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Optimum Design and Performance of GaAlAs/GaAs MQW Lasers with Very Thin Wells

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In recent years great advances have been made in the design and fabrication of multi-quantum well (MQW) lasers. CW lasing action has been achieved at currents as low as 13 mA [1] and at wavelengths well below that of conventional double hetero-structure lasers. Although many laser configurations have been tested, little has been done to determine the shortest wavelength at which efficient operation can be achieved. In this paper we use a quantum mechanical model to optimise the electron density of states, carrier confinement and radiation efficiency, and show that efficient operation can be achieved for well widths as small as 20Å with an aluminium fraction of 0.4 in the barrier layers. We report the first efficient operation of MQW lasers with GaAs well at 7550 Å and indicate the principal criteria for designing small well MQW lasers.

The internal radiative efficiency of MQW lasers is given by $\eta = 1/(1+\tau_R/\tau_{NR})$ where τ_R and τ_{NR} are the radiative and non-radiative recombination times respectively. A high laser efficiency can be achieved if τ_{NR} is maximized and τ_R minimized; this paper is concerned with the minimization of τ_R as a function of well width and well depth. Assuming a no k selection rule we write the radiative recombination rate as $R = B_{np}$, where n and p are the electron and hole concentrations, so that $R \propto \psi_e\psi_e^*\psi_h\psi_h^*$ where ψ_e and ψ_h are the electron and hole envelope wavefunctions. Thus the recombination rate can be maximized by maximizing $\int\psi_e\psi_e^*\psi_h\psi_h^* d\Omega$. We have evaluated this integral for a single quantum well of finite depth, and the recombination rate and the mean extent of the wavefunction are plotted as functions of the well width in figure 1. It can be seen that for a fixed barrier height there exist well widths (almost equal) which maximize the carrier confinement, the density of states, the recombination rate and hence the internal quantum efficiency of the laser.

The discontinuity of mass at the GaAs/GaAlAs interface acts to increase the confinement, increasing the recombination rate and shifting the peak in figure 1 towards smaller well widths. Optimizing the well width in this way we have calculated the optimum well size as a function of barrier height and mass discontinuity and the results are shown in figure 2. The line represents the optimum width for each constituent well in an MQW laser as a function of the barrier aluminium content; for larger or smaller well widths the efficiency will be reduced. We have also calculated the effect of well coupling, and find that the peak gain is reduced if the interwell resonance energy exceeds the spectral linewidth. Details of this calculation will be presented at the conference.

From the above considerations we fabricated MQW lasers with four 25 Å wells and three 50Å barriers using MBE (figure 3), [2]. We used a separate confinement structure of total width 1500 Å, the upper and lower cladding layers having an aluminium fraction of $x = 0.48$ and respective Be and Si doping levels of 2×10^{18} cm^{-3}. For the aluminium fractions of $x = 0.22$ and $x = 0.3$ used in these devices a well width of 25 A is almost optimum (fig. 2); consequently we were able to achieve internal quantum efficiencies of over 80 % at wavelengths down to 7550 Å, which is the shortest wavelength yet reported for MQW lasers with GaAs wells. The output spectrum of an MQW laser with a threshold wavelength of 7550 Å is shown in figure 4. Using this 25 Å / 50 Å structure we obtained CW threshold currents as low as 42 mA.

We conclude that the optimization of the well width as a function of the aluminium content of the barrier results in very high operating efficiencies for MQW lasers, even at an operating wavelength of 7550 Å. We predict that efficient operation should be achievable at a wavelength of 7250 Å using 40 % aluminium in the barriers and well widths of 20 Å.

We should like to thank Mrs. C. Nozaki for measuring the well widths and photoluminescence spectra of our MQW structures.

1. S. Yamakoshi et al. 1982 IEEE IEDM Technical Digest, p342 (San Francisco).
2. M. Mashita et al. 15th Conf. Solid State Devices & Materials, Tokyo 1983, C-6-4LN (p54).

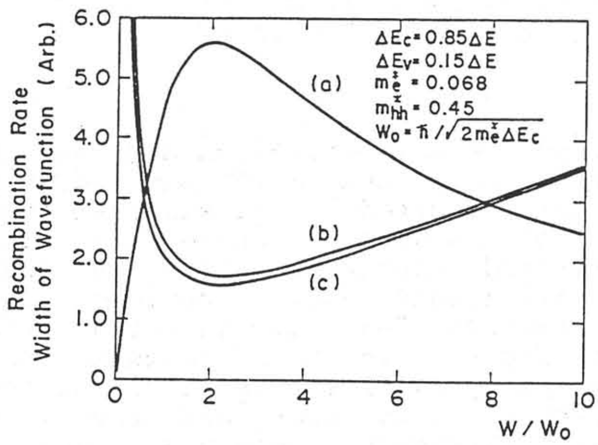

Fig. 1 The recombination rate (a) and widths of the electron (b) and hole (c) wavefunctions as a function of well width.

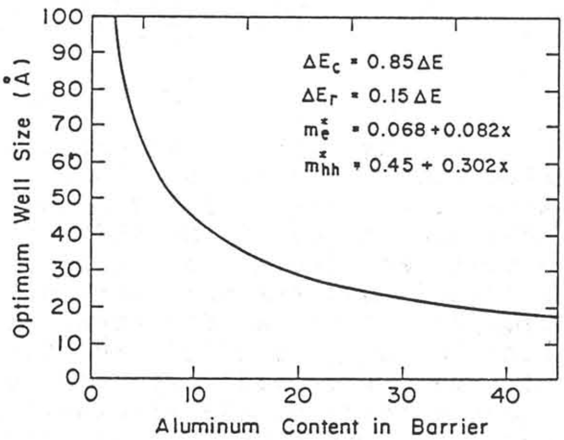

Fig. 2 The optimum well size as calculated from the electron and hole wavefunctions.

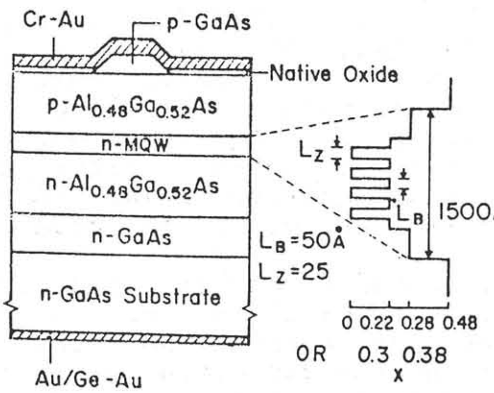

Fig. 3 MQW laser structure.

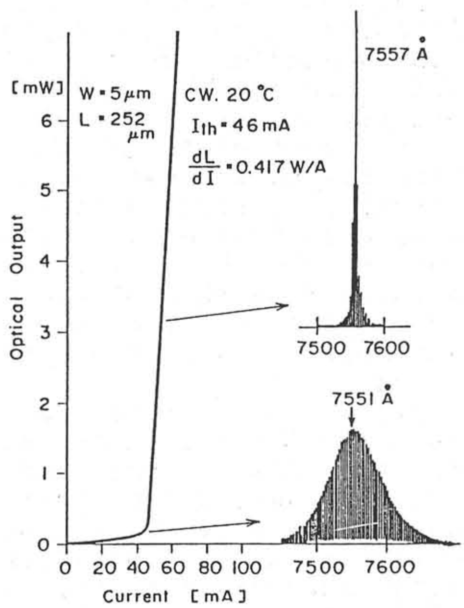

Fig. 4 Typical I-L curve and spectrum.