Proceedings of the XXVI International School of Semiconducting Compounds, Jaszowiec 1997

# RAMAN CHARACTERIZATION OF MBE-GROWN LAYERED MnTe/CdTe STRUCTURES*

W. SZUSZKIEWICZ[a], M. JOUANNE[b], J.F. MORHANGE[b], M.A. KANEHISA[b], H. MARIETTE[c], J.M. HARTMANN[c], E. DYNOWSKA[a], G. KARCZEWSKI[a], T. WOJTOWICZ[a], J. KOSSUT[a] AND J. BARNAŚ[d]†

[a]Institute of Physics, Polish Academy of Sciences
Al. Lotników 32/46, 02-668 Warszawa, Poland
[b]Laboratoire des Milieux Désordonnés et Hétérogènes, UPMC
Case 86, 4 place Jussieu, 75252 Paris, Cédex 05, France
[c]Equipe CEA-CNRS "Microstructures de Semiconducteurs II-VI" de l'Université
J. Fourier et CEA/DRFMC, BP 87, 38054 Grenoble, France
[d]Unité Mixte de Physique CNRS-Thomson, Orsay, France

Raman scattering measurements on $(MnTe)_8/(Cd_{0.64}Zn_{0.36}Te)_8$ multilayer grown by MBE method and on various $(MnTe)_n/(CdTe)_{12}$ multilayers (where $n = 8, 12, 16, 24$) were performed at low temperatures. In the $\bar{z}(x,x)z$ polarization, structures corresponding to folded acoustic phonons were found. In $\bar{z}(x,y)z$ polarization new complex structures were observed in the low-frequency part of Raman scattering spectra. A possible magnetic origin of these structures is discussed.

PACS numbers: 75.30.Ds, 75.70.Ak, 78.30.-j

The objective of this work is to analyse the Raman scattering in superlattices (multilayers) involving thin films of a magnetic semiconductor separated by a non-magnetic spacer. Zinc-blende MnTe (which in a bulk form possesses a long-range antiferromagnetic order of the AF-III type, see, e.g., [1]) was selected as a suitable material for the magnetically active component. As the non-magnetic spacers, thin layers of CdTe were used. The lattice parameter values for both compounds do not differ too much (the lattice mismatch is close to above 2%) so the strain effects are expected to be insignificaut.

Recently, it was demonstrated that the Raman scattering is a very effective tool for investigation of magnetic excitations (magnons) in thick, MBE-grown MnTe [2]. In order to make the Raman scattering intensity measurable, we used multilayers with thin MnTe layers having a constant thickness separated by 12 monolayers of nonmagnetic CdTe. Thus according to the recent neutron scattering

*This work has been partially supported by PB750/T08/95/09 grant from the Committee for Scientific Research (Poland).

†Permanent address: Magnetism Theory Division, Institute of Physics, A. Mickiewicz University, Umultowska 85, 61-614 Poznań, Poland.

data, the interlayer coupling can be neglected in our case. Therefore, for the propagation of the magnetic excitations (spin waves), the investigated samples were not superlattices, but multilayers.

Various $(MnTe)_n/(CdTe)_{12}$ structures were grown by MBE either on semi-insulating (001) GaAs wafers with 3-$\mu$m thick CdTe buffers or directly on $Cd_{0.88}Zn_{0.12}Te$ substrates. A $(MnTe)_8/(Cd_{0.64}Zn_{0.36}Te)_8$ structure grown on $Cd_{0.64}Zn_{0.36}Te$ buffer layer has been also investigated for comparison. It should be mentioned that for the $(MnTe)_8/(Cd_{0.64}Zn_{0.36}Te)_8$ structure, the strain is absent. The number of repetitious of periods varied from 20 to 200. Raman scattering experiments were performed in quasi-backscattering geometry using a Jobin Yvon U1000 double spectrometer equipped with a photomultiplier, the 514.5 nm $Ar^+$ laser line was applied for the excitation. The samples were mounted on the cold finger of a continuous-flow helium cryostat.

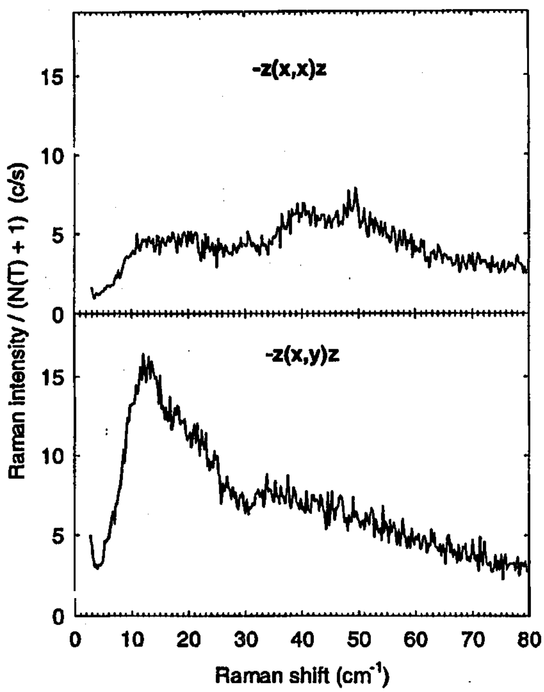


Fig. 1. Raman scattering spectra taken at 27.6 K for $(MnTe)_{24}/(CdTe)_{12}$ structure in different polarizations. Upper experimental curve corresponds to the $\overline{z}(x,x)z$ polarization in which the scattering by folded acoustic phonons is allowed (and the scattering by magnetic excitations is forbidden in the case of bulk material). In the $\overline{z}(x,y)z$ polarization (lower curve) the scattering by folded acoustic phonons is forbidden and by magnetic excitations allowed.

In the low frequency part of the Raman scattering spectra (from 5 $cm^{-1}$ to 70 $cm^{-1}$) taken in the $\overline{z}(x,x)z$ polarization, small structures were seen at all temperatures investigated. In the same frequency range, a complex structure was observed at low temperatures below 80 K in the $\bar{z}(x,y)z$ polarization. In order to discuss the various Raman scattering mechanisms, the original experimental spectra have been divided by the population factor given by the Bose–Einstein distribution function. An example of two spectra under consideration, taken at 27.6 K for the $(MnTe)_{24}/(CdTe)_{12}$ multilayer is shown in Fig. 1.

In the $\bar{z}(x,x)z$ polarization, observation of the folded acoustic phonons is allowed by the selection rules. Thus, we interpret the above-mentioned structures as resulting from the Raman scattering by folded acoustic phonon modes. The detailed analysis of these acoustic phonons is beyond the scope of this work. Such analysis at room temperature was previously performed on our samples and the results of these studies can be found in Ref. [3]. On the other hand, the structures observed in the $\bar{z}(x,y)z$ polarization were previously not observed and we shall concentrate on discussion concerning possible physical mechanism responsible for this scattering.

In spite of experimental difficulties resulting from small Raman scattering intensity corresponding to the observed effect very similar structures were found for all investigated samples. Since they are also present in strain-free samples, the structures cannot simply result from the Raman scattering caused by the strain-related effects. There are also strong arguments against their connection with the folded acoustic phonons. First, the detailed comparison of the Raman spectra taken in the $\bar{z}(x,x)z$ and $\bar{z}(x,y)z$ polarizations shows that the characteristic frequencies are different in these two polarizations. Moreover, observation of the folded acoustic phonons in $\bar{z}(x,y)z$ polarization is forbidden by the selection rules. Finally, it should be stressed that the above-mentioned structures are observed only in the low temperature region and disappear at higher temperatures (e.g., they do not exist at room temperature). Such behaviour is in clear contradiction to the well-known properties of the Raman scattering by acoustic phonons and this mechanism should be definitively excluded.

An alternative possible mechanism which could be taken into consideration is the Raman scattering related to electronic transitions. Such effects have been observed for other II–VI materials (e.g., for CdTe doped with Fe [4]). However, such Raman scattering mechanism strongly depends on temperature: the structures observed at 10–12 $cm^{-1}$ should disappear well below 30 K. In contrast, they are still clearly observable for $T$ approaching 60 K. In our opinion, this temperature behaviour of the discussed structures demonstrates that they are not related to the electronic transitions.

Yet another possibility which could be taken into consideration is the magnetic origin of the structures. Magnetic excitations (magnons) were observed in the $\bar{z}(x,y)z$ polarization for thick layers of cubic MnTe at about 34 $cm^{-1}$ at low temperatures [2]. The structures in the multilayer spectra are seen in the same polarization and, also, disappear at temperatures close to the Néel temperature in the bulk cubic MnTe. For thick MnTe slabs, the bulk-like spin waves could propagate both in the layer plane as well as along the growth direction of the film. Considering a single layer consisting of $n$ atomic planes one can expect that only discrete values of the magnon energy will be allowed for the modes with zero in-plane wave vector (standing modes) due to the quantization of the magnon

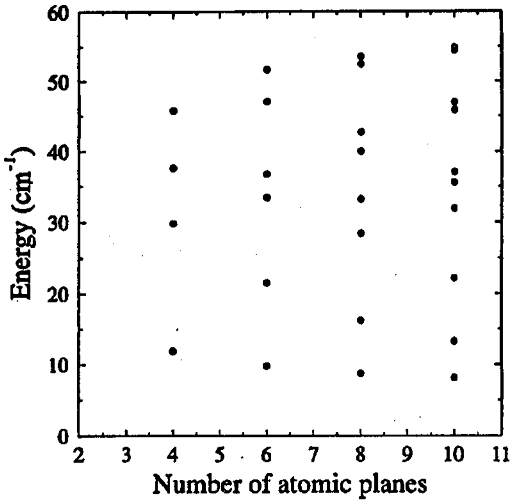


Fig. 2. Frequencies of the standing magnon modes calculated for a few thin MnTe layers.

wave vector perpendicular to the plane [5]. The energies of the standing modes calculated for various thicknesses of MnTe layers are shown in Fig. 2. As one can see, the expected mode frequencies correspond to the spectral region where the discussed structures are observed. It is possible that the observed structure consists of several, unresolved peaks. Traces of such fine structure can be found indeed in the Raman spectra (unfortunately, their quantitative analysis is not possible). Under these circumstances, we attribute this new structure to the magnetic excitations in a thin MnTe layer. This suggested interpretation should be confirmed by more precise measurements performed with a higher spectral resolution on multilayers with a smaller number of MnTe atomic planes. If it confirmed, our study would be the first observation of the magnetic excitations in a II–VI multilayer structure by the Raman scattering measurements.

## Acknowledgments

Authors express their gratitude to Dr. B. Jusserand and Dr. R Świrkowicz for their helpful comment.

## References

[1] T.M. Giebułtowicz, P.K. Kłosowski, N. Samarth, H. Luo, J.K. Furdyna, J.J. Rhyne, *Phys. Rev. B* **48**, 12817 (1993).

[2] W. Szuszkiewicz, E. Dynowska, E. Janik, G. Karczewski, T. Wojtowicz, J. Kossut, M. Jouanne, in: *Proc. 23 Int. Conf. Phys. Semicond., Berlin 1996*, Eds. M. Scheffler, R. Zimmerman, Vol. 1, World Scientific, Singapore 1996, p. 385.

[3] W. Szuszkiewicz, E. Dynowska, E. Janik, G. Karczewski, T. Wojtowicz, J. Kossut, M. Jouanne, *Acta Phys. Pol. A* **88**, 357 (1996).

[4] M. Jouanne, C. Testelin, C. Rigaux, A. Mycielski, *Solid State Commun.* **83**, 1061 (1992).

[5] J. Barnaś, R. Świrkowicz, *Physica B* (in press).