Journal of Crystal Growth 531 (2020) 125381

Contents lists available at ScienceDirect

Journal of Crystal Growth

journal homepage: www.elsevier.com/locate/jcrysgro

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

Wei Sun[a,*,1], Honghyuk Kim[b,1], Luke J. Mawst[b], Nelson Tansu[a]

[a] Center for Photonics and Nanoelectronics, Department of Electrical and Computer Engineering, Lehigh University, Bethlehem, PA 18015, USA

[b] Reed Center for Photonics, Department of Electrical and Computer Engineering, University of Wisconsin-Madison, Madison, WI 53706, USA

ARTICLE INFO

Communicated by C. Caneau

Keywords:
A1. Strain compensation
A3. Metalorganic vapor phase epitaxy
A3. Strain quantum wells
B2. InGaAs
B2. GaAsP
B3. Semiconductor lasers

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

* Corresponding author.
E-mail addresses: wes212@lehigh.edu (W. Sun), hkim527@wisc.edu (H. Kim), ljmawst@wisc.edu (L.J. Mawst), tansu@lehigh.edu (N. Tansu).

[1] These authors contributed equally to this work.

https://doi.org/10.1016/j.jcrysgro.2019.125381
Received 3 August 2019; Received in revised form 27 November 2019; Accepted 27 November 2019
Available online 28 November 2019
0022-0248/