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CHARACTERIZATION AND SELECTED PHYSICAL PROPERTIES OF CdTe/MnTe SHORT PERIOD STRAINED SUPERLATTICES*

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Phonon excitations in $(CdTe)_{12}/(MnTe)_n$ (100) superlattices ($n = 2$, 4, 8) were investigated at 295 K and 25 K with the use of Raman scattering. From the "folded" phonon frequencies the elastic constant c_{11} value for MnTe was estimated. The strain arising from lattice mismatch (determined by X-ray diffraction) results in shifts of MnTe and CdTe "confined" LO phonon frequencies. For the precise determination of LO phonon dispersions an additional shift due to Mn diffusion at the CdTe/MnTe interface should be taken into account.

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A few existing papers devoted to Raman scattering measurements performed on $CdTe/Cd_{1-x}Mn_xTe$ (or $Cd_{1-x}Mn_xTe/Cd_{1-y}Mn_yTe$) superlattices (SLs) correspond to the case when $x \leq 0.3$ (or $|y-x| < 0.4$) (see, e.g. [1–3] and the references therein). Due to small difference of bulk lattice parameter values the possible influence of strain resulting from the lattice mismatch was neglected in the analysis of the phonon spectra published till now. It was an interesting problem to analyze in detail Raman scattering for the short period system CdTe/MnTe (there is about 2.3% lattice mismatch between MnTe and CdTe and the strain-related effects should be important in this case).

$(CdTe)_{12}/(MnTe)_n$ SLs with $n = 2$, 4, or 8 were grown by the MBE on (001) GaAs semi-insulating (SI) substrates misoriented of 2° towards the next (110). SLs with 200 periods were grown on a 3 μm thick CdTe (001) buffer layer, their thickness varied between 0.9 and 1.3 μm. Thin (15 Å) ZnTe layer was employed in order

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to reduce the strong mismatch between CdTe buffer layer and GaAs substrate and to stabilize the growth in the (100) direction. X-ray diffraction measurements on lattice constant were performed by using the high resolution Philips Research Diffractometer (MRD) in double and triple crystal configuration. A set of Bragg angle reflections (004, 115, 335, 117) was used. From these reflections lattice parameters in plane and off plane were calculated. In order to further investigate the structural properties of the layers, reciprocal space maps were made using symmetrical 004 and asymmetrical 335 reflections. Because no tilt was found when mapped the reciprocal space of the symmetrical 004 reflection the asymmetrical 335 reciprocal space map gives direct information about the strain state of the epilayer. It was demonstrated that all investigated SLs were partially relaxed.

Raman spectra were measured both at room temperature and at about 25 K using 514.5 nm Ar^+ laser excitation line. These experiments were performed in a quasi-backscattering geometry, the results for both linear light polarizations were obtained. Since the acoustic dispersion curves of two constituent materials of the SL overlap over a wide frequency range, acoustic phonons can propagate through both layers. Folded LA phonons were observed for all investigated superlattices. First doublets and phonon structures up to at least fourth order were well seen in the Raman spectra taken at room temperature. An example of such Raman spectrum is shown in Fig. 1a. The results were interpreted using an elastic continuum Rytov model [4]. It should be noted that there exists a large discrepancy between two sets of the values of elastic constants for cubic MnTe, reported in the literature [5–7], and such measurements could enable one to determine some of

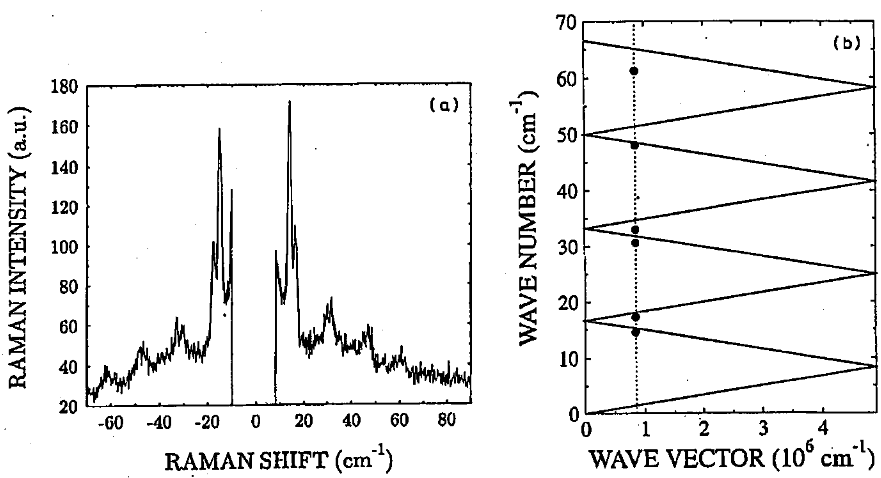

Fig. 1. (a) Part of the Raman spectrum corresponding to the "folded" acoustic phonons taken at T = 295 K for $(CdTe)_{12}/(MnTe)_8$ sample. (b) "Folded" acoustic phonon dispersion for the same sample as shown in Fig. 1a. Points: experimental data, solid curves: phonon dispersion calculated using the elastic continuum (Rytov) theory.

these values in an independent manner. For our particular SLs growth direction only the value of elastic constant c_{11} for MnTe could be estimated. The above--mentioned parameter value close to 6.0 [5,6] seems to describe satisfactorily the Raman scattering data (Fig. 1b). A possible small effect of strain arising from the lattice mismatch on LA phonon frequencies was neglected because it has no influence on the result of discussed estimation.

On the contrary, the behaviour of the optical "confined" phonons strongly depends on the strain. In the case of CdTe/MnTe SLs the frequency ranges corresponding to CdTe and MnTe optical phonons do not overlap. It is the reason that it is possible to observe the effect of "confinement" for both CdTe and MnTe. A few first quantized LO phonons for both SLs constituents were observed (Fig. 2a), small structure corresponding to CdTe TO mode was also seen. Strain parameters determined from X-ray diffraction data explain entirely observed slight high-frequency shift in CdTe LO and TO confined phonons. As an example the reciprocal space map obtained for 335 reflection for SL with $n = 2$ is shown in Fig. 2b.

LO phonon frequency for cubic MnTe directly determined at low temperature is equal to (218 ± 1) cm^{-1} (see [8] and the references therein). The low-frequency shift observed in MnTe LO confined phonon has the greatest value (exceeding 12 cm^{-1}) for $(CdTe)_{12}/(MnTe)_2$ SL. It is a surprising effect because for $(CdTe)_{12}/(MnTe)_4$ SL (for which a similar strain value was found as for the previous one) the observed shift is significantly smaller. The results of calculations demonstrated that the strain and confinement effects are not able to describe quantitatively the observed shift for the SL with the thinnest Mn layer. In order to explain much higher low-frequency shift in MnTe LO confined phonon in this case the process of Mn diffusion (resulting in a non-abrupt distribution of Mn atoms close to the interface) was taken into account (see, e.g., [9]). It is known that for a typical SLs growth temperature (320°C in our case) the Mn diffusion length is of the order of 1–2 monolayers (roughly speaking it means about 4.5 Å). The numerical simulations demonstrated that one can expect a few "pure" MnTe monolayers for each period of $(CdTe)_{12}/(MnTe)_8$ SL, but there are no at all such monolayers for $(CdTe)_{12}/(MnTe)_2$. In the latter case the highest possible Mn content in one monolayer does not exceed about 75% only. Such change in the crystal composition corresponds to the bulk MnTe-like LO phonon low-frequency shift equal to about 5 cm^{-1}. As one can see, the effect of Mn diffusion on the interface during the SLs growth should be taken into account in order to interpret the results obtained for short-period superlattices. Probably the precise strain measurements (by X-ray diffraction methods) accompanied by Raman scattering measurements could enable one to determine the Mn diffusion length in an independent manner.

For thin $Cd_{1-x}Mn_xTe$ epilayers with high values of x an additional structure in the Raman spectra corresponding to the crystalline hexagonal Te precipitations was found [8]. For few MnTe samples these findings were also confirmed by X-ray diffraction measurements. An analysis of the low temperature Raman spectra for SLs suggests that in all cases there is some contribution of the signal due to amorphous Te [10] to the scattering background. However, no trace of the crystalline Te was detected. Further experimental studies are necessary in order to confirm this finding.

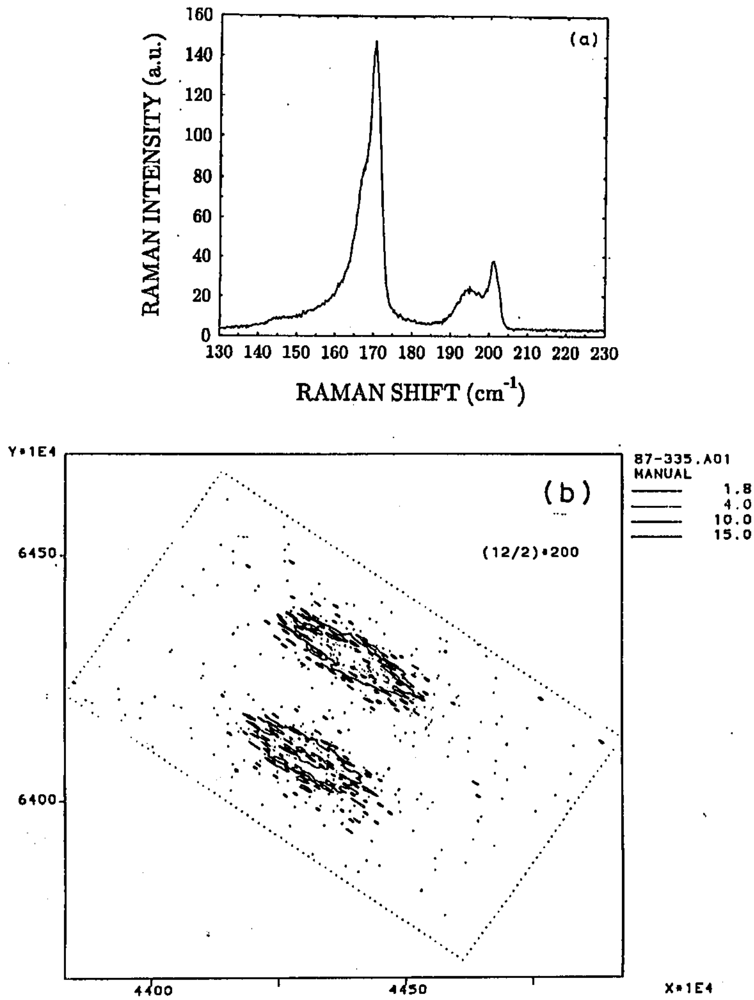

Fig. 2. (a) Confined LO phonons for MnTe and CdTe measured at 25 K for $(CdTe)_{12}/(MnTe)_2$ superlattice. (b) Reciprocal space map for 335 reflection taken for the same sample (superlattice is almost entirely relaxed).

In conclusion, we would like to state that for the first time the strained SLs grown for the system $Cd_{1-x}Mn_xTe/Cd_{1-y}Mn_yTe$ were analysed. In our opinion, the observation of the phonon excitations in the CdTe/MnTe SLs with various growth directions should enable one to estimate the values of all elastic constants for MnTe. From the analysis of the confined MnTe LO phonons the LO phonon dispersion could be determined for this material (the present preliminary data suggest that this dispersion is much smaller than that for CdTe case).

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