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

JÜLICH FORSCHUNGSZENTRUM

Electron microscopy of Co-doped ZnO thin films

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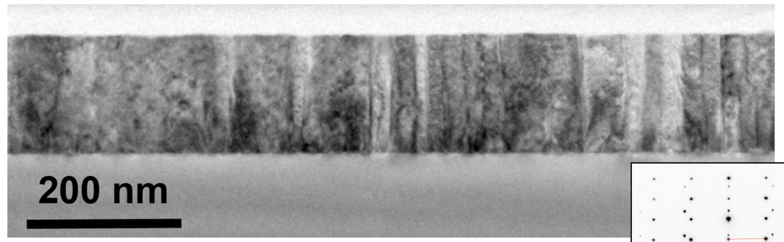
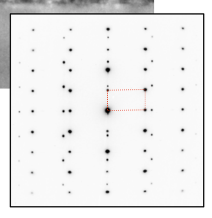
Introduction

Magnetic semiconductors are materials that can exhibit both ferromagnetic and semiconducting properties, and they are widely studied because of their interesting properties and potential applications in future spintronic devices. In ZnO the magnetic properties can be initiated by Co doping. It is important to know information about the Co location in order to understand the magnetic ordering of this material. Poor structural characterization of these materials has led to misinterpretation of the origin of ferromagnetism. In this work, advanced transmission electron microscopy (TEM) is used to study the structure and chemistry of Co-doped ZnO magnetic semiconductor systems.

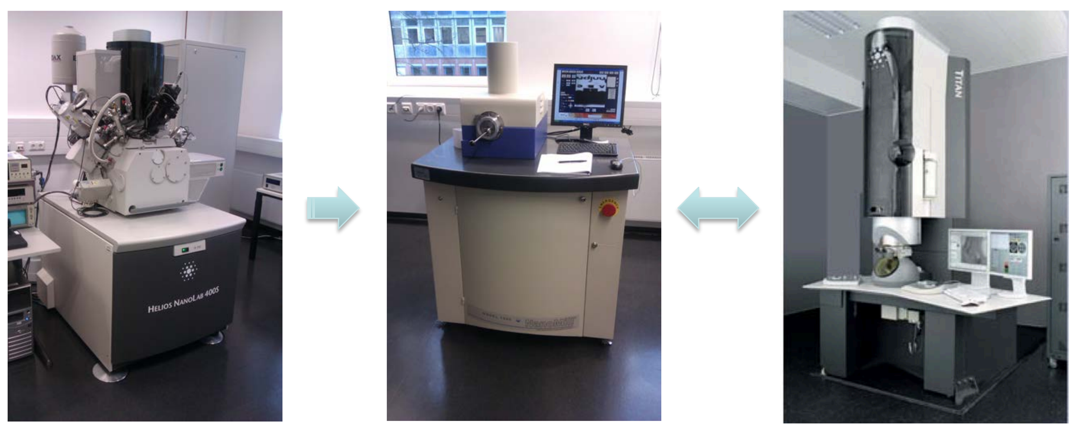
Methods

- Magnetron sputtering $(Zn_{1-x}Co_x)O$, x=10-30 %
- XPS, XLD, SQUID, XANES, XMCD measurements



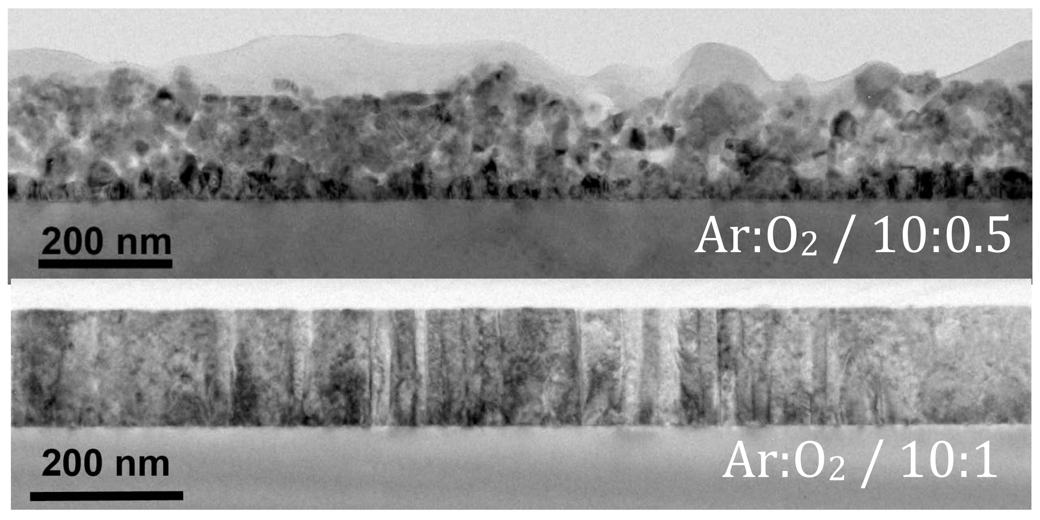


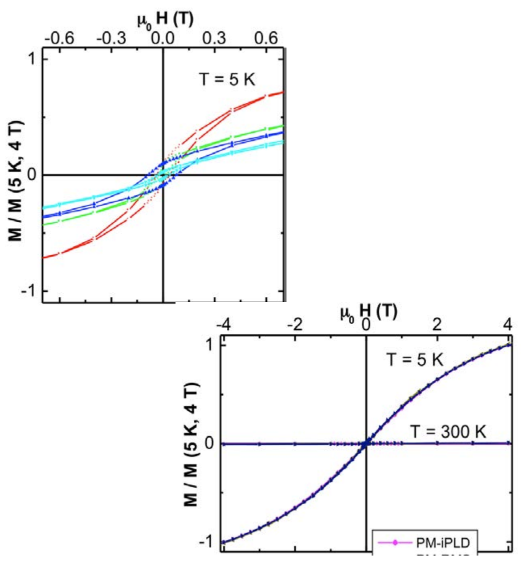
Bright field TEM image of Co:ZnO film deposited on sapphire.



- TEM specimens were prepared by Focused Ion Beam (FEI Helios) using 30 and 5 keV Ga ion beam;
- Surface damaged layer was minimized using low-energy Ar ion milling at 900 and 500 eV (Fischione Nanomill);
- (S)TEM studies were performed using FEI Tecnai and Titan microscopes at 200 and 300 keV respectively.

Effect of deposition conditions

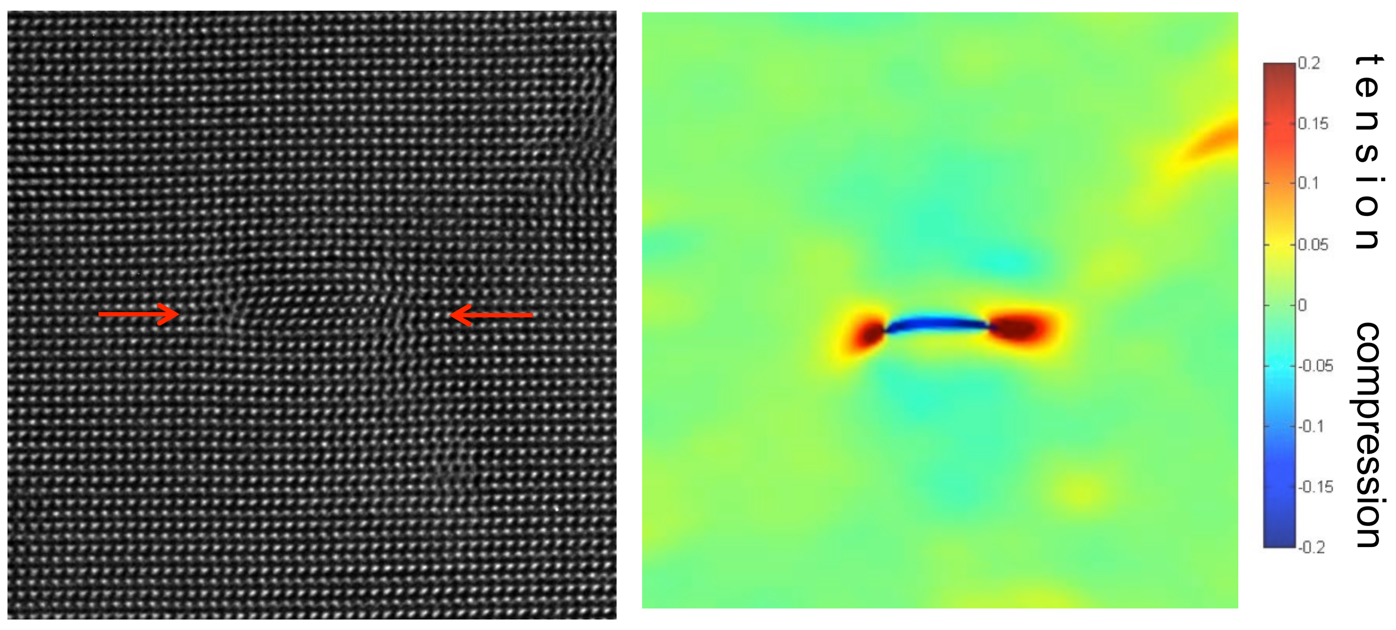




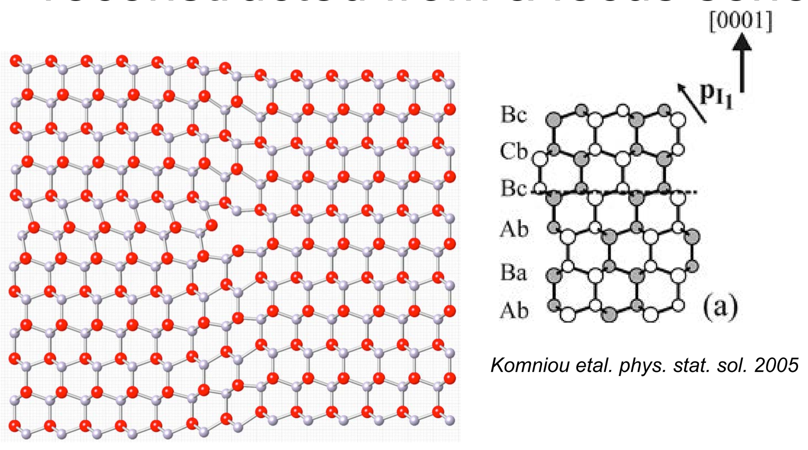
Sputtering conditions were optimized to obtain single-phase wurtzite structure of Co:ZnO. Slight change can change the structure heavily introducing secondary phases that are responsible for super-paramagnetic properties and relatively high Curie temperature of the layers.

Acknowledgements: the authors thanks for valuable help and discussion to Chris Boothroyd, Takeshi Kasama, Martial Duchamp and Martina Luysberg.

Stacking fault in Co:ZnO

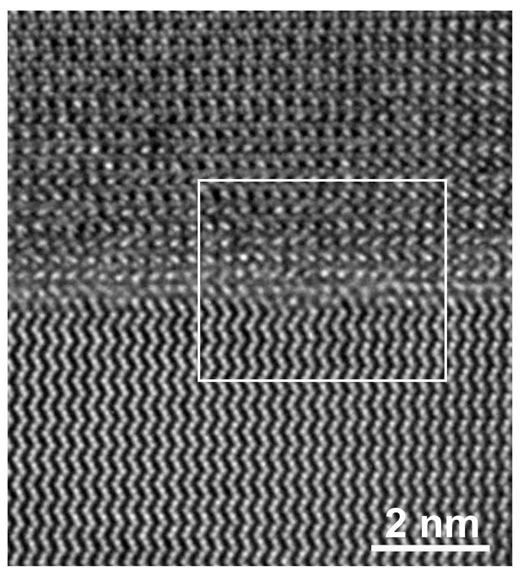


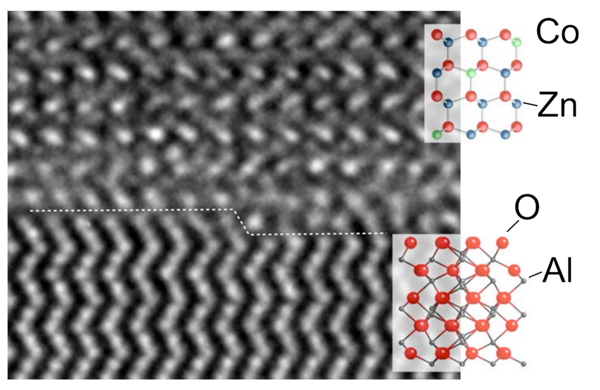
Aberration-corrected TEM image of a stacking fault in Co:ZnO. The imaging conditions were + 12 nm overfocus and -10 μm spherical aberration (C_s). The representative strain map is calculated using GPA method. For GPA, phase image reconstructed from a focus series was used.



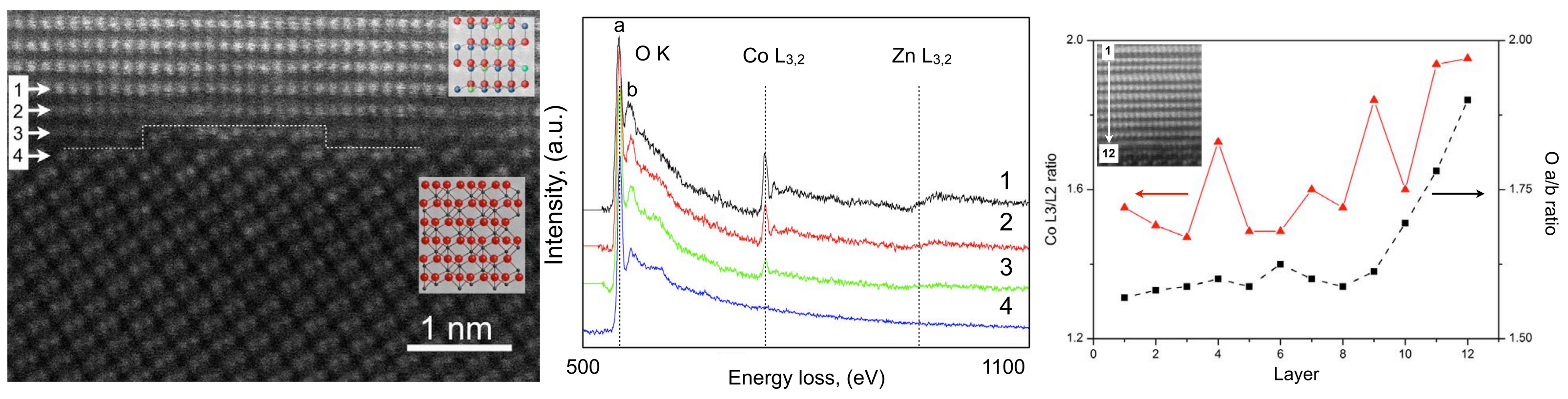
A possible core structure was determined from a HAADF STEM image. The stacking fault is I_1 type with two partial dislocations.

Structure and chemistry of Co:ZnO / sapphire interface

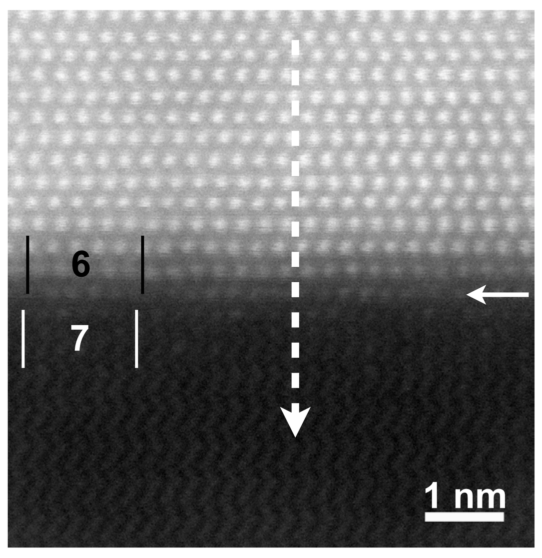


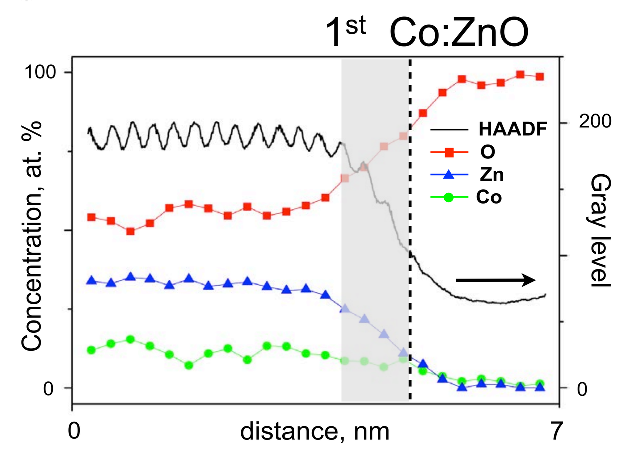


Negative C_s TEM imaging reveals O termination of sapphire and presence of surface steps that did not induce defects into the Co:ZnO layer.



Aberration-corrected HAADF STEM image of the interface shows steps on the sapphire surface. EELS spectra were recorded from the numbered layers showing Co enrichment in the first layers of Co:ZnO. $L_{2,3}$ and $K_{a,b}$ ratios confirm the composition change of Co:ZnO close to the substrate.





HAADF STEM image of the interface and distribution of O, Zn and Co across the interface extracted from a EDXS measurement. The first layers are O-rich and Zn-defficient.

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