Structure-property relationships in $AlFe_2B_2$: A magnetofunctional layered system

Brian Lejeune[1,4] G. Hadjipanayis[2] and L.H. Lewis[1,3,4]
[1]Department of Chemical Engineering, Northeastern University, Boston, MA
[2]Department of Physics and Astronomy, University of Delaware, Newark, DE
[3]Department of Mechanical and Industrial Engineering, Northeastern University, Boston, MA
[4] George J. Kostas Research Institute for Homeland Security, Northeastern University. Burlington, MA

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Introduction

As magnetism becomes developed into prospective and expanding technologies (encompassing electronics, data storage, and energy conversion) the need for novel, inexpensive magnetic materials produced from abundant elements becomes increasingly evident. Previous reports on the ferromagnetic intermetallic compound $AlFe_2B_2$ show it fits these criteria and has promise for magnetic refrigeration based on its near-room-temperature magnetic phase transition, which dictates the operating temperature range for applications [1,2]. In this work the ferromagnetic properties of $AlFe_2B_2$ single crystals are clarified along crystallographic directions of the layered crystal structure (Figure 1). Single crystals possess an unbroken periodic arrangement of atoms through the entire sample, allowing correlations between structure and magnetic response to be studied. In particular, understanding the energetic preference of the magnetic moments to align along one crystallographic direction, (known as the magnetocrystalline anisotropy energy) can be achieved. Understanding the magnetocrystalline anisotropy can shed light on the intrinsic and extrinsic parameters responsible for the magnetic response of $AlFe_2B_2$. This information is a blueprint for discovering pathways to tailor this system for advanced applications

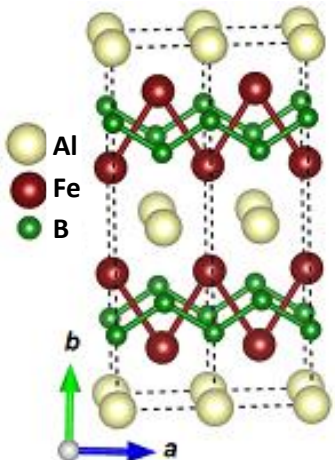

Figure 1. $AlFe_2B_2$ orthorhombic unit cell

Materials and Methods

The objective of isolating single crystals for study was approached by first synthesizing bulk $AlFe_2B_2$ by arc-melting the constituent elements (99.9% purity) in a 3 Al: 2 Fe: 2 B molar ratio that produced a multiphase alloy of $AlFe_2B_2$ in an $Al_{13}Fe_4$ matrix. X-ray diffraction (XRD) was performed to verify the crystal structures and lattice parameters of phases present. Optical and scanning electron microscopy (SEM) were used to confirm your microstructure and phase distribution within the sample. The arc-melted charges were subsequently etched in 50 %v/v HCl for 30 hours to dissolve the surrounding Al-rich $Al_{13}Fe_4$ phase, releasing single crystals. The structure of these extracted single crystals was examined using transmission electron microscopy (TEM). Magnetic characterization was carried out using superconducting quantum interference device (SQUID) magnetometry in magnetic fields up to $\mu_0 H_{app}$ = 5 T and temperatures in the range 50 K $\leq T \leq$ 390 K. The magnetic transition temperature was determined as the inflection point in a curve generated by plotting the derivative of magnetization as a function of temperature and temperature (dM/dT vs. T).

Results and Discussion

SEM and XRD confirm that arc-melted $AlFe_2B_2$ is multiphase, consisting of primarily $AlFe_2B_2$ and $Al_{13}Fe_4$. After 10 minutes of etching a layered morphology was observed along the thickness of $AlFe_2B_2$ crystallites. The microstructure of the extracted $AlFe_2B_2$ crystals after etching for 30 hours was found to consist of layers ~ 100 nm in thickness (Figure 2(a)). Based on this observed layering, it is concluded that extracted crystallites are not complete single crystals. The crystallographic orientation of individual layers of extracted crystallites, and of the magnetic easy axis, was confirmed (Figure 2(a)) via TEM, which also allowed determination of the lattice parameters (a = 2.930(5) Å c = 2.870(5) Å). An appreciable magnetocrystalline anisotropy at T = 50 K is observed in this system by measuring the magnetization along the in-plane crystallographic directions. It is found that the magnetic field necessary to saturate the magnetization of the sample along the c axis is approximately ten times that required along the a-axis (Figure 2(b)).

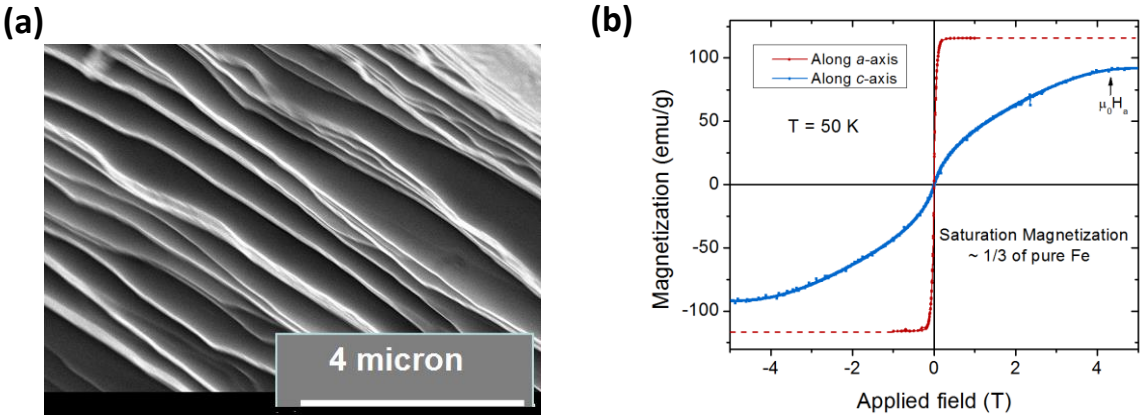

Figure 2. (a) Scanning electron micrograph of $AlFe_2B_2$ single crystal showing hierachical layering ~ 100 nm in thickness. (b) Magnetization verses applied field along a and c in-plane directions used to determine the anisotropy field ($\mu_0 H_a$) ~ 4 T at 50 K.

Conclusions

Correlations between structure and magnetism help to provide a better understanding of the bonding in the crystal structure to develop pathways to enhance the functional behavior. This order of magnitude difference in energy required to align the magnetic moments along the two in-plane crystallographic directions confirms that the structure has a dramatic effect on the magnetism in $AlFe_2B_2$. New findings provide insight into the evolution of magnetism in $AlFe_2B_2$ which is critical for the engineering of a magnetic material with applications in mind. Results suggest that intrinsic property variation such as elemental substitution may be an effective method of altering the functional temperature range of this system as well as the strength of the magnetization. $AlFe_2B_2$ has potential as a new cost effective magnetofunctional material and may provide solutions to current limitations in sensor and solid state cooling applications.

References

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[2] ElMassalami *et al.* J. Magn. Magn. Mater. 16 (2011)

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