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Raman scattering from InAs/AlSb ultrathin-layer superlattices grown by molecular beam epitaxy

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Experimental analysis by Raman scattering has been performed to study characteristic phonon modes in InAs/AlSb ultrathin-layer superlattices (ULS's) grown by molecular beam epitaxy. Zone-folded longitudinal acoustic and confined optical phonons have been observed in the Raman spectra of these ULS's. In addition to them, we have observed new phonon modes localized at the heterointerface for the first time. It is also shown that the excitation of localized modes depends on the types of interface bonds, InSb- or AlAs-like, formed in the ULS's.

1. Introduction

Raman scattering is one of the powerful techniques to probe the lattice vibration of solids. In particular, this technique is useful to characterize fine structures such as interface and periodical properties of superlattices [1]. The introduction of artificial periodicity changes the phonon spectrum by folding the dispersion curves into mini-Brillouin zones. The formation of a mini-Brillouin zone has been experimentally studied up to now on superlattices of GaAs/AlAs [2], GaAs/AlGaAs [3], GaSb/AlSb [4], InGaAs/AlInAs [5], InAs/GaAs [6] and Si/Ge [7]. Each system except Si/Ge is composed for a common anion to be shared between adjacent layers at the heterointerface. In the case of Si/Ge, on the other hand, the interface is composed of a different compound (Si–Ge bonds) from the individual materials, i.e., phonon spectra from Si/Ge are known to have characteristic modes due to the vibration of interface bonds [1,7].

Like Si/Ge, InAs/AlSb superlattices should have characteristic phonon modes due to the interface bonds since any atoms of the anions and cations are not in common with the adjacent layers. Two different types of the interface bonds, AlAs- and InSb-like, are responsible for the characteristic phonon modes of InAs/AlSb superlattices, which are similar to the prediction on InAs/GaSb by using theoretical calculations [8–10]. However, in both superlattices, InAs/AlSb and InAs/GaSb, the lattice vibrational modes have not been analyzed by using Raman scattering.

In this paper, we present the first experimental results of Raman scattering from InAs/AlSb ultrathin-layer superlattices (ULS's) in conjunction with the interface control of MBE growth. This analysis can also make clear the characteristics of optical and acoustic phonons in InAs/AlSb superlattices, which are expected to be confined in one of the two constituents and by extended through both adjacent layers, respectively.

2. Experiments

Samples were grown by using an MBE apparatus containing metallic sources of Al, In, As and Sb. Each sample of ULS structure was grown on thick (0.7 μm) InAs through a buffer layer of AlSb on the (100)-oriented GaAs substrate. These were grown at a low temperature of 420 °C to prevent the unfavorable intermixing reaction between As and Sb atoms near the heterointerface [11]. In order to enhance the migration of surface adatoms at the low growth temperature, the last one or two monomolecular planes of each layer, InAs and AlSb, were grown by the alternative deposition of column III and V elements although the rest part of ULS's was formed by a conventional MBE technique. Two different types of interface bonds, InSb- or AlAs-like, were selectively made in the ULS's by controlling the beam-supply sequence of component elements during the growth. The control of layer-by-layer growth was performed by using the in-situ monitoring system of reflection high-energy electron diffraction (RHEED) signals. Details of the growth procedure will be discussed elsewhere.

Raman scattering has been measured by using a Spex 1403 double monochromater and a photon counting system under the excitation from the 514.5 nm line of an Ar ion laser. The typical resolution of measurement was 1.5 cm^{-1}. We used the quasi-backscattering configuration in an Ar atmosphere at room temperature.

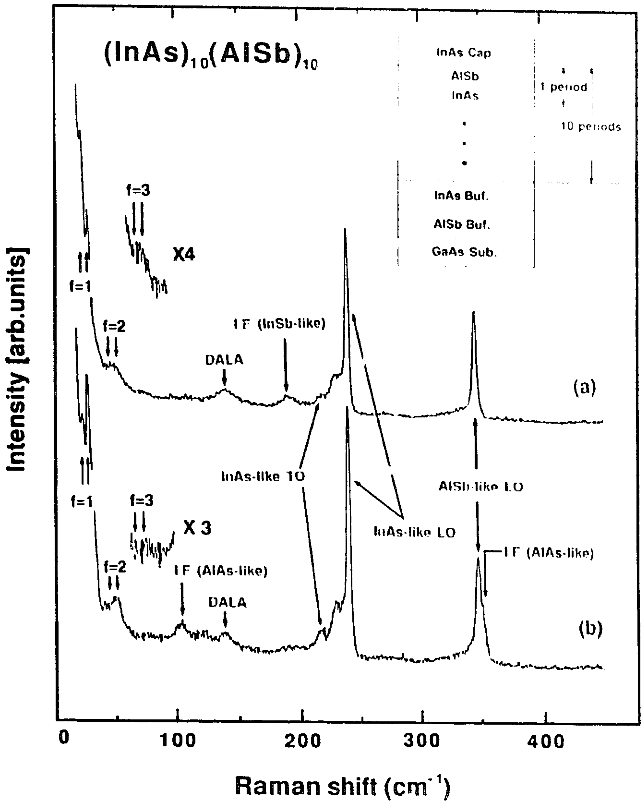

Fig. 1. Raman spectra observed from $(InAs)_{10}(AlSb)_{10}$ ULS's with (a) InSb- and (b) AlAs-like heterointerfaces. *f* is the folding order of the zone-folded LA phonons. Peaks denoted by IF are interface-related phonons.

3. Results and discussions

Figs. 1a and b show typical Raman spectra from the $(InAs)_{10}(AlSb)_{10}$ ULS's with ten periods of which interfaces have been controlled to be InSb- and AlAs-like, respectively. The incident light was polarized in the [011] direction, and the scattered light was collected for all polarizations. The weak peaks below 100 cm^{-1} correspond to the zone-folded longitudinal acoustic (LA) phonon modes, while the peaks around at 240 and 347 cm^{-1} correspond to the InAs- and AlSb-like longitudinal optical (LO) phonon modes, respectively. The weak peak at 218 cm^{-1} is due to the InAs-like transverse optical (TO) phonons which are forbidden in principle. The presence of TO modes in this experiment is owing to the deviation (about 12°) from the strict backscattering configuration. The broad peak at 147 cm^{-1} and the indistinct structure around 115 cm^{-1} seems to be the disorder-activated modes of LA (DALA) and TA (DATA) phonons in the InAs layer respectively. These characteristic signals of the zone-folded LA, InAs- and AlSb-like LO, DALA and DATA phonons were observed in common with both spectra of figs. 1a and b.

In contrast with these common peaks, the small peak around 190 cm^{-1}, which can be seen in fig. 1a, increased in intensity when the interface was controlled to be InSb-like. On the other hand, peaks around 105 and 353 cm^{-1}, shown in fig. 1b (the latter peak exists very close to the intense AlSb-like LO peak at 347 cm^{-1}), increased in intensities only when the interface was controlled to be AlAs-like. Therefore, these peaks can be related to the lattice vibration of the interface bonds. Notice that interface-related signals are close to the respective frequencies in bulk. The signal at 190 cm^{-1} due to the InSb-like interface is close to the LO and TO modes of bulk InSb (LO = 197 cm^{-1} and TO = 185 cm^{-1}), and the signals at 105 and 353 cm^{-1} due to the AlAs-like interface are close to the TA and TO modes of bulk AlAs (TA = 104 cm^{-1} and TO = 362 cm^{-1}), respectively. The InSb-like mode at 190 cm^{-1} was observed in both Raman configurations of the $x(y,y)\bar{x}$ and $x(y,z)\bar{x}$, althought the AlAs-like modes at 105 and 353 cm^{-1} were observed only in the $x(y,y)\bar{x}$. Here, x, y and z are [100], [010] and [001] directions, respectively. This polarization dependence, especially for AlAs-like modes, indicates that these phonons have the transverse mode-like symmetry. Therefore, we have ascribed at present these signals to the interface-related transverse phonon modes of InAs/AlSb. The presence of transverse modes can be attributed to the microscopic disordering of the heterointerface, however, it is not clear to date why the transverse modes were predominantly observed in these ULS's.

Zone-folded LA phonon peaks, which appear below 100 cm^{-1} in figs. 1a and b, have been compared with calculations by using the elastic continuum limit model proposed by Rytov [12]. Arrows shown in fig. 1a and b are the calculated results for $(InAs)_{10}(AlSb)_{10}$, where f is the folding order. Although the higher-order doublets cannot be well resolved in the spectra, all the observed frequencies agree with the calculated results of zone folding.

Signals at 240 and 347 cm^{-1} in figs. 1a and b can be related with the LO phonons in InAs and AlSb, respectively. These LO phonons are expected to be confined in the respective layers of InAs and AlSb, because the LO phonon branches of these two semiconductors are well separated in frequency, and the LO vibrational modes of one material cannot propagate into the adjacent constituent. This confinement can be seen in figs. 1a and b as the shoulder of InAs-like LO phonons below the main peak. This effect is not clearly observed for the AlSb-like LO phonons due to the smaller scattering cross section of AlSb.

The peak position of InAs-like LO phonons scarcely shifts against the bulk phonon frequency (240 cm^{-1}). On the other hand, the AlSb-like LO phonon peak shifts about 7 cm^{-1} toward higher frequency beyond the bulk frequency (340 cm^{-1}). This large shift should be understood to be the effect of compressive strain in the AlSb layer [13]. This compressive strain can be given by the large lattice mismatch between AlSb (0.614 nm) and InAs (0.606 nm). The major part of the biaxial stress must appear as the compressive strain in AlSb because the lattice constant of ULS's must be matched to InAs during the growth of the thick InAs on AlSb buffer layer.

4. Conclusion

Raman scattering has been discussed on two types of $(InAs)_{10}(AlSb)_{10}$ ULS's of which interfaces were controlled to be InSb- of AlAs-like. Raman spectra from these samples consist of the zone-folded LA phonons as well as the confined modes of LO phonons in InAs and AlSb. The observed energy of zone-folded LA phonons was in good agreement with the calculation based on the elastic model. In addition to the analysis, we have succeeded for the first time to detect new Raman modes from the AlAs- or InSb-like interface bonds in the ULS's grown by MBE.

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