4 Current-transient characteristics under different temperature conditions.

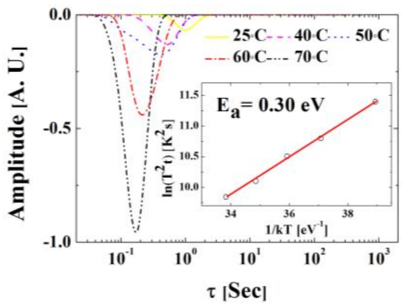

Fig. 5 Time constant of different measurement temperatures and the extracted activation energy of the trap (inset).

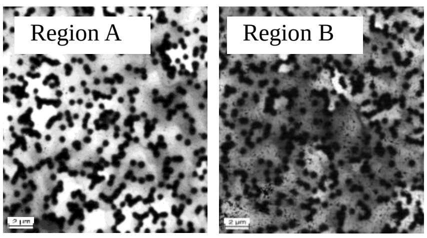

Fig. 6 Cathodoluminescence (CL) images of two regions of InGaN-based LEDs [4].

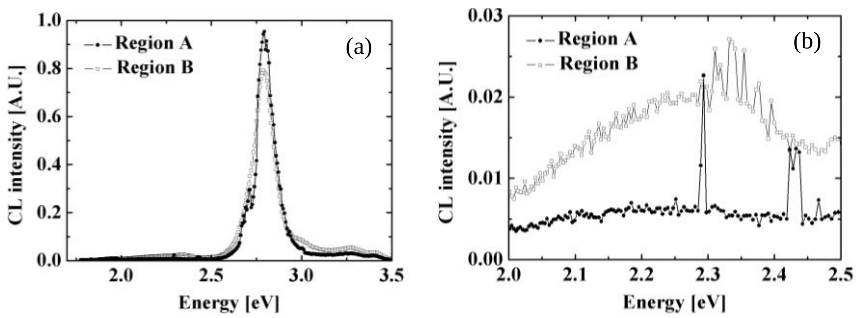

Fig. 7 CL spectrum of region A and region B showing a main peak of 2.7 eV (a) and a peak of 2.3 ~ 2.4 eV peak (b) originated from the trap [4].

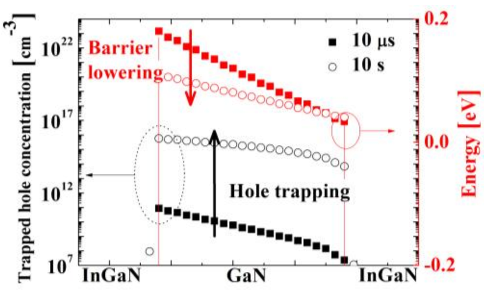

Fig. 8 Trapped hole concentration and conduction of the MQW when constant voltage is applied to anode.

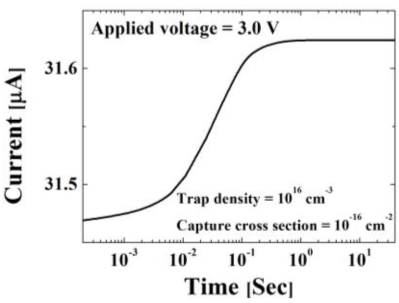

Fig. 9 Current-transient characteristics obtained by numerical simulation.