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SAED and HREM Study of Intermetallic Phases in Ni-Mn-In Alloy System

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The initial purpose of this research project was to search for and investigate skyrmions in Ni-Mn-T (T = Ga, In, Sn) alloys. Magnetic skyrmions, in which the magnetic moments exhibit a characteristic swirling configuration, have attracted tremendous interest in condensed-matter physics because of their potential application in high-density information processing systems with high energy efficiency, spintronics, and microwave oscillators. Following our recent research on skyrmions in Ni-Mn-Ga and Ni-Mn-In [1], the present search is focused on new intermetallic phases in Ni-Mn-In including a quasicrystalline phase.

Ingots in a nominal composition of $(Ni_{0.5}Mn_{0.5})_{65}T_{35}$ (T = In and Sn) were prepared by arc melting high-purity (99.95%) constituent elements in an argon atmosphere and then the crystalline ribbon samples were obtained by rapidly quenching the induction-melted materials onto the surface of a copper wheel rotating at 15 m s^{-1} in the melt-spinner chamber. Selected samples were further annealed at 500 °C for 2 h in a tubular furnace pumped to a base pressure of about 10^{-7} Torr. SAED, nano-beam electron diffraction (NBED) and HREM experiments were carried out on a Thermo Fisher Scientific Tecnai Osiris microscope. The SAED and NBED patterns were analyzed using SAED 4, QSAED 3 and SPICA 3 in the Landyne suite [2].

A major crystalline phase in Ni-Mn-In was identified as a full-Heusler compound with composition of $Ni_{2-x}Mn_{1+y}In_{1-y}$ where x = 0.483, y = 0.206. It is slightly away from the ideal composition of full-Heusler due to partial vacancy in Ni atom sites and a mixture of In and Mn in the In atom sites. The lattice parameter was refined with XRD analysis to obtain as a = 0.6094 nm. Topological Hall-effect contribution corresponding to skyrmion spin structures were observed in the grains of the major phase, which were supported by MFM images from magnetic force microscopy [1]. Besides the full-Heusler compound, far more complicated SAED patterns were also observed as shown in Figure 1(a–d). A detailed analysis shows that these SAED patterns can be interpreted as the composite patterns of the full-Heusler compound with defects and a new Heusler compound with cubic structure, a = 0.9150 nm [3]. The same type of structure has also observed in Ni-Mn-Sn alloys. Together with the two types of Heusler phases, a decagonal quasicrystalline (DQC) phase and a structurally related crystallite were also observed in Ni-Mn-In system [4]. Figure 2 shows a HREM image of the DQC phase with a corresponding SAED pattern along the ten-fold axis. As is well known, most of the DQC phases are aluminum-based intermetallic phases. It is interesting to investigate the aluminum-free DQC phase as a new member of the quasicrystal family. Structural characterization was carried out on the new Heusler compound and the DQC phase in Ni-Mn-In alloy system.

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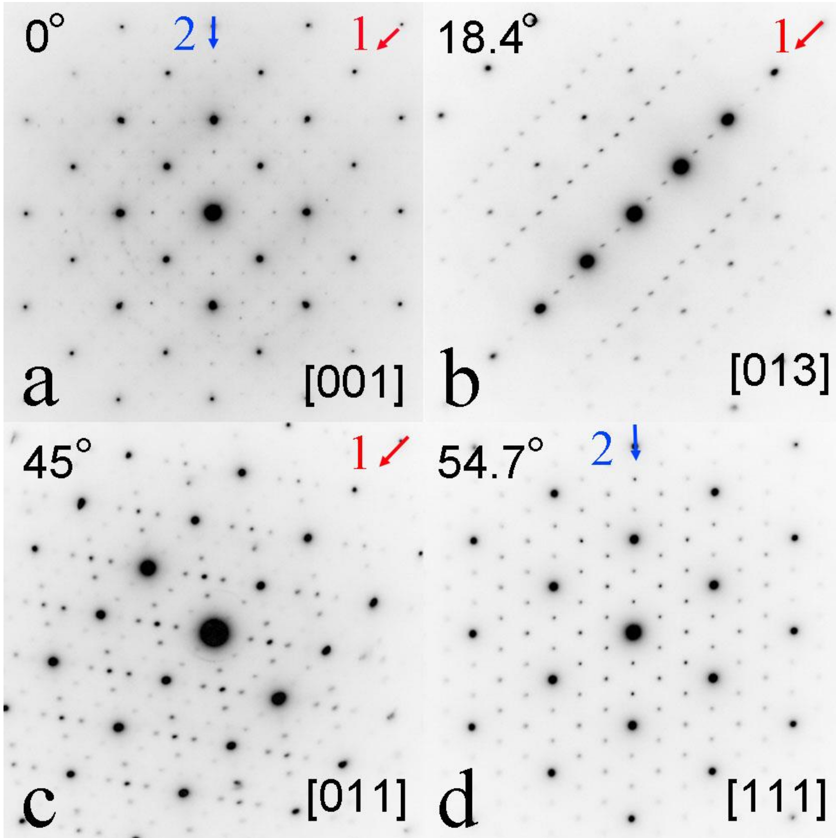

Figure 1. Experimental SAED patterns of two Heusler compounds in the Ni-Mn-In sample. The composite patterns show a fixing orientation between the two intermetallic phases.

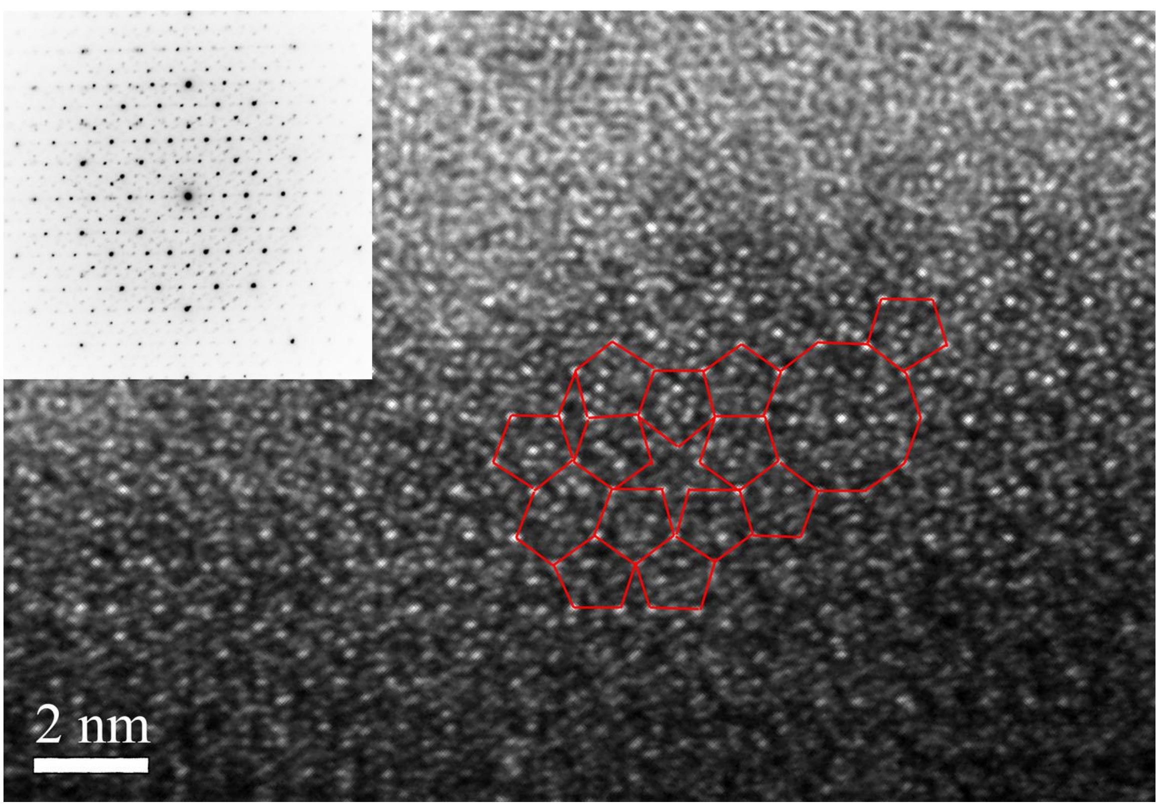

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Figure 2. HREM image of a DQC in the Ni-Mn-In sample with a corresponding SAED pattern along the ten-fold axis. Pentagonal and decagonal tiles can be outlined on the HREM image.

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