Exploring Magnetic Phenomena on the Nanoscale of Functional Materials Using Analytical *In Situ* Transmission Electron Microscopy.

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Couplings between magnetic and structural symmetries provide a promising landscape for creating new functional properties. The prospect of harnessing strain gradients to engineer bulk intermetallics with new magnetic properties is an unexplored frontier. Non-centrosymmetric crystal structures are at the origin of magnetic interactions that form stable magnetic structures. We investigate materials which are by nature non-centrosymmetric and materials that locally become non-centrosymmetric when integrating built-in strain gradients. The research presented here has two objectives.

First, we consider skyrmions. The energetic stability of these topological stable magnetic particles arises from the unique sense of rotation of their magnetic moments (Dzyaloshinskii-Moriya interactions), which occur when structural inversion symmetry is broken and spin-orbit coupling is present. Non-centrosymmetric materials which exhibit skyrmions, are interesting candidates for information carriers in the context of small-scale racetrack-memory devices. Skyrmions were first observed in MnSi at temperatures below 30 K. Recently, CoMnZn alloys were engineered which feature stable skyrmion phases at room temperature. We apply *in situ* Lorentz transmission electron microscopy (TEM), to study the magnetic structures in CoMnZn. Thereby, we investigate how the magnetic substructure depends on an external magnetic field, the tilt angle and on the thickness of the thin TEM lamellae. We demonstrate that in a TEM tilting experiment, a transition from in-plane to out-of-plane skyrmions can be realized, representing an elementary process which may be exploited for device technology.

Second, we explore magnetic Heusler systems that exhibit a two-phase microstructure, where precipitates are coherently embedded in a matrix. These systems are presently receiving interest as candidate materials for magneto caloric applications. Local stresses affect precipitate/matrix interface regions where they locally distort the lattice. This local break of symmetry is central to the macroscopic properties of the material and possible novel magnetic interactions. Here, we characterize the interface structure in the two phase Nb-Co-Sn system consisting of NbCo2Sn full Heusler (FH) precipitates coherently embedded in a NbCoSn half Heusler (HH) matrix. On the nanometer scale, the FH/HH interfaces represent semicoherent interfaces affected by a large lattice misfit of 3.3%. We find that the interface features regularly spaced paired partial dislocations with a joint Burgers vector of $a/2\langle 110\rangle$, which relieve the overall stress state counteracting the misfit stress. The interface exhibits numerous interface steps (disconnections) which in turn determine the precipitate morphology. Overall, the semi coherency between the two phases is associated with misfit dislocation pairs with 11 nm core distances. These create modulated short-range interface strain fields, which accommodate the misfit strain. This is shown to affect the macroscopic magnetic properties of the material.

Both topics considered show that advanced TEM techniques allow to shed light on elementary magnetic phenomena which have the potential to contribute to new ways of data storage and magneto caloric devices.