Design of Tunnel-Injected Sub-300 nm AlGaN-Based Lasers

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There has been recent and extensive research in the development of electrically-pumped continuous-wave operating AlGaN-based UV-B lasers with applications including phototherapy in medical sector; water sterilization, trace gases sensing, polymers curing, in-plant growth and horticulture, as well as stimulating the formation of anti-cancerogenic substance. In this work, we design an electrically-pumped AlGaN-based UV-B laser diode that can provide lower threshold voltage and continuous-wave operation. Our laser design utilizes a novel polarization engineered AlGaN/InGaN/AlGaN-based tunnel junction. The active region used in this device consists of three compressively strained 2-nm-thick $Al_{0.5}Ga_{0.5}N$ QWs separated by 6 nm $Al_{0.65}Ga_{0.35}N$ barriers for an emission wavelength of ~290 nm. Details of this active region to obtain LEDs emitting at 287 nm with 2.8% external quantum efficiency can be found elsewhere [1].

The low-resistive tunnel junction is used as an intracavity contact in the device in place of the resistive *p*-type contact; which leads to improved hole injection and a reduced threshold voltage. Hence, room-temperature continuous-wave laser operation could be enabled. The tunnel junction layer consists of p^+-AlGaN with Mg doping concentration of 5×10^{19} cm^{-3}, 4 nm $In_{0.2}Ga_{0.8}N$, and 5 nm n^+-AlGaN with Si doping concentration of 10^{20} cm^{-3} with the Al composition grading from 58% to 65%. The simulated energy band diagram confirms a sharp band alignment obtained through such a tunnel junction design. Based on previous reports of tunnel junction performance, we can achieve a series resistance lower than 1 mΩ-cm^2 for 75% AlGaN. This corresponds to a resistive voltage drop of less than 5 V at a current density of 5 kA/cm^2. In comparison, if a *p*-layer was used as the top cladding layer, we can estimate that the series resistance of the stack would exceed 40 mΩ-cm^2, leading to a voltage drop > 100 V for 5 kA/cm^2.

The two laser structures, as presented in Fig. 1, designed in this study are expected to enable sufficient carrier injection with a reasonable voltage drop to achieve electrically-pumped lasing. In the conventional Fabry-Pérot structure where the QWs are centered with respect to the waveguide, the tunnel junction is located just only 100 nm away from the peak of the optical mode. This leads to a strong overlap of this mode with the highly absorbing tunnel junction. Such a mode could have a node at the position of the tunnel junction to reduce free carrier absorption loss. Therefore, we propose a refined laser design by deliberately placing the QWs on top of the bottom *n*-doped waveguide. In this configuration, the optical mode overlap with the multi-quantum wells (MQWs) is not the maximum possible level since they are not at the center of the top and bottom waveguide layers. However, the mode overlap with the tunnel junction is reduced since it is farther away from the active region, as shown in Fig. 2. Hence, the mode overlap with the tunnel junction is reduced by more than a factor of 7 without sacrificing Γ for the active region significantly.

Our calculation shows that the series resistance of the device can be substantially reduced with the use of boron-containing AlGaN layers in tunnel junctions [2]. The supporting results will be reported at the conference.

1. Zhang Y et al, *Appl. Phys. Lett*. **112** 071107, 2018
2. Dreyer C E et al, *Appl. Phys. Express* **7** 031001, 2014

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