MOVPE growth of semiconductor disk laser (SCDL) structures

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Introduction

Semiconductor disk lasers (SCDL), also known as vertical external-cavity surface-emitting lasers (VECSEL) or optically pumped semiconductor lasers (OPSLs) represent a new field in semiconductor device research [1,2]. One of the key advantages of these devices is an excellent beam quality together with a scalable output power up to several watts. The structures are pumped optically and use an external second mirror in contrast to vertical-cavity surface-emitting lasers (VCSEL), where both mirrors are included in the epitaxial structure reducing the possible output power to the order of mW only.

Experimental

The layer structures presented here were grown by MOVPE in an Aixtron 200/4 reactor using the 3x2” configuration. The sources used include TMGa, TMAl, TMIn, AsH_3 and PH_3. The MOVPE system is equipped with a LayTec EpiRAS sensor measuring in the wavelength range between 248 nm (5 eV) and 826 nm (1.5 eV) and a fibre-coupled LayTec EpiR-MF for the wavelength range from 400 nm (3.1 eV) and 1650 nm (0.75 eV) simultaneously. The EpiRAS is capable of measuring the reflectance anisotropy and the reflectance while the EpiR-MF is intended for reflectance measurements in a wide spectral range including also the IR. The layer structures for the SCDL devices consist of an AlAs/GaAs DBR mirror with its center wavelength aligned near the laser wavelength of the final laser device (about 1040 nm) and an active region with InGaAs QWs for the same wavelength. To reach the required gain for laser operation 6 to 12 QWs have to be grown in a resonant periodic gain (RPG) structure (active region) with the QWs lying in the antinodes of the laser (and pump) radiation. Thermal management is one of the key points for SCDL structures. Therefore the structures are fabricated either as top-emitters with the active region grown on the DBR mirror or as bottom emitters with the structure grown in reverse order. Using bottom emitters the structures are mounted on the topmost epitaxial layer and the whole substrate is etched off finally. The heat can then be removed very efficiently because the remaining semiconductor structure is only a few microns thick. All structures presented here are bottom emitters.

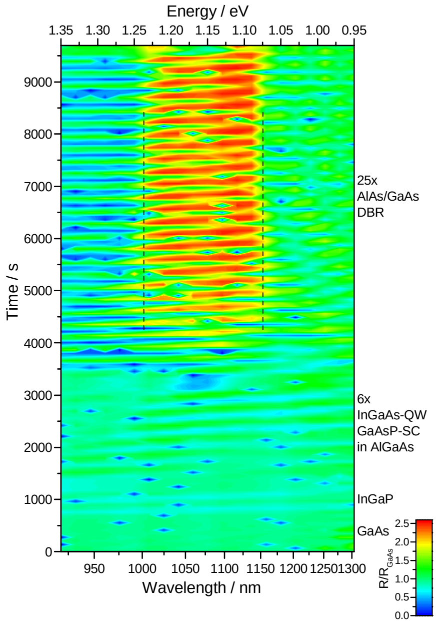

Fig. 1 Reflectance fingerprint of the growth of a complete device structure.

Fig. 1 shows a reflectance fingerprint (also know as ‘color-plot’) of R/R_{GaAs} taken during growth of a complete device structure. Since the structures are grown in reverse order at first the growth of the InGaP etch stop layer followed by the active region can be seen. However, the change in reflectance growing the InGaAs QWs in GaAs with the GaAsP strain compensating layers is small. Therefore only some Fabry-Perot interferences are visible. When the DBR mirror is grown a strong increase in the reflectance around 1070 nm develops. Cooling down the sample after epitaxy shifts the center wavelength of the DBR mirror to the desired 1040 nm.

Growth parameters for the active region

For the bottom emitters the DBR mirrors are grown after the active region. This is disadvantageous because normally the DBR mirror is grown at high temperatures due to the high aluminium content. For the active region, however, the growth temperature should be lower because of the relatively high In content in the QWs. The annealing of the active region during growth of the DBR which is done at 770°C for about 2 h results in indium diffusion causing a blue shift in the emission wavelength of the QWs. Therefore a higher indium content has to be adjusted during growth than desired in the final device [3].

Furthermore, we studied the influence of the strain compensating layers on the defect formation at two different growth temperatures (600°C and 650°C) using cathodoluminescence. Fig. 2 shows the results of two samples with 12 QWs without (a) and with (b) GaAsP strain compensating layers grown at 650°C.

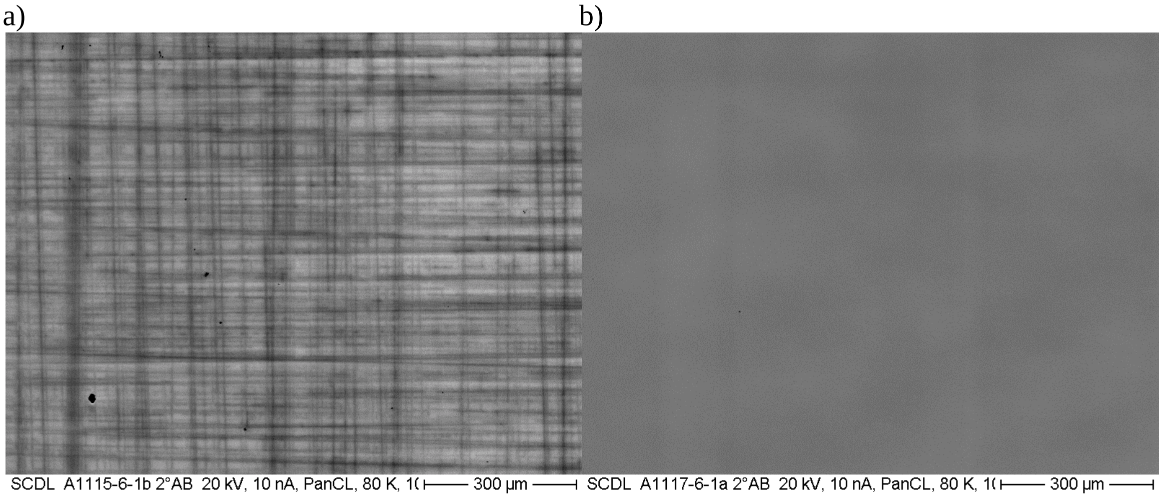

Fig. 2 Cathodoluminescence measurements of the active region of the SCDL structure grown at 650°C: a) without GaAsP strain compensating layers and b) with GaAsP strain compensating layers.

As it is clearly visible, the sample without strain compensating layers shows a strong crosshatch defect pattern which results in a reduced photoluminescence intensity. Introducing tensile-strained GaAsP layers the strain of the InGaAs QWs is compensated to nearly zero net strain and no defects occur any more. This shows that strain compensation is crucial for SCDL structures in this wavelength range.

Characterisation of the epitaxial structure after growth

For the bottom emitters a direct characterisation of the active region directly after growth is difficult since the QWs are sandwiched between the DBR mirror and the substrate. Therefore usual PL measurements are not possible. Other efforts to resolve the QW emission wavelength like etching off the substrate or measuring from the edge are also difficult since the RPG structure behaves also like a cavity resulting in the highest emission intensity being at the cavity resonance.

To circumvent this problem we have investigated the as-grown samples using photocurrent measurements [4]. For these experiments light is injected in-plane, i.e. perpendicular to the cleaved (110) facet, whereas the current is extracted via In-pads mechanically attached to top and bottom. The result of this measurement reflects, up to a certain degree, the absorption in the QW region. As an example Fig. 3 shows two different photocurrent spectra of an

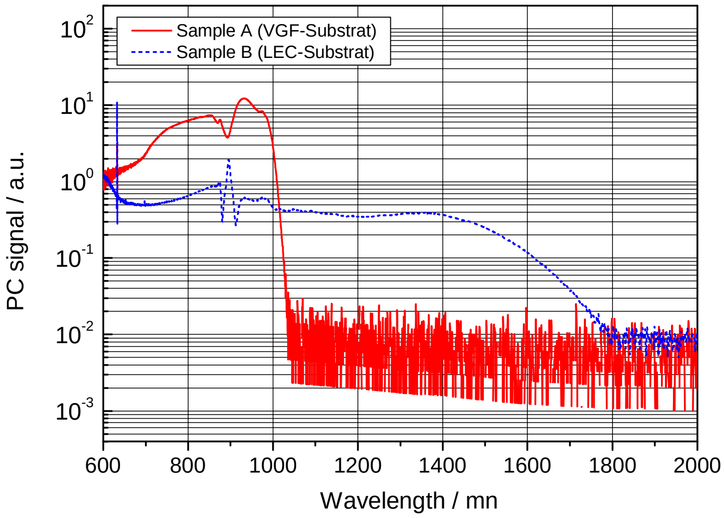

Fig. 3 Photocurrent measurement of two different SCDL structures (bottom emitters) directly after growth.

as-grown bottom-emitter SCDL structure. The difference of the two structures was the substrate used. One substrate is grown by the VGF method (sample A) while the other one was grown by the LEC method (sample B). Both substrates have been used in the same growth run. Sample A shows a pronounced edge at around 1000 nm as it is expected for the InGaAs QWs. Sample B, however, shows a less pronounced edge but an additional broad absorption band above 1000 nm. Detailed investigations showed that this absorption band is caused by defects coming from the substrate resulting also in a decreased performance of the final laser device. The photocurrent technique is therefore very helpful to characterize the grown SCDL structure without time consuming processing.

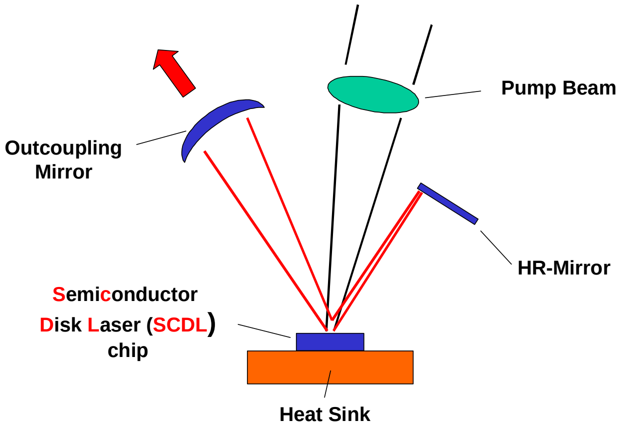

Fig. 4 Sketch of the laser setup

Characterisation of the SCDL structures in laser operation

Finally, laser experiments with the processed SCDL chips were performed in a laser set-up as shown in Fig. 4. The SCDL (chip processed as bottom emitter) was mounted on a heat sink and positioned between a plane high-reflectance mirror and a curved outputcoupler in a nearly hemispherical resonator. We used a laser diode emitting at 808 nm as pump source. Fig. 5 shows the continuous-wave (cw) output power versus the incident pump power for the SCDL laser operating at a wavelength of 1047nm. At an optical pump power of about 3 W an output power of about 300 mW was reached.

Summary

We have presented results on the growth of epitaxial layer structures for semiconductor disk lasers (SCDLs). Due to the thermal problems these devices are grown as bottom emitters. Therefore the active region is buried between the substrate and the DBR mirror. We could show that photocurrent measurements are a very helpful tool to characterize the active region. Furthermore, it could be shown that the high number of InGaAs QWs can only be grown without defects, when GaAsP strain compensating layers are included in the structure.

Finally, laser operation with our SCDL chips was demonstrated .

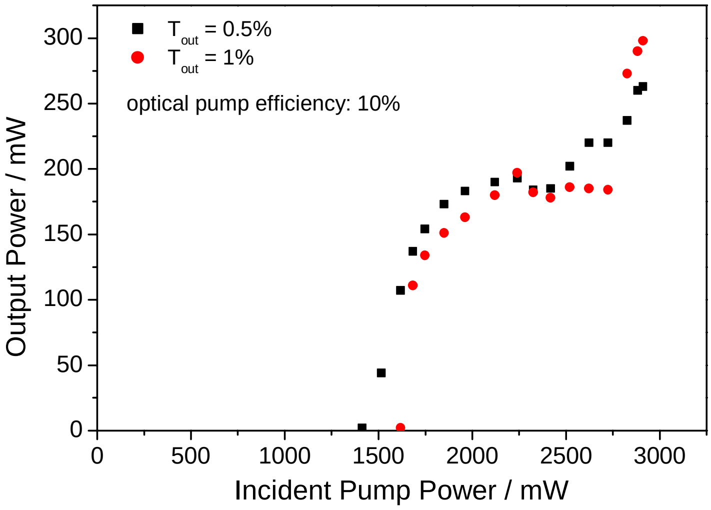

Fig. 5 Output power vs. pump power for a SCDL structure emitting at 1047 nm (T_{out} is the outcoupling transmission)

References

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