Ernst Ruska-Centrum für Mikroskopie und Spektroskopie mit Elektronen ER-C

JÜLICH FORSCHUNGSZENTRUM

Core-shell GaAs/GaMnAs magnetic nanowires

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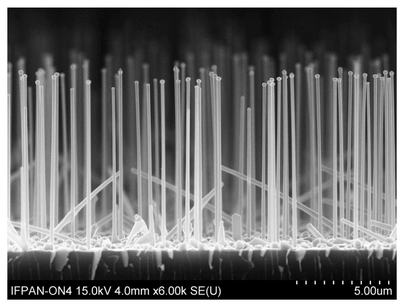
Introduction

Diluted magnetic semiconductors possess characteristics of both semiconductors and ferromagnets and have received significant recent interest due to their spin-dependent physics and novel spintronic functionalities.

The Ga-Mn-As diluted magnetic semiconductor system provides an oppurtunity to prepare nanowires either from pure GaMnAs or in the form of GaAs cores with GaMnAs or MnAs shells [J.Sadowski *et al.* phys.stat.sol B248 (2011) 1576].

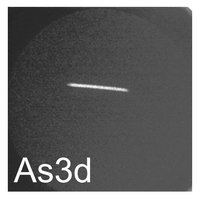
Here, we use transmission electron microscopy (TEM) to study the structures and chemical compositions of GaAs/GaMnAs nanowires.

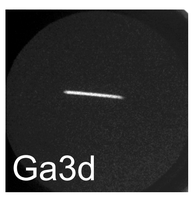
Growth. GaAs nanowires with 15 nm GaMnAs shells were grown self-catalytically on Si (111) using molecular beam epitaxy. The GaMnAs shells were grown at 230 ºC with a nominal Mn concentration of 6.5%. The nanowires typically have zinc-blende structures with <111> growth directions and average diameters of ~150 nm.

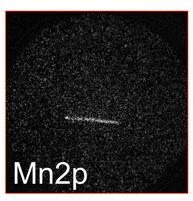


SEM image of as-prepared GaAs/GaMnAs nanowires.

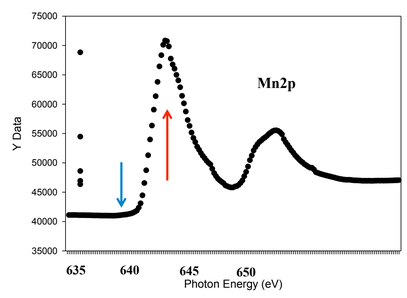
Energy-filtered XPEEM





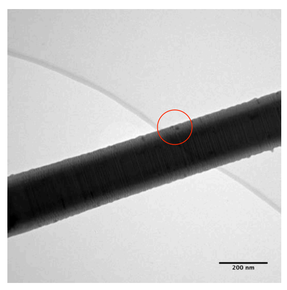


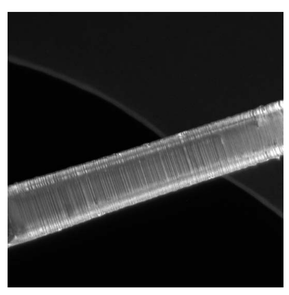
The field of view is 10 µm.

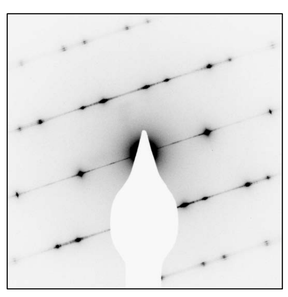


The local chemical state and electronic structure of a single nanowire can be measured using XPEEM. The Mn map indicates a uniform Mn distribution along the nanowire.

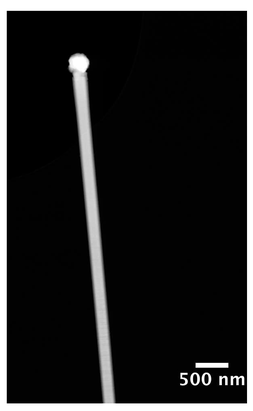
TEM and STEM/EDX

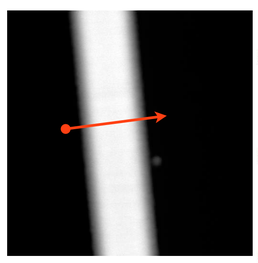


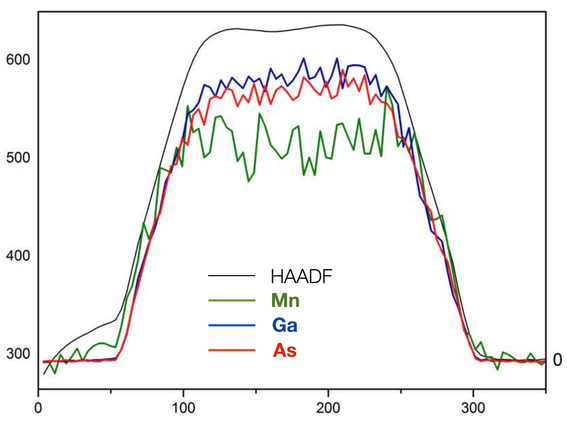




Bright-field, dark-field images and selected area electron diffraction patterns were used to confirm the zinc-blende structure of the GaAs/GaMnAs nanowires, the presence of stacking faults and the presence of additional defects in the GaMnAs shells.

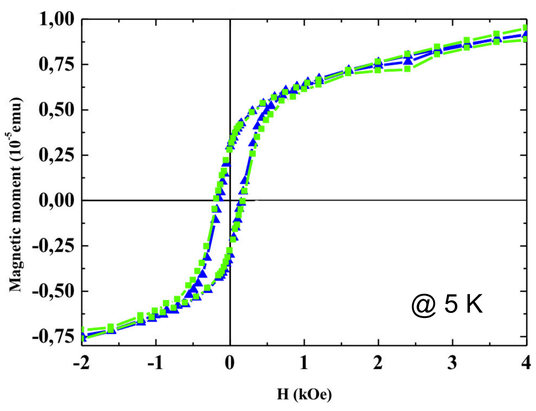


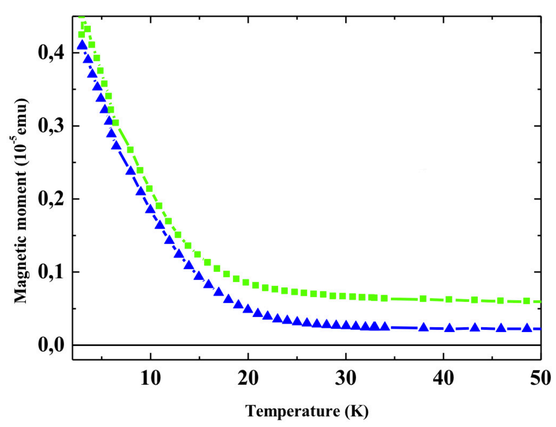




The Mn concentration was measured across a single nanowire using energy dispersive X-ray spectroscopy in the scanning TEM (STEM) and high-angle annular dark-field (HAADF) imaging. The Mn concentration was confirmed to be ~6 at. %. The Mn concentration profile suggests Mn enrichment of the shell.

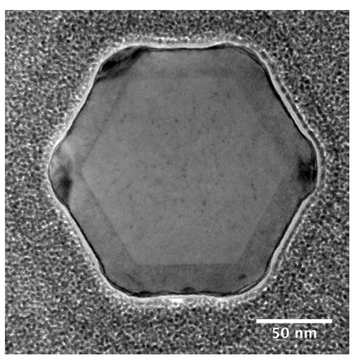
Magnetic properties - SQUID

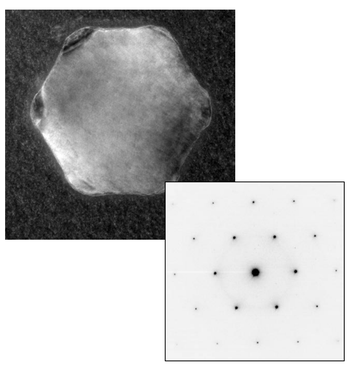


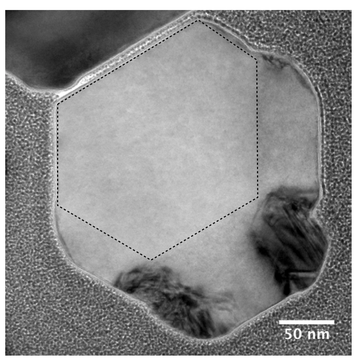


The ferromagnetic properties of the GaAs/GaMnAs nanowires were confirmed using low temperature magnetization measurements performed both perpendicular and parallel to the growth direction.

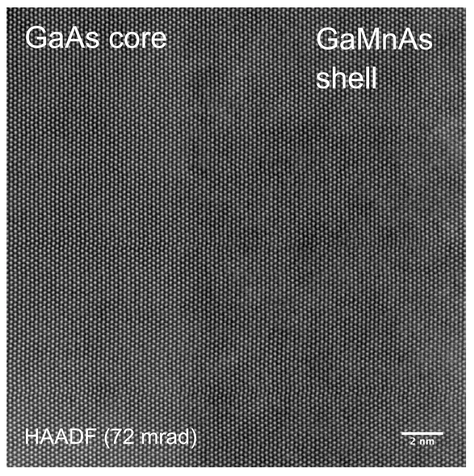
Cross-sectional (S)TEM

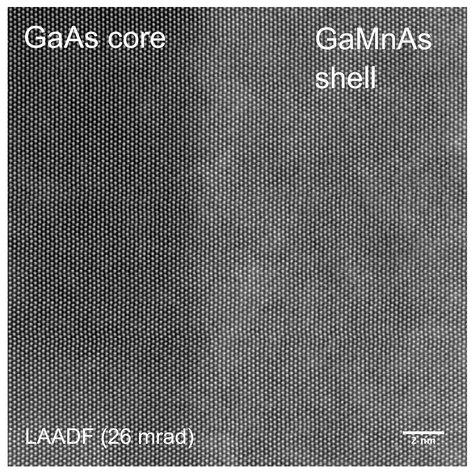




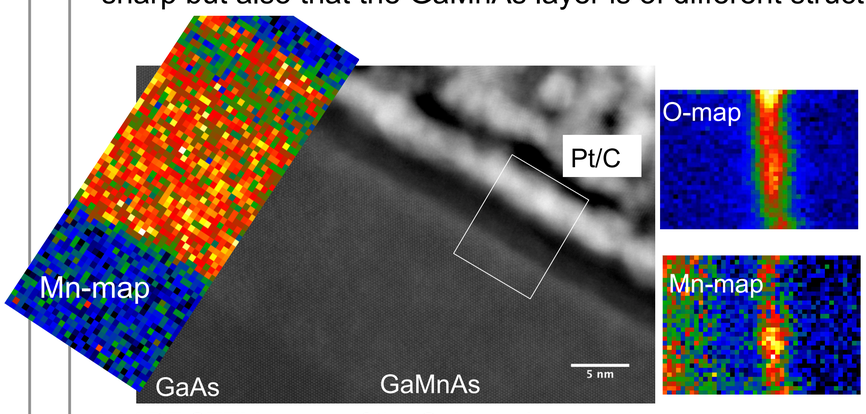


Cross-sectional specimens were prepared using focused ion beam milling and confirmed the epitaxy of the GaMnAs shell on the GaAs core. Bright-field and dark-fields images reveal the presence of defects at the corners of the nanowires.





High-resolution aberration-corrected STEM HAADF and low-angle annular dark-field (LAADF) images indicate that the interface betwen the GaAs and GaMnAs is sharp but also that the GaMnAs layer is of different structural quality than the GaAs.



LAADF STEM image of the GaMnAs layer and corresponding Mn and O maps obtained using EELS spectrum imaging.

Spectrum imaging using electron energy-loss spectroscopy (EELS) reveals a ~1 nm thick amorphous Mn-O layer on the nanowire surfaces. The layer contains ~ 90 at% O and is not thought to be magnetic.

Summary

- Zinc-blende GaAs/GaMnAs core-shell nanowires have been grown on Si (111) with epitaxial ~15 nm thick GaMnAs shells;
- Low temperature measurements confirm that the nanowires are ferromagnetic.
- The shells contain a higher density of structural defects than the cores.
- Future work will focus on imaging magnetic fields in individual nanowires.
- We are grateful to D. Meertens for FIB specimen preparation.