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Large Signal Dynamic Model of Vertical Cavity Surface Emitting Lasers

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Transverse modes operation of vertical cavity surface emitting lasers (VCSELs) degrades their performance in high speed optical communication systems and should be avoided. It is necessary to understand the dynamic behavior of transverse modes for the design of high speed, stable and single mode operation of VCSELs under direct current modulation. In this paper, we present a sophisticated large signal dynamic model of index guided VCSELs. The three dimensional waveguide problem is reduced to one dimension by using effective index method and scattering matrix method. The variation of injection current distribution, refractive index profile, carrier diffusion and spatial hole burning as well as gain spectrum inside the active region are taken into consideration. In addition, the frequency dependence of Bragg reflectors and the longitudinal variation of photon density are also included in our investigation. The dynamic response of VCSELs is calculated by solving the corresponding wave equations and rate equation of carrier concentration in a self-consistent manner. Using this model, the dynamic behavior of transverse modes are analyzed.

The schematic of vertical cavity surface emitting laser (with built-in index guided structure) used in our analysis is shown in figure 1a. The undoped spacer layers have thickness of half-wavelength each and the Bragg reflectors are formed by alternating layers of AlAs and AlGaAs with quarter-wavelength thickness, and consist of 15 such pairs on both the n- and p-side. The active region consists of six GaAs-$Al_{0.3}Ga_{0.7}As$ quantum wells with well width of 100Å and total thickness of half-wavelength. The corresponding longitudinal variation of refractive index profile of the entire multilayer VCSEL structure is also shown in figure 1b.

The laser is initially biased at threshold and modulated by a step current of 1.5 times its threshold value. Figure 2a shows the switch-on transient response of the transverse modes (fundamental mode-solid line, first order mode-dotted line) for device with current confinement structure[1]. The corresponding time evolution of carrier distribution are shown in figure 2b. It can be seen that the current confinement structure suppresses high order modes during the turn-on transient response of the device. The carrier density distribution exhibits less hole burning throughout the transient period and the coupling efficiency between the carrier distribution and optical field profile (of first order mode) maintains at a low value. However, for the case without current confinement, the transient response of transverse modes is quite different to that with current confinement. Figure 3a shows the corresponding transient response of transverse modes. After first 0.5ns, first order mode dominates over the whole duration of time and the switching of modes (occurs at time equal to 's1') is caused by severe carrier hole burning. It is noted that the change of carrier distribution (see figure 3b) enhances the coupling efficiency of first order mode over the fundamental mode.

The above results show that the dynamic behavior of transverse modes exhibit different characteristic to that given in steady state analysis. For the case without current confinement, fundamental mode is excited during the first 0.5ns which cannot be predicted from the steady state analysis[1]. This is because the carrier distribution is varied during the turn-on period. Other nonlinear effects such as carrier transport, hot carriers and self-heating of laser cavity can also be introduced into our analysis and the results will be presented in the conference.

Reference

[1] C.H. Chong & J. Sarma, IEEE Photonic Techn. Lett., vol. 5, pp. 761-764, 1993.

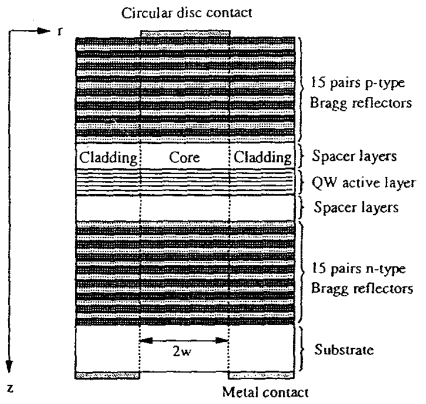

Figure 1a

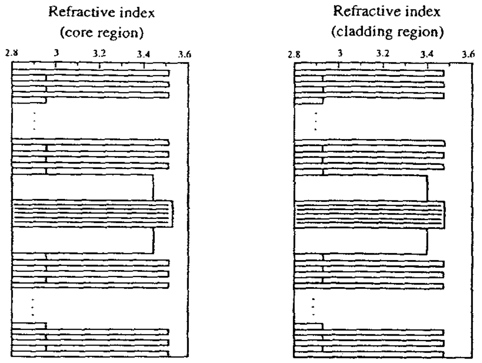

Figure 1b

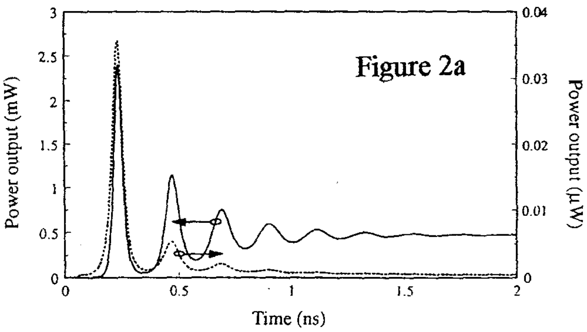

Figure 2a

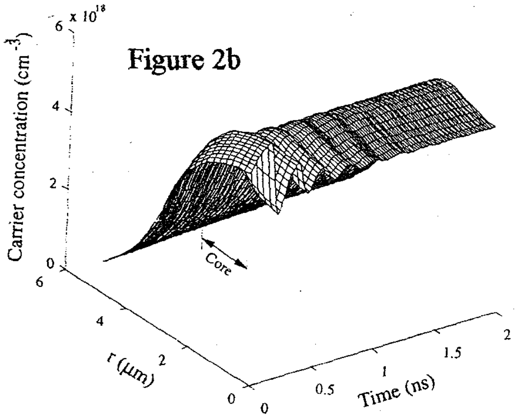

Figure 2b

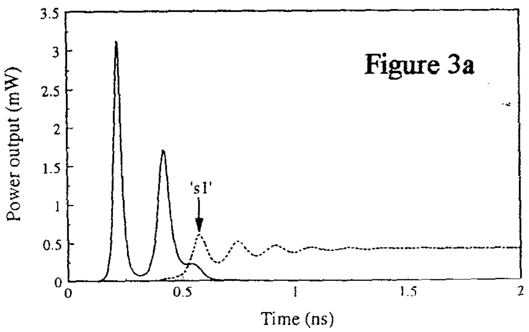

Figure 3a

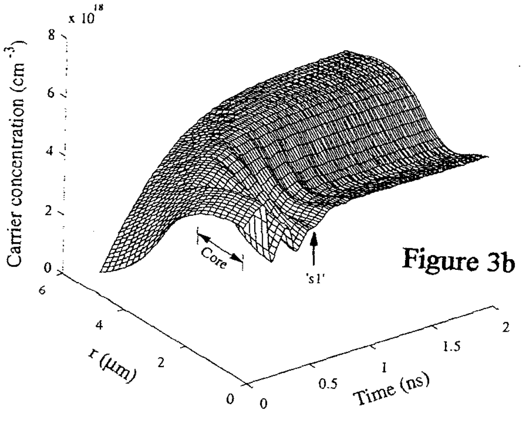

Figure 3b