GaInAsN based lasers for the 1.3 and 1.5µm wavelength range

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Abstract

Since the introduction of the GaAs based material system GaInAsN for long wavelength laser diodes several years ago rapid progress has been made in improving the performance of these devices. We present some of our efforts and results in the optimized growth of GaInAsN/GaAs quantum well structures in the 1.3-1.55µm wavelength region by solid source MBE using a RF plasma source for the generation of active nitrogen. Based on this preliminary work we have fabricated GaInAsN LDs with emission wavelengths up to > 1.5µm. Laser performance data for 1.3 and 1.5µm devices will be presented and compared.

I. Introduction

The quaternary alloy GaInAsN proposed by Kondow et al. [1] for the realization of long wavelength lasers based on GaAs has attracted considerable attention during the last few years. The material offers the advantage of an excellent electron confinement in the active region due to a high conduction band offset when combined with GaAs barriers which results in excellent high temperature device performance at 1.3µm as will be demonstrated in this contribution. In addition, the possibility to monolithically combine GaInAsN active regions with AlGaAs based distributed Bragg Reflectors (DBRs) makes this material system highly attractive for long wavelength vertical-cavity surface emitting lasers (VCSELs) [2].

By plasma assisted MBE we have realized GaInAsN/GaAs SQW testsructures with excellent PL properties up to 1.55µm without the need for any post-growth annealing treatments. These compressively strained QWs have then been implemented in the active region of SCH laser structures. Fabricated ridge waveguide laser diodes at 1.3µm show thresholds of 21mA under cw operation at RT with efficiencies exceeding 0.5W/A and can be operated cw up to temperature of 120 °C. Single mode emission under cw operation with side mode suppression ratios of around 45dB has been achieved by laterally coupled DFB lasers. Results on 1.5µm GaInAsN LDs are so far limited to pulsed operation of ridge waveguide LDs up to maximum temperatures of around 80 °C.

II Epitaxial growth and device fabrication

The GaInAsN structures presented in this contribution were grown by solid source molecular beam epitaxy on an Eiko 100S MBE system. A radio frequency (RF) plasma source supplies active nitrogen from ultrapure N_2 gas. A special shutter construction was designed for this source allowing very abrupt heterointerfaces between the N-containing and N-free layers. By a variety of independent pumping systems a very low N_2 background pressure during the growth of the active region is achieved. The optimum growth temperature for the GaInAsN heterostructures was found between 450 and 470 ° C. Therefore, subsequent layers grown at higher temperature (GaAs at 590 ° C, AlGaAs cladding layers in the LDs at 680 ° C) may cause an unintended annealing effect.

Teststructures

To evaluate the quality of the material to be used as active region in laser diodes we have first grown GaInAsN/GaAs single quantum well (SQW) structures. The samples consist of a compressively strained GaInAsN SQW grown on a GaAs buffer layer and capped by 100nm GaAs. InGaAa reference samples containing no nitrogen were also fabricated for comparison. All layers are nominally undoped. The samples are as-grown with no post-growth annealing treatments performed.
The structural and optical properties of these QW structures have been studied by high resolution X-ray diffraction (HR-XRD) and photoluminescence (PL) measurements. Fig.1 shows the RT photoluminescence of a GaInAsN SQW sample and a corresponding structure not containing nitrogen. As can be seen, the material system GaInAsN can cover the entire wavelength range up to 1.55µm. For the GaInAsN structure shown we estimated by HR-XRD an In- and

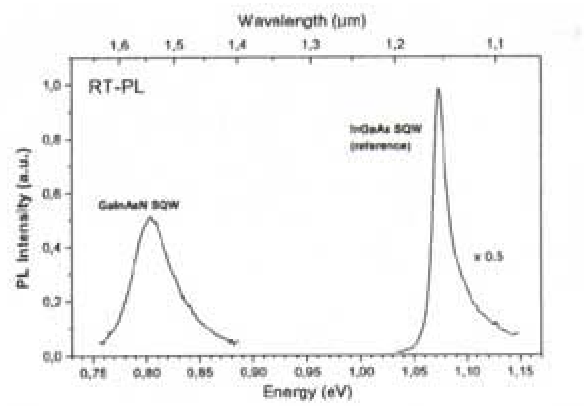

Fig.1 Photoluminescence spectra of a GaInAsN and InGaAs SQW structure at room temperature.

N-content of 38% and 5.3%, respectively. For 1.3µm emission a nitrogen content between 1.5 and 2% is used. In general, we observe approximately the same PL efficiency for the N-containing and N-free samples. Best FWHM of the RT-PL signal achieved so far for the described teststructures emitting in the 1.3µm (1.55µm) wavelength region lie below 30meV (45meV). The quality of the grown GaInAsN material therefore seems appropriate for its implementation in laser structures to be discussed in the following.

Laser structures

In the SCH laser structures used the GaInAsN QW active region is symmetrically embedded in a 300nm thick undoped GaAs waveguide. The n- and p-type cladding layers consist of 1.6µm $Al_{0.35}Ga_{0.65}As$ doped with Si and Be to about $1 \cdot 10^{18}$ cm^{-3}. Some of the presented structures are p-doped by carbon instead of beryllium. A 140nm p+ doped GaAs cap serves as a contact layer. A typical DQW active region for 1.3µm emission would for example consist of two $GaIn_{0.38}AsN_{0.015}$ quantum wells (with a thickness of around 7nm) separated by 15nm GaAs barrier. For 1.5µm emission only the composition and thickness of the active region was chosen appropriately with no other modifications made in laser structure design. Single and multi QW laser structures have been fabricated and further processed. Devices presented in the following almost exclusively use GaAs as barrier material. Although we also investigated N-containing barrier materials (like GaAsN) we believe that at least for 1.3µm emission GaAs is the best choice, also keeping in mind the high temperature performance of the devices.

Broad area (BA) devices fabricated from SQW and DQW Laser structures emitting in the 1.3µm wavelength range exhibit threshold current densities well below 1 kA/cm^2 for device dimensions (100x1000) µm. The BA threshold current density interpolated for infinite cavity length for the 1.3µm SQW based RWG devices discussed in more detail in the following is 490 A/cm^2.

The fabricated laser structures are then processed into ridge waveguide and DFB LDs. Laser ridges are defined by standard photolithography and transferred into the laser layers by dry etching using an electron cyclotron resonance assisted reactive ion etch process (ECR·RIE) with a Cl_2/Ar mixture. For insulation and planarization probimid is spin coated and subsequently etched by an O_2/Ar-plasma. Ti/Pt/Au and AuGe/Au contacts are evaporated and annealed. The lasers are finally cleaved into bars with different lengths. If stated, a high reflectiviry (HR) coating is applied to one facet. The output facet is as-cleaved (C). The unmounted devices are then tested on a temperature controlled heat sink.

III Device performance

1.3µm ridge raveguide LDs

Device performance in the 1.3µm wavelength range will be demonstrated in the following by a SQW GaInAsN laser structure. A laser threshold of 21mA with an external efficiency of 0.52W/A under cw operation at RT has been obtained for a (600x4) µm RWGLD (facets: HR/C) emitting at 1291nm.

Unmounted devices can be operated cw up to temperatures of 130 °C. Fig. 2 shows the P-I characteristics under pulsed condition for a RWG device (dimensions: $800x4µm^2$, facets: HR/C) for temperatures up to 150 °C (the limit of our experimental setup). The output power reduction of the device for an increase in temperature from 20 to 80 °C measured at a constant current of 90mA is smaller 2dB. Very high T_0 values (around 160K) have been obtained under pulsed condition in the temperature range up to 100 °C for a variety of GaInAsN RWG LDs with different composition and dimensions. Compared to InP based lasers a decreased wavelength shift with temperature is observed (for 1.3µm GaInAsN LDs typically 0.34nm/K).

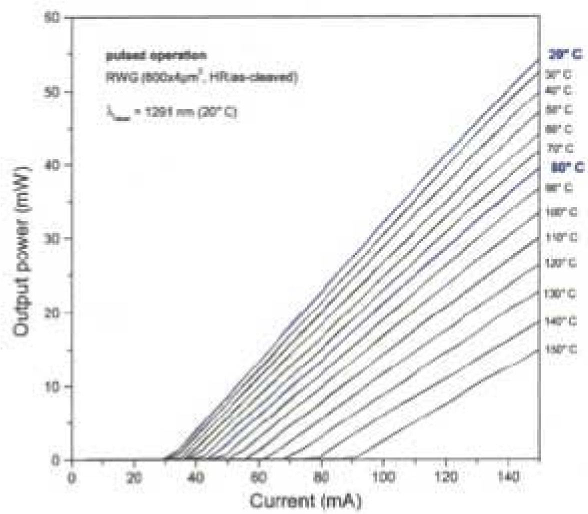

Fig.2 P-I characteristics of a fabricated GaInAsN RWG LD (facets: HR/C) measured up to temperatures of 150 ° C under pulsed condition.

The presented results underline the excellent high temperature performance of the material system GaInAsN.

1.3µm DFB LDs

Due to the reactivity of the Al containing cladding layers in our devices we are using the concept of laterally coupled DFB lasers therefore avoiding overgrowth steps [3]. The concept uses metal Bragg gratings on both sides of the laser ridges as shown in Fig.3 in order to obtain distributed feedback. These gratings -defined using electron beam lithography- act as periodic absorbers for the evanescent part of the laser mode thereby providing gain coupling.

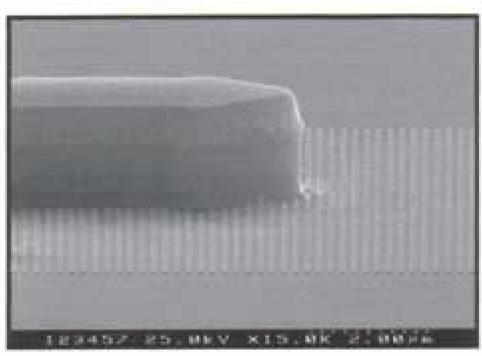

Fig.3 SEM micrograph of a fabricated GaInAsN DFB LD before cleaving. The gratings are well defined even at the vicinity of the Laser ridge.

Using a variety of GaInAsN laser structure we were able to achieve monomode DFB emission in the wavelength range between 1280-1370nm (the latter wavelength being of interest for potential gas sensing applications). An advantage compared to the InGaAsP material system is given by the very low shift of the DFB emission with temperature in the order of 0.07nm/K.

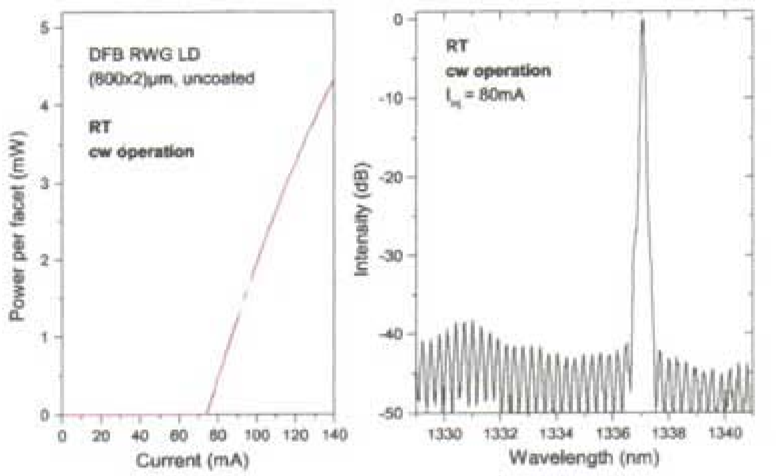

Fig.4 P-I characteristic and emission spectrum under cw operation at RT for a DQW GaInAsN DFB laser diode (facets as-cleaved).

A fabricated device emitting at 1337nm is presented as an example. Fig. 4 shows the output power characteristic and spectrum under cw operation at RT for dimensions 800µm x 2µm (uncoated laser facets). A fine tuning of the laser wavelength with stepwidths of about 1nm can be achieved by the sampled grating technique [3].

Thresholds of uncoated 1.3µm GaInAsN DFB lasers can be as low as 29mA at with external quantum efficiencies of 0.16 W/A per facet and side mode suppression ratios (SMSR) around 45dB.

1.5µm ridge raveguide LDs

As a first step into the long wavelength telecommunication range based on GaAs, we have also achieved pulsed RT lasing operation of a DQW GaInAsN LD in the 1.5µm wavelength region.

The light output power versus current of a fabricated ride waveguide laser for 780µm cavity length with width of 2µm under pulsed operation (period: 1ms, pulse width: 300ns) at RT is shown in Fig. 5. One facet of the device is HR coated; the output facet is as-cleaved. Lasing operation starts at a threshold current of 530mA with a slope efficiency of around 0.1 W/A. The emission wavelength at room temperature as shown in the inset of Fig. 5 is 1513nm. The devices can be operated pulsed up to a maximum temperature of around 80 ° C. The wavelength shift with temperature is 0.46nm/K (a less amount than observed for GaInAsP lasers).

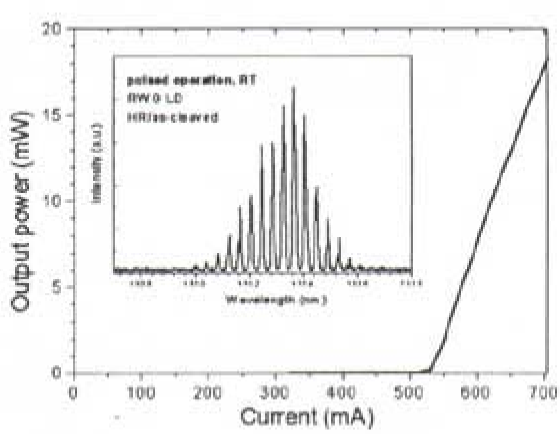

Fig.5 P-I characteristic of a DQW GaInAsN RWG LD (facets: HR/C) under pulsed condition at RT.
inset: lasing spectrum

A decrease in laser performance compared to our fabricated GaInAsN laser diodes in the 1.3µm wavelength region is observed. We are however optimistic that further device optimization is possible; concepts for future improvements will be presented.

IV. Conclusion

We have developed high quality GaInAsN quantum well and laser layers by solid source MBE using a RF plasma source for nitrogen generation.

Excellent laser performance for Fabry-Pe'rot and DFB lasers in the 1.3µm range has been presented, demonstrating that the material system GaInAsN has become a serious competitor to established LDs
based on InP.

In the 1.5µm wavelength region the potential of the material system GaInAsN as active region for edge emitters and VCSELs was demonstrated, but further optimization is required for future device applications.

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References

1. M. Kondow, K. Uomi, A. Niwa, T. Kitatani, S. Watahiki, and Y. Yazawa "GaInNAs: A Novel Material for Long-Wavelength-Range Laser Diodes with Excellent High-Temperature Performance", *Jpn. J. Appl. Phys.*, 1996, 35, pp. 1273-1275

2. G. Steinle, H. Riechert, and A. Yu. Egorov "Monolithic VCSEL with InGaAsN active region ernitting at 1.28µm and CW output power exceeding 500µW at room temperature", *Electron. Lett.*, 2001, 37, pp. 93-95

3. M. Kamp, J. Hofmann, A. Forchel, F. Schafer, J. P. Relthrnaier, "Low-threshold high-quantum- efficiency laterally gain coupled InGaAs/AlGaAs distributed feedback lasers", *Appl. Phys. Lett.*, 1999, 74, pp. 483-485