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Room-temperature yellow–amber emission from InGaP quantum wells grown on an InGaP metamorphic buffer layer on GaP(1 0 0) substrates

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Abstract

In this paper we present a systematic investigation of the structural and optical properties of InGaP using a metamorphic $In_xGa_{1-x}P$ buffer layer grown on GaP(1 0 0) substrates. When grown at 400 °C, the simpler constant-composition metamorphic buffer layer has a smoother surface morphology, as compared to that grown at 500 °C, and results in comparable structural quality of the top layers as a linearly graded metamorphic buffer layer. $In_{0.5}Ga_{0.5}P$ quantum wells with $In_{0.3}Ga_{0.3}P$ barriers grown on a constant-composition metamorphic buffer layer exhibit room-temperature bright photoluminescence in the amber wavelength at 610 nm.
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1. Introduction

Solid-state lighting recently has become one of the most exciting subjects of research in the semiconductor technology area. In particular, white light from light-emitting diodes (LEDs) would offer many advantages for general lighting: reduced electrical energy consumption, reduced carbon-related pollution, increased lifetime, and improved human visual experience. Indeed, solid-state lighting through LEDs is considered a disruptive technology [1], which eventually would replace present incandescent and fluorescent technologies, much like transistors replacing vacuum tubes.

The three wavelengths best for tri-color mixing to produce white light are 460, 540, and 610 nm. The first two are produced from InGaN LEDs,

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and the last, 610 nm, from AlInGaP LEDs grown on GaAs substrates. There are several problems with the latter. The first problem is low quantum efficiency or luminous efficacy in the yellow–amber range due to poor electron confinement and direct-to-indirect crossover. The second problem is the complicated and high-cost procedure of removing the light-absorbing GaAs substrate and wafer-bonding a transparent GaP substrate [2].

Our approach to alleviate these two problems is to grow the desired LED structure on a transparent, larger-lattice-constant $In_xGa_{1-x}P$ metamorphic buffer layer on a transparent GaP substrate. Metamorphic devices have been produced from Si_xGe_{1-x}/Si [3,4], $In_xGa_{1-x}As/GaAs$ [5–7], $In_xGa_{1-x}As/InP$ [8], and $In_xGa_{1-x}P/GaP$ [9,10]. Close to 100% strain relaxation and reduction in threading dislocation density to below the detection limit of plan-view transmission electron microscopy (TEM), $10^6\,cm^{-2}$, have been reported [7,10]. The demonstrated high efficiency of strain relaxation is related to the control of misfit dislocation (in-plane between substrate and epitaxial layer) formation rates in the material. Our current approach differs from our previous work [9,10] in lowering the growth temperature to 400 °C and using quantum wells rather than bulk layers for the active region.

2. Experiment

All samples were grown by gas source molecular beam epitaxy (GSMBE) with a Varian Gen II MBE system. Phosphorus was provided by thermally cracked phosphine, and In, Ga, and Al were provided by conventional solid sources. Two sample structures have been studied, as shown in Fig. 1. Sample structure #1 consists of a 0.5 μm-thick $In_xGa_{1-x}P$ metamorphic buffer layer followed by a 0.5 μm-thick $In_xGa_{1-x}P$ buffer layer. On top of this a 0.4-μm-thick $In_xGa_{1-x}P$ waveguide layer was grown, sandwiched between 0.03 μm-thick $Al_{0.3}Ga_{0.7}P$ barrier layers. We chose 0.4 μm thickness because it is similar to the typical thickness of the active region in AlInGaP-based LEDs. Finally, the structure was capped with a 10 nm-thick $In_xGa_{1-x}P$ layer. The composition x was varied for different samples. Sample structure #2 is the same as that of Structure #1 except a 7-nm-thick $In_yGa_{1-y}P$ quantum well inserted in the middle of the $In_xGa_{1-x}P$ waveguide layer with $y > x$. The metamorphic buffer layer of Structure #1 was grown two different ways: constant composition of $In_xGa_{1-x}P$ on GaP and linearly graded $In_xGa_{1-x}P$, where x was varied from 0 to the desired value by changing the temperature of the In cell during growth. The growth temperature

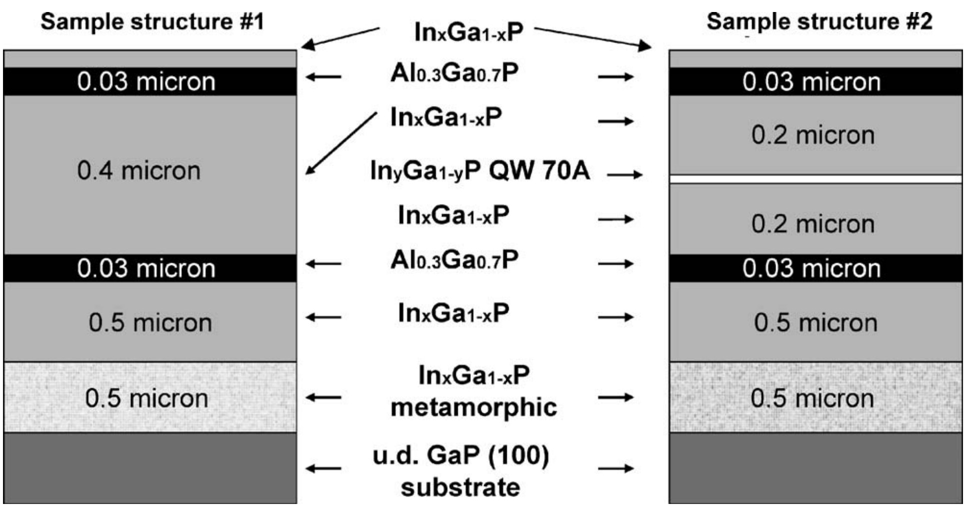

Fig. 1. Layer-by-layer schematic representation of Structures #1 and #2.

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