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Applied Surface Science 75 (1994) 298–302

applied surface science

Heterointerfaces of CdTe/α-Sn/InSb structure grown by molecular beam epitaxy

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(Received 15 May 1993; accepted for publication 7 August 1993)

Abstract

A CdTe/α-Sn heterostructure has been grown on an InSb(100) substrate by molecular beam epitaxy at temperatures of 150 and 220°C. The α-Sn layers were grown up to thicknesses of 64 and 38 Å, respectively, assisted by the stabilizing effect, which prevents the α-Sn to β-Sn transition which normally occurs at 13.2°C. Here we report a transmission electron microscopy study which indicates the blocking of planar defects at the interface of α-Sn and InSb, suppressing their propagation to the CdTe overlayer. However, by Raman spectroscopy, the peaks of In,Te-related compounds can be seen for every thickness of grey tin layers. This indicates that the interdiffusion of In and Te could not be prevented by the grey tin layer. However, we cannot deny the possibility of suppression of interdiffusion, because it depends upon the quality of the grey tin layer.

1. Introduction

The lattice parameters of InSb, CdTe and α-Sn are well matched to each other and this system may be appropriate for application to opto-electronic devices. However, there are several problems in the growth of these material structures.

First of all, each material in this system has a different optimum growth temperature at the usual growth condition; 300 to 400°C for InSb and 150 to 220°C for CdTe. For the α-Sn, those near room temperature were usually used [1–3]

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SSDI 0169-4332(93)E0201-V

because the phase transition from α to a metallic β-phase occurs at 13.2°C. However, α-Sn can be stabilized even at higher temperatures by epitaxial adhesion to the lattice-matched substrates [1,4].

Another problem is the interdiffusion of In and Te, and the precipitation of In,Te-related compounds at the interface of CdTe/InSb. To alleviate these effects, many trials have been made [5–9]. Here, we tried the insertion of an α-Sn layer at the interface, hoping to suppress the expansion of planar defects, which can enhance diffusion, and also suppress diffusion of In and Te at the α-Sn layer.

We have already reported the transmission electron microscopy (TEM) results showing that the propagation of stacking faults stops at the interface of α-Sn and CdTe in an α-Sn/CdTe/InSb structure [9]. However, there was some doubt that the grey tin became amorphous during the ion milling for TEM sample preparation, and planar defects were not clearly observed.

To clarify this issue, we now show that stacking faults which propagate to the α-Sn layer from one side do not extend to another side, by TEM observation of CdTe/α-Sn/InSb structure.

Additionally, Raman spectroscopy has been used to examine the precipitation of In,Te-related compounds at the interface caused by an interdiffusion of In and Te across the α-Sn layer.

2. MBE growth

A modulated SIMAZU PBE-200 molecular beam epitaxy apparatus has been used for the growth. The time constant of the exponential decay of the arrival rate, which was observed right after the beam shutter closing, is less than 2 s for CdTe, In, Sb and α-Sn. Therefore, cross doping was avoided, although the pressure in the growth chamber was 3×10^{-9} Torr during growth.

The growth temperature of the CdTe/α-Sn/InSb(buffer) structure on InSb(100) substrate was 220°C for one group, and for the second group, CdTe/α-Sn was grown at 150°C on the buffer layer of InSb which was grown at 220°C. The growth rate was 0.1 μm/h for all samples.

The RHEED pattern changed directly from streaky to streaky at the interfaces during growth. After that, however, it gradually changed to spotty at the CdTe top layer. Therefore, the quality of the top layer is expected to be degraded.

When the thickness of α-Sn exceeds critical thickness, the RHEED pattern disappeared suddenly. The critical thicknesses of α-Sn estimated by this effect were 38 and 64 Å for the samples grown at 220 and 150°C, respectively.

3. Transmission electron microscopy

In the structure of CdTe/InSb(buffer)/InSb(100) (substrate), if the substrate surface preparation is inadequate, stacking faults are generated and propagate to the CdTe layer across the interface. This effect can be seen in Fig. 1, where a high-resolution cross-sectional transmission electron lattice fringe image (XTEM) in the [110] is shown.

The stacking fault propagation seemed to be suppressed in the structure of α-Sn/CdTe/InSb [9,10], but we could not see the lattice image at that time. Therefore, we tried to examine the structure of CdTe/α-Sn/InSb. The propagation of the fault along the {111} surface stopped and reflected at the α-Sn/InSb interface, and no evidence was found that the extension of such defects could be observed in the CdTe top layer, even though new stacking faults start from the irregular parts of the α-Sn boundary, as shown in Fig. 2. This fact gives proof that the stacking fault did not propagate across the α-Sn layer.

4. Raman spectroscopy

Our attention was focused on the existence of In,Te-related compounds caused by interdiffusion at the interface of CdTe/InSb when α-Sn is inserted there. This was detected by Raman spectroscopy.

The results for the samples which have different thicknesses of α-Sn layers in the structure of

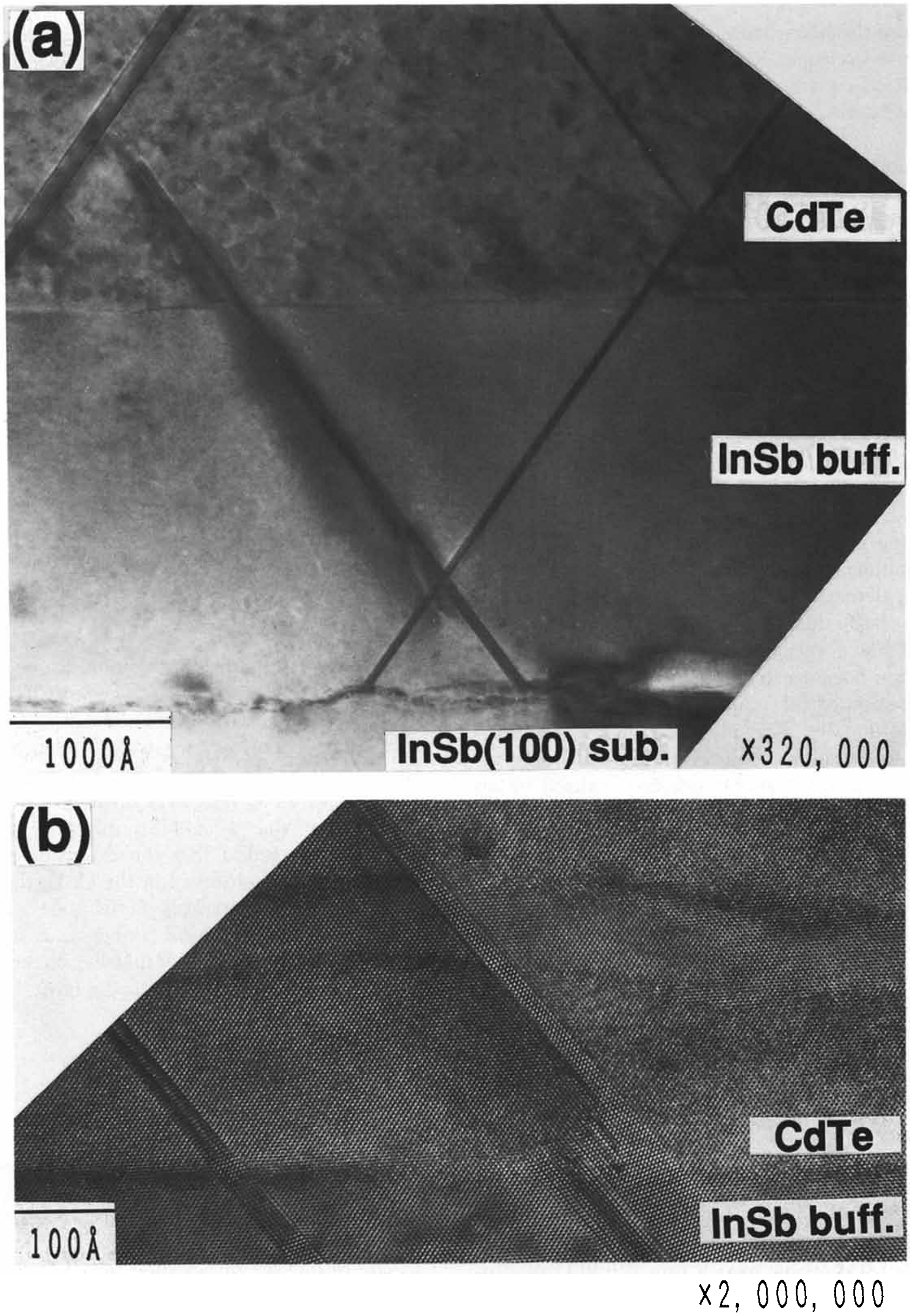

Fig. 1. (a) Bright-field XTEM and (b) high-resolution, cross-sectional transmission electron lattice image of Ar ion-milled structure in [110] projection of CdTe/InSb structure without α-Sn insertion.

CdTe/α-Sn/InSb, grown at 220°C, were shown in Fig. 3, and for the samples grown at 150°C, in Fig. 4. The thicknesses of α-Sn layers of the samples used in Figs. 3 and 4 were estimated by calculation of arrival rates. The sample used for the TEM study (α-Sn thickness = 50 Å) was also used for the Raman study, the results of which are shown in Fig. 4. The estimation of the thickness from the transmission electron micrograph was difficult, because the boundaries are rather rough.

Contrary to our expectation, all curves have peaks corresponding to In_2Te_3 or InTe [11] independent on the thickness of α-Sn, though the peaks could not be specified as indicated by "and /or" in Figs. 3 and 4. We could not give the proof that the α-Sn layer suppresses the diffusions of In and Te for the moment.

5. Discussions and conclusion

As can be seen in Fig. 2, the α-Sn layer is irregular, and some parts appear broken by the precipitation, or by the transition to the β-phase. However, although we could not suppress the interdiffusion of In and Te in this investigation, we cannot deny that it may yet be possible by the growth of a perfect α-Sb midlayer.

In conclusion, we have grown a CdTe/α-Sn/CdTe structure and examined it by XTEM and Raman spectroscopy. Though the α-Sn layer was

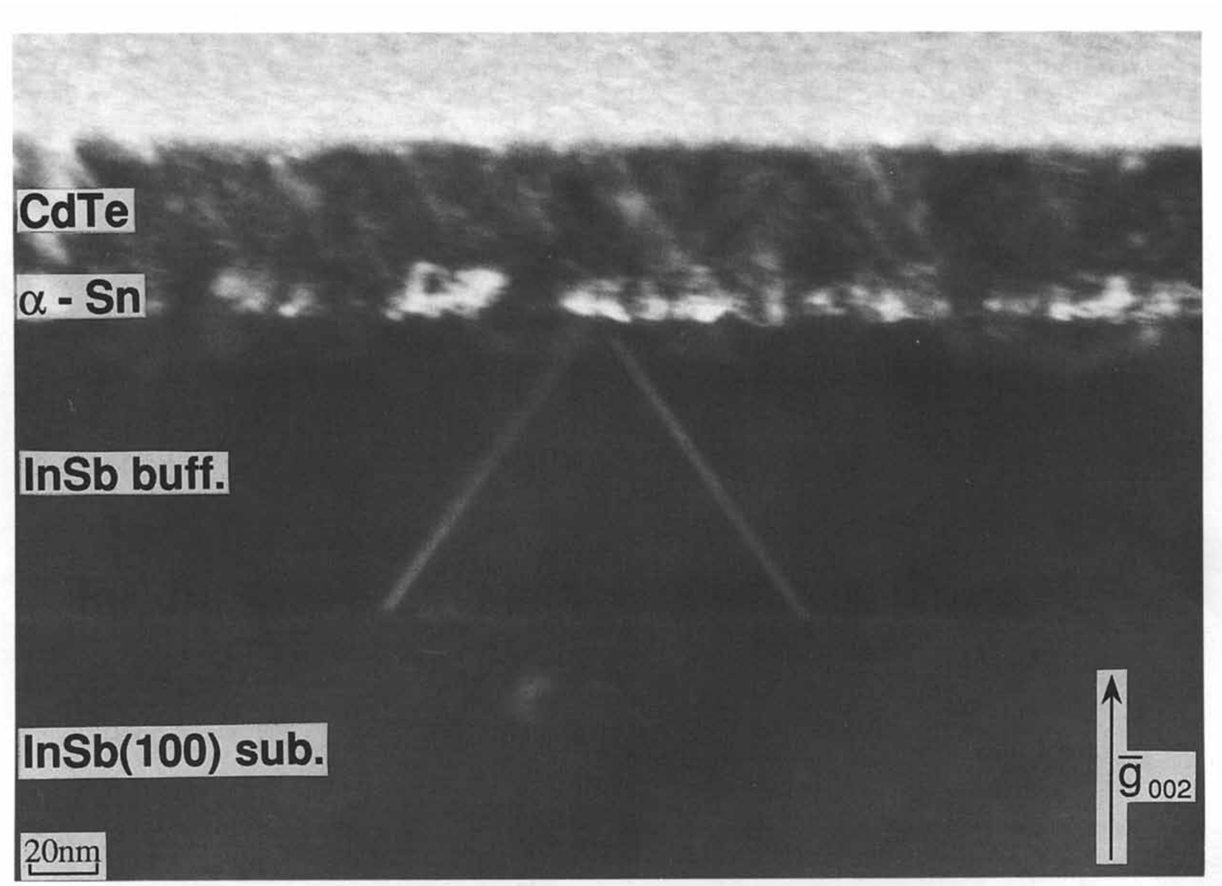

Fig. 2. Dark-field XTEM micrograph of CdTe/α-Sn/InSb(buffer)/InSb(100) substrate.

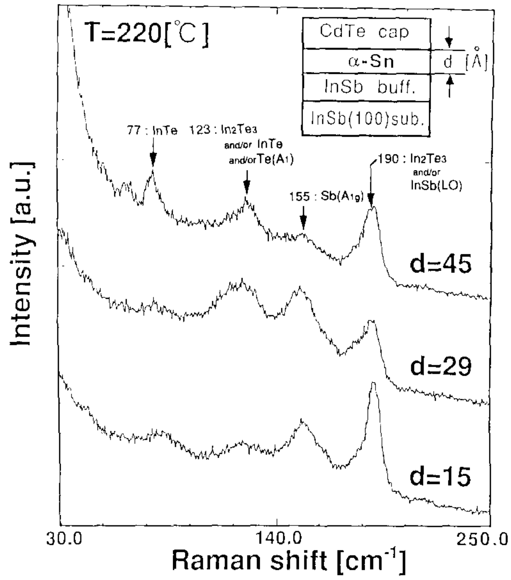

Fig. 3. Raman spectra ($\lambda = 514.5$ nm line of an incident Ar-ion laser) of CdTe/α-Sn/InSb(buffer)/InSb(100) structure grown at 220°C. Thicknesses of α-Sn layers are $d = 15$, 29 and 45 Å. The thickness $d = 45$ Å exceeds the critical value (38 Å) at this growth temperature. Therefore, this tin layer partially changed to the metallic β-phase.

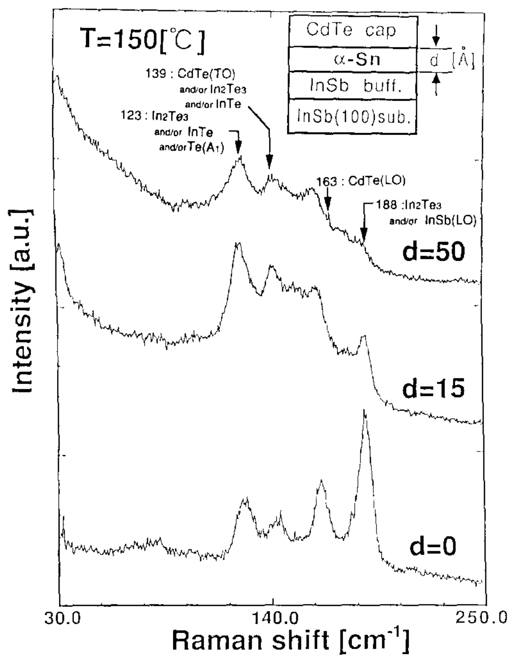

Fig. 4. Raman spectra of CdTe/α-Sn/InSb(buffer)/InSb(100) structure grown at 150°C. Thicknesses of α-Sn layers are $d = 0$, 15 and 50 Å.

not perfect, the propagation of planar defect could be stopped at the boundary of the α-Sn layer. However, interdiffusion of In and Te could not be suppressed, at present, but the possibility of suppression still remains.

Acknowledgement

The authors would like to thank M. Takashima of Mitsubishi Kasei for his help to prepare the TEM micrograph shown in Fig. 1.

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