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Mirror Reflectivity and Doping Considerations for High Performance Oxide-Confined Vertical Cavity Lasers *

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Abstract

We report the effects of mirror doping and reflectivity in 850 and 780 nm oxide-confined vertical cavity surface emitting lasers. Decreased doping throughout the n-type mirror produces significantly higher quantum efficiency, while the optimum reflectivity is dependent upon the gain material.

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High efficiency VCSELs are attractive for several emerging applications, such as optical data links or free space interconnects, since high efficiency implies relaxed power budgets and lower parasitic thermal dissipation. Recently, VCSEL power conversion efficiency greater than 50%[1] has been obtained using a monolithic selectively oxidized VCSEL with enhanced electrical and optical confinement.[2,3] To achieve high wall plug efficiencies requires high external quantum efficiency, η_{ex}. Here we report a systematic study of the effects of doping concentration and reflectivity of the mirror and the oxidation fabrication on the efficiency of 850 and 780 nm oxide-confined VCSELs, the results of which are important for design of high efficiency VCSELs.

The VCSEL wafers are grown by MOVPE, which has exhibited high wafer uniformity and run-to-run reproducibility. The 850 (780) nm VCSELs use five quantum wells of GaAs (AlGaAs) embedded within a one wavelength thick optical cavity. Oxide current apertures[2] (9x9μm) are immediately adjacent on each side of the optical cavity.[3] For the doping experiments, the 850nm VCSELs have 22(33) top C-doped (bottom Si-doped) DBR periods. The doping in the optical cavity is held constant, while the doping in the first 3 periods next to the cavity and the remaining outer periods of each DBR are varied between 0.5 and 4×10^{18} cm^{-3}. For the reflectivity experiments, the mirror doping is held constant, while the number of periods in the top output DBR is varied.

Figure 1 shows that the VCSEL external quantum efficiency monotonically increases as the doping level in the various regions of the p- and n-type DBR are decreased. It has been previously recognized that reduced doping near the optical cavity can improve VCSEL performance, due to penetration of the longitudinal mode in the mirror and the accompanying optical absorption. However, Fig. 1 also shows that the doping level in the n-DBR has a significant impact. Decreased doping throughout the n-type mirror produces significantly higher quantum efficiency, in spite of the small penetration of the optical fields through the outermost portions of the DBR.

Figure 2 shows the dependence of η_{ex} on the mirror reflectivity for both 850 and 780 nm VCSELs. For large number of DBR periods (high reflectivity), η_{ex} is low due to the small transmission of light through the output DBR. For low number of periods (low reflectivity) η_{ex} is reduced due to increased absorption. Thus as evident for the 780 nm VCSELs in Fig. 2, an optimum output reflectivity exists for high efficiency operation. For the 850nm VCSELs in Fig. 2, the optimum reflectivity is less (less number of periods) than that of the 780nm VCSELs, due to the decreased material gain in AlGaAs as compared to GaAs. Finally, in Fig. 3 we show the effects of the oxidation temperature on VCSEL performance. Oxidation of the current apertures at lower temperature leads to smaller threshold current densities, but with a tradeoff of significantly lower oxidation rates and hence longer oxidation times.[4]

In summary, by optimizing the mirror doping profile and reflectivity, $\eta_{ex} >$ 40-50% have been achieved for 780 and 850nm VCSELs. Furthermore, the oxidation temperature can directly influence the VCSEL performance. We will describe additional optimization studies and the implementation of our results in optimal VCSEL structures. This work is supported by the U.S. DOE under contract No. DE-AC04-94AL85000.

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Figure Captions

Figure 1. The dependence of external quantum efficiency on the doping concentration profile in the n- and p-type distributed Bragg reflector mirrors.

Figure 2. The dependence of external differential quantum efficiency on output coupler reflectivity.

Figure 3. Threshold current density plotted against active area at oxidation temperatures of 450, 425 and 400° C.

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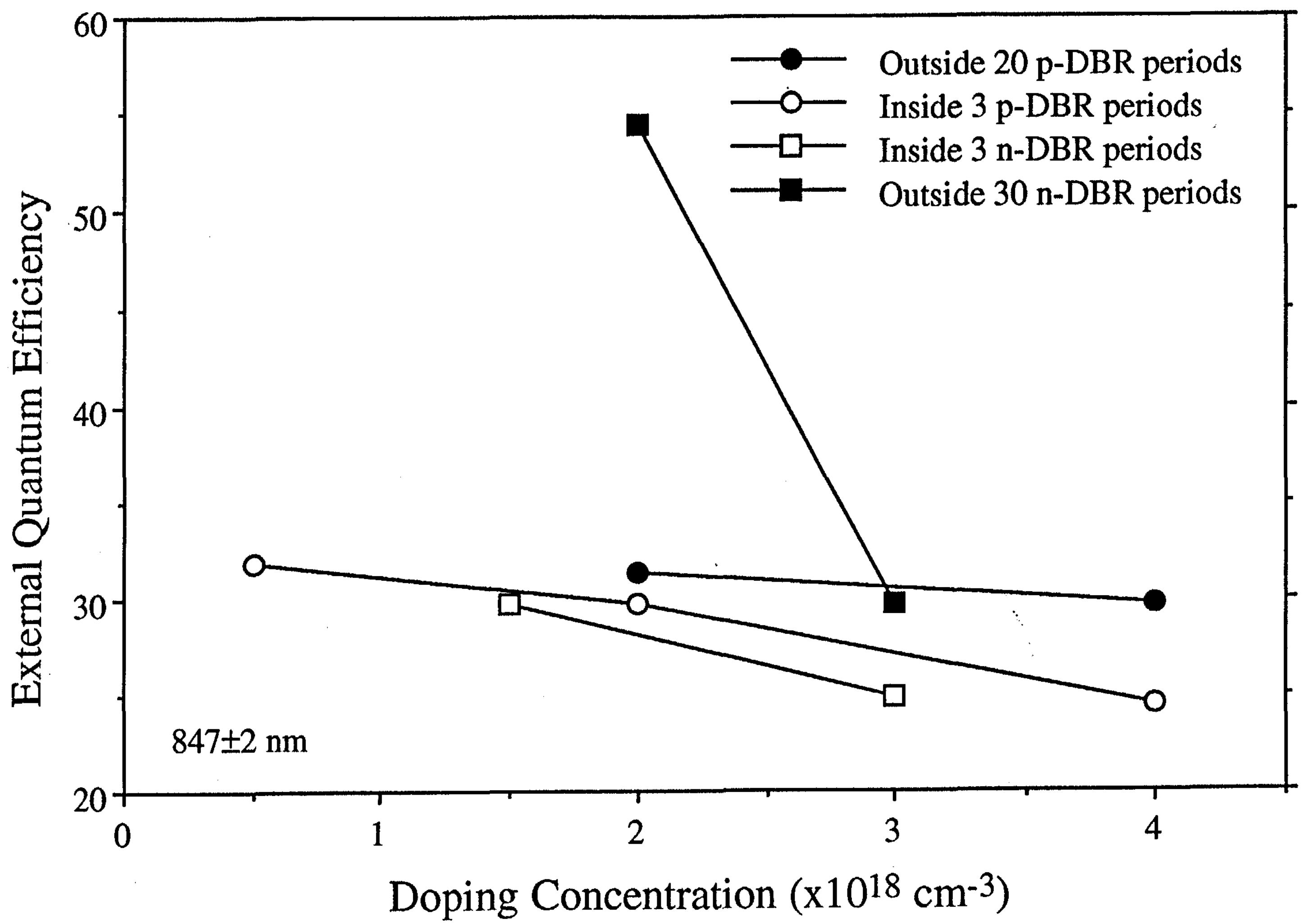
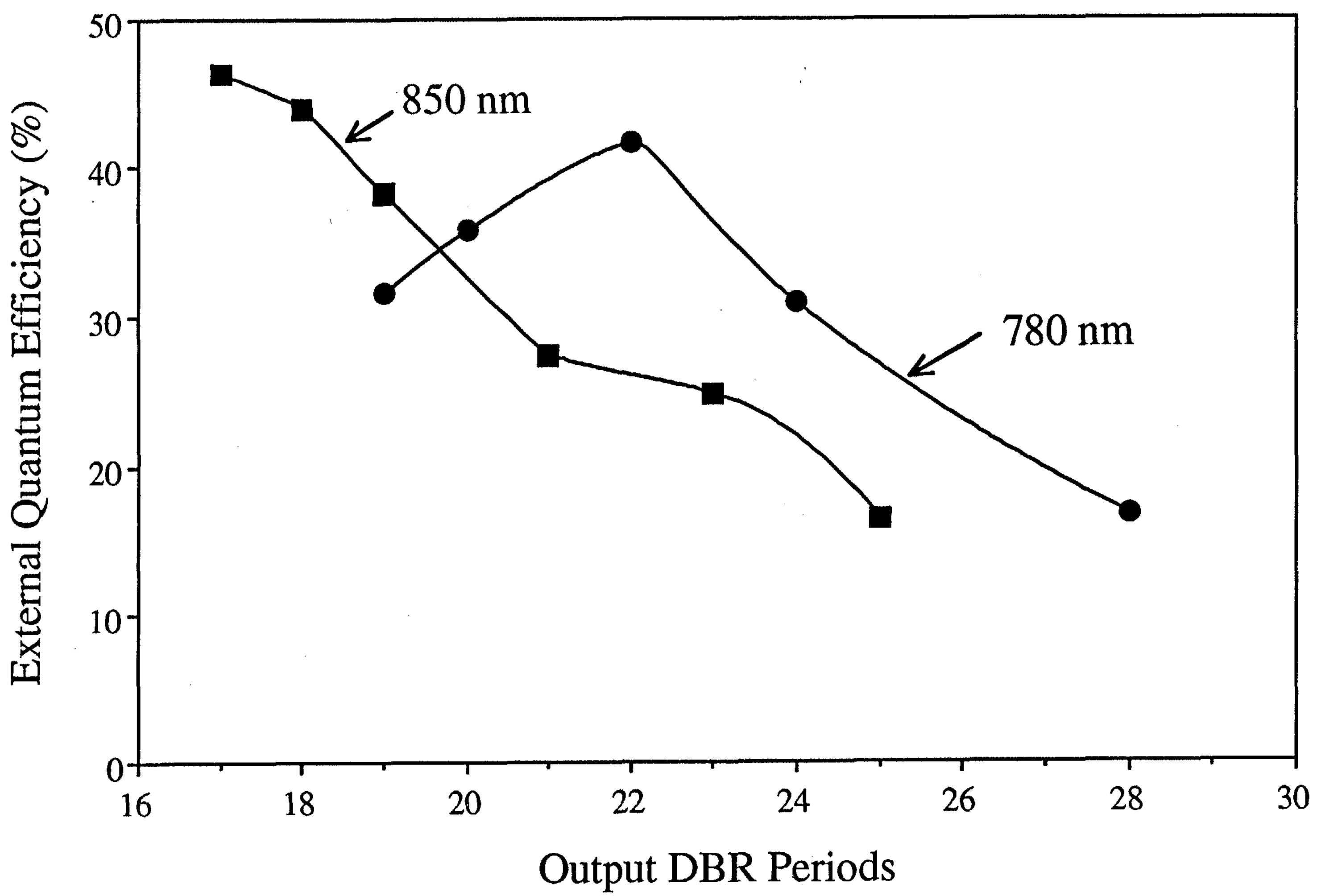
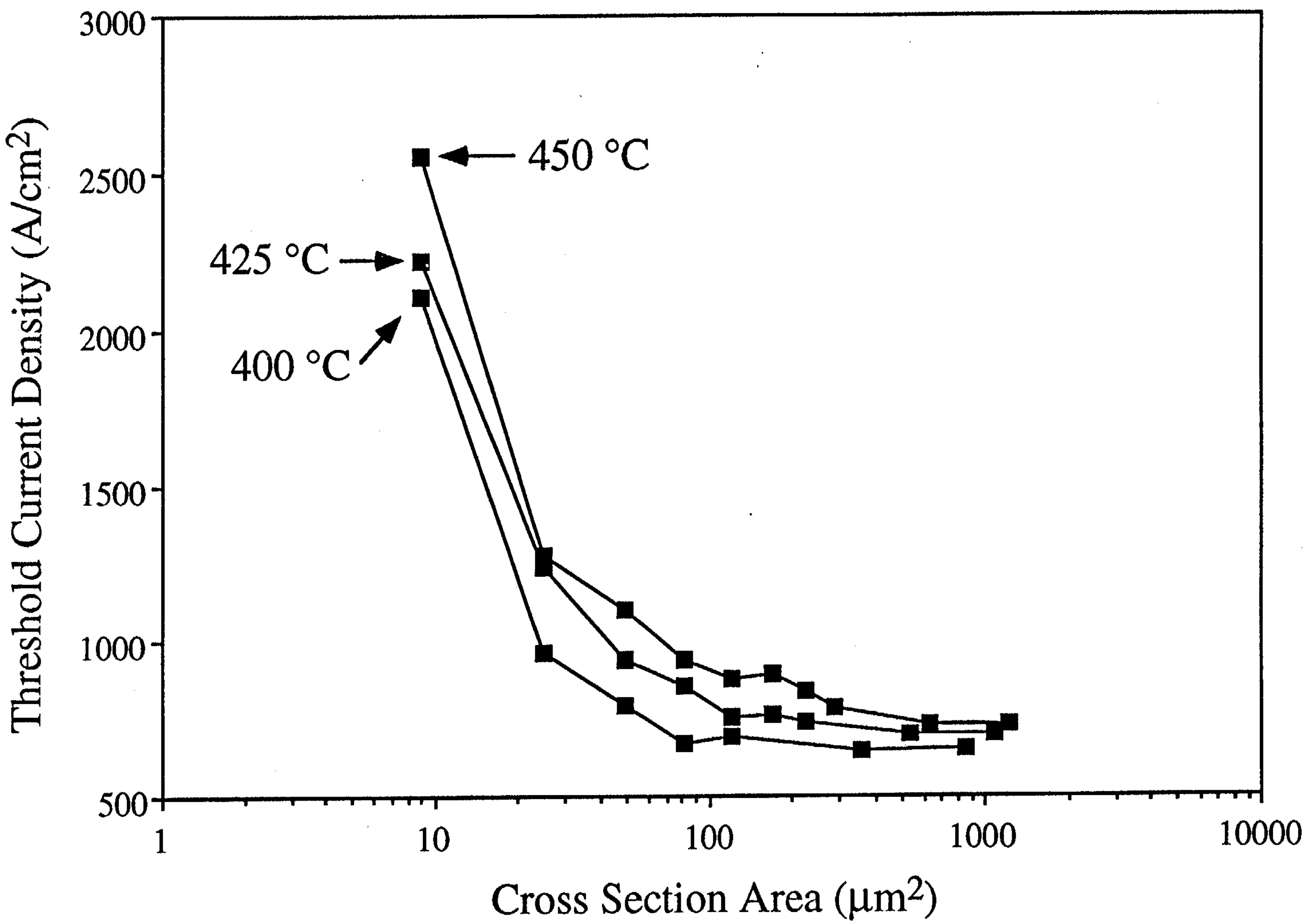


Geib, Figure 1



Geib, Figure 2



Geib, Figure 3