Anomalously enhanced group velocities of phonons in finite superlattices

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We study theoretically the unusual aspects of phonon group velocities in periodic superlattices related to the zone-folding effects. In a perfect, periodic superlattice phonon group velocities are calculated from the dispersion relations. Interesting effects are obtained (1) near frequency gaps (band edges) and (2) inside the frequency gaps. In these regions the group velocities of phonons are quite different from those of bulk materials or even do not exist.

On the other hand, the group velocities in finite superlattices are defined from the motion of phonon wave packets with the help of the stationary phase approximation. The calculated group velocities in frequency band coincide well with those obtained for the infinite superlattices. However, in frequency gaps where the group velocities are not defined for the infinite superlattices, their magnitude becomes larger than that in the low frequency limit and increases as the number of periodicity N increases [see, Figs.1 and 2]. To explain this anomalous behavior, we have developed analytical calculations based on the transfer-matrix method. Numerical example is given for a GaAs/AlAs superlattice sandwiched between the GaAs substrate and GaAs cap layer.
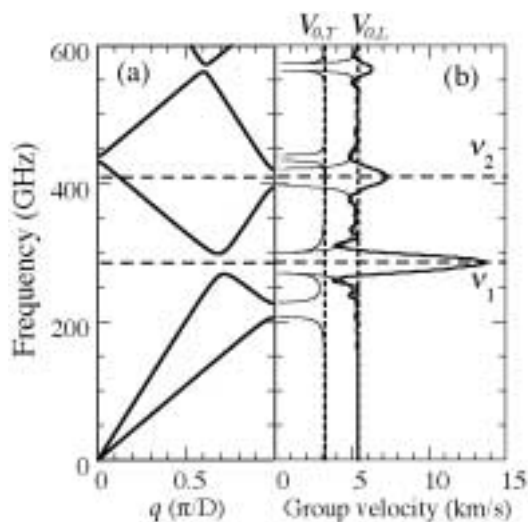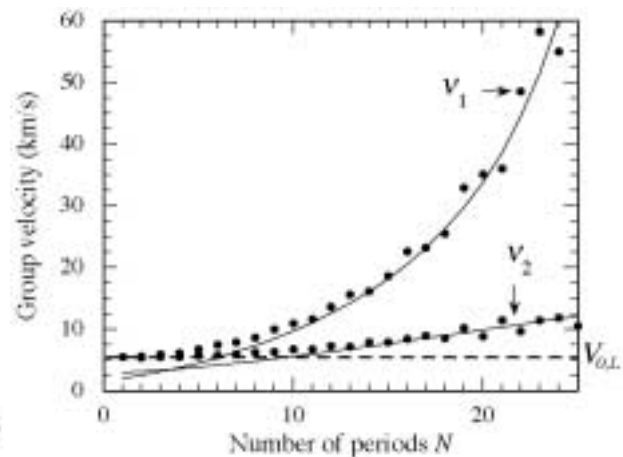

Fig.1.   Fig.2.

Fig.1. (a) Dispersion relations in a GaAs/AlAs superlattice. (b) Group velocities in the perfect, periodic GaAs/AlAs superlattice (thin lines) and those in the GaAs-(GaAs/AlAs)$_{12}$-GaAs system (bold line). A unit period is 8nm and the incident angle is 30 in the GaAs substrate. $V_{0,L}$ and $V_{0,T}$ are the group velocities in the low-frequency limit.

Fig.2. The group velocities versus number of periodicity N for the frequencies at the center of the intermode ($\nu = \nu_1$) and intramode gaps ($\nu = \nu_2$). The dots show the numerical results and the solid lines are analytical results.