GaN-BASED LASER DIODES
Device design and performance

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Abstract: Laser diodes have been fabricated from group-III nitride layer structures grown by metalorganic vapor phase epitaxy on c-plane sapphire substrates. The gain-guided devices emitted at a wavelength of around 400 nm. The threshold current density decreased with increasing the width of the injection stripe, which was attributed to lateral current spreading below the p-metal contact. Device operation was limited to pulsed current injection due to the heating of the material. By measuring the light emission in dependence of the device temperature, the drop in intensity during a single pulse could be converted to a rise in temperature of the active region. This experimental data was in good agreement with simulations of the heat dissipation based on solving the two-dimensional heat-conduction equation. In view of reducing the threshold current density of the device, the confinement of the optical modes guided in the structure was simulated. Coupling of modes mainly guided either in the laser waveguide or in the GaN buffer layer is predicted. The use of an AlxGa1-xN buffer layer or an InxGa1-xN waveguide is suggested for complete suppression of mode coupling.

Key words: group-III nitrides, laser diodes, heat dissipation, optical waveguiding

1. INTRODUCTION

Laser diodes based on group-III nitrides have recently attracted a lot of interest particularly due to their use in high-density optical storage systems. The performance requirements for these devices are fairly stringent. Among other things, cw operation with high output powers for thousands of hours along with a proper beam profile are needed. In order to achieve this, one has to minimize, e.g. device degradation due to heat accumulation. This can
only be achieved by carefully optimizing both the device design and the quality of the used materials.

In this paper we summarize results on the experimental characterization and theoretical simulation of laser diodes that have recently been fabricated in our lab. Although the device performance is still far from what is needed for commercial applications, the conducted investigations are helpful with regard to understand the physics behind the performance limitations. The goal is to provide roadmaps for a further optimization of the device. Here, we focus on the lateral spreading of the current injected through the contact stripes, the heating of the device due to limited heat dissipation and the coupling of optical modes guided in the multilayer structure.

2. EXPERIMENTAL AND THEORETICAL DETAILS

Laser diodes were grown by metalorganic vapor phase epitaxy on c-plane sapphire substrates using a 3 × 2” close-coupled showerhead reactor from Thomas Swan Inc. Standard precursors and carrier gases were employed. The heterostructure consisted of a thick GaN:Si buffer layer (2.7 µm) grown on a thin GaN nucleation layer, an Al_{0.07}Ga_{0.93}N:Si cladding layer (500 nm), a GaN:Si waveguide layer (100 nm), an active region with three In_{0.08}Ga_{0.92}N quantum wells (4 nm) separated by GaN:Si barriers (7 nm), an Al_{0.2}Ga_{0.8}N:Mg electron blocking layer (15 nm), a GaN:Mg waveguide layer (85 nm), an Al_{0.07}Ga_{0.93}N:Mg cladding layer (500 nm) and a GaN:Mg contact layer (90 nm). Gain-guided laser diodes with a cavity length and an injection stripe width of 500 µm and 5–20 µm, respectively, were fabricated using standard photolithography, metallization and reactive ion etching. The smoothness of the laser facets was enhanced by wet chemical etching as described in Refs. [1,2]. One facet was coated with a quarter-wavelength dielectric mirror consisting of four pairs of TiO$_2$ and SiO$_2$.

Heat dissipation in the devices was modeled by solving the heat-conduction equation numerically. An implicit integration scheme on a two-dimensional grid of variable spacing was applied to a cross-section area of 300 µm × 600 µm. The numbers for the thermal conductivity and the specific heat were taken from the literature. Whereas the specific heat of the alloys was derived from a linear interpolation between the corresponding values for the binary constituents, a strongly nonlinear interpolation was chosen for the thermal conductivity as described in Ref. [3] to consider the effect of mass disorder.

Optical waveguiding in the laser diodes was simulated using the software WAVEGUIDE [4]. The complex refractive indices for a wavelength of 400