Study on Confinement Scheme of GaN-based Vertical-Cavity Surface-Emitting Lasers

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Abstract: The GaN-based vertical-cavity surface-emitting lasers (VCSELs) with three sorts of current-confined structure are numerically studied. The simulation results illustrate the proposed hybrid VCSEL design, which shows apparently lower threshold current and turn-on voltage, has superior performance due to the uniformly spread of current distribution and increased lateral optical confinement. These beneficial enhancements reflect the lateral multimode lasing behavior is suppressed via the smaller aperture size. As a result, the consideration provides a very promising design for the high-performance of GaN-based device.

Introduction

Development of potential nitride semiconductors and their applications such as light emitting diodes and laser diodes has attracted momentous attention.[1] The continuous wave (CW) current injection of GaN-based VCSELs was illustrated.[2-3] The current-confined aperture becomes electrically non-conducting layer hence the injected current will be confined into the central region of the VCSELs. This technique has been applied to GaN-based VCSELs where fractional oxidation of a high Al-content layer gives an aperture for current and optical confinement in the transverse direction.

Device Structure and Technical Methods

There are three structures demonstrated in this work, noting as original aperture inside the Indium-tin-oxide (ITO) layer (Type Ⅰ), AlN-aperture inside the p-GaN (Type Ⅱ), and the proposed hybrid structure with the ITO current spreading layer and the AlN current aperture (Type Ⅲ). The original structure is based on our previous report[4] of the room-temperature operated GaN-based device with emission wavelength of 410-nm. The proposed structure has a 7λ thick cavity surrounded by a bottom 29-pair AlN/GaN epitaxial distributed Bragg reflector (DBR) and a top 10-pair Ta_2O_5/SiO_2 dielectric DBR. The cavity composes of a n-GaN layer (900 nm), a 5-pair of $In_{0.2}Ga_{0.8}N$ (3 nm)/GaN (8 nm) multiple quantum wells (MQWs), a AlGaN electron blocking layer (20 nm), a AlN-aperture (30 nm) inserted into a p-GaN layer (100 nm), and a ITO current spreading layer (40 nm). The simulation model owing to the cylinder-symmetry structure can be simplified to the two-dimensional (2D) scheme, defined by the vertical (longitudinal) direction Z and the lateral (transverse) direction R.

Simulation Results

The key essential role to affect the laser behavior is that the overlapping percentage, which determined by the distribution of the cavity modes and the optical gain in the active region. The VCSEL with a small aperture can support only the zeroth-order mode, and other multimode will be suppressed. The main cause to influence on the threshold condition among several designs would be the lateral optical confinement. Here the investigation of the buried AlN-aperture case would not be discussed in the following due to the edge accumulated gain distribution and high absorption loss at the central region.

According to the simulation results as shown in Fig. 1(a), the Type Ⅰ device was set at the node position of the optical field to diminish the absorption loss. We further generalized from the Type Ⅰ design: the smaller overlapping percentage brought about a higher threshold current among smaller aperture size. The consequence of gain-optical zeroth-order mode overlapping percentages for 3.5 μm, 4 μm, and 5 μm devices were 65.7%, 79.6%, and 83.6%, respectively. Besides, the Type Ⅲ had better lateral confinement compared to the Type Ⅰ with the same radius by virtue of AlN-aperture. To accomplish single mode operation, the AlN aperture size should be declined to increase the overlapping between gain region and the zeroth-order mode. Moreover, the device with 4.5 μm aperture size had lowest threshold of zeroth-order mode lasing as a result of much relatively higher gain-optical zeroth-order mode overlapping percentage and relatively smaller gain-optical first-order mode overlapping percentage, as shown in Fig. 1(b).

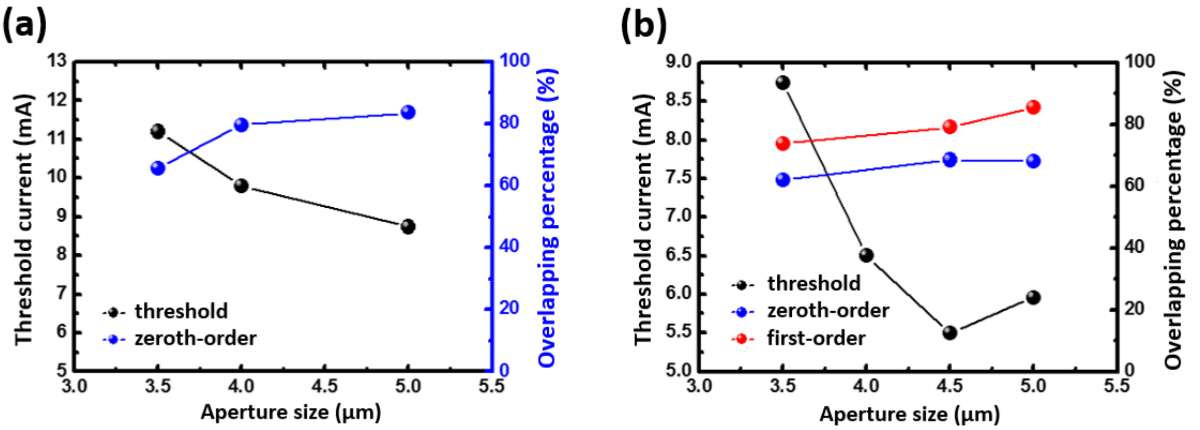

Fig. 1: (a) Threshold and gain-mode overlapping percentage as a function of aperture sizes. (b) Threshold (black dot) and gain-mode overlapping percentage of zeroth-order (blue dot), and first-order (red dot) optical mode as a function of aperture sizes.

Fig. 2 shows the light output power-current-voltage (L-I-V) curves of above mentioned distinct schemes. The Type Ⅲ design had considered the benefits of superior current spreading ability of the ITO layer and optical confinement of the AlN-aperture. The threshold current would be lower even half of the Type Ⅰ. The lager contact area between ITO layer and p-GaN contributed to superior injection ability and current spreading. Such method could provide an omnipotent solution for high performance GaN VCSELs.

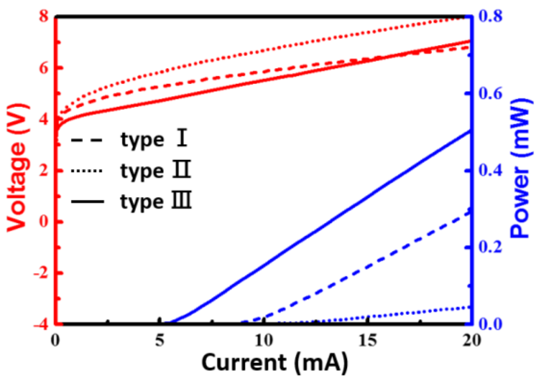

Fig. 2: The calculation of light output power (blue line) and contact voltage (red line) characteristics of Type Ⅰ (dash line), Type Ⅱ (dot line) and Type Ⅲ (solid line) VCSELs with various injected currents.

Conclusions

In conclusion, we have analysed a better design for confinement characteristics of VCSEL structures to identify the proper structure for GaN-based VCSELs. The enhanced confinement leads to lower threshold current and turn-on voltage. Our proposed structure not only improves the current crowding issue but also provides gain enhancement of single-mode operation. Above mentioned propose a better examination than ever before, which can be utilized novel design of GaN-based VCSELs.

References

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