Manufacturability of Vertical-Cavity Surface Emitting Lasers Grown by

Organometallic Vapor Phase Epitaxy

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Organometallic vapor phase epitaxy (OMVPE) technology is increasingly recognized as a superior platform for growth of vertical cavity surface emitting lasers (VCSELs). It is known for high throughput, low surface defect density, continuous compositional grading control, and the flexibility for materials and dopant choices. We show that it is also capable of extremely high wafer uniformity and run-to-run reproducibility.

The growth was performed on an Emcore GS3200 OMVPE reactor equipped with an *in situ* normal-incidence reflectance setup.^[1] The $\text{Al}_x\text{Ga}_{1-x}\text{As}$ in mirror and active layers of 770- and 850-nm VCSELs was typically grown at 750 °C by using TMA, TMG, and 100% AsH_3 . The reactor pressure was 60 torr. Group-V flow, total reactor flow, and the gas-flow distribution along the radial direction of the top flange were carefully optimized for one 4", one 3", and three 2" wafers through measurements of the distributed Bragg reflector (DBR) center wavelength.

The reflectance setup using a W-halogen lamp and a silicon detector through a 10 nm interference filter, combined with a virtual interface model, provides a simple, robust, and accurate measurement of the growth rate.^[1] We use it to monitor the wafer growth routinely, and to calibrate the growth rate periodically. Within a short run growth rates of all the Al and Ga precursors and the etchback effect by CCl_4 (C dopant in AlGaAs) can be obtained from a fitting to the temporal reflectance data. Shown in Figure 1 is the reflectance from such a calibration run, together with the calculated growth rate.

Figure 2 shows the wavelength of the optical cavity mode for an 840-nm VCSEL structure as a function of the distance from the center of the wafer. Excellent uniformity was achieved to $\pm 0.05\%$ in the center 2" area of the 3" wafer, and to $\pm 0.2\%$ over the entire 3" wafer. This uniformity was achieved with an AsH_3 flow of 248.5 sccm in a total reactor flow of 32.6 slm and a top-flange gas-flow partition of 7%:78%:15% between the inner, middle and outer injection zones. The uniformity across a 4" wafer and three 2" wafers is typically $\pm 1.4\%$. A 840-

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nm VCSEL structure was processed into devices with $9 \times 9 \mu\text{m}^2$ oxide apertures on both sides of the optical cavity. Even compounded with the processing tolerance, the wavelength uniformity is still $\pm 0.3\%$ over nearly the whole wafer. The threshold current variation is less than $\pm 10\%$ in the $2''$ area of the $3''$ wafer. The oxide-confined VCSELs with $1 \times 1 \mu\text{m}^2$ oxide apertures show threshold current as low as $26 \mu\text{A}$, the lowest reported to date for 840-nm VCSELs.

The OMVPE growth runs are also highly reproducible. The inset of Fig. 2 shows the cavity wavelengths for 770- and 850-nm VCSELs plotted as a function of run number. We obtained wavelength run-to-run reproducibility of $\pm 0.3\%$ for both 770- and 850-nm VCSELs over the course of about 100 runs.

In summary, we have demonstrated an optimized OMVPE technique for highly uniform and reproducible VCSEL growth, enabling high performance VCSELs with uniform lasing characteristics. This work is supported by the DOE under contract No. DE-AC04-94AL85000.

Fig. 1. The temporal reflectance of a growth rate calibration run and the growth rates by different precursors.

Fig. 2. Wavelength uniformity of the cavity mode across a $3''$ 840-nm VCSEL wafer. The inset shows the typical reproducibility of the cavity wavelength of 770- and 850-nm VCSEL structures versus the growth run number.

DISCLAIMER

[1]. W.G. Breiland and K.P. Killeen, J. Appl. Phys. (to be published).

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