Magnetic Properties of 6-nm Iron Nanoclusters

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We investigated the magnetic properties of iron nanoclusters with an average cluster diameter of 6-nm produced by decomposing metal carbonyl vapors with a resistive heater. The iron nanoclusters were ferromagnetic and had coercivity, remanence, and maximum energy product values much higher than the bulk values, because of the single domain nature of the iron nanoclusters.

Magnetic nanoclusters are especially interesting because they show enhanced magnetic properties compared to bulk metals. Also, the magnetic properties generally become better as the cluster diameter decreases [1-3], implying that it is very important to characterize the magnetic properties of magnetic nanoclusters as functions of the cluster diameter.

Metallic nanoclusters have been produced by a variety of methods, and among these, laser ablation and oven evaporization are the most commonly used ones. In this work, we produced iron nanoclusters by using thermal decomposition [4]. This method combines thermal decomposition of metal carbonyl vapor into a metal atom and carbon monoxides by using a resistive heater with collision-induced clustering between the decomposed neutral metal atoms. Nichrome wire with a 1mm thickness was used as a resistive heater; however, any kind of material can be used as a resistive heater. Black metallic nanoclusters were produced as the final product. We noticed that the carbon monoxides produced during metal carbonyl decomposition did not degrade the purity of the metallic nanoclusters and were evacuated after the experiment. Typical running conditions were filament voltages of 15 - 25 V which corresponded to filament temperatures of 350 - 450 °C, $Fe(CO)_5$ metal carbonyl vapor pressures of 10 - 20 Torr, and diluent Ar pressures of 100 - 300 Torr. The Fe(CO)₅ vapor was directly introduced from a sample bottle into the reaction chamber because the Fe(CO)₅ had a vapor pressure of 10-20 Torr at room temeprature. Under the above condition, metallic nanoclusters with a purity of more than 95 %, as determined by using inductively coupled plasma atomic emission spectrometry, were obtained.

Magnetic properties generally depend on both the cluster diameter [1-3] and structure [5-10]. It is known that both coercivity and remanence increase as the cluster diameter decreases. Thus, it is expected that the magnetic properties of 6-nm iron nanoclusters will show better magnetic properties than those of the bulk metal. We found in a previous work that the structure of metal-

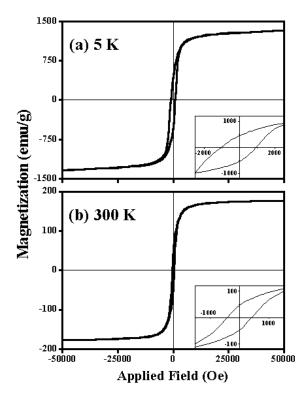


Fig. 1. Hysteresis loops of iron nanoclusters at (a) 5 K and (b) 300 K.

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Table 1. Coercivity (H_c) , remanence (B_r) , and maximum energy product $((BH)_{max})$ values of iron nanoclusters with an average cluster diameter of 6-nm at 5 and 300 K.

H_c (Oe)		B_r (g	gauss)	$(BH)_{max}$ (Oe.gauss)	
5 K	300 K	5 K	300 K	5 K	300 K
1038	410	43904	4716	1.34×10^{7}	5×10^{5}

lic nanoclusters also depended on the cluster diameter [11]. In the case of iron nanoclusters, however, 6-nm iron nanoclusters showed a body-centered cubic (bcc) structure [12], which is the same structure as the bulk metal. Thus, only the cluster diameter dependence of the magnetic properties is important for iron nanoclusters.

The higher coercivity and remanence of magnetic nanoclusters, compared to those of the bulk metal, may allow us to use magnetic nanoclusters as a magnetic recording material [13,14]. In order to characterize the magnetic properties of iron nanoclusters, we measured the hysteresis loops by using a magnetic property measurement system (MPMS). The hysteresis loops measured at both 5 and 30 K are presented in Fig. 1. The iron nanoclusters show saturation in the hysteresis loop, indicating that the iron nanoclusters are ferromagnetic, as is the bulk metal. The coercivities, remanences, and maximum energy products determined from the hysteresis loops are provided in Table 1. Note that the magnetic properties of the iron nanoclusters are much "superior" to those of the bulk metal, because of the single domain nature of small iron nanoclusters. Finally, we compared the coercivities of iron nanoclusters produced in this work with those of larger iron particles reported by others [15,16]. As shown in Fig. 2, the cluster diameter dependence of the coercivities of iron nanoclusters generally follows the trend of the data reported by others. However, the coercivities of the iron nanoclusters produced in this work seem to be somewhat better than those of the larger iron particles reported by others because the coercivity at 300 K (ours) is only slightly lower than that of 8-nm iron particles at 77 K [Refs. 15 and 16] whereas the coercivity at 5 K (ours) is much higher than that of 8-nm iron particles at 77 K [Refs. 15 and 16]. This result suggests that the iron nanoclusters produced in this work may be useful for magnetic recording.

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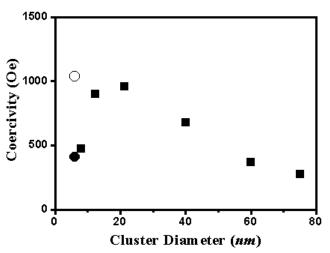


Fig. 2. Coercivities of the iron nanoclusters produced in this work (labelled as o (5 K) and \bullet (300 K)) plotted together with those of larger iron particles reported by others (labelled as \Box (77 K)) [15,16].

us to use their magnetic property measurement system through a cooperative research project and the KBSI for allowing us to use their inductively coupled plasma atomic emission spectrometer at a membership rate.

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