Characterization of FePd Hard Magnetic Nanostructures

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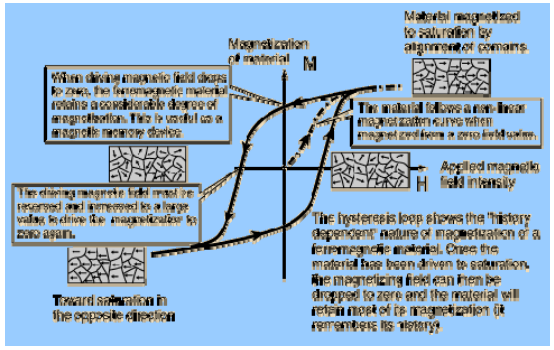
ABSTRACT:

Materials Science research will provide the next generation of hard magnetic materials for use in biotechnology, hybrid vehicles, electronics, etc. Research with FePd nanostructures contributes to the body of knowledge which will further our understanding of the crystalline structure, magnetic properties, and effects of grain size and orientation on their ability to be used as hard magnetic materials. Examination of the X-ray diffraction, hysteresis loop, and SEM images for FePd nanostructures reveal the progress toward an optimal magnetic material. The ultimate goal of this research is fabrication and characterization of a nanoscale magnetic material with an energy product from the hysteresis loop analysis that exceeds current limitations.



Introduction:

By combining the soft magnetic properties of iron with the hard magnetic properties of an iron and palladium composite nanostructure, it is proposed that optimal structure, magnetic properties, and economy will be obtained. Fabrication of the FePd nanostructure sample by cyclic cold rolling then annealing in a magnetic field is a top-down approach. The nanoscale structure is made from larger microscale starting materials. Characterization of the FePd nanostructure to determine final crystalline structure, magnetic properties, and grain size and orientation will contribute to the knowledge base of these hard magnetic materials.

Experimental Design:

Physical preparation includes cyclic cold rolling and subsequent phase transformation annealing in a magnetic field. First, thin sheets of iron and palladium are cut and placed in a sheath before cyclic rolling at room temperature referred to as 'cold' rolling. (Figs.1-2) The process is repeated seven times and involves cutting, stacking, and cyclic rolling. This intermediate product consists of nanoscale (1-100 nm) layers of iron and palladium. Second, the samples are annealed at various high temperatures (450-600°C) for varying times (1-2 hrs) and in a 19T magnetic field both parallel and perpendicular to the sheet surface. (Fig.3) These conditions of preparation are significant in fabricating the optimal nanostructure with the desired crystalline structure, magnetic properties, and grain size and orientation.

Figures 1 and 2

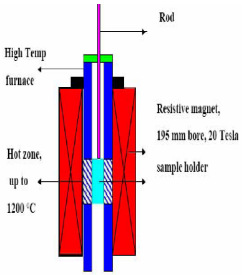


Figure 3

Analysis of the samples includes X-ray diffraction (XRD), superconducting quantum interference device (SQUID), and scanning electron microscopy (SEM). XRD (Fig.4) shows the relative numbers and locations of Fe and Pd diffraction peaks as well as chemically bonded FePd compounds in the nanostructure present before and after annealing. The SQUID (Fig.5) measures magnetic properties resulting in a hysteresis loop indicative of the saturation retention and coercivity of each sample. Finally, the SEM (Fig.6) gives grain size and orientation representative of the anisotropy of the sample. Analyses must be performed in a step-wise fashion with accurate record-keeping as the SEM destroys the sample.

Figure 4 XRD

Figure 5 SQUID

Figure 6 SEM

Representative Results and Discussion:

Initial XRD analysis of the FePd nanostructures reveals the bulk multilayered foils are composed of microscale or nanoscale Fe and Pd after the 3rd or 7th cold-rolling cycle (Figs.7-8), respectively. Patterns after the 7th cold-rolling cycle and annealing at 500°C for 2hr in a 19T field are also provided (Fig.9). Magnetic annealing resulted in the formation of magnetically hard face-centered tetragonal (fct) phase FePd and increased its (001) out-of-plane texture (Fig.9). A higher degree of c-axis orientation and magnetic anisotropy is desired for maximum energy product $(BH)_{max}$.

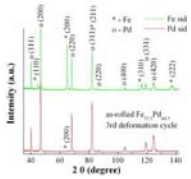


Figure 7

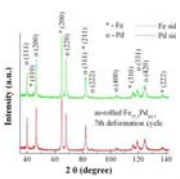


Figure 8

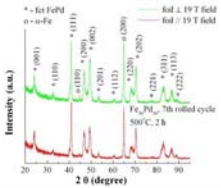
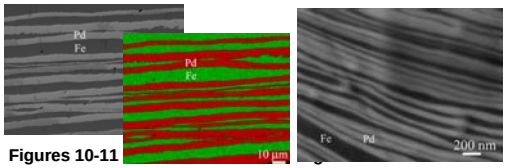


Figure 9

Magnetic properties measured on the 6.5T SQUID are expected to show significant area (the maximum product of B and H) in the 2nd quadrant of the B-H hysteresis loop. The parameters contributing to this area include retention of saturation magnetism and coercivity or ability to retain magnetic alignment in a reversed field. Maximizing this area resulting in a higher energy product is a major goal of current research. The SEM images after the 3rd and 7th cold-rolling cycles demonstrate the microscale and nanoscale structures obtained before annealing in a magnetic field. (Figs.10-12). Additional SEM images are expected to show the composite grains and their orientation. Optimal results will consist of c-axis alignment of fct FePd hard phase indicating magnetic anisotropy which is desired for hard magnetic materials.



Figures 10-11

Glossary of Terms:

Anisotropic - of unequal physical properties along different axes
Anneal - to heat (glass, earthenware, metals, etc.) to have solid state phase transformation (from Fe+Pd to fct FePd in the present work) and also remove the internal stress
Coercivity - The intensity of the magnetic field needed to reduce the magnetization of a ferromagnetic material to zero after it has reached saturation
Energy product – indicates potential ability of the strength of a permanent magnet
Hysteresis loop - A closed curve obtained for a magnetic material by plotting corresponding values of magnetic induction, B, against magnetizing force, H

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