Towards Rare-Earth-Free Permanent Magnets:

The $L1_0$-type Structure in FeNi (Tetrataenite)

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Recently, $L1_0$-ordered materials have attracted considerable attention as candidates for advanced permanent magnets (PMs). PMs convert mechanical to electrical energy and vice-versa, which is vital for many applications ranging from smart phones to wind turbines. Current advanced PMs require rare-earth elements but due to recent geopolitical events, their current availability is in jeopardy. The ultimate goal of the proposed project is to design bulk ferromagnetic alloys from the $L1_0$ phase in the FeNi system for permanent magnet applications. The research proposed here is the first step towards that goal and will focus on understanding the thermodynamics and kinetics of $L1_0$ phase formation and retention FeNi-based alloys.

The maximum energy product $(BH)_{max}$, which is the figure of merit for a PM representing its strength, is created by large magnetic anisotropies. The equiatomic, chemically-ordered $L1_0$ phase has a tetragonal unit cell that induces a high magnetocrystalline anisotropy absent in the common chemically-disordered form. Analysis of magnetocrystalline properties of the $L1_0$-type structure in FeNi indicate a theoretical $(BH)_{max}$ comparable to that of the best rare-earth PMs. Due to low atomic mobilities below the chemical order/disorder transition temperature (320 °C), the ordering transformation is kinetically limited and $L1_0$-ordered FeNi (*a.k.a.* tetrataenite) is only naturally found in meteorites where it forms over millions of years.

It is hypothesized that substitutional elements (Pd, Ti, V, Al, S, P), will stabilize and increase the rate of $L1_0$ phase formation in the FeNi-based system. In the proposed study, the effects of substitutional elements will be studied in two efforts. First, tetrataenite will be characterized to determine baseline properties. Secondly, the effects of varying composition and processing variables will be explored via iterative synthesis and characterization.

Initial studies will focus on compositions $Fe_{50}Ni_zPd_{(50-z)}$ with z = 0, 3, 5 at% and $(FeNi)_{100-y}X_y$, with X = Ti, V, Al, and time permitting S and P, with $y \leq 10$ at%. To detect the $L1_0$ phase and analyze the magnetic characteristics, meteoritic and laboratory-prepared samples will be probed by a variety of techniques including energy-dispersive x-ray spectroscopy (EDS), x-ray diffraction (XRD), differential scanning calorimetry (DSC), magnetic force microscopy (MFM), and superconducting quantum interference device (SQUID) magnetometry. These studies will provide insight into the formation of the $L1_0$-type structure in FeNi-based alloys and their potential to be advanced PMs.