Available online at www.sciencedirect.com
ScienceDirect
Applied Surface Science 253 (2007) 6232–6235
applied surface science
www.elsevier.com/locate/apsusc

GaAs surface passivation by ultra-thin epitaxial GaP layer and surface As–P exchange

A. Aierken *, J. Riikonen, M. Mattila, T. Hakkarainen, M. Sopanen, H. Lipsanen

Micro and Nanosciences Laboratory, Micronova, Helsinki University of Technology, P.O. Box 3500, FIN-02015 TKK, Finland

Received 4 December 2006; received in revised form 20 January 2007; accepted 21 January 2007
Available online 30 January 2007

Abstract

The GaAs surface passivation effects of epitaxially grown ultra-thin GaP layers and surface As–P exchange have been investigated. Optical properties of passivated and unpassivated InGaAs/GaAs near-surface quantum wells (QWs) grown by metal organic vapor phase epitaxy (MOVPE) are studied by low-temperature continuous-wave and time-resolved photoluminescence (PL). By optimizing the growth conditions, smooth surface morphologies and significant improvement of optical properties were observed for both passivation methods. Passivation improved the PL intensity more than two orders of magnitude and notably increased the PL decay time.

PACS : 68.65.Fg; 81.65.Rv; 78.67.De; 81.07.St; 81.15.Gh

Keywords: Surface passivation; Quantum wells; MOVPE; GaAs

1. Introduction

It is well known that the high density of surface states of GaAs may cause a large surface recombination velocity and Fermi level pinning near the middle of the band gap. These characteristics impose some limitations on optical and electrical performance of low-dimensional devices. Various in and ex situ surface passivation techniques using different material combinations and processing methods have been intensively investigated to reduce this effect. Chemical passivation with sulfur is one of the widely studied conventional passivation methods [1,2]. It has also been reported that epitaxial in situ passivation methods are more efficient than other passivation techniques. Significant passivation effects can be achieved by, e.g., metal organic vapor phase epitaxy (MOVPE) grown thin InP and GaN layers [3–6]. Surface As–P exchange treatment has also been studied widely for GaAs surface passivation [7–10]. By exposing GaAs surface to phosphine or tertiarybutylphosphine (TBP) at elevated temperature, a very thin layer of GaP is formed on the GaAs surface via As–P exchange. However, most of the previous phosphorus passivation studies consider only surface As–P exchange while the passivation effects of epitaxially grown GaP are rarely reported.

In this paper, we study GaAs surface passivation by using both epitaxially grown ultra-thin GaP layers and surface As–P exchange. The passivation effects are characterized by studying low-temperature photoluminescence (PL) and time-resolved photoluminescence (TRPL) of the passivated and unpassivated MOVPE grown InGaAs/GaAs near-surface quantum wells (QWs). The growth conditions of GaP and surface phosphorization are investigated for optimum passivation effects. For both methods, the near-surface QWs show significantly enhanced PL intensity and longer PL decay times compared to those of the unpassivated samples.

2. Experimental

All near-surface QW and passivation layers were fabricated on semi-insulating GaAs (1 0 0) substrates in a horizontal MOVPE reactor at atmospheric pressure using trimethylindium (TMIn), trimethylgallium (TMGa), tertiarybutylarsine (TBAs) and TBP as precursors for indium, gallium, arsenic and phosphorus, respectively. The near-surface QW structure consists of a 100 nm thick GaAs buffer layer, a 4 nm thick

* Corresponding author. Tel.: +358 9 451 5360; fax: +358 9 451 3128.
E-mail address: abuduwayiti.aierken@tkk.fi (A. Aierken).

0169-4332/$ – see front matter
doi:10.1016/j.apsusc.2007.01.069

$In_{0.22}Ga_{0.78}As$/GaAs QW and a 5 nm thick GaAs cap layer. An unpassivated deep QW sample, with a 20 nm thick cap layer, was also grown for reference. All the near-surface QWs were grown at 650 ° C and V/III ratios used for GaAs and InGaAs layers were 27 and 23, respectively. The temperatures mentioned in this report are thermocouple readings [11] and V/III ratios are molar flow ratios. Layer thickness and indium composition of the QW was determined by a high-resolution triple-axis X-ray diffractometer (HR-XRD).

Two kinds of passivation methods were utilized, epitaxially grown ultra-thin GaP layer and surface phosphorization. The growth temperature of the GaP passivation layer was varied between 550 and 640 ° C while the V/III ratio was 130. At 580 °C, nominally 1 mono-layer (ML) thick GaP layers were grown with V/III ratios of 130, 200 and 300 to study the effect of V/III ratio. In order to study the effect of the passivation layer thickness, 1–3 MLs of GaP was deposited at 580 ° C with a V/III ratio of 130. The surface phosphorization was realized by exposing the samples to TBP flows of 330, 500 and 730 μmol/min during the cooling from 600 to 400 ° C after the growth of the GaAs cap layer.

The low-temperature (10 K) continuous-wave PL measurements were conducted by utilizing a diode-pumped frequency-doubled Nd:YVO_4 laser emitting at 532 nm for excitation. A liquid-nitrogen-cooled germanium detector and standard lock-in techniques were used to record the PL spectra. The low-temperature TRPL measurements were performed by exciting the samples with 150 fs pulses at 780 nm from a mode locked Ti:sapphire laser and by detecting the signal using a Peltier-cooled microchannel plate multiplier and time-correlated single photon counting electronics. The surface morphology of the samples was investigated by contact-mode atomic force microscopy (AFM).

3. Results and discussion

Fig. 1 shows the AFM images of GaP-passivated (1 ML thick, grown at 620 and 580 °C), surface phosphorized and unpassivated near-surface QW samples. Small islands, possibly Ga droplets, were found on the GaP-passivated sample surfaces if the passivation layers were grown at temperatures above 600 ° C (Fig. 1(a)). The main reason for the three-dimensional morphology in these samples might be the arsenic to phosphorus exchange and arsenic desorption at higher temperatures [12]. Smooth sample surfaces and clear atomic layer terraces are observed from the GaP-passivated samples if the passivation layers are grown at temperature below 600 ° C (Fig. 1(b)) as well as from the phosphorized sample (Fig. 1(c)). Comparison with the unpassivated sample (Fig. 1(d)) indicates that the passivation layer does not degrade the surface morphology of the samples.

Fig. 2 shows the normalized maximum low-temperature PL intensity of the 1 ML thick GaP-passivated samples as a function of the growth temperature of the passivation layer. All

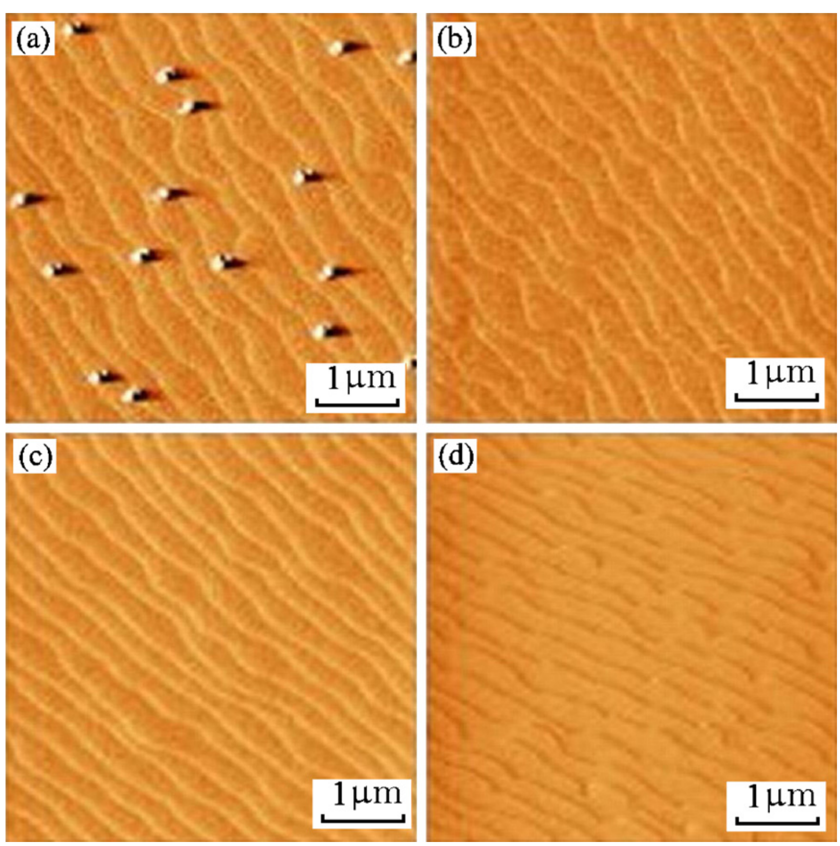

Fig. 1. AFM images of near-surface QW samples: (a) GaP-passivated at 620 °C, (b) GaP-passivated at 580 °C, (c) surface phosphorized and (d) unpassivated. The scan size is 5 μm × 5 μm and the vertical scale is 5 nm.