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New MBE growth method for InSb quantum well boxes

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We propose a new MBE growth method for InSb microcrystals on CdTe which has a nearly equal lattice constant to InSb. The average size of the InSb microcrystals was about 150 nm × 200 nm × 70 nm. This method is based on the Sb incorporation into In droplets and thought to be useful for fabricating quantum well boxes.

1. Introduction

Predictions of enhanced electron mobility [1] and drastic improvements of laser diode characteristics [2] have been made for quantum well box systems. In spite of the fundamental interest in making quantum well boxes, progress in their fabrication has been very slow. Although the electron beam lithography and subsequent argon ion milling have been demonstrated for the fabrication of the quantum well boxes [3] these dimensions are quite difficult to handle and radiation damage is inevitable. It appears highly desirable to look for alternative methods to fabricate quantum well boxes without resort to lithography.

In this paper, we propose a new MBE growth method for InSb microcrystals on a CdTe epitaxial layer. Since the CdTe has a nearly equal lattice constant to InSb and a larger energy gap than that of InSb, it may be possible to fabricate a quantum well box system by covering the InSb microcrystals by a CdTe epitaxial overlayer.

2. Experimental

The MBE system used in this work was a conventional commercial system (ANELVA-620) with a cluster of 40 cm^3 boron nitride effusion cells in a common liquid nitrogen shroud and an electron gun for reflection high energy electron diffraction (RHEED) with a primary beam energy of 30 keV. This system was capable of an ultimate pressure in the low 10^{-10} Torr range.

Elemental In and Sb and compound CdTe in the Knudsen cells were used as molecular beam sources. The incident fluxes of In. Sb and CdTe were separately determined by measuring the weights of these films deposited on glass substrates held at 20 °C and beam equivalent pressure (BEP).

Prior to loading, an InSb (001) substrate of 5×5 cm^2 area was solvent cleaned and mounted onto molybdenum support blocks using gallium solder. Immediately before growth, the native oxide was removed from the substrate surface by heating at 460 °C in an Sb flux.

At first, an InSb buffer layer was grown onto the substrate at 430 °C for 30 min. The thickness of the InSb buffer layer was about 500 nm. The In and Sb fluxes during growth were 4×10^{14} and 9×10^{14} atoms/$cm^2 \cdot s$, respectively. Then 200 nm thick CdTe epitaxial layer was grown onto the InSb buffer layer at 200 °C for 30 min. Next, In which had the same flux during growth of the InSb buffer layer was deposited on the CdTe epitaxial layer for 30 s at 200 °C. After deposition of the In droplets, an Sb flux which was 1×10^{14} atoms/$cm^2 \cdot s$ was supplied for 100 s.

The structures of the samples were analyzed by a field emission type high resolution scanning electron microscope (HRSEM) and transmission electron microscope (TEM).

3. Results and discussions

The RHEED patterns observed on each stage of the growth process are shown in fig. 1 along complementary ⟨110⟩ and ⟨1$\bar{1}$0⟩ azimuths. The surface reconstruction of the InSb buffer layer is pseudo (1 × 3) during growth, which corresponds to that observed by Noreika et al. [4] for the flux ratio of the antimony and indium being larger than unity. The surface reconstruction changed to In-stabilized c(8 × 2) at 200 ° C. Tellurium stabilized (2 × 1) surface reconstruction [5] appeared

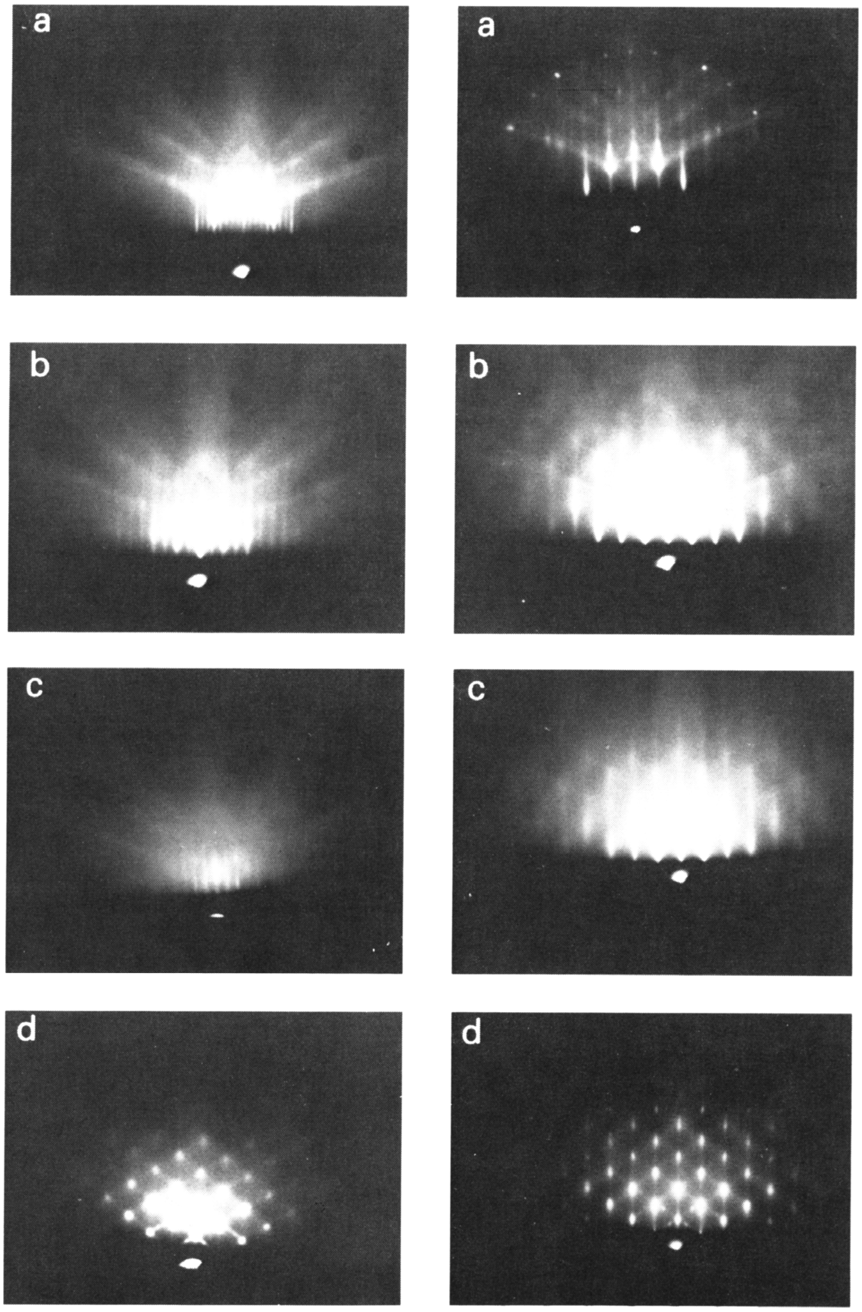

Fig. 1. RHEED patterns observed on the growth process along the complementary ⟨110⟩ azimuths: (a) surface of the InSb buffer layer at 200 ° C; (b) surface of the CdTe epitaxial layer; (c) In deposited surface on the CdTe epitaxial layer; (d) surface after the Sb supply. Left column: [110]; right column: [1$\bar{1}$0].

on the CdTe epitaxial layer. Simultaneous diffraction patterns of halo and (2×1) reconstruction were observed on the In deposited surface. Immediately after the Sb molecular beam radiation, the RHEED pattern changed to the spotty feature with streaks along $\langle 111 \rangle$ and $\langle 100 \rangle$ azimuths. The $\langle 111 \rangle$ streaks were clearly observed along the $\langle 110 \rangle$ azimuth rather than those along the $\langle 1\bar{1}0 \rangle$ azimuth. Some twin spots were observed along both azimuths. The Debye rings caused by antimony were observed simultaneously after about 60 s supply of antimony molecular beam.

These RHEED observations revealed that the In droplets deposited on the CdTe epitaxial layer changed to InSb epitaxial microcrystals truncated by (111) and (100) facets after the antimony molecular beam supply. The $(\bar{1}11)$ facets of microcrystals are well defined, but the (111) facets are not so clear.

The HRSEM photographs of In droplets on the CdTe epitaxial layer and the microcrystals grown by the Sb molecular beam supply to the In droplets are shown in fig. 2. The surface and slightly oblique side views are shown simultaneously in the figures. The shape of the In droplets is a hemisphere and the average diameter of the droplets is 120 nm. The standard deviation of the size distribution of the In droplets is about 10% in any sample prepared. These In droplets changed to truncated pyramidal shape microcrystals having (111) and (100) facets after the antimony flux supply. The base size of the pyramidal microcrystals is 150 nm $\times$ 200 nm and the height is about 70 nm. The $(\bar{1}11)$ facets of the microcrystals

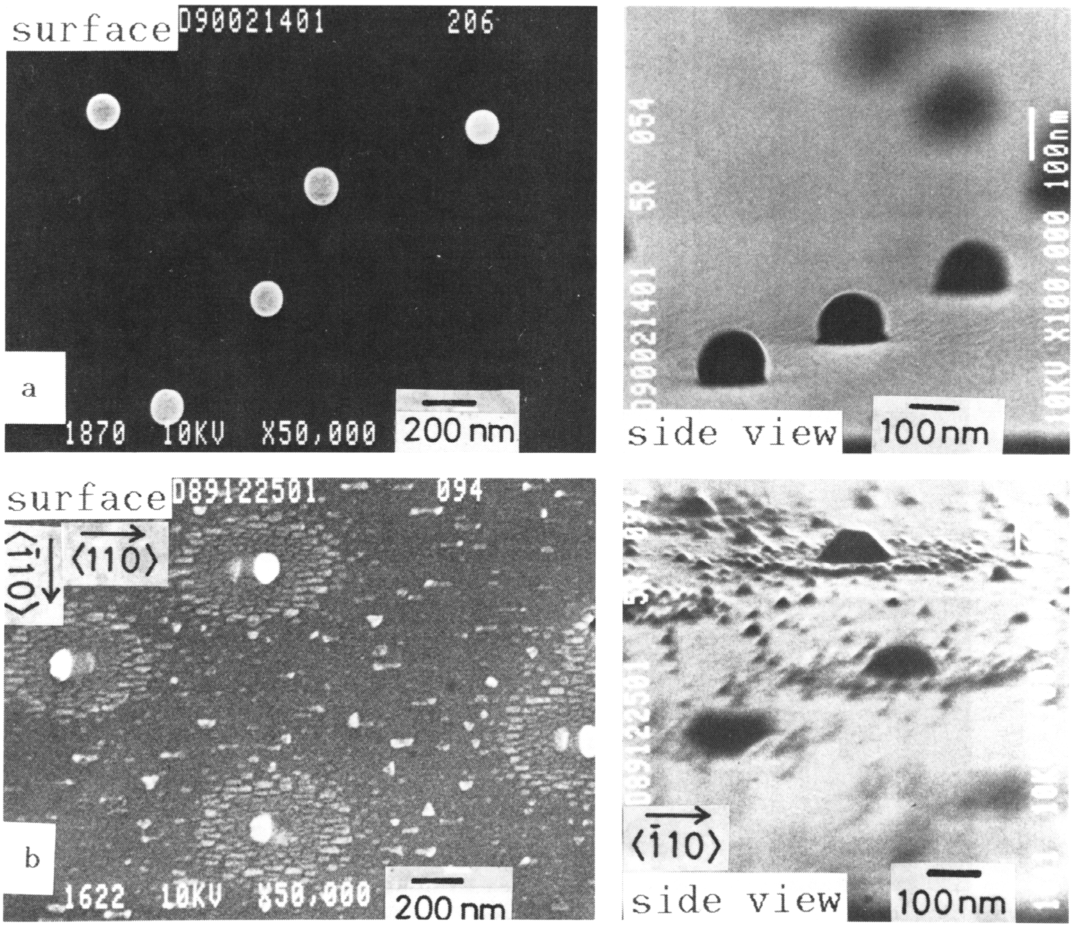

Fig. 2. HRSEM photographs: (a) In droplets deposited on the CdTe epitaxial layer; (b) microcrystals grown by the Sb molecular beam supply to In droplets.

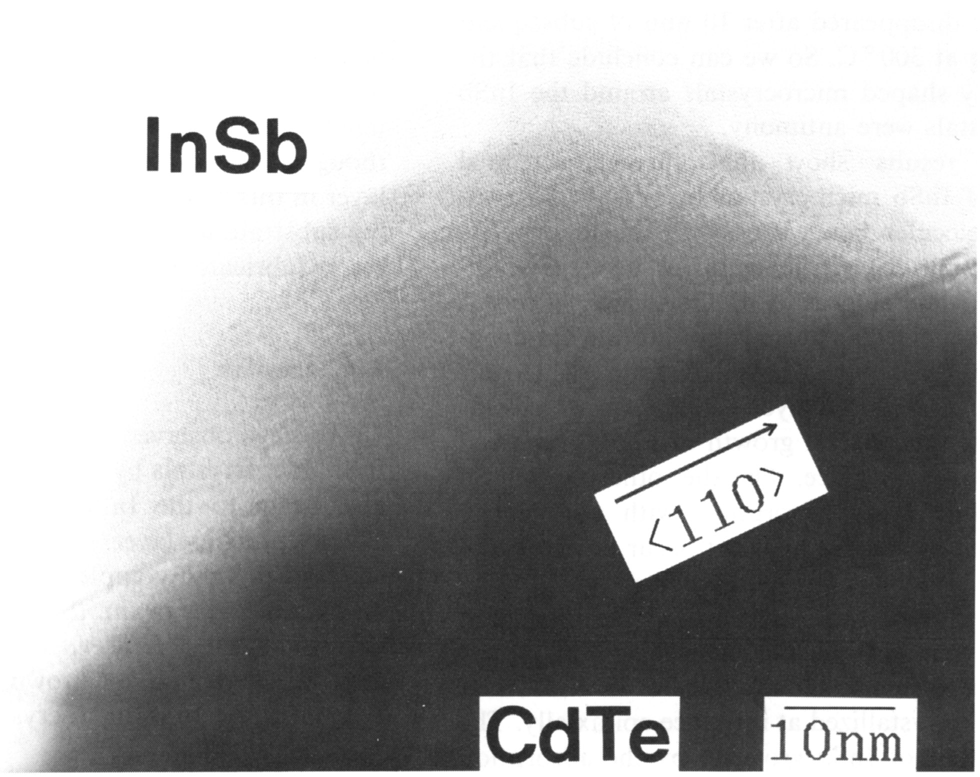

Fig. 3. TEM photograph of the InSb microcrystal.

are well defined, but the (111) facets are not so clear. These results correspond to those of the RHEED observation.

A TEM photograph of the microcrystal taken with the incident electron beam along the ⟨110⟩ direction for the cleaved sample is shown in fig. 3. The (111) lattice fringes appearing in the microcrystal are identified as those of InSb. Some InSb microcrystals covered by the non-reacting In were observed simultaneously for the same specimen.

Irregularly shaped microcrystals, whose size was smaller than that of the InSb microcrystals, were deposited on the substrate simultaneously, as shown in fig. 2. These crystals were crowded around the InSb microcrystals. These irregularly shaped microcrystals and the Debye rings from

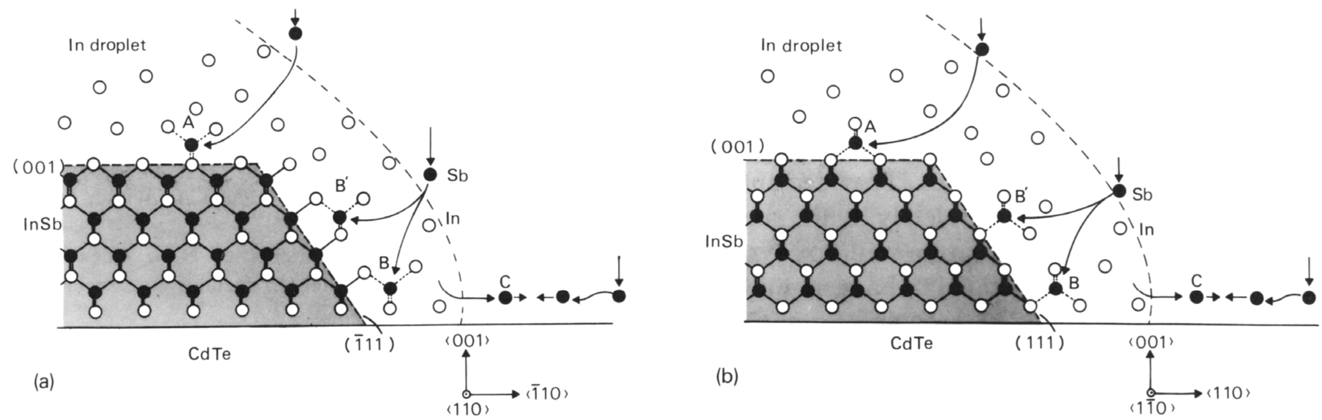

Fig. 4. Schematic explanation of growth mechanism of the InSb microcrystals: (a) cross sectional view along ⟨110⟩ azimuth; (b) cross sectional view along ⟨1$\bar{1}$0⟩ azimuth.

antimony disappeared after 10 min of subsequent annealing at 300 ° C. So we can conclude that the irregularly shaped microcrystals around the InSb microcrystals were antimony.

These results show that three-dimensional growth of InSb microcrystals occurs by the antimony molecular beam supply to the In droplets deposited on the CdTe epitaxial layer. Two-dimensional lateral growth of GaAs was observed by the As molecular beam supply to the Ga droplets deposited on the GaAs substrate [6]. In this case, As monoatomic layer adsorption, which was suitable for the lateral growth of GaAs, occurred on the GaAs surface. On the other hand, Sb monoatomic layer adsorption with zinc-blende type surface structure may not occur on the CdTe surface.

Fig. 4 shows a speculated growth mechanism of the InSb microcrystal. Dissolved Sb atoms in the In droplet diffuse to the interface of In and CdTe. Then InSb crystallized at interface epitaxially. The microcrystals of InSb grow up by the adsorption of Sb atoms like A and B in the figure. On the $(\bar{1}11)$ surface. B and B′ are nearly equivalent site; however, site B is more stable than site B′ on the (111) surface for the growth. Then well defined $(\bar{1}11)$ facet appears but (111) facet is not so clear. Also the base size expansion of the microcrystals is easier in the $\langle 110 \rangle$ direction than in the $\langle \bar{1}10 \rangle$ direction. Since the excess Sb atoms, which were not soluble in the In droplets migrate on the CdTe surface (C), the supersaturation of the Sb atoms around the In droplets increases and then the density of Sb microcrystals is high around the In droplets.

The size of InSb microcrystals depend on that of In droplets. The average diameter of the In droplets on the CdTe epitaxial layer may decrease with a decrease of the substrate temperature and/or an increase of the In flux. Provided the In droplets changed to InSb completely by the supply of Sb molecular beam, a quantum well box system composed of InSb wells and CdTe barriers may be fabricated by the epitaxial growth of an CdTe overlayer on the InSb microcrystals. Zahn et al. [7] reported that the thin interfacial layer of the In_2Te_3 is formed in the InSb–CdTe interface. They pointed out that the thickness of this layer was dependent on the substrate temperature, but that it was below some tens of ångströms thick at temperatures between about 180 and 330 ° C. Although we have not investigated the interfacial layer in this work, it may be necessary for decreasing substrate temperature during the growth process to fabricate an abrupt interface.

4. Conclusion

We have observed three-dimensional growth of InSb microcrystals by suppling a antimony molecular beam to the In droplets deposited on the CdTe epitaxial layer. Provided the In droplets changed to InSb completely by supply of an antimony molecular beam, the quantum well box system composed of InSb wells and the CdTe barrier may be fabricated by growing a CdTe epitaxial layer over the InSb microcrystals.

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