MECHANICAL ENGINEERING

The Department of Mechanical Engineering presents:

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Synthesis and Characterization of Oxide/Metal Exchange-Coupled Nano-Composite Materials for Permanent Magnetic Applications

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Permanent magnets (PMs) are essential to an amazing variety of current and future devices, causing widespread interest in improving PM performance. A promising approach to improving PM performance is exchange coupling between hard and soft magnetic phases. Exchange coupling has been shown to improve the energy product of nano-composite magnets, compared to their single phase counterparts. This dissertation presents a simple and scalable material engineering route that produces exchange coupling in nano-composite PMs. Notably, no rare-earth or precious metals are used. The composites are ferrite based. In one system, $SrFe_{12}O_{19}$ is used as the hard phase and Fe_3O_4 as the soft phase. In the second system $SrFe_{12}O_{19}$ is the hard phase while Co is the soft phase, leading to oxide/metal nano-composites. In order to maximize the beneficial effect of exchange coupling, a fine degree of mixing between the hard and soft phases is required. In order to achieve well intermixed phases at the nano-scale, soft phase precursor is precipitated on $SrFe_{12}O_{19}$ flakes through heterogeneous precipitation by decomposition of urea. The soft phase precursor is reduced and core-shell hard/soft magnetic composite is synthesized. A clear processing window is established to control composition. This requires temperatures high enough to reduce the soft phase precursor, yet low enough to keep the hard/soft interphase reaction free, producing a hard/soft ratio that maximizes the energy product. The resulting nano-composite powder outperforms the energy product of pure hard phase, $SrFe_{12}O_{19}$ by 37%.

The energy product of hard/soft magnetic nano-composite powder is further improved by applying a similar synthesis route to a $SrFe_{12}O_{19}$/Co composite (Co replacing Fe_3O_4 as the soft phase). In order to optimize microstructure and composition ratio, the amount of Co precipitated on $SrFe_{12}O_{19}$ is varied by controlling precipitation time and precipitation $SrFe_{12}O_{19}$:Co ratio. Synthesizing optimized $SrFe_{12}O_{19}$/Co composite powder leads to an energy product improvement of 162% compared to pure $SrFe_{12}O_{19}$ powder.

Bulk dense nano-composite materials have been difficult to synthesize due to grain growth attributed from slow heating rates of traditional sintering techniques. High processing temperatures leads to high density, minimizing property diluting porosity. However, a thermodynamically favored reaction at elevated temperatures deprives the composite of improved magnetic properties. Core-shell $SrFe_{12}O_{19}$/Co nano-composite powders are processed into bulk samples through Current Activated Pressure Assisted Densification (CAPAD). Relatively high processing pressure and heating rates are taken advantage of during CAPAD and a processing window that leads to high density, as well as reaction free samples is established. The result is oxide/metal nano-composites, which would not have been possible though traditional sintering. The processing route developed produces bulk $SrFe_{12}O_{19}$/Co composite material with a 70% improvement in energy product compared to the bulk $SrFe_{12}O_{19}$. First order reversal curve (FORC), δM and recoil loop analysis is used to provide evidence of exchange coupling.