InAlN/GaN Lattice Matched Stepped-Miniband Superlattices as Efficient Electron Blocking Layer for 450 nm Laser Diode

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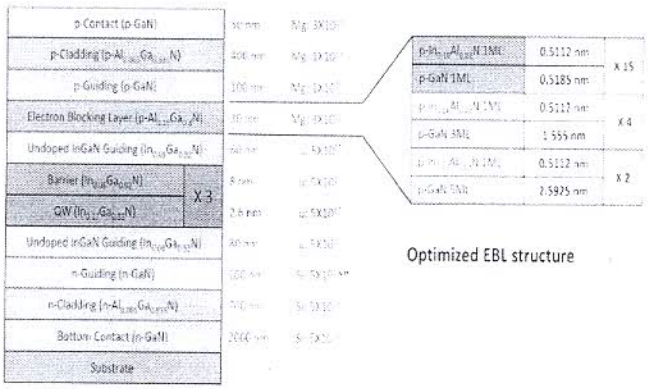
Abstract:

In this work, we have designed lattice matched, stepped-miniband GaN/$In_{0.18}Al_{0.82}N$ short period superlattices (SPSL) electron blocking layer (EBL) for 450 nm high power laser diode (LD) structure. Due to $In_{0.18}Al_{0.82}N$ alloy is lattice matched with GaN, the strain in the SPSL EBL structure layer is negligible. In the original reference LD structure, EBL was 30 nm $Al_{0.15}Ga_{0.85}N$ layer. The optimized stepped-miniband SPSL structure contains 2 periods of 5 monolayers (ML) GaN/ 1ML $In_{0.18}Al_{0.82}N$, 4 periods of 3 ML GaN/1ML $In_{0.18}Al_{0.82}N$, and 15 periods of 1ML GaN/1ML $In_{0.18}Al_{0.82}N$. Thickness of SPSL EBL is 29.9 nm. In optimized EBL, the energy barrier height due to miniband increases toward p-cladding in conduction band such that electron leakage is suppressed efficiently. With 1ML thickness of well and barrier, the miniband of SPSL shifts up in conduction band and down in valence band, which results in increase in effective bandgap. The increased effective bandgap blocks electron overflow efficiently. On the other hand, the holes transport occurs through SPSL miniband in valence band, effectively reduced bandgap due to minibands in 5ML well and 3ML well of SPSL enhances the hole injection into the active region. Due to varied well width of SPSL, the structure of EBL results into a stepped miniband SPSL.

With our optimized SPSL EBL design, the threshold current density decreases from 4.9 kA-cm^{-2} to 4.5 kA-cm^{-2}. Light output power of LD was increases from 146.54 mW to 255.26 mW at 10 kA-cm^{-2} injected current. Slope efficiency increases from 0.548 W/A to 0.924 W/A and leakage current reduces from 2534.6 A-cm^{-2} to 0.45 A-cm^{-2} at injected current 10 kA-cm^{-2}.

Supplementary information



Cavity: 5 μm X 1000 μm, Uncoated Mirror Reflectivity : 0.16 and 0.16

Figure 1 Laser diode structure

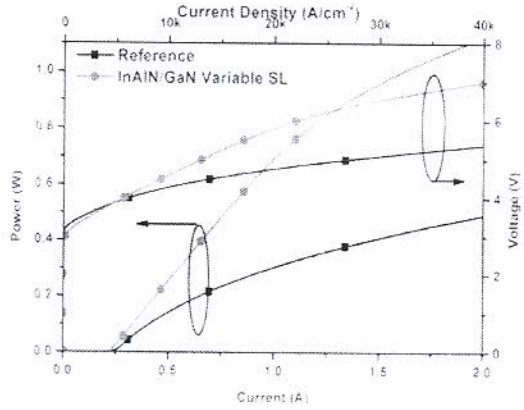


Figure 2 L-I-V Characteristics of laser diodes

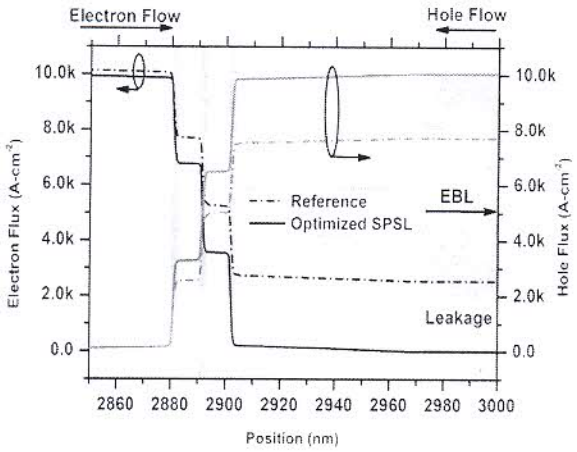


Figure 3 Electon and Hole Flux in laser diode structure

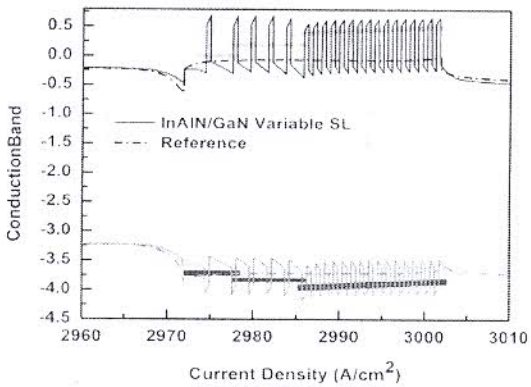


Figure 4 Band diagram of SPSL EBL and Reference EBL showing step-graded minibands

Figure 1 shows the reference LD structure, which is experimentally grown, fabricated and characterized by Muziol et al [1]. We have designed, optimized and simulated stepped miniband lattice matched GaN/$In_{0.18}Al_{0.82}N$ SPSL EBL for the reference LD structure. Figure 2 shows the L-I-V characteristic of the reference as well as our designed EBL LD. The LD power increases considerably with optimized EBL. The carrier fluxes are plotted in Figure 3, electron leakage reduced significantly from 2534.6 A-cm^{-2} to 0.45 A-cm^{-2} at injected current 10 kA-cm^{-2} as well as hole transport to the active region enhanced from 7.7 kA-cm^{-2} to 10 kA-cm^{-2}. Figure 4 represents the energy band diagram of lattice matched stepped miniband SPSL structure. The stepped-miniband configuration increases effective bandgap toward right side and reduces effective bandgap toward left side of the structure. Electron leakage is suppressed due to increased barrier with 1ML GaN/1ML InAlN SPSL miniband. Also hole transport to the active region is enhanced by SPSL miniband in valence band.

Ref: [1] G. Muziol *et al.*, "High power nitride laser diodes grown by plasma assisted molecular beam epitaxy," *J. Cryst. Growth*, vol. 425, pp. 398–400, 2015.