Experimental characterisation of 670 nm red VCSELs

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ABSTRACT

We experimentally investigate the transverse mode and polarisation behaviour of multimode red VCSELs in the GaInP/AlGaInP material system, emitting at 670nm. These devices were fabricated at the University of Stuttgart. More in particular we have measured the optical efficiencies, divergence and far field characteristics of the laser beams, thermal resistivities, polarization behaviour and optical spectra of the emitted radiation on two different dies. Despite multimode emission from threshold onwards, the output beam of these VCSELs is much less divergent than their 850nm counterparts. Moreover, these red VCSELs feature smaller thermal resistivities but suffer from early thermal roll-off. To conclude we present results on the polarisation behaviour of the VCSELs.

1. INTRODUCTION

Visible red emitting VCSELs are promising devices for use in numerous applications such as POF communications, barcode readers, chemical sensing, laser printing and displays[1-2]. We are particularly interested in the polarisation behavior of these new type of VCSELs, since the combination of polarisation switching devices and diffractive optical elements could possibly lead to innovative schemes for optical reconfigurable interconnects for short distance communications[3]. Therefore we study and experimentally characterise 670nm red emitting VCSELs provided by the University of Stuttgart.

2. EXPERIMENTAL RESULTS

We experimentally investigate GaInP/AlGaInP VCSELs fabricated by the University of Stuttgart[4-5]. The optical power is shown as a function of the injection current (LI-curve) at different substrate temperatures (T_s) in Fig. 1. The LI-curves show pronounced kinks, i.e. a local non-linearity that also modifies the slope of the curve. The presence of such kinks is an indication for multimode behavior of these type of 670nm emitting VCSELs. As can be seen in Fig. 1, higher T_s have a strong deteriorating effect on the VCSEL since the emitted optical power decreases dramatically. The output power decreases (at the same injection current (I_c) of 9 mA) from 113 μW down to 9 μW when the substrate is heated from 289K to 303K. Also the threshold current strongly increases when the VCSEL is heated. This can be more clearly seen in Fig. 2. The threshold current shifts almost linearly from 4.27 mA to 6.8 mA over a substrate temperature range of only 20 K.

The far field patterns of the laser emission are obtained with a 8900 goniometric radiometer. Fig.3. shows far field patterns taken at I_c of respectively 7, 8 and 9 mA, at a fixed T_s of 298K. As can be seen from this figure, the field profile noticebly changes when the I_c is increased and higher order modes begin to lase. For instance, the onset of these modes can be seen in inset (b). Analysing the far field characteristics reveals that the VCSEL emits a very low divergent laser beam from the threshold on. The divergence angle is as low as 5° (FWHM). In comparison, 850 nm proton implanted GaAs/AlGaAs VCSELs have a FWHM of 14°.

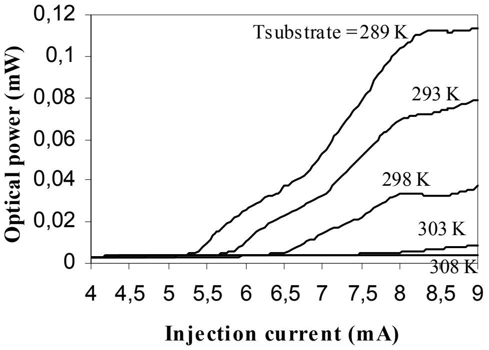

Fig. 1. Optical output power as a function of the injection current (LI-curve), taken at several substrate temperatures.

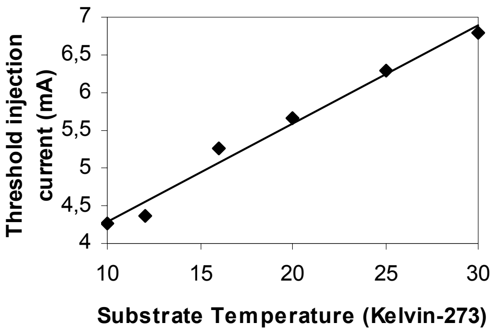

Fig. 2. Shift of the threshold injection current in function of the substrate temperature.

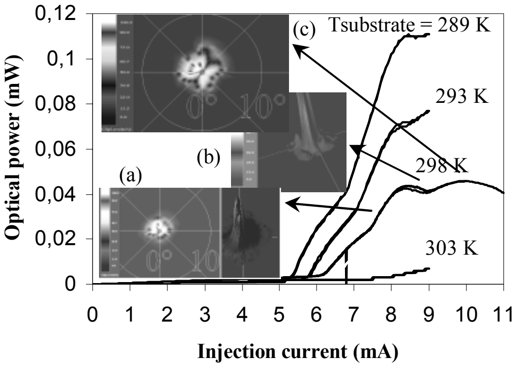

Fig. 3. Far field patterns at injection currents of 7, 8 and 9 mA when the substrate temperature is 298 K.

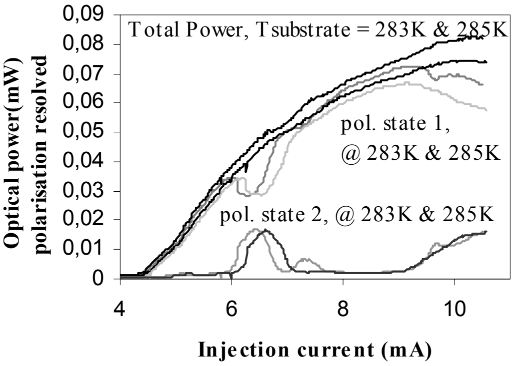

Fig. 4. The total and polarisation resolved optical powers versus the injection current at substrate temperatures of 283 K and 285 K.

As the current is increased, the laser beam broadens to a FWHM of 8° (this estimation is made at $I_c = 9$ mA).

We investigate further the spectral behavior of the emitted light. The lasing peak wavelength appears at 672.8 nm ($T_s = 297$ K). The wavelength peak redshifts when I_c or T_s is increased. The peak wavelength shifts almost linearly with I_c. We find $\Delta\lambda/\Delta I$ to be constant and equal to 0.10 nm/mA. Also, the peak wavelength shifts linearly with the T_s. $\Delta\lambda/\Delta T$ is approximately constant and equal to 0.05 nm/K. When $\Delta\lambda/\Delta I$ is divided by $\Delta\lambda/\Delta T$, a rather low thermal resistivity $\Delta T/\Delta I$ of only 2K/mA results.

In a nex experiment we apply stress on the VCSEL package. By lowering the T_s to 283 K, we are able to see the onset of the orthogonal polarisation mode when the optical output is resolved in polarisation. The results for two different T_s are plotted in function of I_c in Fig. 4. The emission of the orthogonal polarisation state appears in the higher order transverse modes.

A second VCSEL on another die sample, was characterised and shows similar results. The threshold current is slightly higher than the one of the previous VCSEL. The emitted optical power is of the same order of magnitude, but the kinks in the LI-curves are more pronounced. We have plotted some of the LI-curves for several T_s in Fig. 5. Also in this case we notice a strong increase of the threshold current with increased T_s. Also the optical power changes dramatically over a 10 K substrate temperature range. This particular device is more temperature sensitive in comparison with the VCSEL of the first die. In Fig.5. also the voltage across the VCSEL has been plot, for $T_s = 290$ K.

We measured the spectral shift for this device with both spectrum analyser and scanning Fabry-Perot interferometer. In Fig. 6. the wavelength shift is shown as function of the T_s at an I_c of 8.5 mA. The shift can be linearly interpolated. We find $\Delta\lambda/\Delta T$ to be constant and approximately 0.035 nm/K, which is in agreement with the previous measurements on the first die sample. The same measurement with the scanning Fabry-Perot interferometer shows a value of 0.037 nm/K, which is in good agreement.We also measure the spectral shift of the VCSEL as a function of I_c: we obtain for $\Delta\lambda/\Delta I$ a value of 0.11 nm/mA using the spectrum analyser and 0.15 nm/mA using the scanning Fabry-Perot interferometer. To summarise, these measurements again result in a rather low thermal resistivity of only 3.24 K/mA and 4.05 K/mA respectively. They are comparable with the results of the VCSEL on the first die. The behavior of the wavelength shift as a function of I_c is approximately linear.

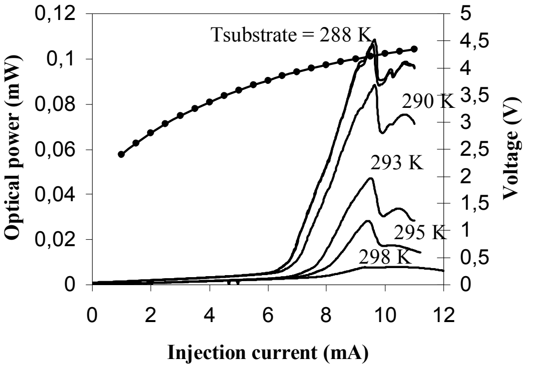

Fig. 5. *VI-graph and LI-curve at different substrate temperatures for a second VCSEL on a second die sample.*

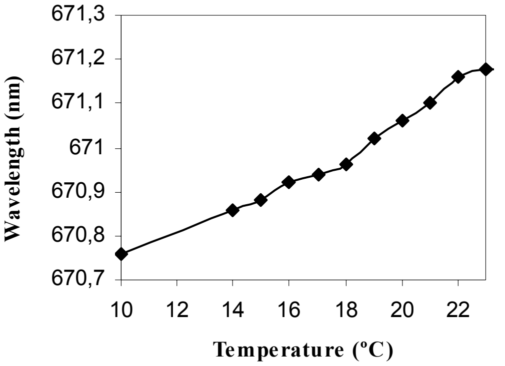

Fig.6. *Spectral shift versus substrate temperature at an injection current of 8.5 mA.*

The polarisation resolved mode structure of the VCSELs is investigated using the scanning Fabry-Perot interferometer – Fig. 7. Even at the laser threshold two lasing modes are already present (Fig. 7.a.). The leftmost peak in the spectrum is believed to be the one of the fundamental transverse mode. When we increase the I_c, higher order modes are taking over the lasing action (Fig. 7.b.). With a further increase, a third and a (hardly noticeable) fourth lasing peak appear in the spectrum (Fig. 7.c.). We are also interested in the relative positions of the

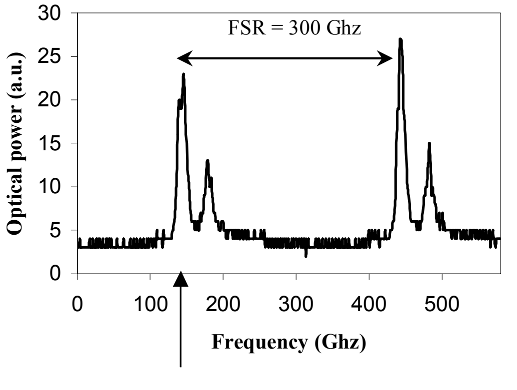

Fig 7. (a) *Spectrum at an injection current of 6.81 mA. Spectra taken with a scanning Fabry-Perot interferometer (subgraphs do not have the same scale). All spectra are taken at Ts = 290 K.*

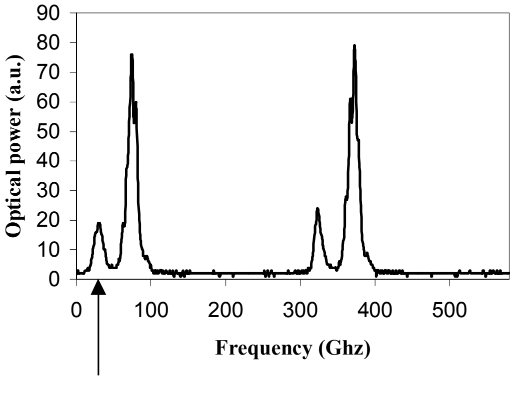

Fig 7. (b) *Spectrum at an injection current of 7.89 mA.*

peaks in the spectrum, i.e. in the frequency splitting between two neighbouring peaks. When the frequency splitting for peak 1 and 2 is plotted versus I_c, we obtain a straight line (top line in Fig. 7.d.) The frequency splitting between peak 2 and 3 is also plotted in Fig. 7.d. (bottom straight line). Both second and third spectral peaks red shift but at slower rate with respect to the fundamental mode. Only the first peak in the spectrum can be completely suppressed by rotating the output polariser, indicating its linear polarisation. Higher order modes tend to be slightly elliptical polarised.

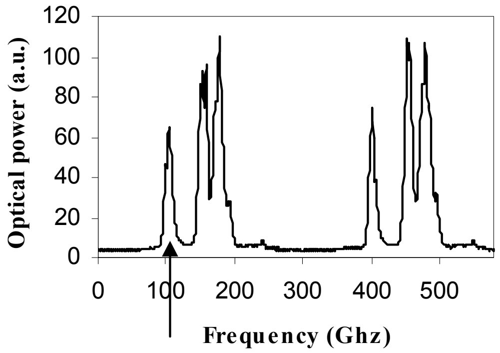

Fig 7. (c) *Spectrum at an injection current of 9.55 mA.*

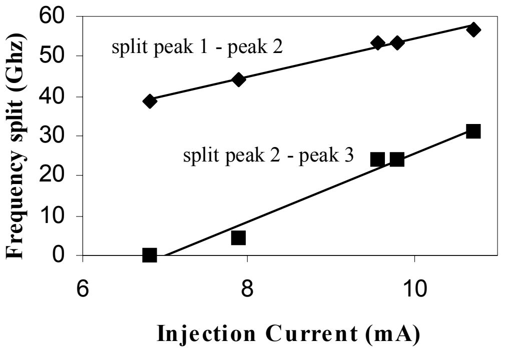

Fig 7. (d) *Frequency split between the first and second peak, respectively between the second and third peak, as a function of the injection current.*

3. CONCLUSIONS

We have experimentally characterised 670nm VCSELs in the GaInP/AlGaInP material system fabricated at the University of Stuttgart. More specifically, we investigated their polarisation and transverse mode behaviour. Despite their multimode emission from threshold onwards, they show interesting polarisation behavior of the higher order transverse modes. By applying an external anisotropic stress we conclude that such red emitting VCSELs are very much likely to experience polarisation instabilities if working in the fundamental mode only.

ACKNOWLEDGMENTS

This work was funded by the FWO, GOA, the DWTC IAP Photon Network and the OZR of the Vrije Universiteit Brussel.

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