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TEM and EBSD Study of Fe_3O_4 Particle Chains Grown and Assembled in External Magnetic Field

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One-dimensional magnetic chains composed of nano-sized magnetic particles can be grown and assembled with assistance of an external magnetic field [1, 2]. These low dimensional magnetic structures show anisotropy not only in their shape, but also their magnetic properties. The chain of spheres model has been used commonly to explain the magnetization reversal and several different modes of magnetization reversal have been proposed [3, 4]. Considering only magnetostatic interactions among the spheres without any exchange interactions, magnetization reversal in an applied field was assumed to proceed by a fanning mechanism. However, there has not been any crystallographic evidence to support this assumption [2, 4]. Recently, we successfully synthesized Fe_3O_4 nano-particle chains in an external magnetic field using a self-assembly technique [2]. These magnetic particle chains were further studied using TEM and EBSD techniques. In this paper, we provide solid evidence for the first time to show the preferred particle direction with respected to the chain axis and the external magnetic field.

Fig. 1 shows a bright field TEM micrograph of Fe_3O_4 particle chains on an ultra thin carbon film. The chains in Fig. 1 are randomly orientated because of TEM specimen preparation. However, it should be noted that these chain axes were parallel to the external magnetic field during the chain synthesis [2]. Therefore, even with ex-situ TEM characterization, we may still understand the influence of the external magnetic field on the particle orientation by studying the orientation relationship between the particles and chain axes. These particles are single crystals with the magnetite crystal structure as revealed by electron backscatter diffraction (EBSD) patterns (Fig. 2) and selected area electron diffraction (SEAD) patterns (Fig. 3). When the electron beam is nearly perpendicular to the chain axis, SAED patterns of the same zone axis (Figs. 3a) can be observed from most of particles in a chain by tilting the chain for several degrees. Small relative rotation was observed between these SEAD patterns. This means that most of the particles have similar orientations or small misorientation between them. Most importantly, the [110] crystallographic direction of these particles is close to the chain axis, indicating that the [110] direction may be the preferred particle orientation which tends to parallel to the external field. Different zone axes (Fig. 3b) can be obtained from other particles in the chain when the electron beam is nearly perpendicular to the chain axis, but the [110] direction is still nearly parallel to the chain axis, which provides strong evidence that the [110] direction is the preferred particle orientation. EBSD patterns (Fig. 2) can provide us with 3-dimensional structural information. The preferred particle orientation determined from EBSD patterns is consistent with that from SAED patterns.

In conclusion, external magnetic field does influence particle orientations during chain synthesis and the [110] direction is the preferred particle orientation and the easy axis of magnetization which lies close to the chain axis [5].

References
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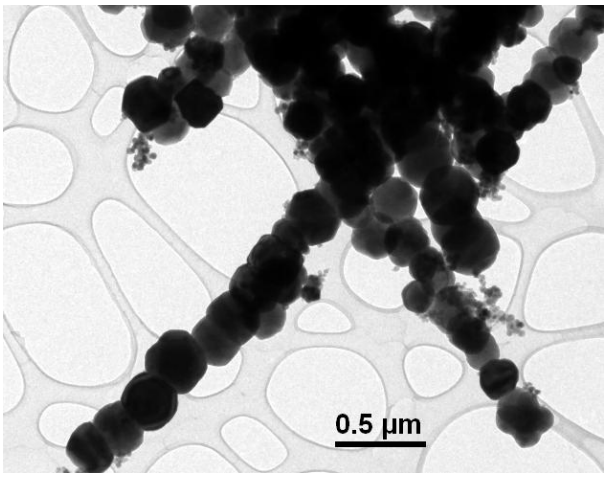


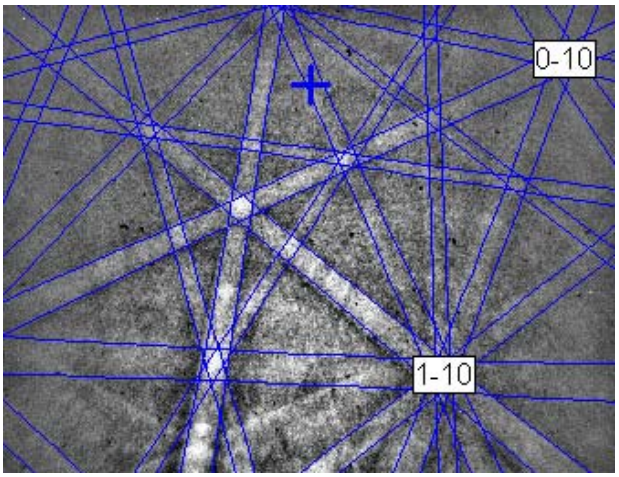
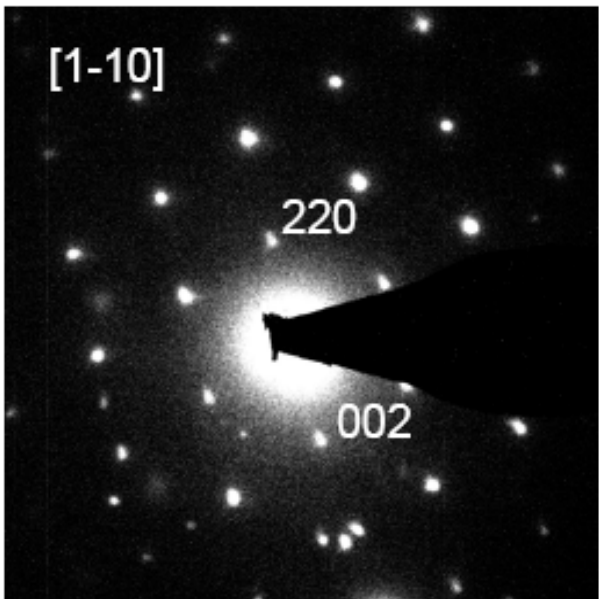


FIG. 1 TEM micrograph of Fe_3O_4 particle chains. Fig. 2 EBSD pattern from one particle in a chain. It is indexed by Fe_3O_4 crystal structure, where the particle orientation can be determined.



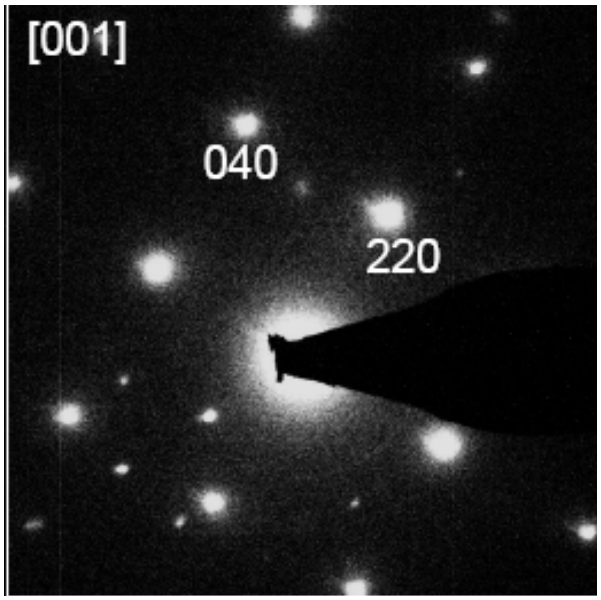


FIG. 3 SAED patterns recorded from two neighboring particles in a chain. 3a) The [1-10] zone axis (left) and 3b) the [001] zone axis (right) of the particles are parallel to the electron beam which is nearly perpendicular to the chain axis.

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