Band-Edge Characterization of Intermixed InGaAsP/InP and InGaAs/GaAs Quantum Wells

G.B. Morrison, J.W. Raring, C.S. Wang, E.J. Skogen, and L.A. Coldren

Quantum well intermixing (QWI) has been widely demonstrated as an elegant method for creating multiple band edges in photonic integrated circuits (PICs). Despite the popularity of QWI, quantitative experimental studies of the effect of intermixing on quantum well band edges are scarce. This study makes extensive use of photocurrent spectroscopy to probe the band edge characteristics of intermixed quantum wells in both the 1550 nm InGaAsP/InP material system and the 980 nm InGaAs/GaAs material system. The photocurrent data is generated using simple photodiodes designed specifically for photocurrent spectroscopy. The photocurrent is collected as a function of both wavelength and bias voltage, and is then transformed into a measurement of absorption at the band edge. Band edge absorption measurements are used to compare quantum well designs for QWI PICs, and also to suggest optimal QWI band shifts for electro-absorption modulators (EAMs). Predictions of EAM chirp by application of the Kramers-Kronig transform are also demonstrated. By comparing the absorption edges of as-grown quantum wells with the absorption edges of intermixed quantum wells, the effect of QWI on the absorption edge is made clear. The effects of intermixing on device performance, such as EAM insertion loss, extinction, and extinction efficiency, are explained. As expected, the QWI process reduces carrier confinement, and can significantly weaken the exciton peak. A weakened exciton peak translates to lower extinction in modulator applications. In the InGaAsP/InP material system, we compare a 65 Å wide well having conduction band depth of 120 meV, to an 80 Å wide well having conduction band depth of 85 meV. Both designs exhibit satisfactory exciton confinement for a QWI modulator, but the 80 Å design is shown to be shallower than is optimal for the overall PIC. For the wells considered in the InGaAsP/InP material system, a band edge shift of approximately 40-50 nm is ideal for modulator components. In the GaAs/InGaAs 980 nm material, an 80 Å well with conduction band depth of 147 meV is examined. A 20-30 nm blue shift by QWI is shown to be appropriate for modulators in this material system. Unfortunately, the QWI process seriously degrades the exciton peaks in these wells. For 980 nm applications, moving to a different material system that allows deeper wells (e.g. InGaAs/AlGaAs or InGaAsP/GaAs) may be necessary. Alternatively, for optimization at 980 nm in the InGaAs/GaAs system, red shifting the laser frequency from the gain peak by about 10 nm would allow a smaller degree of QWI (e.g. 10 nm) in the modulator, resulting in improved modulator performance.

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