

Invention of High Efficient blue LED and Future Solid State Lighting

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Maruska and Tietjen did the first GaN growth by using hydride vapor phase epitaxy in 1969. Since their first GaN growth, a lot of breakthroughs have been achieved for the crystal growth of GaN and InGaN, conductivity control of p-type GaN, and the device structures of LED and laser diodes. Then finally, first high efficient blue LEDs were invented in 1993 [1]. The first white LED was also developed using the blue LED and YAG phosphor by Nichia Chemical Ind., in 1996.

Since first high efficient blue LEDs grown on sapphire were invented in 1993, these blue and white LEDs have been used for all kinds of applications, such as back light of LCD display, general lighting and others. I name these LEDs grown on sapphire and SiC substrate as 1st generation LEDs. These LEDs have been operated at a low current density due to an efficiency droop caused by a high dislocation density and Auger recombination. Recently, high efficient violet LEDs have been developed using GaN substrates by Sora Inc., [2]. It is called GaN on GaN LED. I like to name these high efficient violet LEDs grown on GaN substrates as 2nd generation LEDs because white LEDs made by using the violet LED grown on GaN substrates have superior characteristics in the view of the wavelength stability, efficiency droop, white color quality with a high CRI and the low peak intensity of the blue light which disrupt the circadian cycle.

First violet laser diodes (LDs) were invented in 1995 [3]. Then, those violet LDs have been used for the Blue-Ray DVDs. Now, these blue LDs are used for the application of laser projectors and automobile head lamps with the advantage of the directionality and high light output power density. These laser lighting could be used for a general lighting in the future by reducing the cost and improving the efficiency. I like to name the laser lighting as the 3rd generation solid state lighting.

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[2] C.A. Hurni, A. D. David, M.J. Cich, R. I. Aldaz, B. Ellis, K. Huang, A. Tyagi, R. A. DeLille, M. D. Craven, F. M. Steranka and M. R. Krames, "Bulk GaN flip-chip violet light-emitting diodes with optimized efficiency for high-power operation." *Appl. Phys. Lett.*, vol. 106, 2015, 031101

[3] S. Nakamura, M. Senoh, S.-I. Nagahama, N. Iwasa, T. Yamada, T. Matsushita, H. Kiyoku, Y. Sugimoto, "InGaN-Based Multi-Quantum-Well-Structure Laser Diodes," *Jpn. J. Appl. Phys.*, vol. 35, 1996, pp. L74-L76.