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Interaction between exsolution microstructures and magnetic properties of the magnetite-spinel solid solution

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ABSTRACT

Magnetic properties of exsolved samples of the $(Fe_3O_4)_x(MgAl_2O_4)_{1-x}$ solid solution were measured over the temperature range 4–923 K and were correlated with microstructures observed by transmission electron microscopy. Several stages of microstructural development were identified. The early stages of exsolution are characteristic of spinodal decomposition with sinusoidal fluctuations in composition occurring parallel to {100}. Satellite peaks observed in both electron and X-ray diffraction patterns indicate an average wavelength for the fluctuations of 100 Å. Further development of this microstructure is characterized by an increasing amplitude of the fluctuations and a sharpening of the compositional profile. A fully exsolved sample produced at 700 °C consists of two phases with approximate compositions $x = 0.19$ and $x = 0.92$.

Saturation magnetization (M_s), saturation remanent magnetization (M_{rs}), and coercivity (H_c) were determined from hysteresis loops measured at temperatures in the range 4–300 K. Alternating-field susceptibility (χ) was measured at high temperatures up to 923 K. The temperature dependence of magnetic properties was found to be a complex function of the intrinsic properties of the homogeneous solid solution and the observed microstructure. A common feature of all exsolved samples is a pronounced decrease in M_s at temperatures below the Curie temperature of material with $x < x_c$, where x_c is the compensation point identified by Harrison and Putnis (1995). In the early stages of spinodal decomposition we observed samples with pronounced coercivity (H_c = 173 mT) and unusually high remanence (M_{rs}/M_s = 0.82) at 4 K, characteristic of magnetization reversal by strongly pinned conventional domain walls. At temperatures in the range 50–100 K the coercivity and remanence decrease rapidly, with hysteresis loops characteristic of magnetization reversal by weakly pinned interaction domain walls above 100 K. This transition in domain state is related to the development of paramagnetic boundaries around the Fe-rich components of the compositional fluctuations.

In the advanced stages of exsolution we observed coercivity and remanence more consistent with single-domain behavior. This is related to the sharpening of the compositional profile and the development of distinct lamellae with high shape anisotropy.