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Citation: J. Appl. Phys. **76**, 7619 (1994); doi: 10.1063/1.357929
View online: http://dx.doi.org/10.1063/1.357929
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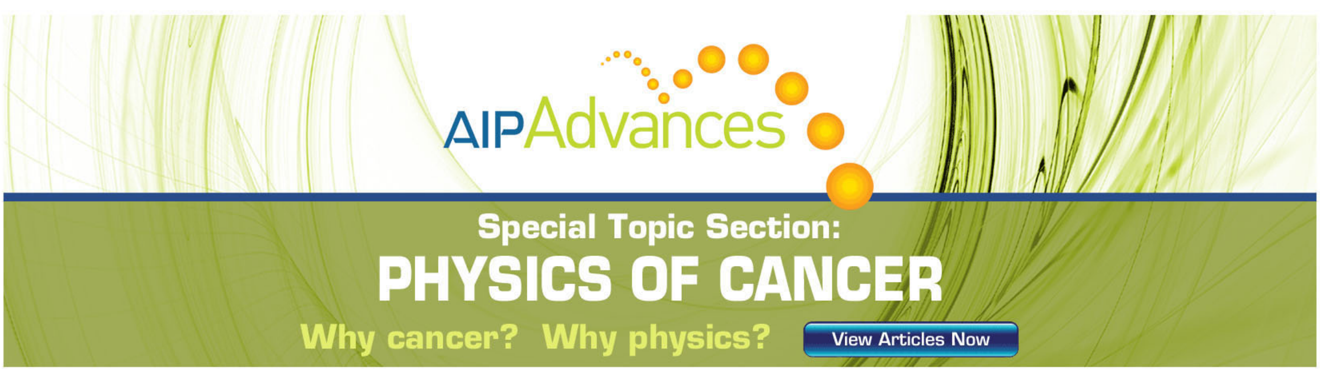

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Brillouin scattering from surface acoustic phonons in a ZnSe-$ZnSe_{1-x}S_x$ strained-layer superlattice

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(Received 11 April 1994; accepted for publication 1 August 1994)

Brillouin scattering studies were performed on ZnSe-$ZnSe_{1-x}S_x$ strained-layer superlattices with the composition $x\sim0.2$. We have observed scattering from longitudinal guided modes (LGM) whose velocities are determined primarily by the C_{11} elastic constant. From the measured velocity of the first-order LGM of the quasitransverse acoustic mode and of the quasilongitudinal acoustic mode, the C_{11} and C_{44} elastic constants in ZnSe-$ZnSe_{1-x}S_x$ superlattice film have been observed. © *1994 American Institute of Physics.*

Recently, much attention has been paid to devices based on ZnSe/ZnS, ZnSe/ZnSeS, and ZnCdSe/ZnSe strained-layer superlattices (SLSs), and multiple quantum wells (MQWs) have shown the greatest potential of this family of materials for device applications. However, most of them have inherent stress at the heterojunction interface due to lattice mismatch. The rough growth front causes wavy interfaces in II–VI superlattices layers that result in a broadening of the luminescence emission peaks[1,2] and weak x-ray satellite peaks.

Elastic properties of modulated multilayers with various stacking orders, such as periodic, quasiperiodic, and fractal multilayers, have been investigated both theoretically and experimentally. In the long-wavelength regime, when the acoustic wavelength becomes large compared to the modulation period of the superlattices multilayers, the elastic behavior of which is predicted to be independent of modulation period, these multilayers behave like effective homogeneous media whose elastic constants can be taken as an arithmetic average of the corresponding quantities of the constituents.

Since the Camley *et al.*[3] 1983 prophecy of the existence of longitudinally guided modes (LGMs) in thin films, research in this field has become more active. The LGMs are film-guided acoustic modes that have displacements primarily along the propagation direction in the film plane and velocities that are strongly dependent on the longitudinal elastic constant C_{11}. In 1986, Bassoli *et al.*[4] found the LGM in gold film. And Lee *et al.*[5] found scattering from the LGM in a ZnSe/GaAs epilayer. In this communication we report for the first time the results of the propagation process of the LGM in ZnSe-$ZnSe_{1-x}S_x$ SLS and a calculation of the C_{11}, C_{44}, and wave velocities using the LGM, quasitransverse acoustic mode (QTA) and quasilongitudinal acoustic mode (QLA).

The superlattice samples were fabricated in a computer controlled atmospheric pressure by metalorganic chemical-vapor deposition (MOCVD) on (100) GaAs substrates. Their optical properties relevant to the effects of elastic strain have been emphasized in most earlier work.[6–8] Because of a 0.27% lattice mismatch between ZnSe and GaAs, the strain due to mismatch can be fully relaxed by choosing a buffer layer with $X=0.05$. Therefore, for the present study, the samples were grown on a buffer layer of 0.5-μm-thick $ZnSe_{0.95}S_{0.05}$.

The typical sample studied here is of well width d(ZnSe) $=100$ Å and of barrier width $d(ZnSe_{1-x}S_x)=70$ Å. The total thickness of the superlattice studied here was 1.7 μm. Brillouin light scattering was performed with 50 mW of p-polarized 5145 Å radiation in air and at room temperature. The scattering light was analyzed using a tandem Fabry–Perot interferometer, having a finesse of about 150 and a contrast ratio greater than 5×10^{10}. The sampling time per spectrum was typically 2 h. The backscattering geometry was chosen to investigate modes with their acoustic wave vector component parallel to the surface, with q lying both along the [100] or [110] direction of GaAs substrate.

Theoretical calculations of the effective elastic constants of a superlattice, based on effective medium model,[9] were performed. In this case, the superlattice behavior was just like an effective homogeneous medium whose elastic, piezoelectric, and photoelastic constants are only an arithmetic average of the corresponding quantities of the constituents.

Brillouin spectra of a typical ZnSe-$ZnSe_{1-x}S_x$ SLS are shown in Fig. 1, corresponding to composition $x\sim0.2$. It can be seen that the dominant characteristic of the spectrum is dominated by the inelastic peaks corresponding to the Stokes and anti-Stokes scattering of the phonons. It has been found that, with a decreasing or an increasing mirror interval in the interferometer, there are no observable shifts for such phonon modes. For a scattering angle (normal to the surface) $\theta=67.5°$, the frequency shifts of three acoustic modes are found to have values of 15.6, 24.0, and 43.1 GHz, respectively. They should correspond to an acoustic mode of the LGM, an acoustic mode of the quasitransverse (QTA), and that of the QLA. In addition, a broadening peak, associated with quasilongitudinal phonons of GaAs, can be clearly observed at 75 GHz. However, the surface acoustic phonons have been merged into a strongly quasielastic scattering peak, ranging from 0 to 10 GHz.

The calculation of the propagation velocities, based on the obtained phonon spectra with respect to different θ has been carried out by

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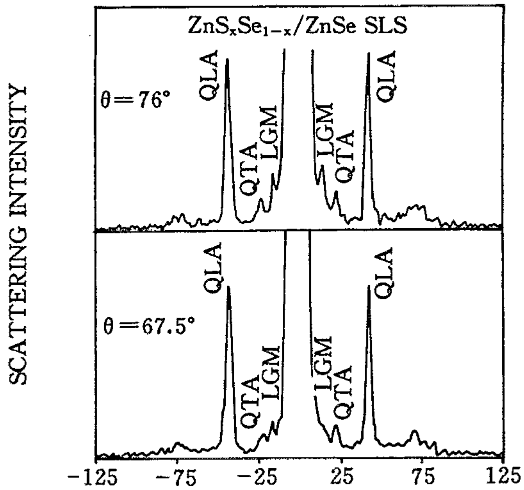

FIG. 1. Brillouin spectrum of acoustic phonons from a ZnSe-ZnSe$_{0.8}$S$_{0.2}$ SLS with d=170 Å.

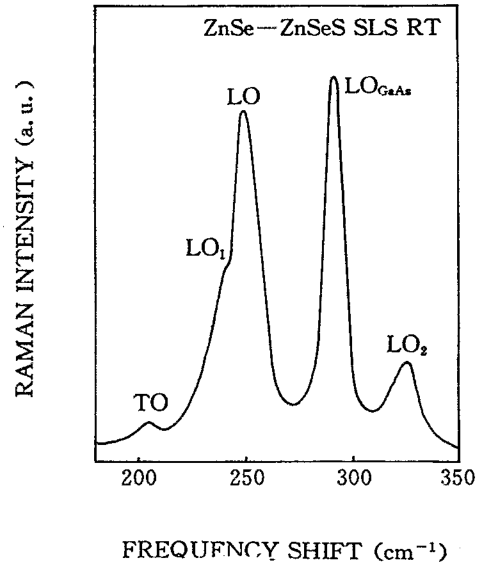

FIG. 2. First-order Raman spectra of a ZnSe-ZnSe$_{1-x}$S$_x$ SLS.

$$n=\frac{\Omega_{\mathrm{QLA}}\sin\theta}{\Omega_{\mathrm{LGM}}},\tag{1}$$

$$v_t=\frac{\Omega_{\mathrm{QTA}}\lambda}{2n},\tag{2}$$

and

$$v_l=\frac{\Omega_{\mathrm{LGM}}\lambda}{2\sin\theta}.\tag{3}$$

Generally speaking, the transverse elastic wave velocity in a quasiperiodic structure are in the form of $v_t=(C_{44}/\rho)^{1/2}$, $v_l=(C_{11}/\rho)^{1/2}$, and $\bar{v}_l=(C_{33}/\rho)^{1/2}$, respectively. Within the limit of large wavelengths, the superlattice sound velocity $v_l=\omega/q$ becomes[10]

$$\bar{v}_l=d\left[\frac{d_1^2}{v_1^2}+\frac{d_2^2}{v_2^2}+\frac{d_1d_2}{v_1v_2}\left(\frac{1+k^2}{k}\right)\right]^{-1/2},\tag{4}$$

where $k=v_1\rho_1/v_2\rho_2$; d_1, d_2, and $d=d_1+d_2$ are the thickness of the ZnSe well, the ZnSe$_{1-x}$S$_x$ barrier, and the period; v_i,ρ_i are the sound velocities and mass densities of relevant layer, respectively. The parameters of the ZnSe, ZnSe$_{1-x}$S$_x$ layers and calculation results are listed in Table I.

To obtain a clear picture of intrinsic strain, Fig. 2 gives the phonon spectrum from the same ZnSe-ZnSe$_{1-x}$S$_x$ SLS sample in the optical regime. It displays a two-mode behavior, corresponding to the ZnSe-like and ZnS-like modes. The three peaks at 250 (LO), 244 (LO$_1$), and 325 (LO$_2$) cm^{-1} are designated as the longitudinal optical vibrations confined in the ZnSe, ZnSe$_{1-x}$S$_x$, and ZnS. The weaker peak located at 208 cm^{-1} is the transverse optical (TO) mode of the ZnSe layer.

In conclusion, the elastic properties and the related effects of the elastic strain from a ZnSe-ZnSe$_{1-x}$S$_x$ SLS have been studied by means of inelastic Brillouin spectroscopy. Measurement of the phase velocity with different wave vectors enabled us to derive some effective elastic constants.

This research was supported by the National Laboratory of Solid State Microstructure, Nanjing University, and the Laboratory of Excited State Process, Changchun Institute of Physics, Chinese Academy of Sciences.

TABLE I. Elastic constants and mass densities for a ZnSe, ZnSe$_{1-x}$S$_x$, and ZnSe-ZnSe$_{1-x}$S$_x$SLS.

	ZnSe	ZnSe$_{0.8}$S$_{0.2}$	SLS^{cal}	SLS^{exp}
C_{11} (GPa)	85.9	89.4	88.1	97.5
C_{12} (GPa)	50.6	53.4	51.8	
C_{33} (GPa)	85.9	89.4	88.1	88.3
C_{44} (GPa)	39.2	40.3	39.6	30.3
ρ (g cm^{-3})	5.266	5.030	5.169	
v 10^5 m s^{-1}	4.054	5.047	4.134	
v_l 10^5 cm s^{-1}				4.344
v_t 10^5 cm s^{-1}				2.421

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