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3단계 완화층을 이용한 GaSb 박막 성장

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Thin film growth of GaSb layers by using Three-Step buffer layers

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요 약 : 우리는 분자선 에피탁시 법으로 3단계 ZnTe 완화층을 사용하여 GaSb층을 성장시켰다. 얇은 ZnTe 완화층(저온-완화층)은 250℃에서 성장을 하였으며, 그 후 330℃에서 열처리를 실시하였으며, 마지막으로 310℃에서 두꺼운 ZnTe 완화층이 성장되었다. 성장한 GaSb층의 표면과 구조적인 부분에 대하여 3단계 완화층의 효과를 조사하였다. GaSb층의 2차원 역격자 공간 맵핑의 결과는 3단계 ZnTe 완화층의 사용으로 GaSb층의 구조적인 변형이 크게 감소되어, GaSb층의 결정성을 크게 향상시킨다는 것을 명확히 알 수 있다.

핵심용어 : Molecular beam epitaxy, ZnTe, GaSb, 완화층, 이종성장

ABSTRACT : *We report the MBE growth of GaSb layer by using three-step ZnTe buffer layer. A thin ZnTe buffer layer was grown at 250 ℃ (LT-buffer), then it was annealed at 330 ℃ (HT-annealing), finally thick buffer layer growth followed at 310 ℃ (HT-buffer). The effect of three-step buffer to the surface and structural quality of GaSb layer has been investigated. Two-dimensional reciprocal space mapping (RSM) results of the GaS blayers clearly indicate that*

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the structural deformation of the GaSb layer is greatly reduced by introducing the three-step ZnTe buffer, which makes remarkable improvement of the crystallinity of GaSb layer.

KEY WORDS : Molecular beam epitaxy, ZnTe, GaSb, bufferlayer, heteroepitaxy

1. Introduction

The GaSb-based compound semiconductors have great potential for various military and civilian applications such as laser diodes, photo-detectors and high frequency electronic devices. Therefore, numerous efforts have been made to grow high quality GaSb and related compounds. However, the crystal quality of GaSb layers has been restricted due to the large lattice mismatch to the conventional substrates. A lot of approaches have been tested to solve the problem. A buffer layer with graded or staircase composition profile makes high quality GaSb heteroepitaxy possible [1]. However, cumbersome and time-consuming processes with highly accurate control of growth conditions are required to improve the crystallinity of heteroepitaxial layer. Therefore, it is inevitably needed to develop a new buffer layer growth technique.

Buffer layer growth is a widely adopted technique to accommodate mismatches. It is understood that buffer layer performs four important roles such as 1) heterointerface formation: it is especially important for the heteroepitaxy, 2) the accommodation of lattice mismatch: actually it is the main role of a buffer layer for most of heteroepitaxy, 3) dislocation reduction: it is obtained through the various ways such as bending, interaction, and looping of dislocations during the buffer layer growth, 4) provides optimum surface for epilayers: a smooth surface enhances 2-dimensional growth, which is indispensable for the high quality epilayers growth. There have been many reports on the successful buffer growth [2-7]. Kanisawa et al. [4] reported the reduction of interface fluctuation by using the low temperature buffer layer for InSb. Song et al inserted a thin buffer layer to reduce stacking faults due to Ga-Se reaction at the hetero-interface [5]. Chang et al. reported that this technique could be successfully applied to reduce the propagation of dislocations also to achieve high quality heteroepitaxial ZnTe layers [6]. In this report, we introduce three-step ZnTe buffer layer for the growth of high quality GaSb layer. Since, ZnTe (Lc = 6.104 Å) has very close lattice constant to GaSb (Lc = 6.094 Å), it is regarded as one of the best buffer layers for GaSb growth. And, by the combination of low-/high-temperature buffers and annealing, we expected the successful accommodation of large lattice mismatch and smooth surface for high quality GaSb growth. Also, the role of buffer layer, especially for the structural quality of GaSb layers, has been discussed by using reciprocal space mapping (RSM) results.

2. Experimental

Two samples were prepared for this experiment; sample-A is GaSb/GaAs, and sample-Bis GaSb/HT-ZnTe/LT-ZnTe/GaAs. GaAs (001) substrates were degreased and etched by using NH_4OH solution. Then it was mounted on Mo-holder using In. Thermal treatment was performed at 640 ℃ for 15 min in the ultra-high-vacuum (UHV). During the thermal treatment (4×2) reconstruction pattern was observed. The reflection high energy electron diffraction (RHEED) pattern was almost streaky at the end of thermal treatment and it becomes completely streaky when the growth starts.

The growth rate was optimized to 300 nm/h for ZnTe and 500 nm/h for GaSb layers. Flux ratio was controlled -2 (VI/II) for ZnTe and -5 (V/III) for GaSb, respectively. The ZnTe-buffer was grown by three steps; first of all thin (30 nm) low temperature buffer (LT-buffer) was grown at 250 ℃, then high temperature annealing was performed at 330 ℃ for 30 minutes, finally relatively thick (300nm) high-temperature buffer (HT-buffer) was grown at 300 ℃. After finishing the buffer growth, GaSb layers were grown at 540 ℃. During the growth, reflection high energy electron diffraction (RHEED) pattern was observed. High resolution X-ray diffraction measurement (HRXRD) was used to evaluate the structural quality of the samples, and the surface morphology was observed by atomic force microscopy (AFM).Reciprocal space mapping (RSM) was used to observe the structural deformation of the GaSb layers.

3. Results and discussion

First of all, ZnTe-buffers were grown on GaAs (001) substrates. After finishing the thermal treatment of the GaAs (001) substrates, the substrate temperature was lowered down to 250 ℃ under Zn-exposure for the growth of LT-buffer. After finished the thin LT-buffer growth, the growth temperature increased up to 330 ℃ for the annealing process, and HT-buffer layer growth followed at 310 ℃ [6]. As explained above, two GaSb samples were prepared to contrast the effect of ZnTe-buffer; Sample-A (GaSb/GaAs) and sample-B (GaSb/ZnTe/GaAs). The growth of GaSb was performed at 540 ℃, and the thickness of GaSb layer was controlled to 500 nm. In the case of sample-A, the initial growth mode is very similar to that of ZnTe/GaAs due to the similar lattice mismatch (7.8 %).

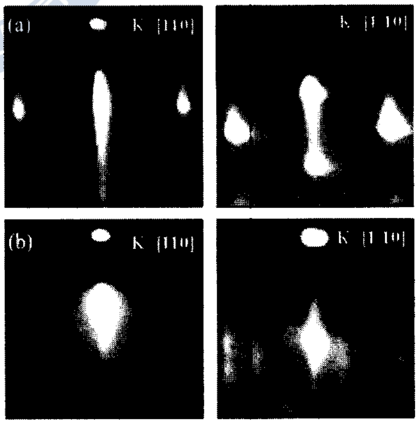

Fig. 1. RHEED images of (a) sample-A (GaSb/GaAs) and (b) sample-B (GaSb/ZnTe-buffer/GaAs)

As shown in Fig. 1 (a), the growth was

initiated from 3-dimensional (3D) growth, then after a few minutes of 3D growth, the growth mode was changed into 2D growth. During the growth a (1×3) reconstruction pattern was observed. But the growth of sample-B shows a remarkable difference from sample-A. The initial 3D growth was not observed and RHEED pattern during the growth was streaky from the very beginning of the growth. Note that the lattice misfit of GaSb/GaAs substrate is 7.8 %, while it is just 0.14 % for GaSb/ZnTe-buffers. Generally, the 0.14 % misfit can be accepted as a nearly lattice matched condition [8]. Therefore initial 3D growth was not able to observe during the growth of GaSb/ZnTe-buffer.

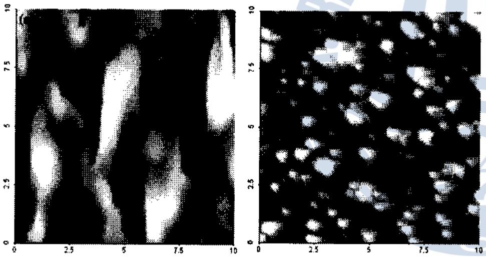

Fig. 2. AFM images of (a) sample-A, and (b) sample-B

Fig. 2 shows atomic force microscopy (AFM) images. As one can expect from the RHEED observation, sample-B shows much smoother surface morphology than sample-A. The sample-A shows rough surface with root-mean-square (RMS) roughness of 107 nm from 10 × 10 μm^2 area. But the sample-B shows very smooth surface with a RMS roughness of 3.3 nm from the same observation area. The difference could be understood in terms of the difference of an initial growth mode. The sample-B should have smooth surface, because it was grown without 3D mode even at the initial stage. Once the 3D growth initiates, the migration length of adaptom will be decreased and the surface will be roughen. Therefore, the remarkable difference of surface morphology can be deduced to the growth mode which difference provided by ZnTe-buffer. Surface smoothness is known as a function of growth temperature, grain size, growth rate, and so on. Since large grain size means smooth surface, it indirectly reveals the crystal quality of the film. Therefore, it is assumed that the ZnTe-buffer improves the structural quality of sample-B.

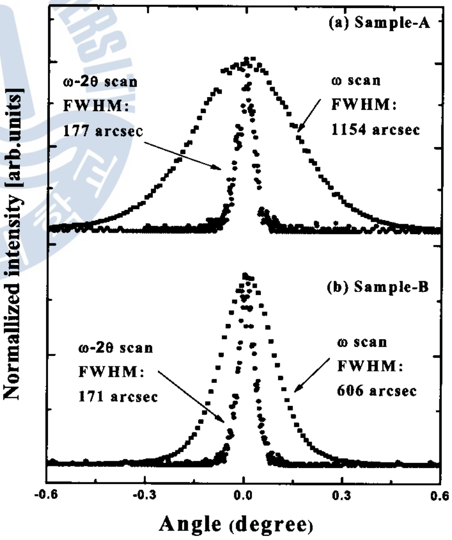

Fig. 3. High resolution X-ray diffraction measurement results of (a) ω/ω-2θ scan of sample-A, and (b) ω/ω-2θ scan of sample-B

Fig. 3 shows ω- and ω-2θ scans of GaSb layers (sample-A, and sample-B). The linewidth decreases from 177 to 171 arcsec in ω-2Θ scan. But drastic decrease of linewidth is observed in ω-scans. It decreases 1154 arcsec to 606 arcsec in ω-scans. If oneconsiders the large lattice misfit in GaSb/GaAs, the narrow XRD line width of sample B clearly demonstrates the improvement of crystal quality by ZnTe buffer. It is worth to explain about the various parameters which determine the XRD linewidth. The linewidth of X-ray rocking curve includes various effects such as rotation of mosaics, crystal size effect, local strain and defect density in the film. The measured linewidth of the XRD rocking curve can be explained in numerically as [9]

$$\beta^2_{mean} = \beta^2_0(hkl) + \beta^2_d(hkl) + \beta^2_\alpha(hkl) + \beta^2_\varepsilon(hkl) + \beta^2_L(hkl) + \beta^2_\gamma(hkl)$$

where the β_0 is the intrinsic line width [9], the β_d is the intrinsic rocking curve width for the first crystal, the β_α is the linewidth due to angular rotation at the dislocations, the β_ε is the linewidth by the strain surrounding dislocations, the β_L is the term of crystal size effect, and the β_r is the bending effect. Among them, only the layer thickness (β_L) and dislocation density in the layer (β_α , β_ε) may affect the linewidth of XRD scans. In this experiment, since the layer thickness was the same, the improvement of XRD linewidth is deduced to the reduction of dislocation (grain boundary) density. Also the surface-normal lattice constants are evaluated as 6.118 Å (sample-A) and 6.098 Å (sample-B), respectively from (004) ω-2Θ X-ray rocking curve. Sample-B has the lattice parameter which is very close to that of bulk GaSb, while considerable residual strain was observed from the sample-A. The residual strain is estimated as -0.377 % and -0.049 % for sample-A and sample-B, respectively. Note that the lattice mismatch relaxation accompanies the dislocation generation. Therefore, lattice misfit relaxation broadens the XRD linewidth of epi-layer. However, sample-B has narrower XRD linewidth than sample-A, this fact strongly indicates that the ZnTe-buffer is effective for the accommodation of lattice mismatch.

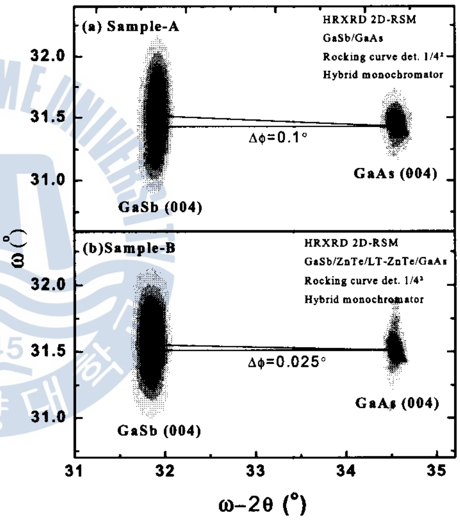

Fig. 4. High resolution X-ray diffraction reciprocal space mapping results of (a) sample-A, and (b) sample-B

Fig. 4 shows reciprocal space mapping (RSM) results of GaSb layers. The RSM result of sample-A shows significant misalignment between the reflection planes of film and substrate as large as 0.1°, while it is diminished to 0.025° from sample-B. Such a misalignment is known that due to the monoclinic distortion or tilting, which is originated from the partial relaxation of lattice strain. The results imply that the ZnTe-buffer is a successful template for the growth of GaSb. The effects of ZnTe-buffer described in this experiment can be summarized as follows; (a) the efficient accommodation of the large lattice misfit, (b) providing smooth surface for the following layers, (c) the reduction of residual strain (of course, it is very closely related with the relaxation of lattice misfit), and (d) the diminishment of the structural deformation due to incomplete relaxation of strain. These effects can be understood through the consideration of the role of three-step buffer. It was reported that the accommodation of lattice misfit is mainly accomplished by the LT-buffer [6]. During the growth of LT-buffer, high density misfit dislocations are generated by the relaxation of lattice mismatch. Those dislocations are terminated by making loop or bending during the annealing, thus the annealing process is indispensable for the growth of high quality HT-buffer with low dislocation density. Therefore, we can conclude that the role of three-step ZnTe-buffer is really essential for the remarkable improvement of GaSb layer quality in terms of providing high quality pseudo-substrate.

4. Conclusion

Remarkably improvement of crystal quality of GaSb heteroepitaxial layer is achieved by inserting three-step ZnTe-buffer. The effect of ZnTe-buffer to the structural properties of GaSb layers has been investigated. By using the three-step ZnTe buffer, smooth surface morphology, narrow rocking curve linewidth, and the reduction of residual strain in GaSb layer have been achieved. It is concluded that ZnTe-buffer layer is really effective for the accommodation of the misfits to grow high crystallinity GaSb layer.

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