Project Title:

Design and investigation of DUV-LED and THz-QCL

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The deep ultraviolet (DUV) wavelength range has become more critical due to its inactivation feature of coronavirus particles. Based on the background above, the DUV-LEDs have been spotlighted for the quick elimination of the coronavirus. However, its wall-plug efficiency (WPE) is still too low, below 10%, compared with Mercury lamps. The low light extraction efficiency (LEE) is the most responsible factor of such low WPE. To search for a solution to the low LEE with a different point of view, in this fiscal year, we investigated the possibility of the adoption of AlGaN metasurface onto DUV-LEDs.

For the AlGaN metasurface investigation, we utilized BigWaterfall and SailingShip supercomputer systems and the finite-difference time-domain (FDTD) method. MPI-OpenMP parallelization scheme is adopted for the efficient calculation of large Yee cell numbers. The consumed CPU time of BigWaterfall for this investigation is 2,285,823.5 hours.

After optimizing AlGaN metasurface for the wavelength of 280 nm, we attach the optimized one onto n-AlGaN of AlGaN-based DUV-LEDs. After that, its expected LEEs are calculated and compared based on the form of chip structures, as shown in Fig. 1 and Fig. 2. Extracted LEEs for each structure are shown in Fig. 3. Extracted results show that the AlGaN metasurface alone is not enough for the LEE enhancement when compared with roughed cone structure. However, when the sidewall structure is simultaneously adopted for LEE increase, the synergetic effect can be extracted, as shown by Fig. 3 (b). After adopting the inclined side-wall and AlGaN metasurface LEEs for TE and TM modes increase to 57.8% and 37.7%, respectively, when p-AlGaN is adopted as the p-type cladding layer.

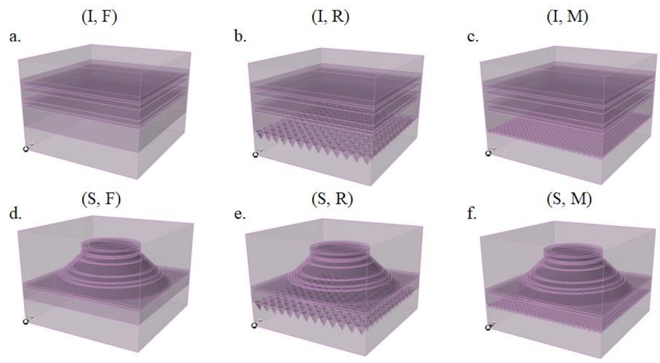

Fig. 1. I, S, F, R, and M mean the assumption of infinite lateral area, inclined sidewall, flat n-AlGaN, roughed n-AlGaN, and AlGaN metasurface, respectively. Therefore, these figures show LED structures (a) adopting the infinite lateral area with flat n-AlGaN, (b) the infinite lateral area with roughed n-AlGaN, (c) the infinite lateral area with the optimized AlGaN metasurface, (d) the inclined sidewall with flat n-AlGaN, (e) the inclined sidewall with roughed n-AlGaN, and (f) the inclined sidewall with the AlGaN metasurface, respectively.

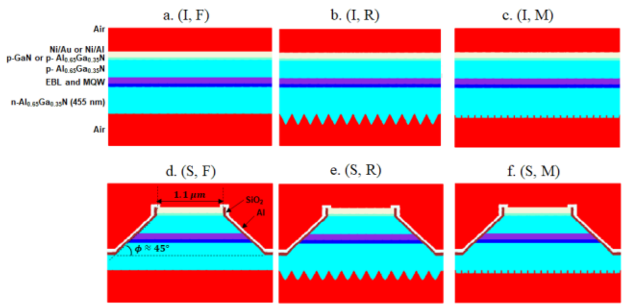

Fig. 2. (a)-(f): The cross-sectional views at the cutlines of the middle of the *y*-axis of Fig. 2(a)-(f), respectively.

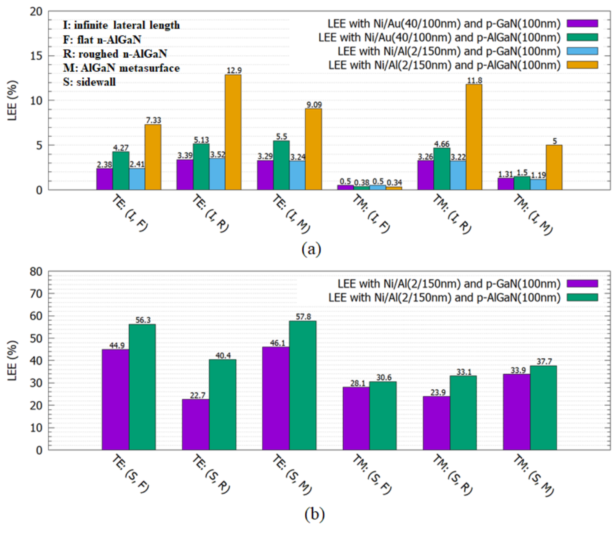

Fig. 3. LEEs for the structures of Fig. 2(a)-(f) with fixed 100 nm p-GaN or p-$Al_{0.65}Ga_{0.35}N$ thickness. Adopting the inclined sidewall, Ni/Al, Ni/Au, p-GaN, or p-$Al_{0.65}Ga_{0.35}N$ becomes variables for the analysis. (a) and (b) show the results of LEEs without and with inclined sidewall, respectively. The caption on each bar represents the LEE value for the given structure.

Usage Report for Fiscal Year 2020

Fiscal Year 2020 List of Publications Resulting from the Use of the supercomputer

[Paper published by a journal]

1. Joosun Yun and Hideki Hirayama, "Investigation of Light-Extraction Efficiency of Flip-Chip AlGaN-Based Deep-Ultraviolet Light-Emitting Diodes Adopting AlGaN Metasurface", IEEE Photonics Journal **13**, 1 (2021).

[Conference Proceedings and oral presentation]

1. Joosun Yun and Hideki Hirayama, "AlGaN metasurface to increase the light-extraction efficiency of deep ultraviolet light-emitting diodes by perfect transmittance before critical angle", SPIE Photonics Europe, Strasbourg, France, Mar. 29 – Apr. 2, 2020 (changed to online conference due to COVID-19).