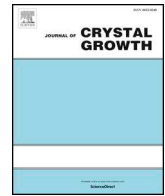




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Interplay of GaAsP barrier and strain compensation in InGaAs quantum well at near-critical thickness

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ABSTRACT

The effect of GaAs_{1-y}P_y tensile-strained barriers on suppressing the partial strain relaxation of InGaAs/GaAs multiple quantum wells (MQWs) is investigated when the thickness of a heavily strained In_xGa_{1-x}As QW is near-critical thickness. The strain relaxations of In_{0.4}Ga_{0.6}As MQWs *with* and *without* strain-compensating GaAs_{1-y}P_y barriers are characterized using X-ray diffraction reciprocal space mapping (RSM) and micro-photoluminescence (μ-PL) mapping. A significant amount of strain relaxation (~1.53%) is measured when the thickness of each In_{0.4}Ga_{0.6}As QW within a 4-period MQW becomes 9.5 nm in the absence of strain-compensating layers. By adding two ~5 nm GaAs_{0.67}P_{0.33} tensile-strained barriers sandwiching each QW, the strain relaxation in the In_{0.4}Ga_{0.6}As/GaAs_{0.67}P_{0.33}/GaAs MQWs is reduced to ~0.3% together with decreased surface roughness. Our study shows that tensile barriers with proper elastic energy densities are essential to achieve efficient strain compensation in a heavily-strained InGaAs MQW structure, which provides an important insight into the understanding of how to better achieve the benefits of strain compensation in III-V based QWs and superlattices.

1. Introduction

The demand for high-performance diode lasers in optical communications has driven the extensive development of In_xGa_{1-x}As strained quantum wells (QWs) grown on GaAs substrates. Specifically, employing heavily strained In_xGa_{1-x}As QWs with up to 40% In-content enables high-performance temperature-insensitive laser diodes operating at ~1.1–1.3 μm [1–6]. Meanwhile, the implementation of InGaAsN QWs emitting at ~1.3 μm and beyond also depends on improving the growth of highly-strained In_xGa_{1-x}As QWs [6–10]. However, the severe compressive strain of those In_xGa_{1-x}As QWs leads to partial strain relaxation, which can be detrimental to the optical properties as a result of excessive defect formation in the active region, especially when thicker In_xGa_{1-x}As QWs *with* high In-content (i.e. close to the critical thickness) are necessary for long wavelength emission near 1.1–1.3 μm.

High-performance laser diodes emitting near 1.1–1.3 μm have been demonstrated previously, which employed either InGaAs [11–17] or InGaAsN QW [18,19] active regions in conjunction with GaAs_{1-y}P_y strain-compensating layers. This approach was based on the pursuit of highly-strained QWs with an In-content as high as 40% and with the QW thickness thinner than the critical thickness. The strain

compensation approach was introduced into either In_xGa_{1-x}As SQW (single quantum well) or MQW by sandwiching the compressively strained QWs with GaAs_{1-y}P_y tensile barriers [11–18], in order to lower the average net strain of the QW active region. The strain compensation provided by using tensile barriers to surround the highly-strained In_xGa_{1-x}As QW at near-critical thickness allowed the realization of ultra-low-threshold diode lasers operating at up to 1.24 μm [12]. In addition, prior studies have demonstrated reliable operation from strain-compensated highly-strained InGaAs/GaAsP active region lasers [13,15,17]. Recent studies have also presented the use of GaAs interlayers between high In-content In_xGa_{1-x}As and the tensile strained GaAs_{1-y}P_y barriers to suppress mismatch strain and improve the crystal quality of large-period MQW-based solar cells [20–22].

The high speed, optical gain, and carrier transport properties of high-performance strain-compensated 1.1–1.3 μm emitting In_xGa_{1-x}As (N) based QW diode lasers were reported previously [23–25]. However, despite the observed advantages of the strain-compensated In_xGa_{1-x}As MQWs with GaAs_{1-y}P_y barriers, the effect of GaAs_{1-y}P_y barriers on suppressing the detrimental impact of strain relaxation is still not fully understood, especially when the thickness of the In_xGa_{1-x}As QW within the MQW is close to the critical thickness for strain-relaxation. Furthering this understanding is essential if high-performance devices

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