

# Quantum Well Intermixing and MOCVD Regrowth for the Monolithic Integration of UTC Type Detectors with Quantum Well Based Components

J. W. Raring, E. J. Skogen, J. S. Barton, S. P. DenBaars, and L. A. Coldren

The traditional limitations of a 1-dimensional growth platform and a 2-dimensional fabrication scheme makes the monolithic integration of optimal photonic circuits a great challenge due to the common waveguide architecture and material compositions that the individual components within the circuit are often forced to share. Here we present an innovative fabrication/growth scheme using quantum well intermixing (QWI) and blanket MOCVD regrowth for the realization of a unique waveguide architecture and material composition in the photodetector region of an integrated circuit. Through the use of QWI, we blue-shift the as-grown InGaAsP base structure QWs in regions where low loss waveguides or alternative component architectures are desired. An MOCVD regrowth is then performed in which the layer structure necessary for an InGaAs uni-traveling-carrier (UTC) type photodetector is grown. The UTC layer structure is then selectively removed such that mesas remain only in detector regions with blue-shifted, transparent QWs below. Following a thin p-InP regrowth and dry etch ridge definition, a p-InP cladding is grown to yield a buried ridge stripe (BRS) device with three distinct regions: The as grown InGaAsP QWs for use in components such as diode lasers, blue-shifted QWs for low loss waveguides, and UTC type detectors with blue-shifted QWs below. The benefits offered by the InGaAs UTC type detector over that of a detector making use of the as-grown base structure QWs are threefold: The redshifted bandedge relative to the input wavelengths reduces the bias dependence of the absorption coefficient. Without the limitation of hole transport within the UTC the saturation current density is increased allowing for smaller diode areas and hence increased bandwidth.

In recent work, we have demonstrated the ability to achieve high quality QW material grown short distances above a regrowth interface subjected to defect diffusion during the QWI process. Here, we build off this capability by developing the necessary MOCVD growth conditions and processing techniques to enable the fabrication of a BRS device containing UTC type detectors and components employing the base structure QWs. We study the effects of growth rate and growth temperature on the resulting profile at the sidewalls of the UTC mesas, which suffer from undercutting during wet etch definition. Since ridges must be defined and buried across these sidewalls, the regrowth profile is a key aspect to successful device fabrication. We found that using a two-stage temperature profile at a rate of  $3.8 \text{ \AA/s}$  provided an optimum growth profile. Finally, by fabricating both UTC type and QW pin type photodetectors on the same chip, we demonstrate a 2X and 4X increase in large-signal voltage amplitude from UTC detectors with  $1/5$  and  $3/5$  the diode area, respectively, as the QW pin detectors.