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Composition control of $InAs_x Sb_{1-x}$ grown by molecular beam epitaxy

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Abstract: The molecular beam epitaxy growth of InAsSb film is presented. Dependence of Sb compositions on Sb_4 fluxes was studied. Utilizing the high combination tendency of In and Sb atoms, the composition of InAsSb layer is highly controlled.

Key words: molecular beam epitaxy(MBE), InAsSb, composition control
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分子束外延生长 InAsSb 材料的组分控制

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摘要:采用分子束外延方法在 GaAs 和 GaSb 衬底上生长了一系列 InAsSb 薄膜,研究了 Sb 组分与 Sb_4 束流间关系.实验发现,在分子束外延生长中,相比 As 原子,Sb 原子更易并入晶格中.利用该特性可较好实现 InAsSb 材料的组分控制.

关 键 词:分子束外延(MBE);铟砷锑;组分控制
中图分类号:O484.1 **文献标识码**:A

Introduction

Currently, infrared detectors operating in the mid-wave infrared range are based on HgCdTe, InSb and quantum well infrared photodetector (QWIP). Besides its high costs, the high vapor pressure of Hg results in the difficulty in growing HgCdTe material[1]. The InSb infrared detector works in a low temperature which requires bulky cooling equipment. QWIP works also at low temperature, and its quantum efficiency is low. The InAsSb based nBn detector is a good alternative for the mid-wave infrared detection. The nBn type detector which presented by S. Maimon and G. W. Wicks has a reduced dark current and high operating temperature[2]. Using the nBn structure, dark current related to depletion region can be suppressed effectively. Meanwhile the wide band gap barrier in this structure can eliminate surface leakage currents[3]. Thus, the nBn detector can work in a high operating temperature condition. InAsSb-based nBn detectors grown on GaAs and GaSb substrates have been reported by several groups[4-5]. Epitaxial layers with good quality are required for high quality devices.

Most of the InAsSb based nBn detectors were grown on GaSb substrates since the lattice parameter can be

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perfectly matched with them for $InAs_xSb_{1-x}$ layers with $x = 0.09$. The energy gap and lattice parameter of InAsSb are decided by composition. So, the composition control of InAsSb alloy is highly important for the fabrication of nBn type infrared detectors. The compositions of compounds containing more than two group-Ⅲ elements could be controlled by the ratio of beam fluxes. Nevertheless, because that molecular beam epitaxy growth is basically under the condition of excess group-Ⅴ elements, the compositions of compounds containing more than two group-Ⅴ elements can not be easily controlled by beam fluxes.

In this paper, composition control of InAsSb film during molecular beam epitaxy growth was studied. Utilizing the high incorporation possibility of Sb atoms, InAsSb films with lattice parameter matched with GaSb substrates were grown successfully.

1 Experimental

The epitaxial growth of the samples was carried out in a solid source molecular beam epitaxy (VG Semicon. V80) with a reflection high-energy electron diffraction (RHEED). The group-Ⅴ elements from the cells were As_2 and Sb_4. The group-Ⅲ sources were in effusion cells. Beam fluxes were measured by an ion gauge positioned in the growth chamber. The samples were grown on 2 inch semi-insulating GaAs and quarter 2 inch undoped-GaSb (100) substrates. In our experiments, we define flux ratio as the beam equivalent pressure (BEP) ratio of $Sb_4/(As_2+Sb_4)$.

Tests were performed on the samples to characterize surface morphology, composition, and crystal quality. Surface morphology was evaluated using atomic force microscope (AFM). Composition and crystalline quality of the epilayers were characterized by double-crystal X-ray diffraction (XRD), using a Cu Kα source and (0 0 4) reflection.

2 Results and discussion

InAsSb with a Sb composition of 9% is lattice matched with GaSb substrate. So, we focus on the growth of InAsSb with Sb compositions near 9%. Because As composition is rather high in such films, we first studied the dependence of compositions on As fluxes. However, it was found that the composition is not very sensitive to the As flux once it reaches certain level to maintain the stoichiometry. Such phenomenon suggests that the incorporation ability of As and Sb atoms into the growth front might be different. If the incorporation ability of Sb atoms into the layers is stronger than that of As atoms, the composition of InAsSb film is only depends on Sb flux. Therefore, Sb flux provides us a powerful tool to modulate the composition of InAsSb films.

In order to check such assumption, we control the compositions by varying Sb beam fluxes while keeping indium and arsenic unchanged. 1.5 μm InAsSb layer was grown on GaAs substrate at 450℃ with 20 nm InAs nucleation layer. Different Sb compositions were achieved by varying Sb beam fluxes. The samples were analyzed by X-ray diffraction to determine the compositions of epilayers. Figure1 shows Omega-2Theta curves of the epilayers. Dependence of Sb compositions on Sb_4 fluxes is presented in Fig. 2. It can be seen that there is a linear relation between compositions and Sb_4 fluxes for InAsSb epitaxial layers. The linear relationship we found in Fig. 2 confirms not only the higher incorporation ability of Sb atoms than that of As atoms but also the possibility of using Sb flux as a tool to adjust the composition of InAsSb films.

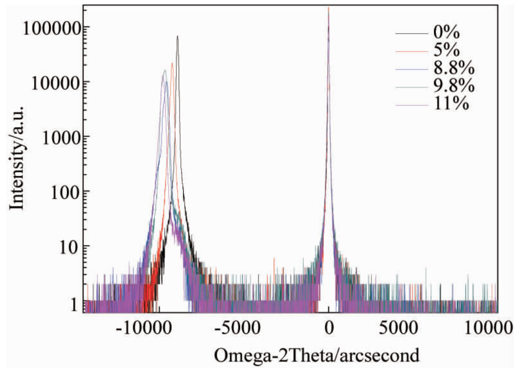

Fig. 1　Omega-2Theta curves of InAsSb on GaAs substrates

图 1　GaAs 衬底上 InAsSb 外延膜的 Ω-2θ 曲线

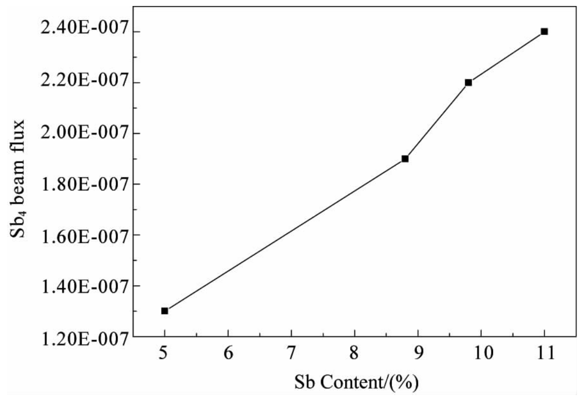

Fig. 2　Dependence of Sb compositions on Sb_4 fluxes

图 2　Sb 组分与 Sb_4 束流间关系

Figure 3 is the XRD patterns of samples grown on GaSb substrates by varying flux ratio. Samples were grown at $Sb_4/(As_2+Sb_4)$ ratios of 0.013 and 0.015. XRD results show that the Sb compositions are 4.5% and 10%, respectively.

When grown at the same temperature, the high Sb flux ratio would lead to a high Sb composition. It is evident that the high proportion of Sb_4 in the ambient of the surface leads to a high level incorporation of Sb into the epitaxial layers. The composition of InAsSb is decided by the interaction between Sb_4 and As_2. Through the optimization of InAsSb epitaxial films on GaSb substrates, the lattice matched InAsSb film was acquired. XRD result and AFM image are presented in Fig. 4. There is only one peak with narrow full width at half maximum (FWHM) in XRD pattern. The surface roughness is 2.1 nm acquired from AFM result. From the results of XRD

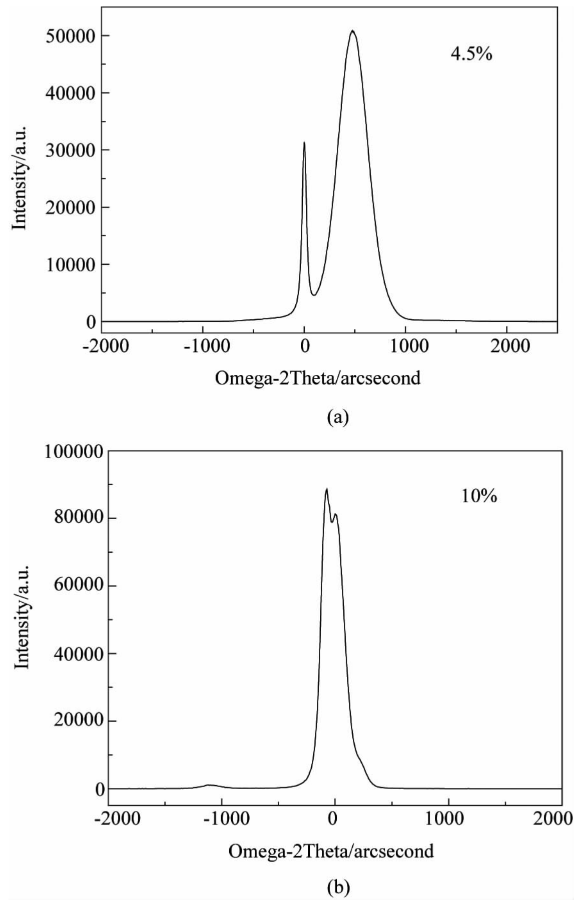

Fig. 3 Omega-2Theta curves of $InAs_{1-x}Sb_x$ on GaSb substrates. (a) 4.5%. (b) 10%

图 3 GaSb 衬底上 $InAs_{1-x}Sb_x$ 外延膜的 Ω-2θ 曲线 (a) 4.5%, (b)10%

and AFM, we can see that the lattice matched InAsSb grown in our experiment has a high crystal quality.

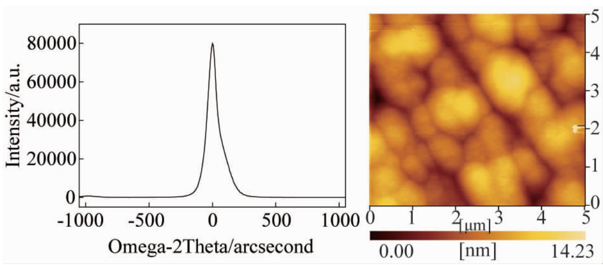

Fig. 4 Omega-2Theta curve and AFM image of $InAs_{0.91}Sb_{0.09}$ epilayers on GaSb substrates

图 4 GaSb 衬底上 $InAs_{0.91}Sb_{0.09}$ 外延膜的 Ω-2θ 曲线和原子力显微镜照片

Because of its excellent properties and the bandgap can be tuned in a wide range, antimonide based semiconductors have great potential applications in many fields, such as electronic devices[6-8], infrared lasers[9-10] and infrared detectors[11-12]. The crystal lattices of antimonide based compounds have little or no mismatch with GaSb substrate. So, investigation of the relation between Sb compositions and Sb_4 beam fluxes is useful for the optimization of the growth of Sb-based material by molecular beam epitaxy. The growth of InAsSb provides reference for the growth of other antimonide based materials and device structures.

3 Conclusions

The dependence of Sb compositions upon Sb_4 fluxes was investigated. Linear relation between Sb compositions and Sb_4 fluxes for InAsSb has been acquired. The composition of InAsSb could be controlled by Sb_4 beam flux. High Sb_4 flux ratio is beneficial to the incorporation of Sb_4. Through the optimization of InAsSb films on GaSb, the lattice matched InAsSb film was acquired.

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