doi:10.1017/S143192761600934X
Microsc. Microanal. 22 (Suppl 3), 2016

TEM Study of the Cobalt-Rich Hf-Co Intermetallic Compounds

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The recent push toward renewable energy and green technology has created a surge in the demand for permanent magnets. However, the highest energy product magnets require rare-earth elements such as samarium and neodymium. New rare-earth-free magnetic materials with high energy products are urgently needed. The studies from various research groups show that a Co-rich Hf-Co intermetallic compound with non-cubic high anisotropy structure is a potential permanent magnet candidate due to its high Curie temperature. Early research on the magnetic properties in the Hf-Co system was carried out about 35 years ago [1]. Recent investigations focus on the improvement of the magnetic behavior on melt-spun ribbons and nano-particles with the addition of alloying elements.

Compositions and crystal lattices of the Co-rich non-cubic Hf-Co phase reported in the literature were inconsistent, which could be the reason that both Hf_2Co_{11} and $HfCo_7$ were used for the ideal composition of the Hf-Co magnetic materials. The Hf_2Co_7, Hf_6Co_{23} and $HfCo_7$ phases are listed in the well-used phase diagram [2]. The first reliable lattice parameters of the $HfCo_7$ phase were reported by Demczyk and Cheng [3]. Although they used $HfCo_7$ to represent the phase, Demczyk and Cheng [3] pointed out the actual composition of the compound was probably closer to $HfCo_6$ rather than $HfCo_7$. In the most recent work by Lu *et al*. [4], Hf_2Co_{11} instead of $HfCo_7$ was identified as a stoichiometric phase. Needless to say, the composition and structure of the Co-rich Hf-Co compounds needs to be further clarified and studied.

In this work, the Co-rich Hf-Co compounds in a range of compositions from $HfCo_4$ to $HfCo_8$ have been investigated by TEM, HREM, SAED and EDS techniques. Especially, the composition and structure of the orthorhombic Hf-Co phase were systematically studied by EDS and tilt series of SAED experiments. JEOL JEM2010 and FEI Technai Osiris (scanning) transmission electron microscopes are used in the SAED and HREM experimental works. Simulated SAED patterns are calculated using SAED2s [5] and experimental SAED patterns are measured using JECP/QSAED2a software [5]. Figure 1 shows (a) BF and (b) DF TEM images of a sample with the nominal composition $HfCo_7$. The Co-rich orthorhombic μ-phase $HfCo_{6+\delta}$ ($-0.5\leq\delta\leq1$) phase, the FCC Co phase and the Hf_2Co_7 phase are marked. Figure 2 shows (a) SAED patterns of the μ-phase in tiling series, which were selected from multiple experiments and arranged together from [010] to [100] and from [100] to [001] zone axes with the help of the SPICA software [5]; enlarged SAED patterns (b) along the [010] zone-axis and (c) about 1.2° away from the [010] zone-axis.

The research was performed in part in the Nebraska Nanoscale Facility: National Nanotechnology Coordinated Infrastructure and the Nebraska Center for Materials and Nanoscience, which are supported by the National Science Foundation under Award ECCS: 1542182, and the Nebraska Research Initiative. This work is partially supported by the U.S. Army Research Office under Award WF911NF-10-2-0099 and by the U.S. Department of Energy/Ames Laboratory under Grant DE-AC02-07CH11358.

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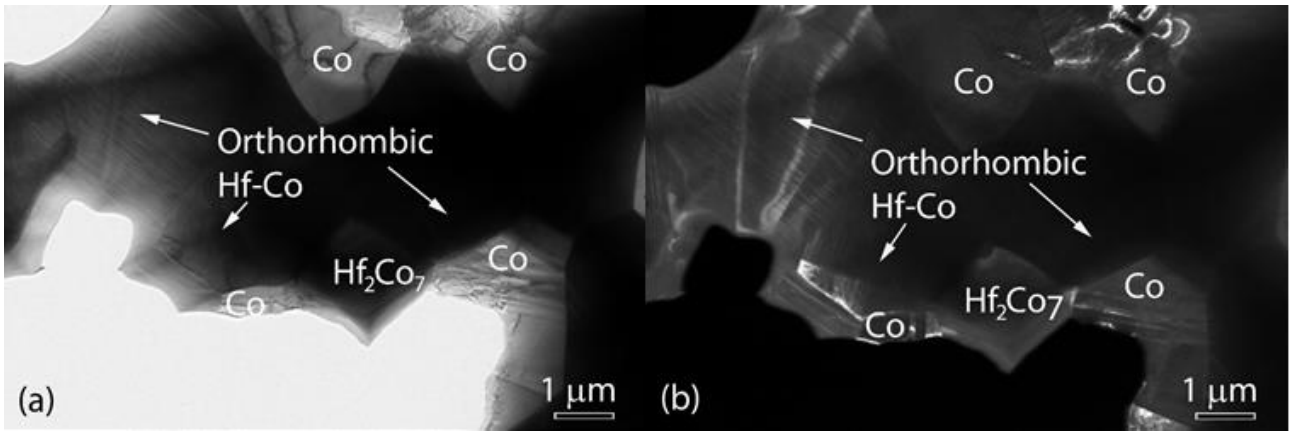

Figure 1. (a) BF and (b) DF TEM images of a sample with a nominal composition $HfCo_7$. Grains of the µ-phase ($HfCo_{6+\delta}$), the FCC Co phase, and the Hf_2Co_7 phase were marked.

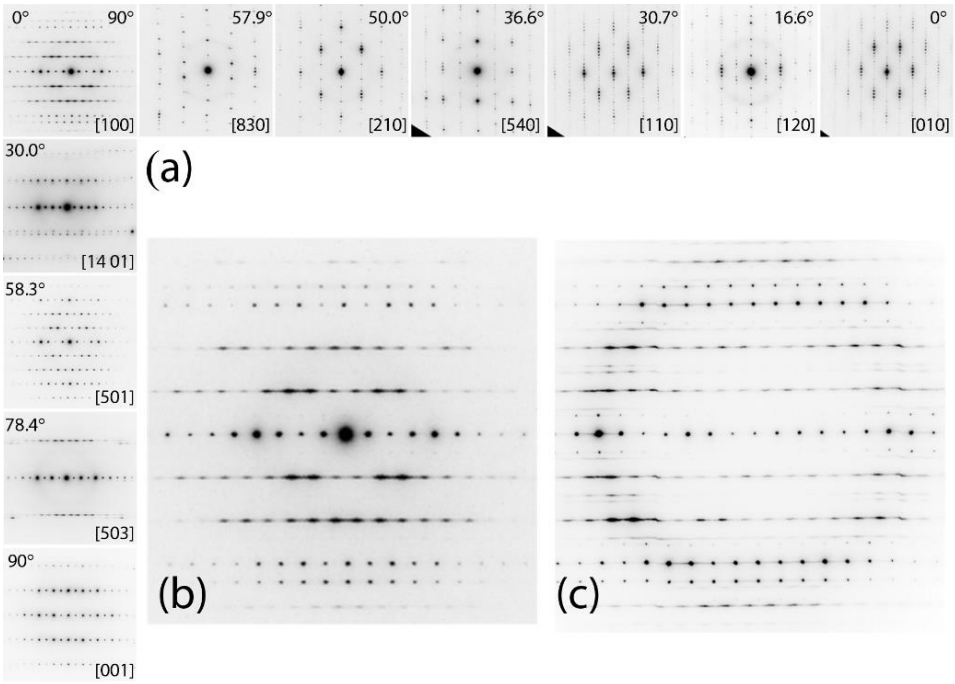

Figure 2. (a) SAED patterns of the µ-phase in tilting series. Enlarged SAED patterns (b) along the [010] zone-axis and (c) about 1.2° away from the [010] zone axis.

https://doi.org/10.1017/S143192761600934X Published online by Cambridge University Press