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Type-II InAs/GaSb superlattice grown on InP substrate

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ABSTRACT

Type-II InAs/GaSb superlattices are promising for the absorption layers of mid-infrared sensors. Since GaSb substrates absorb infrared light, other substrates with high transparency are favorable for back-illuminated sensors. InP substrate is attractive due to high transparency, relatively small lattice mismatch and near thermal expansion coefficient to silicon CMOS read-out integrated circuit. In this study, type-II InAs/GaSb SLs were successfully grown on InP substrates. The crystalline and optical quality of SL improved as GaSb buffer layer thickness increased due to the reduction of threading dislocations. By using thick GaSb buffer layer, SL with strong PL intensity was successfully obtained.

1. Introduction

Mid-infrared sensors with cutoff wavelength over 3 μm are expected for precise sensing of environmental gases, toxic gases and so on. In particular, focal plane arrays (FPAs) are useful for image sensing of distribution of gases. Type-II InAs/GaSb SLs are attractive materials for absorption layer of sensors because they are expected to realize lower dark current and better controllability of cutoff wavelength compared to conventional HgCdTe [1,2]. GaSb substrates are generally used for the epitaxial growth of this type-II SL. However, GaSb substrate has some problems. For example, its large absorption coefficient in mid-infrared region diminishes the external quantum efficiency of sensors with back-illuminated type such as FPAs [3]. Also, the difference of thermal expansion coefficient between GaSb substrate and silicon CMOS read-out integrated circuit (ROIC), which are bonded to each other with indium bumps, makes the reliability of bonding poor, because the FPAs are used by cooling down to a temperature lower than 100 K. These problems can be resolved by removing GaSb substrate and leaving only epitaxial layers. But this method is technically difficult. Recently, the type-II InAs/GaSb SLs grown on GaAs substrates with higher transparency is proposed and demonstrated [3]. But the epitaxial growth is difficult owing to the large lattice mismatch between GaAs and GaSb (7.8%) [4,5]. And the problem of the large difference of thermal expansion coefficient between GaAs substrate and ROIC still remains.

InP substrates seem to be more favorable because of not only high transparency in mid-infrared region but also smaller lattice mismatch as listed in Table 1(a). Moreover, InP has a closer thermal expansion coefficient to that of Si than GaAs and GaSb (Table 1(b)).

In this study, we report on successful growth of type-II InAs/GaSb SLs on InP substrates for the first time.

2. Experiments

InP substrates with low carrier concentration seem to be preferable because it is reported that GaAs substrates with lower carrier concentration exhibit higher transparency [8]. Therefore semi-insulating InP:Fe substrates were used in this study.

Epitaxial growth was performed by the solid source MBE method. In and Ga were supplied by conventional effusion cells. As and Sb beams were controlled by needle-valve cracking cells. The cracking temperatures were kept at 600 °C and 800 °C for As and Sb, respectively. The substrate temperature was measured by a pyrometer.

Prior to growth, the InP:Fe(100) substrates were thermally cleaned in the growth chamber under As flux. 0.15 μm-thick $In_{0.53}Ga_{0.47}As$ layers were grown in order to smoothen the surfaces of the substrates. The growth rate was 1.17 μm/h. GaSb buffer layers were followed. The growth temperature was 480 °C. Finally, type-II InAs/GaSb SLs, which consist of 50 pairs of 3.5 nm-thick InAs and 2.1 nm-thick GaSb, were grown. The growth temperature of the SL was 450 °C. To characterize the crystalline quality of GaSb buffer layers, samples without growing SLs were also prepared. The growth rates of GaSb and InAs were both 0.55 μm/h. A SL on a GaSb substrate was also grown using a 0.5 μm-thick GaSb buffer layer as a reference. The SL has the same

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periodic structure with the SLs on InP substrates mentioned above. The SLs on the InP substrate and the GaSb substrate were not grown simultaneously.

The crystalline quality of GaSb buffer layers and SLs were characterized by X-ray diffraction (XRD) with Cu Kα_1 ($\lambda = 1.54056$ Å), cross sectional transmission electron microscopy (TEM) and photoluminescence (PL). For PL measurement, a YAG laser (1064 nm) and a HgCdTe detector were used.

3. Results and discussions

3.1. GaSb layers on InP substrates

Two GaSb layers with different thicknesses were grown: 0.5 μm and 2 μm. In the X-ray rocking curves (XRCs), the diffraction peaks of GaSb (400) were broad but single as shown in Fig. 1. The calculated diffraction peak positions of bulk GaSb are also shown as dotted lines. The GaSb layers are inferred to be almost fully relaxed from the peak positions. However, no crosshatch was observed on the surfaces (Fig. 2). The thicker GaSb showed a diffraction peak with narrower full width half maximum (FWHM), indicating crystalline quality is improved by growing thicker layer.

Table 1
Parameters of GaSb, GaAs and InP.

(a) Lattice constant

	Lattice constant (Å)	Lattice mismatch with GaSb (%)	Ref.
GaSb	6.096	–	[6]
GaAs	5.653	7.8	[6]
InP	5.870	3.9	[6]

(b) Thermal expansion coefficient

	Thermal expansion coefficient (10^{-6} K^{-1})	Ref.
Si	3.34	[7]
GaSb	7.74	[6]
GaAs	6.86	[6]
InP	4.75	[6]

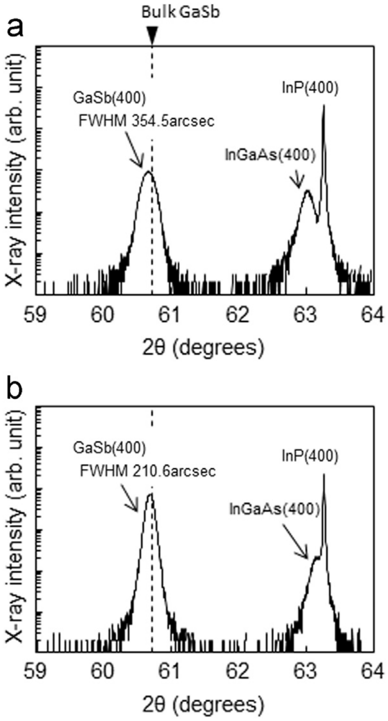

Fig. 1. XRCs of GaSb layers grown on InP substrates. (a) 0.5 μm-thick and (b) 2 μm-thick.

3.2. Type-II InAs/GaSb SLs on InP substrates

Several SLs were grown on InP substrates using GaSb buffer layers with different thicknesses. On the surfaces of the SLs, no crosshatch was observed.

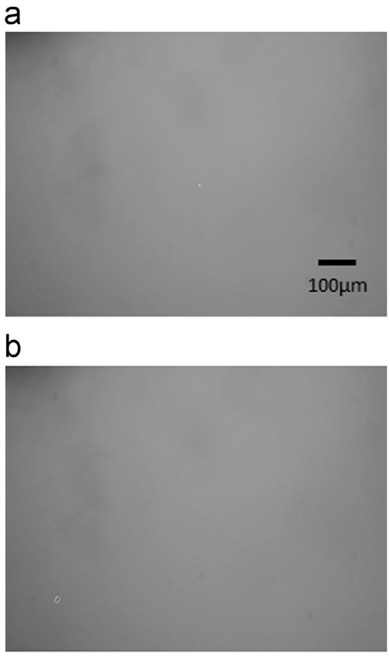

Fig. 2. Surfaces of GaSB layers grown on InP substrates observed by optical microscopy. (a) 0.5μm-thick GaSb and (b) 2μm-thick GaSb.

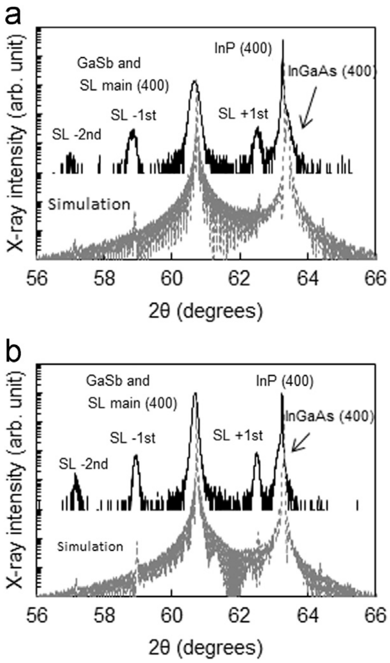

Fig. 3. XRCs of SLs grown on InP substrates. (a) 0.5μm-thick GaSb buffer layer and (b) 2.5μm-thick GaSb buffer layer.