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Interfacial layer formation of the CdTe/InSb heterointerfaces grown by temperature gradient vapor transport deposition

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CdTe epitaxial films were grown by a simple method of temperature gradient vapor transport deposition on p-InSb (111) orientation substrates in the growth temperature range between 200 and 300 °C. The stoichiometry of the CdTe/InSb heterostructure was observed by Auger electron spectroscopy, and Auger depth profiles demonstrated that the CdTe/InSb heterointerface was not abrupt. Transmission electron microscopy verified the formation of an interfacial layer in the CdTe/InSb interface and the formation of the stacking faults in the CdTe thin film. These results indicated that the films grown at approximately 270 °C contained a formation problem of an interfacial layer due to interdiffusion from the InSb prior to the growth of the CdTe, and that the interfacial layer might deteriorate the electrical property of the CdTe epitaxial layer. © *1994 American Institute of Physics.*

With the rapid advances in molecular beam epitaxy (MBE) and metalorganic chemical vapor deposition (MOCVD) over the past 20 years, it has been possible to fabricate several kinds of semiconductor heterostructures, multiple quantum wells, and superlattices on III–V compound semiconductor substrates.[1] New fundamental physical phenomena have been investigated,[2–5] and novel quantum devices have been constructed utilizing them.[6,7] However, among the new types of structures, relatively little work has been performed on II–IV/III–V mixed heterostructures due to inherent problems from the interdiffusion or intermixing during growth.[8–10] A CdTe/InSb heterostructure is of particular interest due to the almost perfect lattice match ($\Delta a/a \cong 0.04\%$ at 25 °C) and the many promising electronic applications.[8–15] The considerable interest in the growth of high-quality CdTe films is also important because of its use as a buffer layer for the epitaxial layers of $Hg_{1-x}Cd_xTe$ for infrared detectors.[15] Although some works concerning CdTe/InSb heterostructures have been reported,[10–15] most structures were grown by MBE and MOCVD.[10–14] Recently, the growth of CdTe/InSb heterostructures via a simple technique with simple equipment was reported by Kim *et al.*[10,13,14] Further, until now, attempts to clearly demonstrate the existence of a high mobility two-dimensional electron gas (2DEG) at the CdTe/InSb heterointerface have not succeeded due to interface problems.[11] The failure to obtain a high mobility 2DEG was thought to be a significant problem at those heterointerfaces.[11] CdTe/InSb interface reactions led to the formation of interfacial layers, and these interfacial layers were found to be rich in indium and tellurium.[16–18] Substantial components investigated by soft x-ray photoelectron, Raman spectroscopy, and Auger electron spectroscopy (AES) indicated that these interfacial layers might be In_2Te_3.[10,17,18] However, to the best of our knowledge, the direct observation of an interfacial layer formation prior to the creation of the CdTe films has not been reported yet.

This letter presents data for CdTe thin films on p-type (111) A surface InSb substrates grown in the temperature range between 200 and 300 °C by the simple technique of temperature gradient vapor transport deposition (TGVTD) in order to investigate the quality of the CdTe epitaxial layer and the existence of an interfacial layer at the CdTe/InSb heterointerface. AES was performed to characterize the stoichiometry of the grown films, and transmission electron microscopy (TEM) was carried out in order to study the atomic structure of the CdTe/InSb interface.

Polycrystalline stoichiometric CdTe with purity of 99.9999% grown by the Bridgman method was used as the source material and was precleaned by repeated sublimation. The carrier concentration of the Cd-doped p-InSb substrates with a (111) A surface orientation used in this experiment was $2.1–2.6\times10^{15}$ cm^{-3}. The InSb substrates were degreased in warm trichloroethylene (TCE), rinsed in deionized water thoroughly, etched in a solution of lactic acid, HNO_3, and HF (25:4:1) at 40 °C for 5 min, and rinsed in TCE again. As soon as the chemical cleaning process was finished, the wafer was mounted onto a molybdenum susceptor. Prior to CdTe growth, the InSb substrates were thermally cleaned at 280 °C for 5 min *in situ* in the growth chamber at a pressure of 10^{-8} Torr. The deposition was done in the range of substrate temperatures from 200 to 300 °C at a system pressure of 10^{-6} Torr. The substrate temperatures were changed systematically by moving the susceptor in a given temperature gradient profile, and the typical growth rate was approximately 1.2 μm/h. A detailed schematic diagram of the TGVTD system was reported previously[13] and this sys-

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tem is a modified version of the one based on the vapor transport technique.

The TEM observations were performed in a JEOL 200CX transmission electron microscope operating at 400 kV. The samples for TEM measurements were prepared by cutting and polishing to approximately 30 μm thickness using diamond paper, and then argon-ion milled at liquid-nitrogen temperature to electron transparency. The Raman scattering measurements were made in the backscattering geometry with 5145 Å line of the Ar^+ ion laser. The photoluminescence (PL) spectra were measured using a 75 cm monochromator equipped with an RCA 31034 PM tube. The excitation source was the 4880 Å line of an Ar ion laser or the 6328 Å line of a He–Ne laser. The samples were mounted on a cold finger in a cryostat and kept either at room temperature or 15 K throughout the experiment.

The results of the x-ray diffraction pattern for a CdTe epilayer on an InSb substrate grown at 270 °C show that the (400) $K\alpha_1$ and $K\alpha_2$ diffraction peaks of CdTe (111) together with those of InSb (111) are clearly observed. Although the growth of the CdTe films was performed in the temperature range between 200 and 300 °C, only the physical properties of the film grown at 270 °C are reported because it had the clear formation of the interfacial layer as the films grown above 270 °C. The lattice constant of CdTe film determined from an x-ray diffraction peak was 3.7618 Å, and this value matches closely to the theoretical lattice constant of CdTe (111). As-grown films by TGVTD indicated the formation of interfacial layer when they are examined by scanning electron microscopy (SEM). Since the detailed structural properties of the layers were impossible to interpret by SEM, AES, Raman scattering, PL, and TEM measurements were carried out in order to investigate the quality of a CdTe layer and the existence of the interfacial layer at a CdTe/InSb heterointerface.

The composition of the CdTe thin layer was investigated by AES. The results showed that the film consisted of cadmium, tellurium, and carbon at the surface of the CdTe. The existence of the carbon impurities could be due to contamination from the source materials or the growth chamber at the final growth stage. The results of the AES measurements showed that the film consisted of cadmium and tellurium at the 1.0 μm depth, and of cadmium, indium, and tellurium between 1.1 and 1.3 μm depth. Figure 1 shows that the interfaces between the interfacial layer were not abrupt at the 1.2 μm depth and that substantial components of indium and tellurium were formed at the CdTe/InSb heterointerface.[10] Thus, the thickness of the CdTe was approximately 1 μm, which is in good agreement with that obtained from capacitance-voltage (C-V) and ellipsometric measurements. Since the sputtering time is 100 Å/min, the thickness of the interfacial layer was approximately 0.2 μm.

In addition to AES measurements, Raman spectroscopy and PL measurements were carried out to detect and chemically identify the crystallization of the CdTe layer and the formation of In_2Te_3 at the CdTe/InSb heterointerface. A Raman spectrum shows that the CdTe transverse optical (TO) phonon and the longitudinal optical (LO) phonon are observed at 140.2 and 166.0 cm^{-1}. The peaks occurring at 91.4

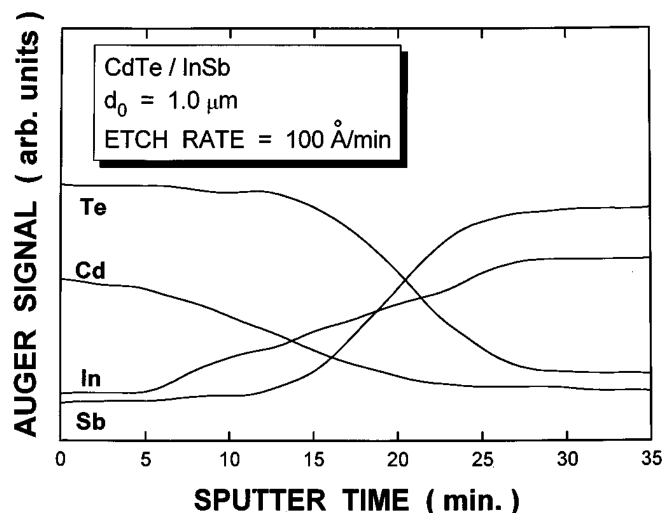

FIG. 1. Auger depth profile of the CdTe/InSb heterostructures grown at 270 °C. The d_0 indicates the depth at $t=0$.

and 122.0 cm^{-1} are related to the layer of In_2Te_3.[10] Although the In_2Te_3 was formed due to the interface reaction at 270 °C, those peaks did not appear for the samples grown at 200 °C.[10] The PL spectra showed that the peak originating from excitons bound to neutral donors which were caused by indium impurities interdiffused from the InSb substrate at the initial stage of the growth was observed. The ratio of the PL peak intensity of the defect-related emission to that of the bound exciton for the CdTe/InSb heterostructure grown at 270 °C was much smaller than that grown at 200 °C.

A bright-field TEM of the CdTe/InSb heterostructure grown at 270 °C in Fig. 2 shows an interfacial layer between the top CdTe layer and the bottom InSb substrate. The results of the TEM measurements indicate that an interfacial layer was formed at the CdTe/InSb interface and that the thickness of the interfacial layer was approximately 0.2 μm, which is in reasonable agreement with that obtained from the AES measurements. The CdTe layer was cut into column shapes, and existed fine lines with a shape of the teeth of a comb. The fine-toothed pattern was caused by the stacking faults in the CdTe layer. A bright-field TEM of the CdTe/InSb hetero-

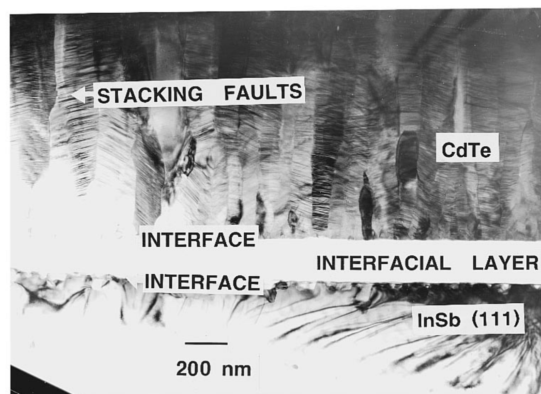

FIG. 2. A bright-field transmission electron microscopy image of the CdTe/InSb heterostructures grown at 270 °C.

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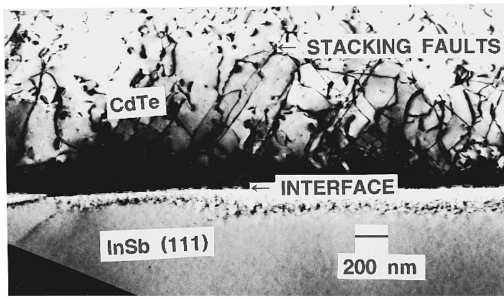

FIG. 3. A bright-field transmission electron microscopy image of the CdTe/InSb heterostructures grown at 200 °C.

structure grown at 200 °C was shown in Fig. 3. The interfacial layer between the CdTe layer and the InSb substrate did not appear at the CdTe/InSb heterostructure grown at 200 °C. However, the partial formation of the indium outdiffusion on the InSb surface due to annealing prior to the growth of the CdTe layer at 280 °C could not be neglected totally. An electron diffraction pattern obtained from a selected area near CdTe/InSb interface shows many streaky lines, and these lines are originated from the stacking faults in the CdTe layer as shown in Fig. 4. The diffusion of the ring originates from the interfacial amorphous layer, and the interfacial layer might be In_2Te_3 which was confirmed by the AES measurements. This layer originated from the reaction of Te with the InSb surface.[9,10] A high-resolution TEM image of the CdTe and interfacial layers were shown in Fig. 5. The results of the TEM measurements indicate that an interfacial layer was an amorphous layer. The CdTe layer has formed many stacking faults. These stacking faults originated from the formation of the interfacial layer prior to the creation of the CdTe layer. The stacking faults and the interfacial layer were not observed at the CdTe/InSb heterostructures grown at 200 °C. The results of TEM measurements have confirmed that the observed deterioration in structural quality of CdTe layers was related to growth temperatures.

In summary, AES and TEM measurements showed that an interfacial layer was formed between the CdTe thin films and the InSb substrate. AES measurements indicated that the interfacial layers within the CdTe/InSb heterostructures were In_2Te_3, and that the interface was not abrupt. TEM measurements showed that the CdTe epitaxial layer has many stacking faults, and that the interfacial layer is an amorphous layer. Although more detailed studies on the origin of interfacial layer formation remain to be carried out, the interfacial layer does interrupt the high quality of the CdTe epitaxial layer, and the CdTe thin films grown by TGVTD on InSb at 270 °C indicates a substantial interdiffusion problem.

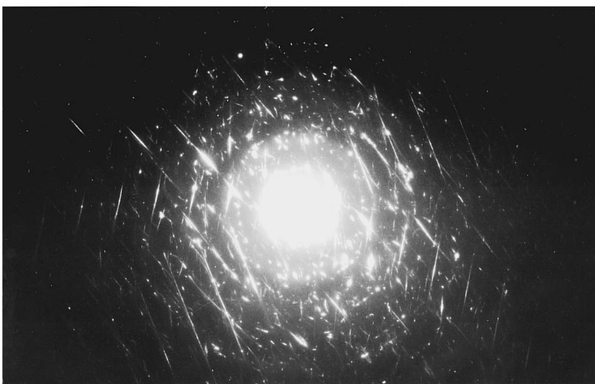

FIG. 4. A transmission electron microscopy image of the CdTe/InSb heterostructures grown at 270 °C.

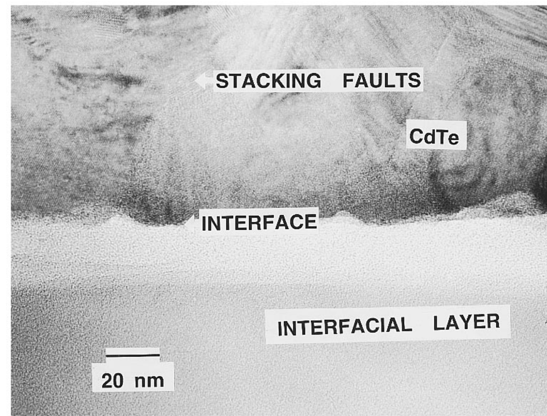

FIG. 5. A high-resolution transmission electron microscopy image of the CdTe/InSb heterostructures grown at 270 °C.

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