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InGaAsN as a Material for Novel Long-Wavelength Lasers

H. Riechert, R. Averbeck, M. Galluppi, L. Geelhaar and G. Jaschke

Infineon Technologies AG, Corporate Research Photonics, D-81730 Munich, Germany

Phone: +49-89-234-45230 Fax: +49-89-234-955 5536

E-mail: henning.riechert@infineon.com

I. Introduction

Vertical cavity surface emitting lasers (VCSELs) emitting in the 1.3 µm wavelength window are highly desirable devices for data communication over metro area distances. Ideally, such devices should be based on the well-established GaAs-AlAs VCSEL technology used for 850 nm devices.

Amongst the various approaches to reach an emission wavelength of about 1300 nm from GaAs-based material the most promising one is the use of the novel alloy InGaAsN [1]. This material benefits from both a strong reduction of bandgap as well as from the reduction of strain which results from the incorporation of N into InGaAs. Due to their high electronegativity, N atoms strongly change the band-structure of (In)GaAs and at low nitrogen concentrations, each percent of N reduces the band-edge by about 150 meV. Thus the addition of only about 2% of N is sufficient to achieve 1.3µm emission from InGaAsN.

First InGaAsN-based VCSELs were presented in the year 2000 (for references see the review given in [1]) and have reached product maturity very rapidly.

This paper will give a brief overview over the state of the art of InGaAsN-based VCSELs. We will then deduce further challenges from the materials point of view. Finally, we will present a systematic investigation about the limits of emission wavelength and laser performance in InGaAsN.

II. Status of InGaAsN-based lasers for 1300 nm

Typical requirements for VCSELs to be employed in data communication systems are single-mode operation and an output power of about 1mW over the whole range of operating temperatures up to 85°C.

Single-mode devices have typical diameter of the current-constricting oxide aperture of about 6µm. Production-type devices from Infineon with this geometry exhibit single-mode output-powers at 1280 nm of about 2.5 mW at 25°C and of more than 1mW at 85 °C [2]. Therefore these devices are now employed in optical transceiver systems for 2.5Gb/s spanning a transmission distance of up to 10km.

Despite the excellent VCSEL-performance achieved so far, InGaAsN-based edge-emitting lasers for 1300 nm are presently still inferior in performance when compared with their InGaAlAs-based counterparts grown on InP. Two reasons have been pointed out for this [3]: Even in state-of-the-art InGaAsN lasers, about 50% of the total current at threshold is consumed by nonradiative recombination due to point defects of unknown origin, which accounts for the somewhat higher thresholds of InGaAsN lasers. Secondly, Auger recombination is much more pronounced in InGaAsN, which limits their high-temperature performance.

The first issue is clearly related to material quality, which is compromised by the incorporation of N. If it could be resolved, also the issue of Auger recombination (which increases with the third power of the current density) would be alleviated. Therefore, optimising material quality of InGaAsN is a primary challenge. All experience to date shows that the optical quality of InGaAsN deteriorates with increasing N content, i.e. when attempting to reach longer-wavelength emission. Thus the challenges of reducing nonradiative recombination and of reaching longer wavelengths are obviously related.

III. Issues of InGaAsN growth

In the talk we will illustrate the main problems which are specific for the growth of InGaAsN QWs. Although our work is based on MBE growth, the same holds for growth by MOVPE.

A very prominent problem is the very pronounced tendency for three-dimensional (3D) growth. This is evidenced by comparing the growth of InGaAs and InGaAsN QWs with the same In-contents. Despite the lower compressive strain in InGaAsN, the transition from 2D to 3D growth occurs at a lower thickness in InGaAsN. Likewise, to suppress 3D growth in InGaAsN, lower growth temperatures must be chosen. Thus it is common in MBE to grow InGaAsN at about 420 °C.

Moreover, the low growth temperatures require post-growth annealing. This apparently removes or passivates non-radiative recombination centers but also causes a blue-shift of the emission wavelength. It is found that the annealing routine must be matched to the growth temperature and to the composition of the material.

III. InGaAsN lasers emitting beyond 1.3µm

Recent work to achieve lasers emitting beyond 1300 nm based on high N-content InGaAsN QWs [4] or by alloying Sb into InGaAsN [5] have shown great promise on this way.

It is, however, still unclear how far the performance of edge-emitting lasers based on simple InGaAsN/GaAs QWs, can be taken. Such structures are best suited as a test of material quality. We have therefore conducted a systematic investigation of this question, based on SQW lasers with varied N-content, where parameters of MBE growth and thermal annealing were adapted to the compositions.

All lasers consist of a 6.5 nm InGaAsN single QW embedded in an undoped 400 nm thick GaAs waveguide layer. The n- and p-type AlGaAs cladding layers are 1.8 µm thick, have an Al content of 35% and are doped to $5x10^{17}$ cm^{-3} with Si and Be, respectively. The In content of the quantum well was deliberately kept fixed at 34% while the N content was varied from 2.5% (?=1280 nm) to 4% (?=1430 nm).

Broad area lasers with 800x100 µm² stripe contacts and as-cleaved facets were measured under pulsed conditions. Figure 1 shows threshold current density j_{th} as a function of laser wavelength. While the increase in j_{th} is only moderate up to 1380 nm (factor 2 per 100 nm), it becomes dramatic above this value (factor 2 per 50 nm). For wavelengths of 1400 and 1430 nm we obtain 0.9 and 1.6 kA/cm², respectively, well below current literature data [5]. 1200 µm long devices yield 690 and 1090 A/cm² at these wavelengths. These values are clearly lower than those of any Sb-free lasers reported so far. Remarkably, η_i = 0.35±0.05 and $T_0 \approx$ 50-60 K are both nearly independent of laser wavelength.

The fact that we observe a clear inverse correlation between j_{th} and PL intensity suggests that the increase in j_{th} with N-content is mainly caused by monomolecular recombination.

IV. Conclusion

InGaAsN VCSEL emitting at about 1300 nm have reached maturity. A systematic study of InGaAsN SQW edge-emitting lasers has resulted in record-low thresholds which promise that VCSELs with emission wavelength well beyond 1400 nm are feasible based on simple, Sb-free InGaAsN QWs.

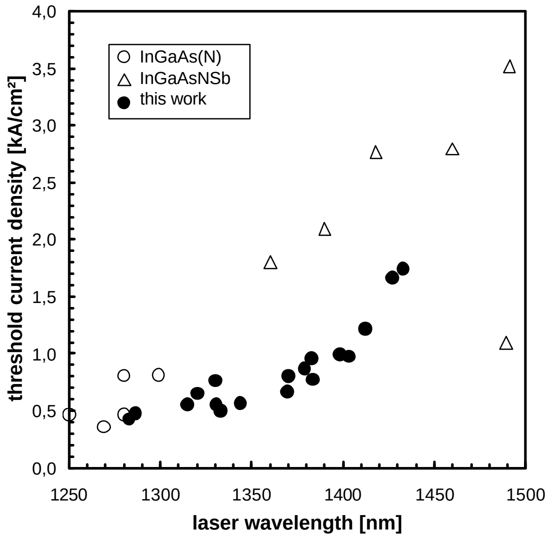

Fig. 1 Threshold current density of 800 µm long InGaAsN/GaAs SQW lasers with N concentrations ranging from 2.5 - 4% measured at 25°C (full symbols) compared to data taken from literature (open symbols) [5]

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