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Optical properties study of $In_xGa_{1-x}As/GaAs$ structures using spectral reflectance, photoreflectance and near-infrared photoluminescence

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ABSTRACT

Optical properties of $In_xGa_{1-x}As$ films grown on GaAs substrates by metalorganic vapor phase epitaxy were investigated. Spectral reflectance (SR) and photoreflectance (PR) at room temperature and near-infrared photoluminescence (PL) at 10 K were performed. SR signals in the range of 200–1700 nm provided the *x*-dependence of the critical point energies E_1, $E_1 + \Delta_1$ and E_2. Furthermore, band-gap and spin-orbit splitting energies, as well as their broadening parameters were determined from PR spectra and studied as function of In composition ranging from 0 to 0.37. On the other hand, the origins of luminescence bands observed in PL spectra were revealed. A redshift of 16 meV/%In in the band-to-band transition was obtained. All results issued from different characterizations tools are correlated and compared to the literature.

1. Introduction

$In_xGa_{1-x}As/GaAs$ structures present a practical use in the active zone of microelectronics and optoelectronics devices notably in the areas of infrared emitters or detectors [1–3]. These structures are of specific interest in the study of low-dimensional systems such as quantum wells and quantum

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dots [4,5] and also allow the understanding of InGaAsX (X = N, Bi, etc.) quaternary alloys behavior [6,7]. The growth optimization of $In_xGa_{1-x}As$ thin films is a determinist step to improve the performance of these materials. Thus, many researchers have successfully quantified the evolution of indium composition in $In_xGa_{1-x}As$ layers as function of growth parameters by metalorganic vapor phase epitaxy (MOVPE) [8,9]. *In situ* monitoring of InGaAs layers epitaxy can be performed using laser reflectometry (LR) [8,10]. In addition, LR was used to determine indium composition dependence of refractive indices n and extinction coefficients k of InGaAs alloys [10]. Results showed a quadratic variation of n and k with x ranging from 0% to 50%.

In a previous work [11], spectral reflectance (SR), photoreflectance (PR) and near-infrared photoluminescence (PL) measurements were carried out to investigate optical properties of $In_xGa_{1-x}As/GaAs$ structure with a low indium composition of 8%. We have determined the critical points (CPs), bandgap (E_0) and spin-orbit splitting (Δ_0) energies at 300 K for both GaAs and $In_{.08}Ga_{.92}As$ materials. Moreover, the origins of PL peaks were also revealed. However, optical properties knowledge of InGaAs structures over a wide spectral range is crucial. As continuity to our previous work, in this paper we extend the investigations of $In_xGa_{1-x}As/GaAs$ structures to a large indium composition range $0 \leqslant x \leqslant 0.37$ using optical techniques (SR, PR and PL). CPs E_0 and Δ_0 variations, as well as PL bands luminescence are analyzed as function of indium composition. Besides, the behavior of broadening parameters Γ_0 and Γ_0' related to E_0 and $E_0 + \Delta_0$ respectively was compared to the full width at half maximum (FWHM) of layer peaks obtained by high-resolution X-ray diffraction (HRXRD) measurements in rocking curve mode. All data were discussed and compared to previous works reported in the literature.

2. Experimental procedure

Series of $In_xGa_{1-x}As/GaAs$ samples, denoted S_1(for $x = 0$), S_2(for $x = 0.02$), etc., and S_8(for $x = 0.37$) were grown on (001) GaAs substrate by MOVPE in horizontal-type atmospheric pressure reactor. In order to cover the solid indium composition range of 0–0.37, the vapor indium composition x^v was varied from 0 to 0.16 and the growth temperature T_g was changed from 450 to 605 °C as reported in Table 1. Indium compositions were determined by HRXRD. Trimethylgallium (TMGa), trimethylindium (TMIn) and arsine (AsH_3) were used as precursors. Bubblers were kept in thermal baths at 5 and 20 °C for TMGa and TMIn respectively. The carrier gas was Pd-diffused hydrogen (H_2). V/III ratio was

Table 1
Summary of $In_xGa_{1-x}As$ parameters ($0 < x \leqslant 0.37$) derived from MOVPE, HRXRD, SR, PR and PL measurements.

Samples		S_1	S_2	S_3	S_4	S_5	S_6	S_7	S_8
MOVPE									
x		0	0.02	0.08	0.13	0.16	0.20	0.23	0.37
T_g (°C)		605	605	520	605	605	450	450	450
HRXRD @ 300 K									
FWHM (deg)		0.009	0.056	0.090	0.256	0.197	0.265	0.217	0.601
SR @ 300 K									
C_{1200} (a.u.)		0	1.9	4.4	8.5	13.0	14.0	12.9	18.7
P_{1200} (nm)		–	170	150	164	137	293	227	285
$\langle d \rangle$ (μm)		1.20	1.08	1.60	1.18	1.21	0.56	0.63	0.63
PR @ 300 K									
Γ_0 (meV)		5	13	10	51	23	36	73	60
Γ_0' (meV)		9	14	25	32	49	58	72	75
F(kV/cm)		–	–	17.2	–	–	–	145.1	–
$\hbar\Omega$ (meV)		–	–	10	–	–	–	41	–
PL @ 10 K									
FWHM (meV)	Peak1	12	25	15	31	–	–	–	81
	Peak2	15	35	29	24	–	–	–	21
	Peak3	39	100	23	–	26	–	–	117