Coherent folded acoustic phonons in GaAs/AlAs superlattices with limited periodicity

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The study of coherent vibrations with ultrashort laser pulses is an interesting subject because the dynamics of phonons in materials is directly observed in time-domain. Coherent folded longitudinal acoustic (FLA) phonons in semiconductor superlattices (SLs) are observed at and near the Brillouin zone center [1,2]. In the previous works for coherent FLA phonons, SL samples used had more than 100 periods and were treated as an infinite periodic structure. No attention has been paid to effects of finiteness along a growth direction on coherent acoustic phonons, while there is a report on the finite-size effect on the Raman scattering from FLA phonons [3]. In the present work, we report on the coherent FLA phonons in $(GaAs)_{10}/(AlAs)_{10}$ SLs with 20 and 195 periods observed by using a pump-probe technique, where the subscripts denote the monolayer numbers of GaAs or AlAs.

The time derivative traces of reflectivity changes observed in SLs with two different numbers of periods are shown in Fig. 1(a). The oscillatory structures with beats in the SL with 195 periods are observed in the time range more than 100 ps, while those in the SL with 20 periods decay exponentially and almost disappear after about 80 ps. This quick damping of the time-domain signal reflects the propagation of the FLA phonons through the SL layer.

In order to analyze the oscillations, we performed the Fourier transform (FT) of the time-domain signals as depicted in Fig. 1(b). In the SL with 195 periods, three peaks are observed at 0.86, 0.90, and 0.96 THz, while four peaks in the SL with 20 periods are observed at 0.81, 0.84, 0.87, and 0.91 THz. The peaks observed in the SL with 20 periods shift to the lower frequency side than those in the SL with 195 periods. These frequency differences will be caused by the fluctuation of the constituent layer thicknesses.

We identify the peaks comparing the FT spectra to the dispersion curves of the FLA phonons calculated by using an elastic continuum model. In the SL with 195 periods, the strong peak at 0.90 THz is assigned to the zone-center mode with A_1 symmetry and the side peaks at 0.86 and 0.96 THz to the $q=2k$ modes, where the value k is the wavevector of the probe light [2]. In the SL with 20 periods, the peaks at 0.81 and 0.91 THz can be also assigned to the $q=2k$ modes. The central peaks at 0.84 and 0.87 THz correspond to the frequencies of A_1 and B_2 modes at Brillouin zone center, respectively. In the SL with 195 periods, the B_2 mode is not observed, which is in agreement with the selection rule of Raman scattering. On the other hand, the FT spectrum observed in the SL with 20 periods clearly shows coherent FLA phonon with B_2 symmetry. The observation of the B_2 mode is considered to be caused by the break of the mode symmetry due to the limited periodicity. We will discuss the intensity and the line width of FLA phonons from the viewpoint of the finite-size effect.

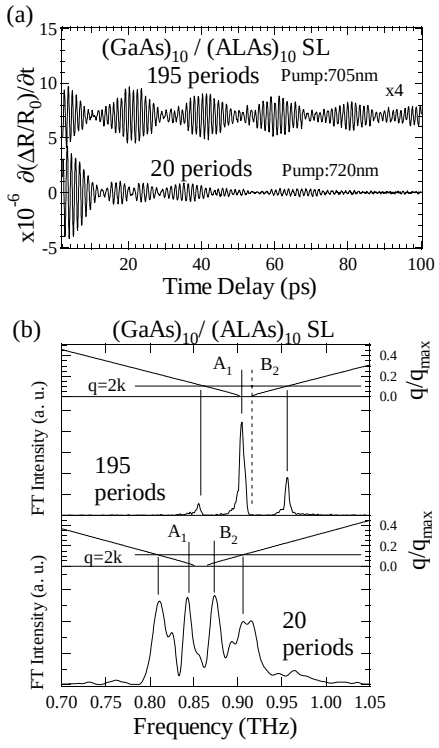

Fig. 1. Time derivative traces of reflectivity changes (a) and Fourier transform spectra of the time-domain signals (b) observed in $(GaAs)_{10}/(AlAs)_{10}$ SLs with 195 and 20 periods.

[1] T. Dekorsy, et al., *Light Scattering in Solids VIII*, edited by M. Cardona and G. Güntherodt (Springer-Verlag, Berlin, 1999), and references therein.
[2] K. Mizoguchi, et al., Phys. Rev. B**60**, 8262 (1999), and references therein.
[3] M. Nakayama, et al., J. Appl. Phys. **60**, 3289 (1986).