I. ACCOMPLISHMENTS AT THE TIME OF COMPLETION OF THE CONTRACT

Much of the work in the past three years has concentrated on creating a predictive simulation tool for edge emitting semiconductor quantum well laser diodes. This simulator (MINILASE II) has been completed and has been compared to modulation response experiments from the Santa Barbara group. Modulation response has been chosen because it is the most difficult characteristic to predict since nonlinearities enter in a crucial way. The close agreement between experimental and simulation results that is described in publication 15 has necessitated a careful treatment of the device physics:

(i) We have included an 8 band $k\cdot p$ bandstructure including the effects of strain. The effects of bandstructure are twofold. It had already been known that bandstructure determines the optical matrix element and therefore is crucial to obtain correct values for optical absorption, spontaneous emission and stimulated emission. Our self-consistent simulator has shown however, that of equal importance is the non-parabolicity which effects the location of the quasi-Fermi levels and therefore the gain. Only a complete simulator such as MINILASE II can show this with all its quantitative aspects.

(ii) We have resolved the energy distribution of charge carriers within the quantum well by numerically solving a Boltzmann equation. This energy distribution is key to the nonlinearities of gain in quantum well lasers. No other simulator has previously modeled the energy distribution of the charge carriers. Nevertheless modulation response cannot be quantitatively understood without it since the modulation response is influenced by minute deviations of the distribution function from the Fermi-type. The extreme sensitivity of the laser gain to the form of the distribution function $f$ has been "automatically" shown by MINILASE II and can be understood from the following argument. The photon number $S_v$ in a given mode $v$ is proportional to

$$S_v = (G(f) - L)^{-1}$$  \hfill (1)

The laser operating point is close to the pole $G(f)=L$. Thus minute changes of the distribution function $f$ may cause large changes in $S_v$. These changes in $f$ arise from changes in the electron energy (raised electron and phonon temperature) and also from spectral hole burning which is of importance only at high power.

The precise calculations of the deviations from the Fermi distribution need to include deviations of the polar optical phonon occupation from equilibrium, heating of the charge carriers through phonons and carrier-carrier interactions, the rapid removal of carriers by stimulated emission, the carrier-carrier interactions, the rapid carrier-carrier capture, and charge carrier scattering to lower energies in the quantum wells. All this has been accomplished in MINILASE II and is described in detail in the referenced publications. It has been necessary for this purpose to develop a special scattering mechanism that simulates carrier-carrier interactions and at the same time permits ultrafast simulation that could be included in MINILASE II without creating impossible computational demands.

Our simulator is generally recognized as the most advanced and predictive laser simulator with respect to device physics. We have closely collaborated with Capasso's group at Lucent Bell Laboratories and have on several occasions transferred our technology and experiences to them. Their simulator is now extremely similar to MINILASE II, down to an identical treatment of quantum well capture, although their simulator still works with Fermi-distributions.
The work on laser diodes and nonlinearities in the modulation response has also inspired our most recent work on p-n junction capacitance which has proved all past work on the diffusion capacitance incorrect. This is described in [16]. One of the important results of this work is that diffusion capacitance exists only for short diodes. Long diodes in which all minority carriers have a chance to recombine do not show diffusion capacitance (in spite of the opposite notion in all textbooks).

Other important research results have been obtained for several quantum aspects of interface transport [1,2], and we have performed detailed simulations of quantum well capture [6]. A number of the most recent publications deals with the giant isotope effect in transistor lifetime [20,21,22] which was recently discovered in our group.

II. INDEX OF PUBLICATIONS

In the past grant period we have published (submitted) a total of 23 papers and have presented 15 invited lectures at international conferences as well as numerous contributed papers not included in this listing.

Publications


23) K. Hess, "High Field Transport," to be published in the Webster Encyclopedia of Electrical Engineering

III. INVITED PRESENTATIONS


22) “Carrier Capture in Narrow and Wide Quantum Wells: Simulation of the Transition from Weak to Strong Scattering,” presented at 190th Meeting of the Electrochemical Society, San Antonio, TX, October 7-10, 1996.