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Journal of Crystal Growth 260 (2004) 50–53

JOURNAL OF CRYSTAL GROWTH

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$Ga_{1-x}Mn_xSb$ grown on GaSb substrate by liquid phase epitaxy

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Received 23 June 2003; accepted 19 August 2003
Communicated by M. Schieber

Abstract

The $Ga_{1-x}Mn_xSb$ epilayer was prepared on the n-type GaSb substrate by liquid phase epitaxy. The structure of the $Ga_{1-x}Mn_xSb$ epilayer was analyzed by double-crystal X-ray diffraction. From the difference of the lattice constant between the GaSb substrate and the $Ga_{1-x}Mn_xSb$ epilayer, the Mn content in the $Ga_{1-x}Mn_xSb$ epilayer were calculated as $x = 0.016$. The elemental composition of $Ga_{1-x}Mn_xSb$ epilayer was analyzed by energy dispersive spectrometer. The carrier concentration was obtained by Hall measurement. The hole concentration in the $Ga_{1-x}Mn_xSb$ epilayer is $4.06 \times 10^{19}\,cm^{-3}$. It indicates that most of the Mn atoms in $Ga_{1-x}Mn_xSb$ take the site of Ga, and play a role of acceptors. The current–voltage curve of the $Ga_{1-x}Mn_xSb$/GaSb heterostructure was measured, and the rectifying effect is obvious.

PACS: 81.10.Dn; 81.15.Lm; 81.05.Zx; 81.15.−z; 61.82.Fk

Keywords: A1. X-ray diffraction; A3. Liquid phase epitaxy; B2. Semiconducting ternary compounds

1. Introduction

Semiconductors and magnetic materials are two very important materials in the current electronics industry and two large fields of solid-state physics. Diluted magnetic semiconductors (DMSs) are semiconductors with a fraction of their host lattice replaced by transition metal elements. The discovery of carrier-induced ferromagnetism [1] in Mn-based DMS has received much attention because of the potential device applications that utilize both information processing and data storage within one material system. Combining the interesting properties of both magnetic materials and semiconductors, DMSs are expected to play an important role in interdisciplinary materials science and electronics. For magnetic elements are easily doped into II–VI compounds, II–VI-based DMSs have been extensively studied. However, carrier control is generally difficult in II–VI DMSs.

As to III–V compounds, it is commonly believed that the equilibrium solubility of magnetic ions is quite low ($\sim 10^{19}\,cm^{-3}$). In order to incorporate magnetic ions such as Mn into III–V materials beyond thermodynamic solubility limits,

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doi:10.1016/j.jcrysgro.2003.08.022

Table 1
Summary of liquid phase epitaxy parameters

Substrate	Melt composition (atomic fraction)			Growth temperature (°C)	Solid composition
	Ga (g)	GaSb (g)	Mn (g)		
GaSb	1.06	0.16	0.02	525	$Ga_{1-x}Mn_xSb$

a nonequilibrium growth process is usually adopted [2]. Manganese in III–V DMS materials provides not only hole carriers due to its acceptor nature, but also localized spins. Because the equilibrium solubility of Mn in GaSb can be as high as 15% [3], $Ga_{1-x}Mn_xSb$ could be grown with liquid phase epitaxy (LPE). Curie temperature T_c is an important parameter for DMSs, and $Ga_{1-x}Mn_xSb$ is an interesting candidate for improving T_c. with the higher-equilibrium solubility of Mn [4–6].

In this paper, $Ga_{1-x}Mn_xSb$ samples were grown by LPE.

2. Material preparation

$Ga_{1-x}Mn_xSb$ were grown by LPE on (1 0 0) GaSb wafer with an area of 10 mm × 10 mm in a conventional horizontal graphite slide boat within a quartz reactor tube heated by a precise temperature controlled furnace. The ambient is flowing Pd-membrane purified hydrogen at atmospheric pressure. The LPE growth conditions are summarized in Table 1. The growth solutions were homogenized and purified for 4 h at 790°C. To remove the thin residual oxide layer from the GaSb substrates surface, they were etched in the solution of $HF:HNO_3:CH_3COOH = 1:9:20$. After the GaSb substrate was loaded, the furnace were heated to 600°C for 4 h to completely dissolve the growth solutions, then the temperature was slowly reduced to 525°C, and the epitaxial layer was grown by means of the super-cooling technique.

3. Compositional and structural analyses

The samples have been cleaved and stained with basic $K_3Fe(CN)_6$ for epitaxial layer thickness measurements. The layer thickness d was about 2 μm. In order to investigate the structure and composition of Mn in $Ga_{1-x}Mn_xSb$ epitaxial layer, double-crystal X-ray diffraction (DCXRD) and Hall measure were employed.

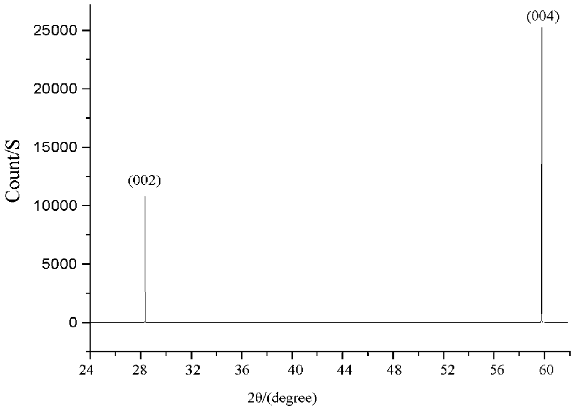

Fig. 1. DCXRD spectra for $Ga_{1-x}Mn_xSb/GaSb$.

3.1. Structural analyses

The DCXRD system used in this experiment is Philips X'pert-MRD (X'pert Materials Research Diffractometer System) with a multipurpose sample stage. The wavelength of X-ray radiated from the CuKα is 0.1540562 nm. The DCXRD spectra of the samples were measured with $2\theta - \theta$ scan. Fig. 1 shows the DCXRD patterns of $Ga_{1-x}Mn_xSb/GaSb$. The two diffraction peaks are corresponding (0 0 2) and (0 0 4) planes of the cubic crystalline $Ga_{1-x}Mn_xSb$, respectively. It indicates that $Ga_{1-x}Mn_xSb$ has the zinc-blende structure without detectable second phase.

Fig. 2 is the typical rocking curve of $Ga_{1-x}Mn_xSb/GaSb$ near (0 0 2) reflection. The Mn elements in $Ga_{1-x}Mn_xSb$ taking the sites of

Ga make the lattice parameter of $Ga_{1-x}Mn_xSb$ epilayer 0.086% larger than that of GaSb substrate. The content of Mn in $Ga_{1-x}Mn_xSb$ resulting in the lattice expanse can be calculated as $x = 0.016$ [7].

3.2. *Compositional analyses*

For comparison, the elemental composition in $Ga_{1-x}Mn_xSb$ epilayer was analyzed by energy dispersive spectrometer (EDS). The atomic ratio of Mn in $Ga_{1-x}Mn_xSb$ epilayer is 0.9%. The detailed result of EDS analyses is shown in Table 2. This result is consistent with X-ray diffraction analyses.

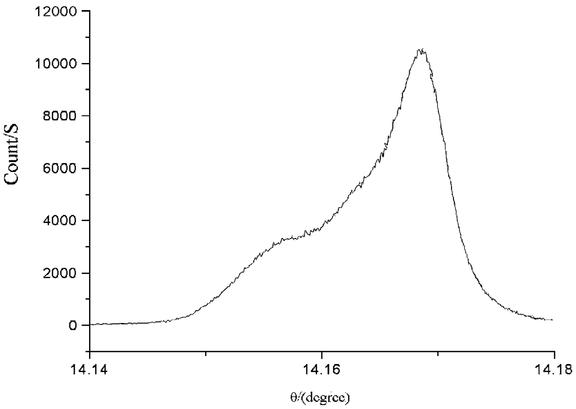

Fig. 2. Typical X-ray rocking curve of $Ga_{1-x}Mn_xSb$/GaSb near (0 0 2) reflection.

Table 2
Result of energy dispersive spectrometer (EDS)

Element	Weight (%)	Atomic (%)
Mn	0.53	0.90
Ga	39.84	53.35
Sb	59.63	45.74

3.3. *Hall measurement*

Table 3 is the result of hall measurement. The hole concentration of $Ga_{1-x}Mn_xSb$ is $4.06 \times 10^{19}\,cm^{-3}$, indicating that most of the Mn atoms in $Ga_{1-x}Mn_xSb$ take the site of Ga and play a role of acceptors. The hole concentration is lower than the Mn content calculated according to the DCXRD results. The reason is that only a part of Mn is activated.

3.4. *Current–voltage characteristics*

According to the result of Hall measurement, the GaSb substrate is n type and the $Ga_{1-x}Mn_xSb$ layer is p type. The n-type GaSb substrate and the p-type $Ga_{1-x}Mn_xSb$ layer constitute the $Ga_{1-x}Mn_xSb$/GaSb p–n junction. Fig. 3 is the current–voltage characteristics of the $Ga_{1-x}Mn_xSb$/GaSb p–n junction. It is prospective to apply to magnetic control diode.

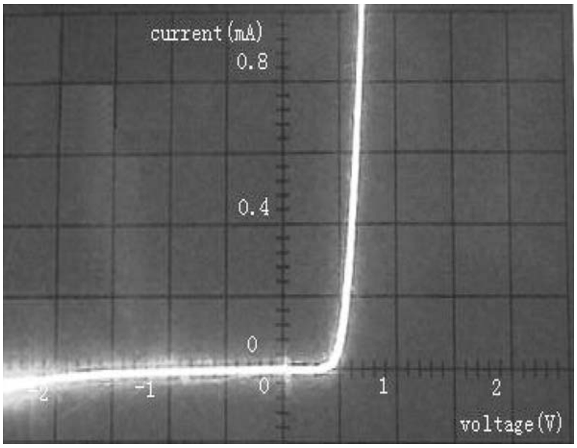

Fig. 3. Current–voltage curve of p–n junction.

Table 3
Result of hall measurement

Sample	Measurement temperature (K)	Resistivity (Ω cm)	Mobility (cm^2/V s)	Carrier concentration (cm^{-3})	Hall coefficient (cm^3/C)	*f*-factor
Layer: $Ga_{1-x}Mn_xSb$	300	4.866e−4	316.0	4.062e+19	1.538e−1	0.9985
Substrate: GaSb	300	2.804e−3	2461.0	9.058e+17	−6.900e+0	0.9994

4. Summary

The $(Ga_{1-x}Mn_x)Sb$ single crystals have been prepared on n-type GaSb substrate by LPE. X-ray diffraction analyses show that the $Ga_{1-x}Mn_xSb$ sample has the zinc-blende structure, and the Mn composition x in the $Ga_{1-x}Mn_xSb$ single crystals is 0.016. The result of EDS is consistent with X-ray diffraction analyses. Hall measurement shows that the hole concentration of $Ga_{1-x}Mn_xSb$ is $4.06 \times 10^{19}\,cm^{-3}$, indicating that most of the Mn atoms in $Ga_{1-x}Mn_xSb$ take the site of Ga, and play a role of acceptors. The property of current–voltage curve of the $Ga_{1-x}Mn_xSb/GaSb$ shows that it is p–n junction

Acknowledgements

This work was supported by the National Natural Science Foundation of China (Grant No. 60176001) and Special Funds for Major State Basic Research Projects of China (Grant No. 2002CB311905).

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