Cylindrically confined superparamagnetic MnAs nanocrystals embedded in wurtzite (In,Ga)As-(Al,Ga)As core-shell nanowires

J. Sadowski,[1,2,3] **S. Kret,**[2] **A. Kaleta,**[2] **B. Kurowska,**[2] **M. Sawicki**[2]

[1] *Department of Physics and Electrical Engineering, Linnaeus University, SE-391 82 Kalmar, Sweden*

[2] *Institute of Physics, Polish Academy of Sciences, Aleja Lotników 32/46, PL-02-668 Warszawa, Poland*

[3] *MAX IV laboratory, Lund University, P.O. Box 118, SE-221 00 Lund, Sweden*

The nanometer-size superparamagnetic MnAs nanocrystals confined in the nanotube geometry have been fabricated by high-temperature annealing of the MBE-grown core-shell nanowires comprising (Ga,Mn)As dilute ferromagnetic semiconductor. The annealing induced decomposition of (Ga,Mn)As, has already been studied, but only for layered structures based on the native zinc-blende (Ga,Mn)As parent phase. We have demonstrated before, that it is possible to obtain (Ga,Mn)As in the wurtzite structure, by low temperature MBE growth at the side-walls of wurtzite (In,Ga)As nanowires [1,2]. Because of the well-known thermal instability of (Ga,Mn)As [3] the moderate-to-high temperature (300 – 600 ^{o}C) post-growth annealing of NWs with (Ga,Mn)As shells causes decomposition of (Ga,Mn)As solid solution into ensemble of MnAs nanocrystals embedded in the GaAs host matrix. MnAs is a ferromagnetic metal with interesting properties, e.g. strong magnetocaloric effects, ferromagnetic phase transition combined with structural phase transition (hexagonal to orthorhombic phase) at a critical temperature T_C of about 40^{o}C. In the nanocrystals embedded in wurtzite GaAs matrix, the hexagonal MnAs phase can be stabilized by strain, hence the T_C in this case can possibly be enhanced with respect to T_C of MnAs in the bulk or layered form.

We have studied different kinds of samples with parent (Ga,Mn)As NW shells grown either directly on (In,Ga)As core NWs, or surrounded by (Al,Ga)As shells. The latter are blocking Mn diffusion during the post-growth annealing process, supporting cylindrical confinement of the nanocrystals. Annealing processes have been performed both *ex-situ* after the MBE growth of initial (In,Ga)As-(Al,Ga)As-(Ga,Mn)As core shell NWs, and *in-situ* in the transmission electron microscope, with use of the specially designed holders enabling annealing up to 700 ^{o}C. Beside radial confinement of MnAs nanocrystals, we have observed their preferential location at the vicinity of the stacking faults defects (typical for III-V nanowires). This effect enables adjusting the axial distribution of MnAs nanocrystals.

This work has been supported by the research projects granted by Carl Tryggers Stiftelse för Vetenskaplig Forskning (Sweden) CTS 16: 393, and by the National Science Centre (Poland) - project no. 2014/13/B/ST3/04489.

[1] A. Siusys, J. Sadowski, et. al., Nano Lett. 14, 4263 (2014).

[2] J. Sadowski, S.Kret, A. Siusys, T. Wojciechowski, K. Gas, M. F. Islam, C. M. Canali and M. Sawicki, Nanoscale, **9**, 2129 (2017).

[3] H. Ohno, Science **281**, 951(1998).

[+] Author for correspondence: Janusz.Sadowski@lnu.se