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광소자로 사용되는 ZnTe 박막의 결정성에 따른 결함 관찰

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Crystallinity and Internal Defect Observation of the ZnTe Thin Film Used by Opto-Electronic Sensor Material

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Abstract

ZnTe films have been grown on (100) GaAs substrate with two representative problems. The one is lattice mismatch, the other is thermal expansion coefficients mismatch of ZnTe /GaAs. It claims here, the relationship of film thickness and defects distribution with (100) ZnTe/GaAs using hot wall epitaxy (HWE) growth was investigated by transmission electron microscopy (TEM). It analyzed on the two-sort side using TEM with cross-sectional transmission electron microscopy (XTEM) and high-resolution electron microscopy (HREM). Investigation into the nature and behavior of dislocations with dependence-thickness in (100) ZnTe/(100)GaAs hetero-structures grown by transmission electron microscopy (TEM). This defects range from interface to 0.7㎛ was high density, due to the large lattice mismatch and thermal expansion coefficients. The defects of low density was range 0.7㎛~1.8㎛. In the thicker range than 1.8㎛ was measured hardly defects.

Keywords: ZnTe, GaAs, XTEM, HREM, dislocation

1. Introduction

The growth of ZnTe layers by hot wall epitaxy (HWE) is an important crystal growth technique for applications to optoelectronic device operating in the visible spectral region. Growing for a single and multi-layer films of ZnTe for optoelectronic device such as light emitters in the pure green spectral region. This material is a promising because of its application in electro-optics, acusto-optics, green laser generation, and also as substrate material for II-VI laser diodes and as a photorefractive material for optical data processing[1]. It is known that during heteroepitaxial growth a high density of dislocations can appear in the interface region. These structural defects strongly influence the optical properties of epilayers.

To realize such devices, high quality epitaxial layer must be produced. For this purpose, such as molecular beam epitaxy (MBE)[2)], metalorganic chemical vapor deposition (MOCVD)[3)], and hot wall epitaxy (HWE)[4)] have been employed. The lack of adequate bulk ZnTe substrates for homoepitaxy has made GaAs the substrate of choice in many cases because of its availability and high quality.

However, the two problems exists in heterostructure involving ZnTe epilayer on GaAs substrate. The one is lattice mismatch, the other is thermal expansion coefficients mismatch of ZnTe /GaAs. The room temperature with lattice parameters a0 of ZnTe (6.1037Å) and GaAs (5.6533Å) have a mismatch between GaAs and ZnTe of about 0.8 as defined by f = (aZnTe- aGaAs)/ aGaAs ≒ 8%. At the same time, thermal expansion coefficients mismatch of ZnTe and GaAs possibly occurs because there is a large difference in the thermal expansion coefficient between ZnTe ($8.3\times10^{-6}K^{-1}$) and GaAs ($5.8\times10^{-6}K^{-1}$).

The two problem are expect to give rise to be relaxed misfit dislocations at the film-substrate interface. In spite of this large difference, epitaxial layer has been successful. Therefore, understanding the mechanism of relaxation and nature of dislocations in ZnTe layers is important because optoelectonic and transport properties of the layers are affected by them, the performance of devices. Recently, ZnTe has received great interest because selective acceptor doping is expected to produce n-type materials that could yield p-n junctions in the heterostructure of CdTe-ZnTe, ZnSe-ZnTe[5, 6)].

In this paper, we have investigated and discussed to the dependence on the film thickness with distribution of defect by using TEM. Furthermore, we have employed cross-sectional transmission electron microscopy (XTEM) and high-resolution electron microscopy (HREM) to characterize the microstructure of the thin film of ZnTe grown by HWE directly onto (100) GaAs substrate. Film quality and interface structure observed by XTEM have been correlated with experimental growth parameters. Furthermore, it has been shown that film quality determined by four crystal X-ray diffraction data[7)] correlation very well the quality determined by XTEM characterization. And we have investigated ZnTe films of different thickness, to determine the behavior of dislocations related to the lattice mismatch, thermal expansion coefficients mismatch and growth processes.

II. Experimental

The ZnTe epilayers were grown in a hot wall epitaxy (HWE) system and the experimental conditions for the growth of ZnTe layers has been in detailed elsewhere[7)].

High resolution X-ray diffraction was measured with a Phillips. X'Pert-MRD 188/HR having a 3kV Cu radiation source. The X-ray beam from a Cu tube is monochromated by the four reflections of a Bartels monochromator at the (220) face of perfect channel-cut germanium (Ge) single crystals. The results beam has a divergence of 12 arcseconds.

For TEM study, three specimens with different thickness (4.3, 12 ,24 μm) were used. Thin specimen for TEM observation were prepared by mechanical polishing and ion milling. Low magnification was obtained by using JEM-2000EX of accelerating voltage of 200kV, and then a HREM study was carried out by using JEM-ARM1250 with an accelerating voltage of 1250 kV and a point-to-point resolution of 0.1 nm.

III. Result and Discussion

High quality ZnTe epitaxial layers were grown on (001) GaAs substrates with HWE. The thickness dependence of the crystalline quality and distribution of defect for ZnTe/GaAs grown at the optimum condition is discussed. And it is going to observe minutely existence of defect, a form, etc. by the thin film thickness from a substrate to the surface.

A HREM image of interface between ZnTe epilayer and GaAs substrate obtained with the incident electron beams parallel to the [110] direction is shown in Fig. 1. This HREM image is representative of all the interfaces of epitaxial layers observed. The interface appears well defined without the presence of oxide or foreign layer over the areas examined. Arrows in Fig. 1 indicate the misfit dislocations due to the lattice mismatch. An array of misfit dislocations is responsible for the relaxation of the elastic strain. In the Zinc-blend lattice, the Burgers vectors of misfit dislocations are parallel to the interface (screw and sessile edge dislocation) or are inclined 45° with respect to the interface (60° dislocation) μm[8-10]. A small fraction of misfit dislocation in the thinnest film were of the 60° dislocation, which are only half as effective in relaxing the strain as the edge type dislocation[8-10]. The 60° dislocations can interact with each other to produce the edge type after they glide in from the surface of the film along <111> planes[8, 9]. By previous reports[8], an average separation spacing of these misfit dislocation for all ZnTe epilayer grown by MBE is estimated to by about 5.4 nm, whereas equilibrium spacing is 5.9 nm for edge type dislocation. In our samples, these misfit dislocations, which are not periodic, for all ZnTe epilayer have an average separation of about 6.3 nm and run parallel to [110] direction in the interface plane. The measured spacing in our samples is not close to the equilibrium spacing. Consequently, these misfit dislocations in the interface plane are existent as three types of dislocation, which is screw, sessile edge and 60° dislocation.

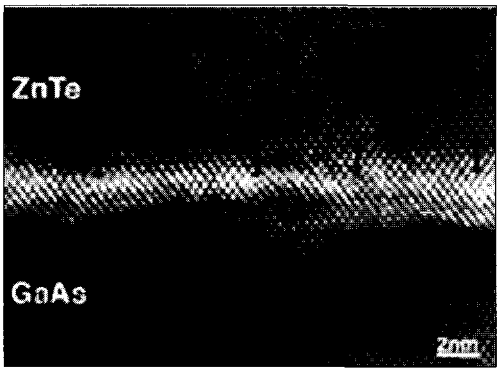
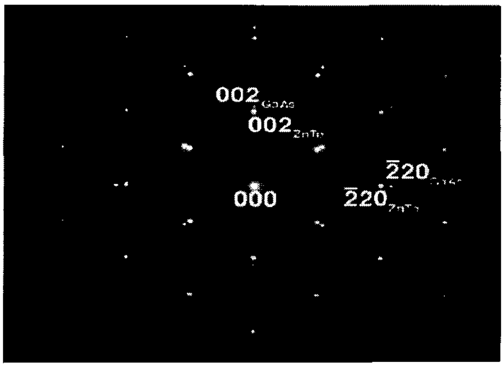


Fig. 1 HREM image of the ZnTe-GaAs interface projected along [110] direction

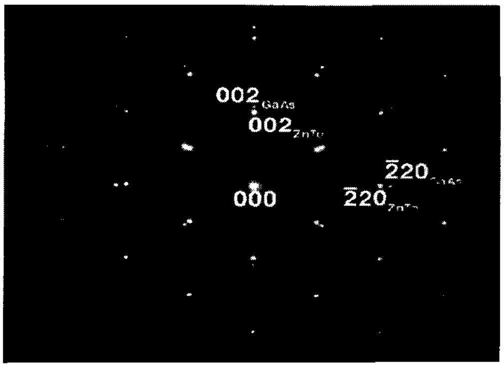
Fig. 2 show electron diffraction pattern (a) and a bright-field image (b) of the 1.7 μm film on ZnTe-GaAs epilayer. Fig. 2 (a) shows a selected area diffraction (SAD) pattern of the ZnTe film/GaAs interface taken with the incident beam parallel to [110]ZnTe/GaAs directions. This SAD pattern indicates that the ZnTe film grown on GaAs substrate was single crystal and epilayer.

Fig. 2 (b) can be divided into two distinct zones with regard to the dislocation density. A first region, about 700 nm extending from the interface towards the surface, indicated by an arrow has high dislocation density, whereas a second region has low dislocation density. These new dislocations probably nucleate at the surface during growth and glide toward the interface along <111> planes driven by the residual elastic strain. The density of these new dislocations[8] increases with increasing the thickness of the epilayer and do not affect the density of misfit dislocations at the interface. The present observation is similar to the previous investigations of II-VI on III-V heterostructures with large mismatch and thermal expansion coefficient. In Fig. 2, the new dislocations in 1.7μm epilayer is exist from interface to surface and relax the remaining stress either themselves or by interacting with existing misfit dislocation. Because of the distribution of these new dislocations above interface, the FWHM of FCRC on 1.7 μm epilayer is wide than thicker epilayer.

Fig. 3 shows a bright-field image of the 12μm film that displays the dislocation structure above interface. Fig. 3 can be divided into three distinct zones with regard to the dislocation structure.



(a) electrin diffraction pattern



(b) a bright-field image

Fig. 2 Cross-Sectional transmission electron microsope image of a ZnTe layer on GaAs substrate

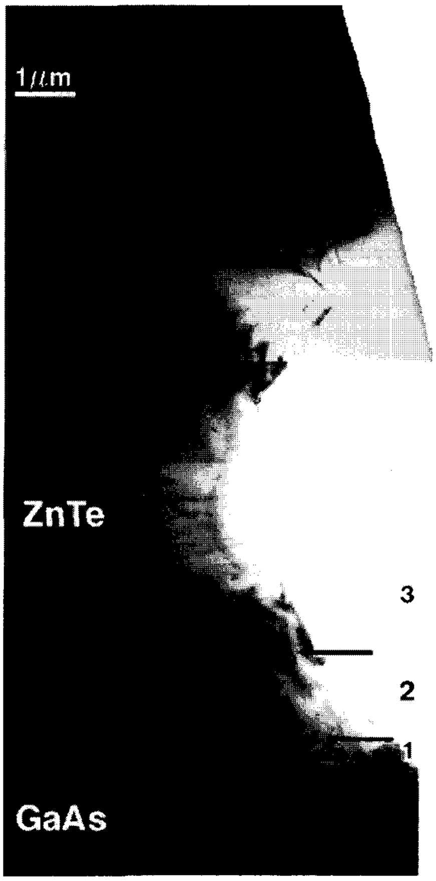


Fig. 3 Brighr-field image of the 12μm thick znTe film in ceoss section displaying therr

The first region being from the interface and extending about 720 nm towards the surface, a high density of these new dislocations is found. Contrary to the case of the 1.7 ㎛ film, the first region wide of high dislocation density has decrease as shown Fig. 3. This very interesting feature for change of the first region wide contributes to the crystallinity of ZnTe epilayer. This special phenomenon is expected that the epilayer strain for lattice mismatch and thermal expansion coefficient may be relaxed toward the substrate at optimum growth condition. This relaxation mechanism is yet investigated by reciprocal lattice mapping method using X-ray spectroscopy, Nano-beam diffraction method and high-resolution electron microscopy with TEM. The best crystallinity of a 12 ㎛ ZnTe epilayer is probably attributed to this special phenomenon. Consequently, the crystallinity for a 12㎛ epilayer gets better than thinner epilayer such as 1.7㎛ in thickness. In addition, the second region is very low density of dislocations from 720 nm to 1860 nm. This low density of dislocations is not surprising since the bulk of the lattice mismatch and thermal expansion coefficient has been accommodated by the dislocations near the interface. Fig. 3 shows very important features concerning the behavior of dislocations in the ZnTe epilayer. The important feature occurs in the third region from 1.86㎛ to the surface where no density of dislocation is present. It is evidence that elastic strain for lattice mismatch and thermal expansion coefficient between ZnTe epilayer and GaAs substrate has been relaxed perfectly by these new dislocation in the region from interface to 1.86㎛. The region of no dislocation density from 1.86㎛ to the surface is perfectly the same with the bulk of ZnTe.

Ⅳ. Conclusion

In details, the relationship between film thickness and defects distribution at the internal ZnTe film on GaAs have studied. The nature and the behavior of dislocations heterostructures growth were investigated on (100) ZnTe/GaAs by HWE using transmission electron microscopy (TEM). No evidence of oxide or foreign interface layer was found in these samples. The relaxation steps include the creation of dislocations away from the interface in the fashion that appear to be dependent on the epitaxial layer thickness. A correlation between the dynamic of dislocation generation and growth stage is presented. These results provide an experimental for theoretical models about the growth and misfit relaxation in high strained semiconductor hetero-structures. In our samples, the misfit dislocations, which are not periodic, for all ZnTe epilayer have an average separation of about 6.3 nm and run parallel to [110] direction in the interface plane. Consequently, these misfit dislocations in the interface plane are existent as three types of dislocation, which is screw, sessile edge and 60° dislocation. The perfect growth of ZnTe epilayer (12㎛ sample) with similar to bulk was convinced that the elastic strain for lattice mismatch and thermal expansion coefficient between ZnTe epilayer and GaAs substrate has been relaxed perfectly by these new dislocation in the region from interface to 1.86㎛.

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