Exploring the magnetic microstructure of spinodal alloys with differential phase contrast (DPC) - STEM

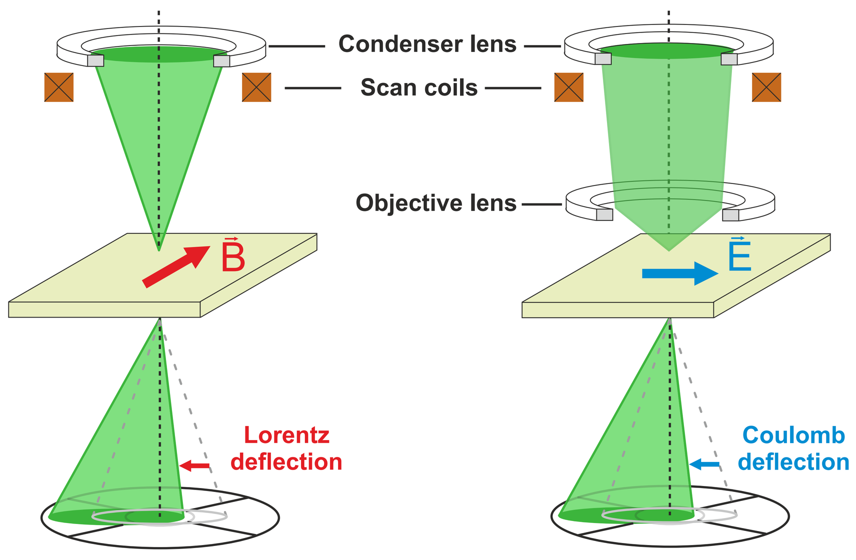
Thomas Radlinger[1], Ferdinand Hofer[1,2] and Gerald Kothleitner[1,2]

1. Institute of Electron Microscopy and Nanoanalysis, Graz University of Technology, Steyrergasse 17, 8010 Graz, Austria
2. Graz Centre for Electron Microscopy, Steyrergasse 17, 8010 Graz, Austria

Motivation

Spinodal alloys have shown to be promising materials in terms of manipulating magnetic properties by controlling their microstructure. Despite extensive research activities on such nano-scale magnetic materials for several decades now, the relationship between the evolution of the microstructure and its magnetic properties still remains to be fully explored.
The chemical structure of CuNiFe alloys segregates into two distinct phases, a NiFe-rich and a Cu-rich one, upon isothermally annealing. Similarly, FeCrCo alloys segregate into FeCo- and Cr-rich phases. Both alloys get ferromagnetic due to the spinodal decomposition.
The aim of this work was to image the unknown magnetic domain structure of both alloys and determine ist relationship to the chemical microstructure.

DPC - STEM

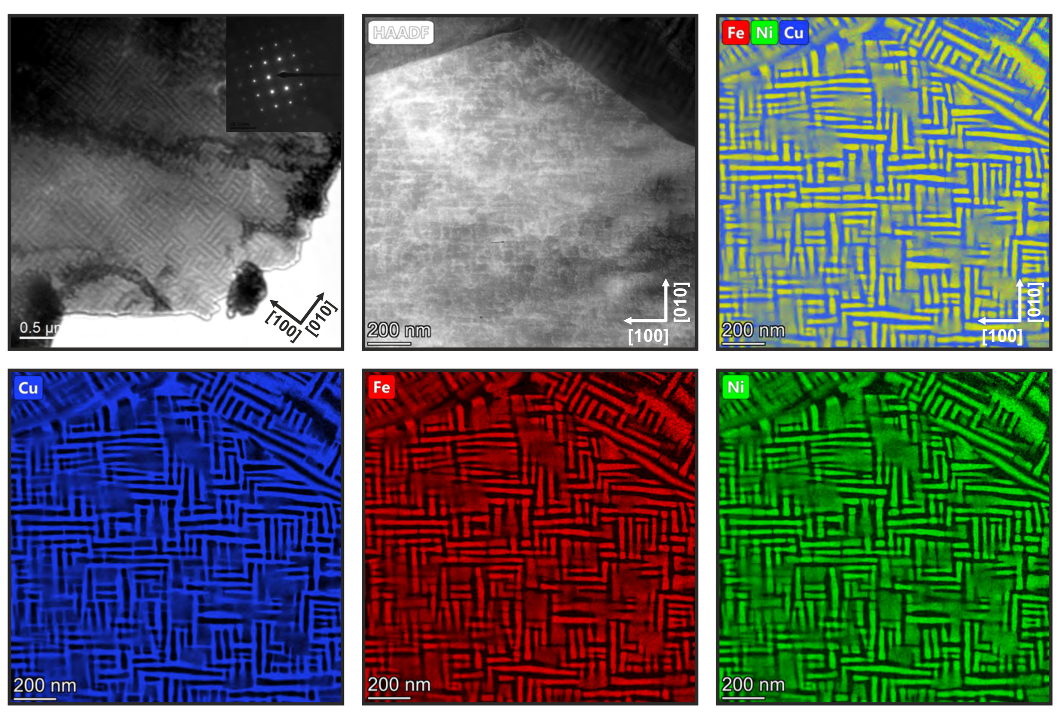


Magnetic and/or electric fields deflect the electron beam (Lorentz or Coulomb deflection). For magnetic measurements, the objective lens has to be switched off.

In DPC - STEM the interaction of the probing electrons with the electromagnetic fields of a specimen is used to image these fields. Upon passing through the field region, the electrons will be slighty deflected and by recording this deflection with a position sensitive detector it is possible to reconstruct the magnetic or electric field structure of the specimen.

Spinodally decomposed $Cu_{52}Ni_{34}Fe_{14}$

Chemical Microstructure



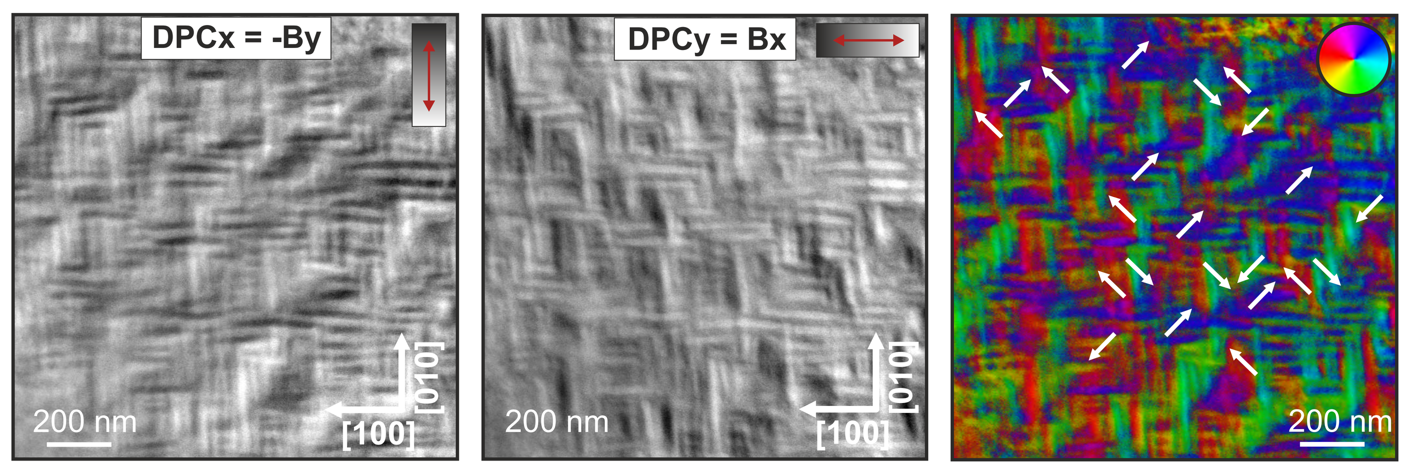
The chemical microstructure was determined using TEM BF and STEM HAADF images together with Cu, Fe and Ni EDXS elemental maps.

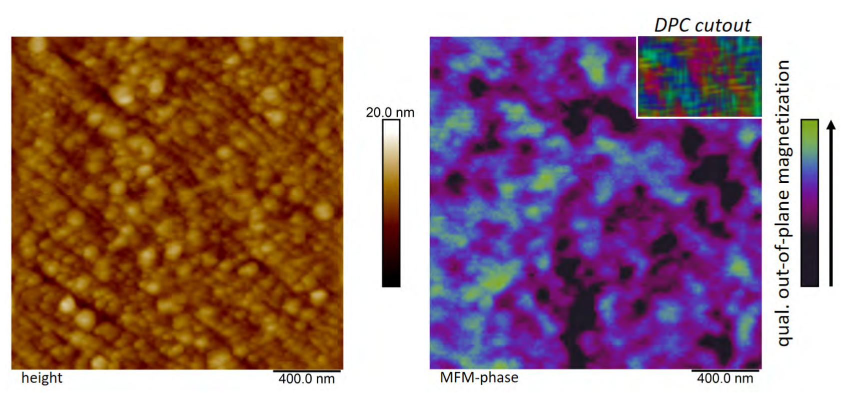
The alloy decomposes into ferromagnetic NiFe-rich platelets growing along the <100> crystallographic directions embedded in a Cu-rich Matrix

Magnetic DPC measurements reveal block-like domains that are confined by the platelet-like structure along <100>

The magnetization within the domains is found to point along <111> meaning that these are the directions of magnetic ease

Magnetic Microstructure



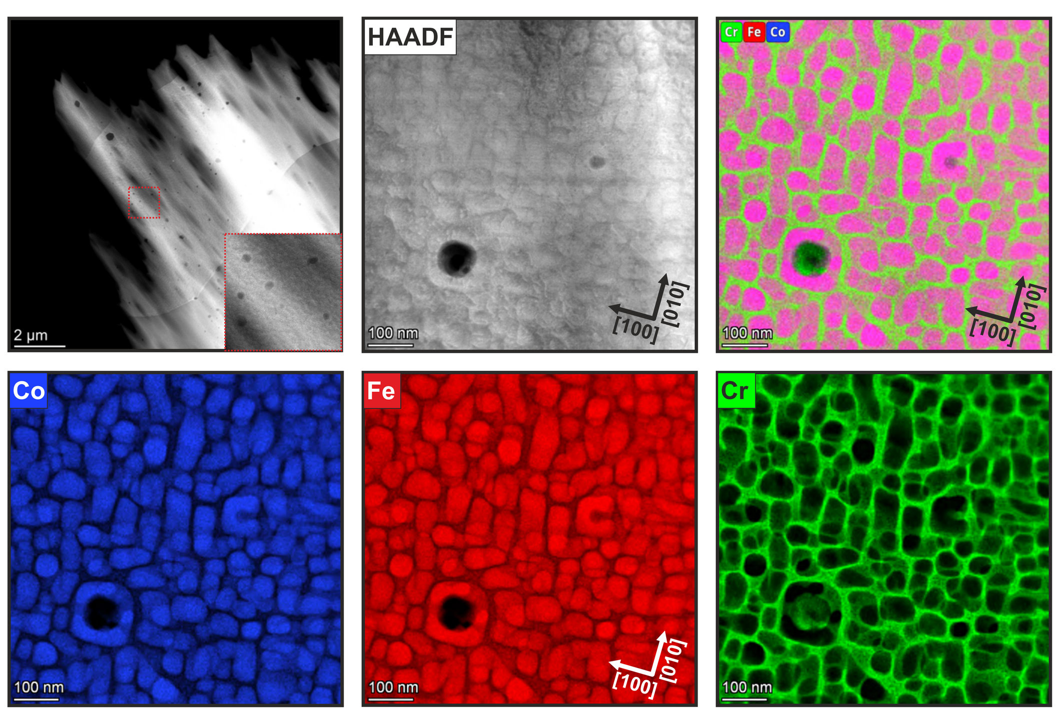


DPC images reveal the in-plane magnetic domain structure

AFM / MFM images reveal a similar out-of plane magnetic structure

in-situ alloyed spinodal $Fe_{54}Cr_{31}Co_{15}$

Chemical Microstructure



The chemical microstructure was determined using STEM imaging together with Co, Fe and Ni - EDXS elemental mapping.

The alloy was additively manufactured and *in-situ* alloyed during the printing process (LPBF process).

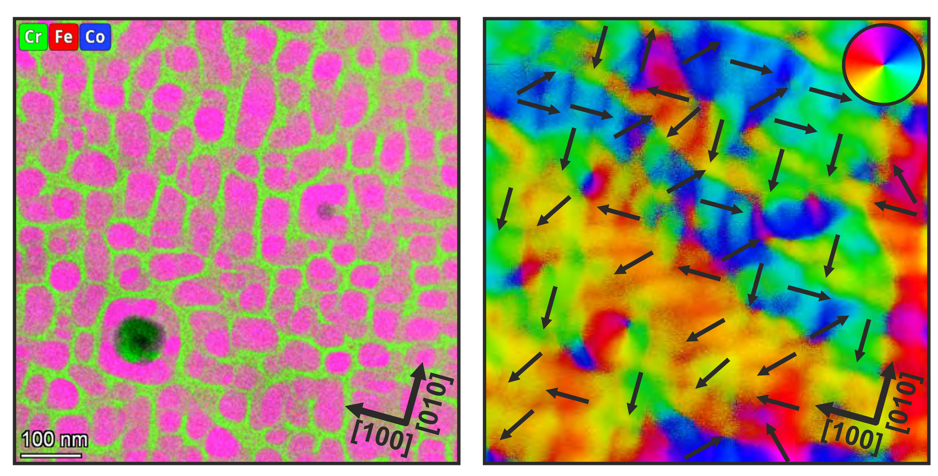
The alloy decomposes into FeCo-rich particles embedded in a Cr-rich Matrix whith the cuboids‘ edges aligning along <100>.

The FeCo-particles cause ferromagnetic behaviour of the alloy.

Magnetic DPC investigations reveal the domain structure. The magnetic domains are considerably larger than the cuboids.

Within the colorized DPC image, the direction of the magnetization is shown as a function of hue.

Magnetic Microstructure



DPC measurements reveal the magnetic domain structure. Direct comparison with the overlay of the EDXS - elemental maps of the same region reveal the coupling of several FeCo-particles to form larger domains. The magnetzation vectors within the domains tend to roughly point along the <100> crystallographic directions.

Conclusion

We have demonstrated the applicability of DPC-STEM to determine the magnetic domain structure of crystalline spinodal alloys using spinodally decomposed CuNiFe and FeCrCo alloys.

Both alloys segregate into ferromagnetic particles within non-magnetic matrices. With EDX spectroscopy the chemical microstructure of the decomposed alloys were determined and linked to the magnetic structure determined by DPC-STEM.

This studies display the new insights we can gain by combining DPC-STEM measurements with other well known (S)TEM imaging and spectroscopy methods

Acknowledgements

Thanks to the European Microscopy Society (EMS) for the financial support (EMS Scholarship).
We thank Prof. Josef Zweck for helpful discussions and Martina Dienstleder for the preparation of the TEM specimens.

Contact

thomas.radlinger@felmi-zfe.at
radlinger@tugraz.at
www.felmi-zfe.at