Geophysical Research Abstracts
Vol. 16, EGU2014-10444, 2014
EGU General Assembly 2014

High-field magnetic characterization of natural and synthetic nanostructures in ilmenite-hematite samples

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Natural rocks containing exsolved hemo-ilmenite or ilmeno-hematite, or minerals from the hematite-ilmenite solid solution series are known to show extreme magnetic properties. Amongst them are strong exchange bias, high remanence combined with low magnetic susceptibility, and extremely high coercivity. Experiments within magnetic fields up to 7T commonly indicate that these materials are not even close to magnetic saturation in this field range. To obtain a reliable physical understanding of these phenomena, the magnetization of a series of synthetic quenched and annealed metastable ferri-ilmenite solid solutions and several naturally exsolved samples, showing lamellar magnetism, were measured in fields up to 60T in the Dresden High Magnetic Field Laboratory (HLD). Magnetization change is measured by integrating the voltage induced in a secondary coil during the primary field pulse lasting 6 ms, and then subtracting a corresponding background signal from a pulse with an empty holder. The voltage signal is individually calibrated by comparison to PPMS/MPMS measurements on the same samples. In the synthetic samples, saturation field and critical exponent of the approach-to-saturation law depend primarily on the degree of order Q as inferred from Bloch's law, or a mean-field model of $M_s(T)$ curves. Details of the approach-to-saturation curves relate to the nanoscale microstructure of antiphase domains evolved during incremental ordering. The metamagnetic transition of ilmenite is visible in natural ilmenite and in a ferri-ilmenite solid solution containing 97% ilmenite. Most remarkably, it also occurs in natural exsolved titanohematite samples, which show exchange bias at low temperature. This provides additional evidence for the crucial role of nanoscale ilmenite lamellae for the unusual magnetic properties of these minerals.