Absence of elastic anomalies for Co/Ni superlattices with oscillatory transport

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We report on Brillouin light scattering investigations of the elastic properties in Co/Ni superlattices which exhibit localized electronic eigenstates near the Fermi level causing an oscillation of the resistivity as a function of the superlattice periodicity Λ. No oscillations of the Rayleigh and Sezawa modes as a function of Λ could be observed within an error margin of $\pm 2\%$, indicating that the localized electronic states do not contribute to the elastic constants. [S0163-1829(97)09221-7]

Very recently oscillations of the resistivity ρ and of the anisotropic magnetoresistance in Co/Ni superlattices as a function of the superlattice periodicity Λ were reported.[1,2] As suggested by the authors, the oscillatory behavior can be understood within the framework of an electron localization model, in which d electrons are assumed to be localized within the superlattice structure, giving rise to strong s-d scattering, when the d states cross the Fermi level with changing Λ.[1]

One of the implications of these results is that the electronic structure, in particular the density of states at the Fermi level, is expected to influence the elastic constants.[3,4] We therefore investigated the elastic constants as a function of the superlattice periodicity to search for characteristic oscillations and to test the sensitivity of elastic properties to above oscillatory modifications of the electronic states.

On a surface of a semi-infinite material, a long-wavelength acoustic surface excitation, the so-called Rayleigh mode, exists, which is characterized by an exponential decay of the displacement amplitude with increasing distance from the surface. If a film is deposited onto a substrate, higher-order localized acoustic phonon modes may exist, characterized by the number of nodes in the displacement field within the film, if the transverse sound velocity of the film is smaller than that of the substrate. These modes, which are characterized by an exponential decay into the substrate, are called Sezawa modes. From measurements of the modal sound velocities of the Rayleigh and Sezawa modes, the elastic constants can be determined.[5] The sound velocities depend in a complicated manner on the densities of the substrate and film material, and on most components of the elastic tensors of the substrate and film. The contributions of the different tensor elements change with modal order and with wave vector. An analysis of the dispersion curves by a fit to an appropriate model using the elastic constants as fit parameters allows for the reliable determination of many of the elastic constants.[5]

An anomaly in any of the elastic constants should therefore manifest itself in a characteristic modification in the parts of the dispersion curves of the Rayleigh and Sezawa modes which are affected mostly by the respective constant. Therefore a measurement of the dispersion curves allows for a clear characterization of the presence or absence of any elastic anomaly.

The Co/Ni (fcc/fcc) superlattices were grown by molecular beam epitaxy (MBE) onto single-crystalline (110)-oriented sapphire substrates with (111) texture of the Co and Ni films.[1] The sample parameters are listed in Table I. The elastic constants were determined by Brillouin light scattering from surface and film acoustic phonons; the method is described elsewhere.[5] The measurements were performed in backscattering geometry using a tandem Fabry-Pérot interferometer and a single-moded 514.5-nm Ar^+-ion laser.[6] The laser power was about 30 mW at the sample, and the typical measuring time per spectrum was between 20 and 40 min. The obtained spectra show Rayleigh and Sezawa modes. The onset of the continuum of bulk modes above the Sezawa modes was observed, but not further investigated due to the weak signal strength and the rather limited information content.

If we study the dependence of the sound velocities of the Rayleigh and Sezawa modes as a function of the superlattice periodicity Λ and total thickness h, simple model calculations show that the dispersion of the guided acoustic modes can be calculated in a good approximation using an effective-medium model for the elastic constants,[7] if Λ is small compared to the wavelengths of the investigated

TABLE I. Parameters of the investigated samples.

Sample	Superlattice periodicity (Å)	Number of bilayers	Thickness (Å)
A	20.0	47	998
B	23.3	35	880
C	26.5	37	1041
D	32.6	31	1073
E	34.7	27	987
F	38.6	23	940
G	44.9	27	1276
H	49.9	23	1214
I	55.1	21	1225
J	59.2	19	1195

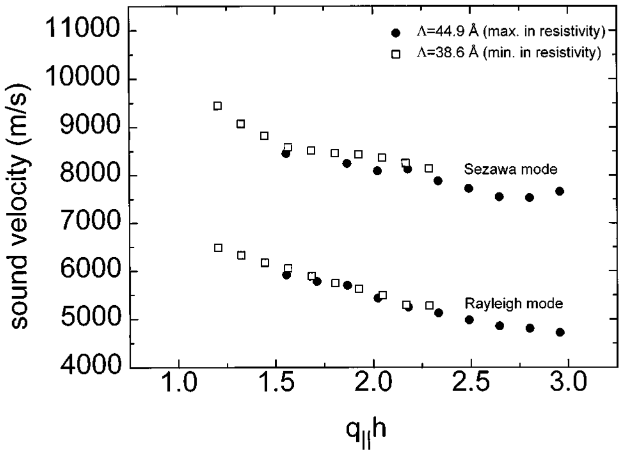

FIG. 1. Experimental sound velocity dispersion curves as a function of the product of the wave vector $q_{\|}$ and the superlattice stack thickness h, of the acoustic mode (Rayleigh mode and first Sezawa mode) for samples F and G.

modes.[5] The dispersion of the modes is obtained as a function of the product of the in-plane wave vector $q_{\|}$ and the sample thickness h, using the effective elastic constants of the superlattice stack as input parameters. If the layers have a crystallographic texture with in-plane isotropy, the elastic properties of the entire stack show hexagonal symmetry.[7]

Our experimental data are displayed in Fig. 1 as a function of $q_{\|} \cdot h$ for samples F and G (see Table I), which show extremal values in the resistivity oscillation. With increasing $q_{\|} \cdot h$ both the Rayleigh and Sezawa modes decrease in velocity. As can be seen in Fig. 1, the dispersion curves of these two samples overlap within a large region of $q_{\|} \cdot h$, indicating that the elastic properties are very close.

For a more detailed analysis, the different thicknesses of the individual samples must be taken into account. To test any presence of oscillatory behavior, a common $q_{\|} \cdot h$ value of $q_{\|} \cdot h = 2.3$ has been chosen and the dispersion curves of all samples have been interpolated or extrapolated to this value. These data are shown in Fig. 2 together with the resistivity data from Ref. 1. The main result is that all data lie at constant values; i.e., both the Rayleigh and Sezawa modes are independent of the superlattice periodicity Λ.

From Fig. 2 it is evident that within the experimental error of $\pm 2\%$ the obtained sound velocities are independent of Λ. In particular, no correlation with the resistivity $\rho(\Lambda)$ is found. Since the sound velocities of the Rayleigh and Sezawa modes are determined by different combinations of elastic constants, these results indicate that either the Λ dependence on the electronic density of states near the Fermi energy, causing the anomaly in $\rho(\Lambda)$, is too weak to cause detectable oscillations in any of the major contributing elastic constants or the contribution of the density of states near the Fermi level to the elastic properties is rather small. Calculations of these elastic contributions of the superlattice structure as a function of electronic properties are highly needed to understand more deeply this point.

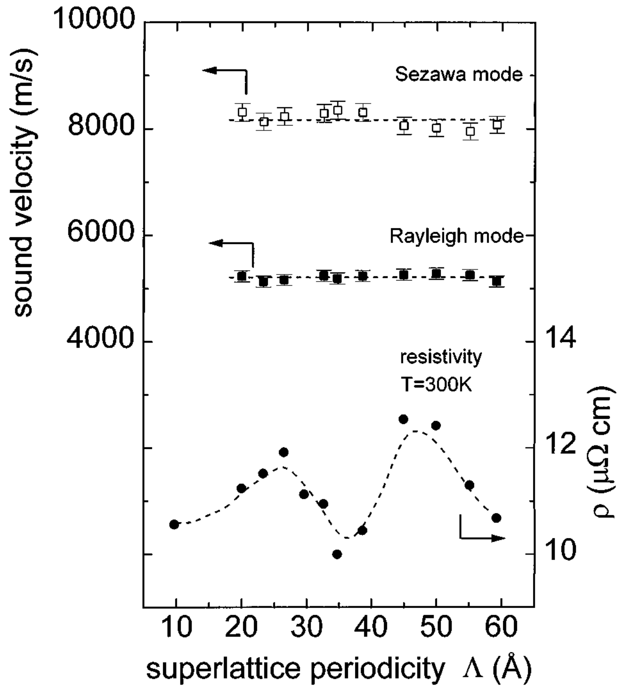

FIG. 2. Obtained sound velocities of the Rayleigh and Sezawa modes for a common value of $q_{\|} \cdot h = 2.3$ as a function of the superlattice periodicity Λ. The dashed lines are linear fits to the data. For reference, the resistivity data $\rho(\Lambda)$ of Ref. 1 are shown as well.

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