Structural characterization of partially relaxed hybrid radial (Pb,Sn)Te/WZ-GaAs nanowires as promising candidates for topological insulator nano-devices

M. Wojcik[1], *S. Dad*[1], *W. Zajkowska-Pietrzak*[1], *P. Dziawa*[1], *S. Kret*[1], *W. Pacuski*[2], *J. Sadowski*[1,2,3]

[1] *Institute of Physics, Polish Academy of Sciences, Aleja Lotnikow 32/46, PL-02-668 Warsaw*
[2] *Faculty of Physics, University of Warsaw, Pasteura 5, 02093 Warsaw, Poland*
[3] *Ensemble3 Centre of Excellence, Wolczynska, 01-919 Warsaw, Poland*

Introduction

Topological crystalline insulators (TCIs) belong to extensively investigated research area of topological quantum matter. The interest in TCIs stems from the presence of topologically protected Dirac states on high symmetry surfaces of TCI crystals. (Pb,Sn)Te solid solution is one representative of TCIs, with topological phase occurring above some critical Sn content. Since topologically protected states in TCIs are surface properties we have studied this material in quasi one dimensional nanowire (NW) geometry providing high surface-to-volume ratio. To further enhance the surface-related properties we have chosen to investigate core-shell NW heterostructures with wurtzite (WZ) GaAs cores and (Pb,Sn)Te shells [1] instead of uniform NWs [2,3].

Experimental

Core-shell NW heterostructures have been grown by molecular beam epitaxy using two distinct MBE systems dedicated to III-V, and IV-VI semiconductors. The interface structure of WZ-GaAs/(Pb,Sn)Te NWs is investigated using wide range of characterization techniques, such as high resolution transmission electron microscopy (HR-TEM), scanning transmission electron microscopy (STEM), geometric phase analysis (GPA) and energy dispersive x-ray spectroscopy (EDX).

Dislocation and moiré fringes distances as well as lattice mismatch values were calculated using simple equations:

$$f = (a_{sub} - a_{lay})/a_{lay}$$

$$d_{dist} = a_{lay} * \left(\frac{a_{lay}}{a_{sub} - a_{lay}}\right)$$

$$d_{moire} = \frac{a_{sub} * a_{lay}}{a_{sub} - a_{lay}}$$

Conclusions

We have shown that (Pb,Sn)Te can be successfully grown as continuous full or half-shells on the sidewalls of GaAs NWs. This provides opportunity for investigation of topological surfaces of TCIs in the tubular geometry.

Measured moiré distances match measured dislocation distances in measured samples. This provide opportunity for complementary method of strain analysis in investigated materials.

References and acknowledgements

[1] Dad, S., Dziawa, P., Zajkowska-Pietrzak, W. et al. „Axially lattice-matched wurtzite/rock-salt GaAs/Pb1−xSnxTe nanowires". Sci Rep 14, 589 (2024)
[2] P. Dziawa, et al., Cryst. Growth Des. 10, 109 (2010)
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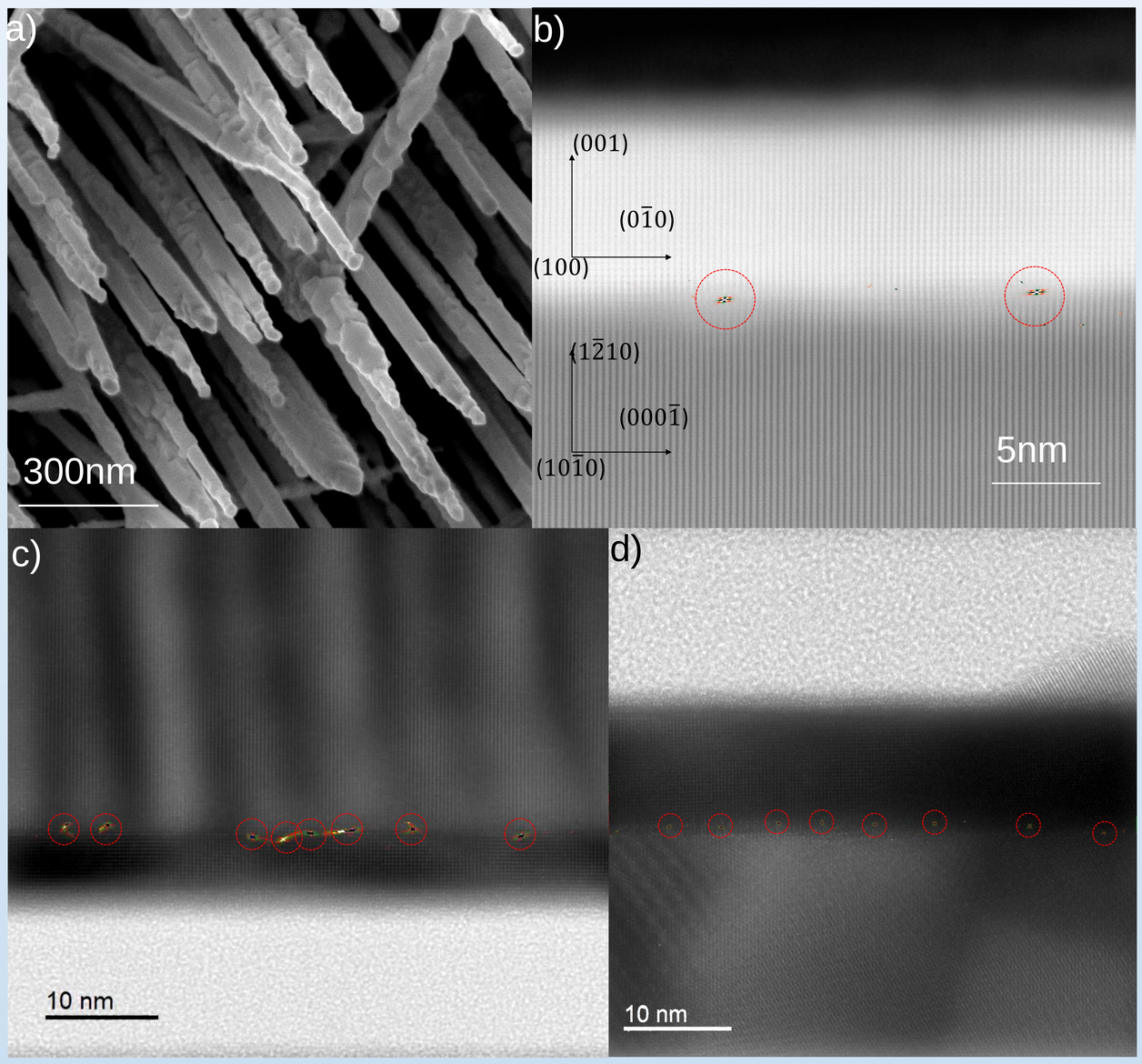
Results



Results are presented for three selected nanowire samples: WZ-GaAs/$PbSn_xTe$ x=0.53, x=0.63 and WZ-GaAs /PbTe.

Misfit dislocations are observed as a direct result of the lattice mismatch between the core and the shell materials. Measured distances of moiré fringes match calculated spacings of misfit dislocations, which are observed to be higher than the calculated values, suggesting the presence of a residual strain within the structures.

Fig. 1 SEM image (a) and STEM image of core-shell interface (b) of WZ-GaAs/PbSnxTe x=0.53 nanowires, HR-TEM images of core-shell interfaces of WZ-GaAs/PbSnxTe x=0.63 (c) and WZ-GaAs/PbTe (d) nanowires. Red circles marks positions of dislocations.

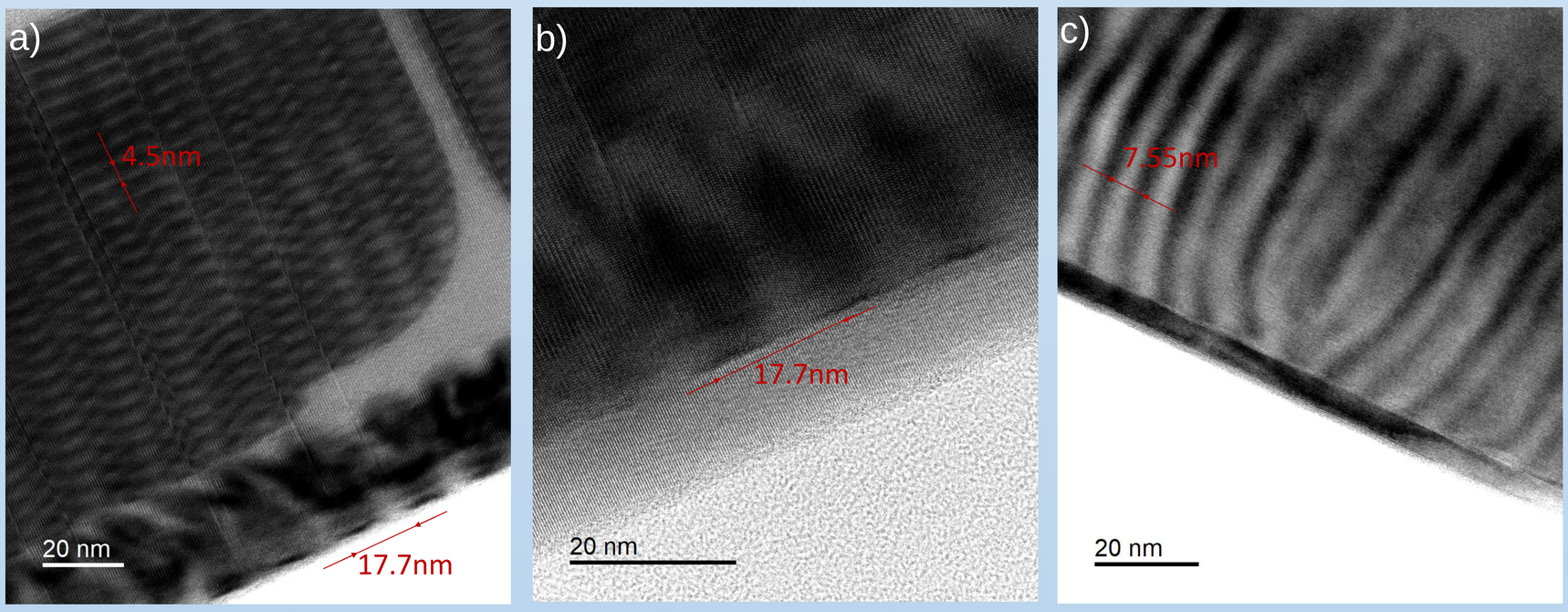
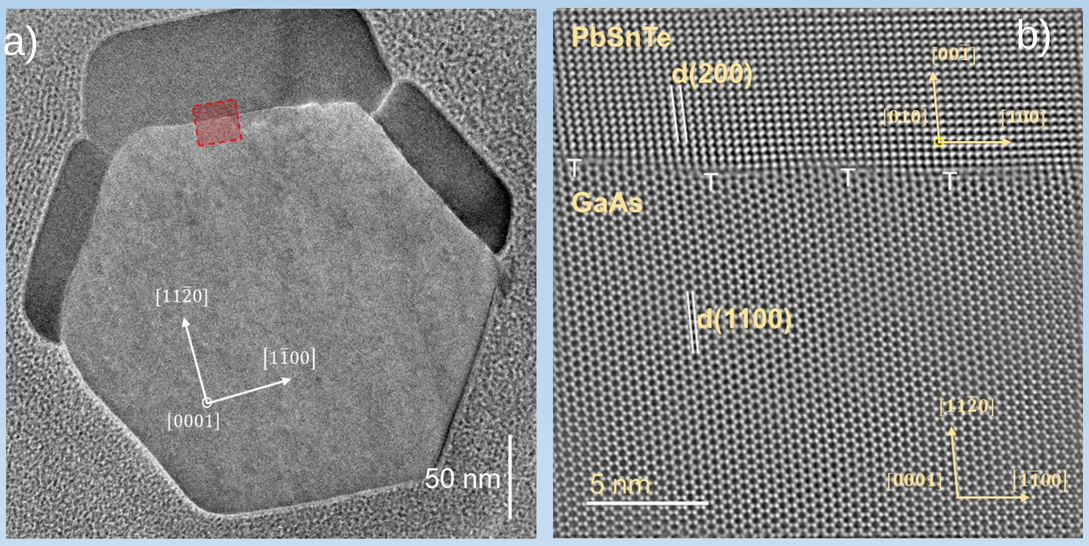


Fig. 2 HR-TEM images of WZ-GaAs/$PbSn_xTe$ x=0.53 (a,b) and WZ-GaAs/$PbSn_xTe$ x=0.63 (c) nanowires with marked averaged moiré fringes distances.

Sample	a_{Shell} (nm)	a_{Core} (nm)	dislocation distance (calculated, nm)	dislocation distance (measured, nm)	moiré distance (calculated, nm)	moiré distance (measured, nm)	lattice mismatch (calculated)
PbSn0.53Te	0.333	0.345	8.99	17.13	9.57	17.73	0.036
PbSn0.63Te	0.321	0.336	6.81	9.34	7.19	7.55	0.047
PbTe	0.318	0.342	4.23	4.99	--	--	0.075

Tab. 1 calculated and measured dislocation and moiré fringes distances and calculated lattice mismatch for presented samples.



aShell (nm)	aCore(nm)
0.322	0.345
Dislocation distance (calculated, nm)	Dislocation distance (measured, nm)
3.37	5.3
Lattice mismatch (calculated)	
0.814	

Tab. 2 Experimental and theoretical parameters of tangential interplanar spacings, lattice mismatch to GaAS core and strain in WZ-GaAs/$Pb_{0.44}Sn_{0.56}Te$ NWs from Fig. 3.

Fig. 3 TEM image of WZ-GaAs/$Pb_{0.44}Sn_{0.56}Te$ NW cross-section: low-resolution image of the cross-section (a) and high-resolution image of core-shell interface taken at red rectangle marked region from (a). Misfit dislocations in the core-shell interface are marked with white "T" symbols [1].