Coherent Longitudinal Optical Phonons in GaSb/AlSb Superlattices

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Recently, coherent phonons in GaAs/AlAs superlattices (SLs) have been investigated extensively. Mizoguchi et al. discussed the generation and deteciton mechanism of coherent folded longitudinal acoustic (FLA) phonons by using a two-color pump-probe technique[1]. Yee et al. reported the electron miniband effect on the generation of coherent GaAs-like longitudinal optical (LO) phonon-plasmon coupled modes[2]. However, the coherent AlAs-like LO phonon, which is confined in the barrier layer of GaAs/AlAs SLs, have not been detected. In the present work, we report the first study on the coherent LO phonons in GaSb/AlSb SLs. We observed the coherent AlSb-like LO phonon confined in the barrier layer in addition to the coherent GaSb-like LO phonon confined in the quantum well layer.

The samples used were the $(GaSb)_m/(AlSb)_m$ (m=8,18,33) SLs, where the subscript m denotes the number of GaSb or AlSb monolayers (a thickness of 0.31nm). Hereafter, we will call the $(GaSb)_m/(AlSb)_m$ superlattice "(m,m) SL". Reflective-type pump-probe experiments were performed at room temperature by using a mode-locked Ti:sapphire pulse laser. The pump power is 150mW. The photon energy of the pump and probe pulses was 1.55eV, which is lower than the band gap energy of AlSb, while the energy is higher than the first interband transition energy in the SLs. Thus, photoexcited carriers are generated only in the GaSb layer. The time derivative of the reflectivity change was recorded as a function of the delay time between the pump and probe pulses.

Figure 1(a) shows the time derivative of the reflectivity change in the (8,8) SL and bulk GaSb. The decay time of the oscillation in the (8,8) SL is longer than that in bulk GaSb. In bulk crystals, the relaxation process of the coherent optical phonons is dominated by the energy relaxation into acoustic phonon branches[3]. In the SLs, the phonon dispersion is folded in the mini-Brillouin zone. This is considered to be a possible explanation for the restriction in the energy relaxation process, which results in the longer decay time.

The Fourier transformed (FT) spectra of the time derivative signals are depicted in Fig. 1(b). All spectra show the peak at 7.0 THz. This frequency agrees with that of the LO phonon of GaSb. The bandwidth of the coherent GaSb-like LO phonon in the SLs is narrower than that in bulk GaSb. This reflects the longer decay time in the SLs than that in bulk GaSb as shown in Fig.1 (a). The FT spectra of the SLs show another peak at 10.2 THz. This frequency agrees with that of the LO phonon of AlSb: Both the coherent GaSb-like and AlSb-like LO phonons are simultaneously observed in the SLs. The full width at half maximum of the coherent AlSb-like LO phonon band is almost equal to that of the coherent GaSb-like LO phonon (about 0.04 THz). This means that the relaxation time of the coherent AlSb-like LO phonon is coincident with that of the coherent GaSb-like LO phonon, which suggests that the energy relaxation process of the coherent AlSb-like LO phonon is also restricted.

To investigate the dynamics of the coherent LO phonons in the SLs, the Cole-Cole's plot, which corresponds to the plot of the real and imaginary part of the FT components, $A(\omega)$, is shown in Fig. 2. The $A(\omega)$ of the coherent GaSb-like LO phonon with 7.0 THz and that of the coherent AlSb-like LO phonon with 10.2 THz are indicated by closed and open squares, respectively. The fitted results of the data are represented by the two circles whose centers are depicted by the crosses. The angle between the solid and broken lines corresponds to the initial phase difference between the coherent GaSb-like and AlSb-like LO phonons. The initial phase difference in the (8,8) SL is 85 degree. This value is almost the same in all SLs. We consider that the initial phase difference is caused by the difference in the generation time; namely, the polarization of the GaSb-like LO phonon, which is generated at first by the pump pulse, induces the coherent AlSb-like LO phonon.

In summary, we have studied the coherent LO phonons in GaSb/AlSb SLs. The coherent GaSb-like and AlSb-like LO phonons have been simultaneously observed. The values of the decay time of the coherent LO phonons in the SLs are longer than that in bulk GaSb, because the energy relaxation processes of the coherent LO phonons are restricted by the folded phonon dispersion in the SLs. The initial phase difference with 85 degree between the coherent GaSb-like and AlSb-like LO phonons is considered to be due to the difference in the generation time between the two coherent phonons.

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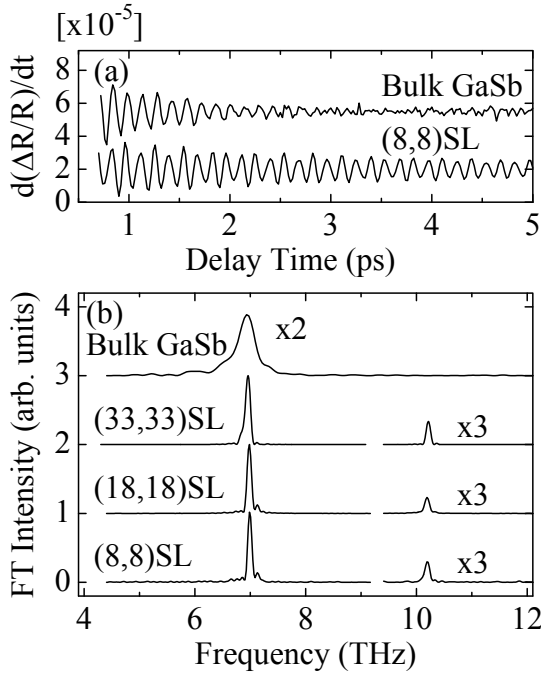

Fig. 1 (a) Time derivative of reflectivity change as a function of delay time at room temperature. (b) Fourier transformed spectra in bulk GaSb, (33,33) SL, (18,18) SL and (8,8) SL.

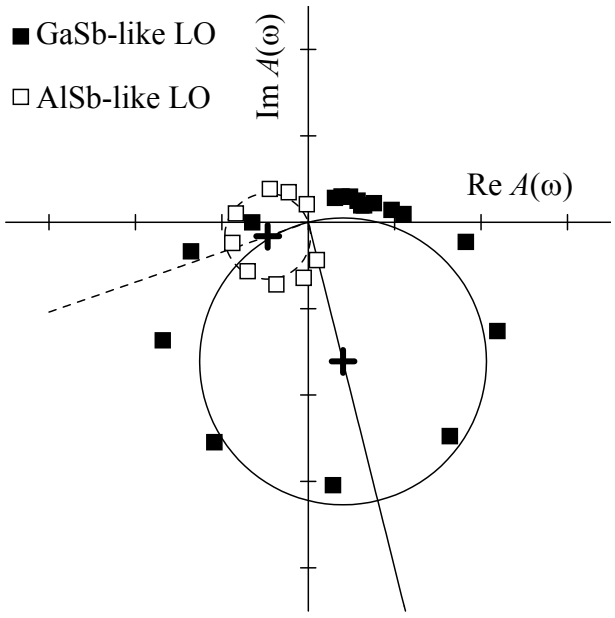

Fig. 2 Cole-Cole's plot of the FT components $A(\omega)$ of the coherent LO phonons in the (8,8) SL.