Development of Heusler crystals for neutron polarization analysis

Polarized neutron technique is indispensable for research in condensed matter physics. It is a powerful tool to separate nuclear and magnetic signals and determine detailed spin directions in the magnetic materials. We performed development of Heusler Cu_2MnAl crystals that will be used for polarizer on neutron spectrometers. We succeeded in finding optimum conditions to obtain high quality crystals with good polarization and high reflectivity.

Neutron has the spin degree of freedom (±1/2). Because of the interaction between the neutron spin and magnetic moments in materials, it is possible to separate nuclear and magnetic signals and also determine detailed spin directions in magnetic materials. Incident neutron beam should be polarized and the scattered beam's polarization should be analyzed to utilize these capabilities. There are several possibilities for the neutron polarizer and analyzer. Polarizing crystal, supermirror, and ^{3}He filter are widely used. Each device has merits and demerits, depending on instrument conditions, such as range of neutron energies and sample environments. Among these devises, we choose to use the crystal polarizer since it can be used with cryomagnet, the polarization property does not change with time, and it is almost free of maintenance.

Heusler Cu_2MnAl [1] is mostly used for the crystal polarizer because it shows reasonably good polarization and beam reflectivity or transmission. The crystal homogeneity and a slight amount of masaicity are essential to have good polarization and high reflectivity, respectively. However, commercially available crystals are sometimes not of high quality, although they are very expensive. In order to obtain high quality neutron polarizer (and analyzer), it is best to develop Heusler crystals in-house.

Institute for Material Research (IMR) at Tohoku University has the crystal growth and process facility. The Heusler crystals were grown and annealed at IMR. The crystal characterization was performed with neutron diffraction technique at High Flux Isotope Reactor (HFIR) at Oak Ridge National Laboratory (ORNL).

Heusler Cu_2MnAl crystals were grown using the Bridgeman method. Since the (111) reflection, which is a mixture of nuclear and magnetic reflections, is used to polarize and analyze neutron beam, the crystals are cut parallel to the (111) plane. Neutron beam is ideal to characterize the crystals because it can measure the bulk properties and directly measure polarization and reflectivity. The neutron scattering diffraction measurements were performed on the sample alignment instrument CG-1B and the polarized triple-axis spectrometer HB-1 at HFIR, ORNL.

Figure 1 shows a picture of typical crystals of Heusler Cu_2MnAl, which we used to characterize the crystal quality. The dimensions of the crystals are about 20 X 20 X 5 mm^3, in which the wide and flat plane is the (111) plane.

Figure 2(a) shows a rocking curve scan of the (111) Bragg peak in an as-grown crystal. We measured several crystals to check the sample dependence. Many of the as-grown crystals are found to show multi-grain structure and/or broad masaicity. The peak intensities are also similar when normalized by the crystal area. We also measured the reflectivity of the crystals. The reflectivity was estimated to be ~20%, excluding

Fig. 1 Typical Heusler Cu_2MnAl crystals used in this study. The flat plane is the (111) plane.

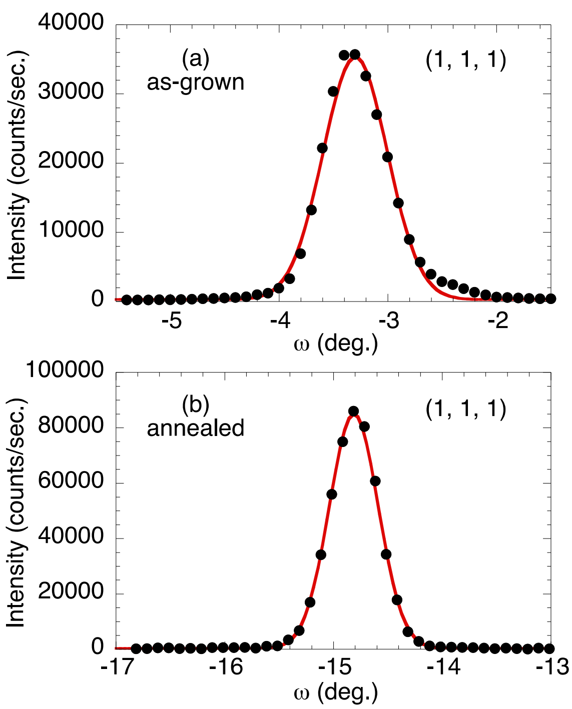

Fig. 2 Rocking curve scans of the (111) Bragg reflection in as-grown (a) and annealed crystals (b) of Heusler Cu_2MnAl. The measurements were performed using unpolarized neutrons. The solid lines are the results of fits to a Gaussian function.

the 1/2 polarization factor. This value is far below the required one (> 35%). The degree of order between Mn and Al is an important factor to realize good polarization. This can be estimated from the intensity ratio between the (111) and (222) Bragg peak intensities. *R* [=*I*(222)/*I*(111)] is about 2 for many of the crystals, indicating that the Mn and Al are well ordered and good polarization is expected.

Figure 2(b) shows a rocking curve scan of the (111) Bragg peak in an annealed crystal from the same lot, which the as-grown crystal is cut from. It is clear that the annealed sample shows stronger intensity and narrower mosaic (~0.5°) with single grain structure. The enhanced intensity by a factor of 2 implies that the reflectivity is improved to above 40%. The mosaic of 0.5° is ideal for polarizing monochromator and analyzer. *R* is calculated to be about 2, which is the same as that in the as-grown crystals.

The flipping ratios of the annealed crystals were also measured and found to be above 20 at a neutron energy of 13.5 meV, which corresponds to ~90% of polarization and is suitable for the neutron polarizer and analyzer. We also measured polarization of the crystals annealed with different conditions. The polarization is good for many of the annealed crystals. However, the reflectivity depends significantly on the annealing conditions. The highest reflectivity so far has been obtained with annealing at 600 °C for 4 hours and at 860 °C for 2 hours, then quench to room temperature. The post annealing makes the good reflectivity and less grain structure possible, although the polarization is already good in as-grown crystals.

Using these high quality crystals, we are first planning to make a neutron polarizing analyzer for the triple-axis spectrometer HB-1, which is more compact than the polarizing monochromator and easier to design. In order to enhance the scattering signal, the polarizer should have vertically focusing mechanism with the crystals magnetized vertically. As the next stage, we also plan to make the polarizing monochromator. Since high neutron beam flux is available on HB-1, more efficient and high quality polarization analysis will be feasible in the near future. This capability will enhance the research in strongly correlated electron systems, including high-T_c superconductors and multiferroic materials.

In summary, we succeeded in finding optimum conditions to obtain high quality Heusler Cu_2MnAl crystals with good polarization and high reflectivity. We plan to make neutron polarizing monochromator and analyzer, which have vertically beam focusing mechanism, for more efficient and high quality neutron polarization analysis.

This work was performed in collaboration with Y. Yamaguchi, K. Sato, K. Suzuki, M. Fujita (IMR), and H. Hiraka (KEK). This research at ORNL's High Flux Isotope Reactor was sponsored by the Scientific User Facilities Division, Office of Basic Energy Sciences, US Department of Energy.

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Keywords: neutron scattering, crystal growth, magnetic
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