850 nm transparent-substrate wafer-fused bottom-emitting VCSELs

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This report deals with the fabrication and characterization of bottom emitting VCSELs at an emission wavelength of 850 nm. The devices were realized by exchanging the absorbing GaAs substrate for a transparent GaP substrate using the wafer-fusion technique.

1. Introduction

Although vertical-cavity surface-emitting lasers (VCSELs) with emission through the substrate (bottom emitting device) are less prevalent than their counterparts emitting through the epitaxial surface (top emitting device) they offer several advantages. Bottom emitting VCSELs can easily be mounted upside down by a flip-chip technique onto high-speed CMOS chips in optical transceiver modules. They might be efficiently cooled by placing a heatsink near the active zone instead of on the opposite side of the considerably thick substrate, and finally, it is not necessary to leave an emission window in the top contact which leads to a less homogeneous carrier injection compared to full area contact devices.

Due to the fundamental absorption of GaAs at wavelengths shorter than 870 nm bottom emitting VCSELs at 850 nm need their GaAs substrate to be exchanged for a transparent material. GaP is an attractive solution because of its transparency and its conductivity although its lattice constant (0.5451 nm) is severely differing from the one of GaAs (0.5653 nm). Wafer-fusion in contrast to epitaxial techniques offers the possibility of combining semiconductor materials with significantly different lattice constants. This has been demonstrated by the fusion of InP and GaAs in long-wavelength VCSELs [1] as well as GaP and InAlGaP in high-brightness (Al\textsubscript{x}Ga\textsubscript{1-x})\textsubscript{0.5}In\textsubscript{0.5}/GaP LEDs [2]. The conception of the wafer-fused transparent-substrate 850 nm VCSEL is sketched in Fig. 1.

2. Technological Details

The fabrication of the devices starts by etching grooves using chemically assisted ion beam etching (CAIBE) into the GaP material that prevent residual gases and liquids from being captured at the fused interface during the fusing process. A subsequent thorough cleaning of both of the samples – the GaAs-based VCSEL structure as well as the GaP substrate – ensures that no native oxide or organic contamination affects the electrical or optical quality of the interface. The wafer-fusion is carried out at temperatures of 675 °C or higher under elevated mechanical pressure for 30 minutes. After removing the GaAs substrate by polishing and selective wet-chemical etching the devices are fabricated by standard VCSEL processing techniques including mesa etching, oxidation for current confinement, and contact metal evaporation.

This concept is similar to the one published by Sandia National Laboratories in [3]. In contrast to our structure they use n-type GaP and, according to this, an n-type top DBR in order to get an n-n-junction at the fused interface.
As depicted in Fig. 1 the p-side contacts are evaporated on the p-type GaAs layers rather than on the p-GaP substrate although this would allow more homogeneous carrier injection. Investigations of different metallizations on GaP have shown that it is hardly possible to achieve ohmic contacts with low resistances on GaP at $p = 1 \cdot 10^{18}$ cm$^{-3}$ using Zn doping.

### 3. Performance

Fig. 2 shows the output characteristics of a wafer-fused 850 nm-VCSEL in CW operation at room temperature. A threshold current of 20 mA, a threshold voltage of 2 V and a maximum wall-plug efficiency of 12 % is observed at an active diameter of 28 $\mu$m. These results are superior to those published in [3] with respect to the threshold current density as well as to the threshold voltage.

![Room temperature CW characteristics of a wafer-fused transparent-substrate 850 nm VCSEL with 28 $\mu$m active diameter.](image)

The threshold current of the fused devices rises by a factor of 3 compared to unfused VCSELs made out of the same epitaxial material. Apart from thermal and mechanical stress that may lead to suffering optical properties of the material the changing mirror reflectivities due to different refractive indices have to be considered. The p-DBR of the unfused VCSEL terminates with a GaAs-air interface which gives an additional benefit in mirror reflectivity. By fusing the topmost p-GaAs layer to the GaP substrate this benefit is eliminated resulting in rising threshold current. This drawback has been counterbalanced by adding a few mirror pairs to the p-DBR.
4. Conclusion

Very successful transparent-substrate bottom emitting VCSELs with an emission wavelength of 850 nm have been demonstrated by using wafer-fusion to add transparent GaP substrate to conventional GaAs vertical cavity lasers. A slight rise of the threshold current is mainly caused by a decrease in the p-DBR reflectivity due to adding the GaP material. The considerably large devices having an active diameter of 28 μm operate under room temperature CW conditions at reasonable threshold currents and voltages of 20 mA and 2 V, respectively.

References

