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STRUCTURAL AND ELECTRICAL PROPERTIES OF LOW CONCENTRATION SnTe LAYERS AND PbTe/SnTe HETEROSTRUCTURES GROWN BY MBE

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We analyse properties of thin SnTe layers and PbTe/SnTe heterostructures grown by MBE on $BaF_2(111)$ substrates. Reflection high energy electron diffraction patterns registered during MBE growth of the samples as well as post-growth X-ray diffraction measurements evidence a high structural perfection of 0.6 μm thick SnTe layers and (50 Å PbTe)/(50 Å SnTe) superlattices. The full width at half maximum values of (222) X-ray rocking curves measured for these thin SnTe layers crystallized in the optimal MBE growth conditions are about 300 arcsec; the carrier concentrations can be tuned from 5×10^{19} cm^{-3} to 10^{21} cm^{-3} depending on the MBE process parameters.

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1. Introduction

PbTe, SnTe and ternary PbSnTe compounds have been extensively studied because of applications in mid-infrared photodetector and laser structures [1, 2]. This interest was especially driven by the fact that due to the symmetry inversion of valence and conduction band states between PbTe and SnTe [3, 4], the band gap value of PbSnTe alloys can be tuned from 190 meV, for PbTe at 4 K, down to 0 meV. The MBE growth technique offers a possibility of crystallizing PbTe and SnTe thin films with low concentrations and high carrier mobilities. In this work we have investigated structural and electric properties of 0.6 to 2 μm thick SnTe layers, PbTe/SnTe heterostructures and superlattices (SLs) grown by MBE on $BaF_2(111)$ substrates.

Samples were grown in the MBE system designed and manufactured in the Institute of Physics of the Polish Academy of Sciences in Warsaw. As the source materials *p*-type PbTe and SnTe effusion cells were used. To control the carrier

concentration the additional Te effusion cell was applied. The background pressure during growth was about 10^{-9} hPa. Freshly cleaved $BaF_2(111)$ oriented platelets were used as substrates. On cleaving (in air) they were immediately mounted to the MBE introduction chamber. Prior to the growth, the substrates were heated to 300°C for 15 min. After preheating reflection high energy electron diffraction (RHEED) diffraction pictures evidenced smooth, monocrystaline BaF_2 substrate surface. Flux intensities were controlled by the quadrupole mass spectrometer, the growth rate — by recording RHEED intensity oscillations.

Three kinds of samples were grown: (i) single SnTe layers without (sample 1) and with additional Te flux (sample 2), (ii) two layer SnTe/PbTe heterostructures (sample 3), (iii) (50 Å SnTe)/(50 Å PbTe) superlattices on SnTe, $Pb_{0.5}Sn_{0.5}Te$ and PbTe buffer layers grown on $BaF_2(111)$ substrates (samples 4-SL4, 5-SL5 and 6-SL6, respectively).

The lattice constants of BaF_2, SnTe and PbTe are: 6.200 Å, 6.321 Å and 6.461 Å. As a consequence the superlattice grown on $Pb_{0.5}Sn_{0.5}Te$ is lattice matched to the buffer layer, SLs grown on SnTe and PbTe buffers are under compressive or tensile strain, respectively.

2. Structural parameters

RHEED diffraction patterns registered during MBE growth of the samples evidenced the presence of smooth, monocrystalline surfaces. Usually a specular spot and a weak (2×1) reconstruction of PbTe or SnTe surface was seen. The streaky RHEED patterns were observed even for about 50 Å thick SnTe layers.

X-ray diffraction measurements were performed using a low-resolution diffractometer for a preliminary structural characterization, and then, a high-resolution one equipped with a four-reflection Bartels monochromator for precise studies of rocking curves and reciprocal space maps (RSMs). The FWHM values of the 222 rocking curves of 0.6 μm and 1.5 μm thick SnTe films were 360 and 190 arcsec, respectively, which mean that the crystal quality of the films was good enough.

Figure 1 shows the 222 rocking curves for the superlattices SL4, SL5 and SL6. Diffraction satellites up to four order are visible. From their angular distances the superlattice periods were determined: $C_{SL4} = 130$ Å, $C_{SL5} = 100.8$ Å and $C_{SL6} = 106$ Å. The narrowest diffraction lines observed in the rocking curve of SL5, as well as the number of satellites, suggest the best structural quality in comparison to SL4 and SL6.

RSMs of symmetrical 222 and asymmetrical 242 reflections have been performed. Especially useful are the asymmetrical RSMs (presented in Fig. 2) because they give directly information about the strain state of the SLs. The analysis of these results allows us to conclude that all SLs are relaxed — in the case of SL4 and SL6 the reciprocal lattice points (RLPs) of satellites and buffer do not lie along the same line which means that 0-satellite and buffer have different lateral lattice constants. In the case of SL5 the RLP positions of 0-satellite and buffer are in the same place which means that the average value of lattice constant of SL is equal to the buffer one or, in other words, the lattice mismatch between buffer and SL is equal to zero.

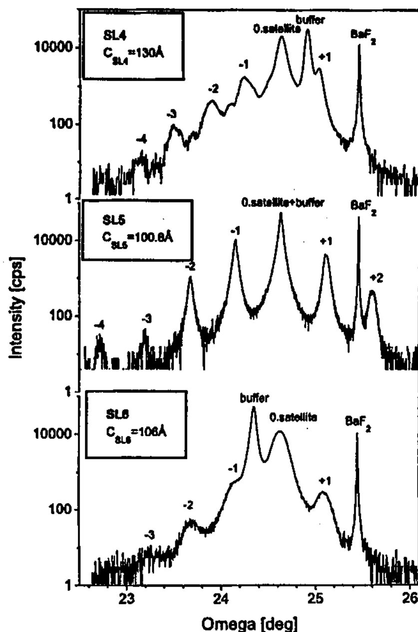

Fig. 1. 222 rocking curves for superlattices: SL4 — grown on SnTe buffer, SL5 — grown on $Pb_{0.5}Sn_{0.5}Te$ buffer, and SL6 — grown on PbTe buffer.

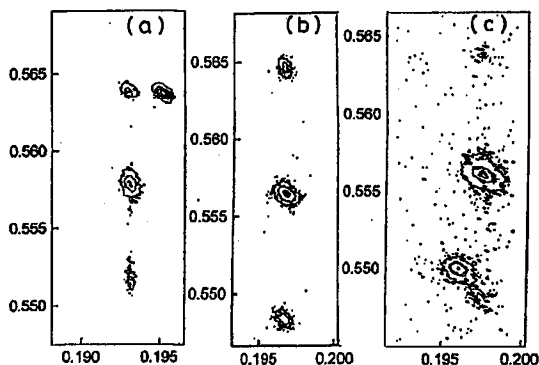

Fig. 2. Reciprocal space maps of asymmetrical 242 reflection for superlattices SL4 (a), SL5 (b), and SL6 (c). The axes are marked in units of $\lambda/2d$.

3. Electrical parameters

The electrical parameters of single SnTe layers (samples 1 and 2), SnTe/PbTe 2-layer structure (sample 3) and PbTe/SnTe SLs (samples 4, 5 and 6) are listed in Table. From earlier measurements we know that our single PbTe layers are n-type with carrier concentrations of 5×10^{17} cm^{-3}. All the PbTe/SnTe heterostructures measured exhibited the p-type conductivity. R_H values for the structures with thick SnTe buffer layers (samples 3 and 4) are significantly lower (two orders of

TABLE

Electrical parameters of SnTe layers, PbTe/SnTe 2-layer structure and PbTe/SnTe superlattices measured at $T = 4.2$ K and magnetic field $B = 1$ T.

Sample No.	Sample description	R_H [cm^3/C]	σ [(Ω cm)$^{-1}$]	n [cm^{-3}]	μ [cm^2/(V s)]
1	SnTe layer	0.138	3.03×10^4	4.63×10^{19}	4084
2	SnTe + Te layer	0.00662	3.29×10^4	9.43×10^{20}	217
3	PbTe/SnTe	0.054	2.98×10^4	1.15×10^{20}	1483
4	PbTe/SnTe SL	0.0455	5.10×10^4	1.37×10^{20}	2320
5	PbTe/SnTe SL	1.028	1.07×10^3	6.06×10^{18}	1105
6	PbTe/SnTe SL	0.85	3.93×10^3	7.33×10^{18}	3341

magnitude) in comparison with those grown on PbTe and $Pb_{0.5}Sn_{0.5}Te$ buffers (samples 5 and 6). In the case of PbTe/SnTe heterostructures and SLs the values of concentration, defined as $n = 1/eR_H$ and mobility $\mu = \sigma R_H$ have no straightforward physical meaning — they are calculated as for single layers with a thickness equal to the sum of a buffer and SL structure thickness. However, from the data presented in Table one may conclude that the R_H and σ values for PbTe/SnTe SL reveal rather the parameters of the 2 μm thick buffer layer, than the parameters of a 0.5 μm thick SL structure.

4. Conclusions

We have demonstrated the possibility of controlling the carrier concentration in the MBE grown SnTe thin films, in the range of 5×10^{19}–10^{21} cm^{-3}. X-ray diffraction (XRD) measurements of the short period PbTe/SnTe superlattices crystallized on different buffers: lattice matched ($Pb_{0.5}Sn_{0.5}Te$), compressive strain (SnTe) and tensile strain inducing (PbTe) showed the different structural parameters of these structures. The best — for the lattice matched SL, and the worse — for SL under tensile strain (crystallized on the PbTe buffer). Electrical properties of these structures obtained from the Hall measurements in the geometry parallel to superlattice planes, have shown that the electrical parameters of the whole structure are determined much more by the buffer layer. The dislocation density and strain state of the superlattice are less important.

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