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Formation and magnetic properties of Fe–Pt alloy clusters by plasma-gas condensation

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Size-monodispersed Fe$_x$Pt$_{1-x}$ alloy clusters were synthesized using a plasma-gas-condensation technique which employs two separate elemental sputtering sources and a growth chamber. The composition of the alloy clusters was controlled by adjusting the ratio of the applied sputtering power. We found that high-temperature disordered fcc–Fe$_x$Pt$_{1-x}$ clusters whose mean diameters of 6–9 nm depend on the Ar gas flow ratio were formed for a wide average composition range (x ~0.3–0.7), and the lattice constant of as-deposited clusters increases almost linearly with decreasing x, being extrapolated to the value of pure Pt metal. For Fe$_{30}$Pt$_{70}$ cluster-assembled films, high coercivity (8.8 kOe) was obtained by annealing at 600 °C within 10 min due to improved chemical ordering, although as-deposited cluster-assembled films have lower blocking temperatures than room temperature, and show a small coercivity value (~25 Oe) at room temperature due to intercluster magnetic interaction.

There has been a growing interest in the nanostructurally tailored materials because they are expected to become the basic infrastructure of next-generation devices. In these material designs, nanometer-sized particles or clusters serve as elemental functional units. Thus, a key to the success of this technology is an ability to control geometrical and chemical structures of nanometer-scale clusters. With the decrease of the memory unit size, on the other hand, superparamagnetism becomes a serious problem because the magnetization becomes a serious problem because the magnetization

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standard deviations here, the mean cluster diameter, \( d \), the Fe–Pt alloy films\(^3,12,13\) or nanoparticles\(^5–7\) obtained by vapor phase, being the same with the observation results for nonequilibrium nature of Fe–Pt alloy cluster formation in the dered fcc Fe–Pt alloy phase. This result suggests that the 

croscopy observations of these clusters exhibit a narrow peak at % Fe, being consistent with the average composition of 52.5 at % Fe from EDX spectrum taken with the spread beam.

The composition of individual clusters with \( d \approx 9 \) nm was also analyzed for the average composition of 52.5 at % Fe. We randomly selected 36 different clusters and took the EDX spectra by nanoelectron beams. The estimated compositions of these clusters exhibit a narrow peak at \( \approx 52.5 \) at % Fe, corresponding to Fe content of 39%, 49%, 55%, and 69%, respectively. Ar gas flow rate: \( R_\text{Ar} = 400 \) sccm; sputtering powers: Pt target 150 W (fixed), and Fe target: (a) 90, (b) 105, (c) 110, and (d) 130 W.

We also carried out magnetic measurements on as-deposited Fe\(_x\)Pt\(_{1-x}\) alloy cluster assemblies \((x \approx 0.35–0.7)\). The results revealed that the as-deposited Fe\(_x\)Pt\(_{1-x}\) cluster-assembled films have lower blocking temperatures than room temperature and show a very small coercivity (a few tens of oersteds) at room temperature due to intercluster magnetic interaction. However, it is well known that chemically or-
ordered fct FePt clusters may show large coercivity originating from their large $K_u$. The degree of ordering depends strongly on the annealing time and temperature. Figure 4 shows the coercivity ($H_c$) variation of Fe$_{49}$Pt$_{51}$ alloy cluster-assembled film with thickness of 50 nm as a function of the annealing time, $t_{an}$, at the annealing temperature of 600 °C. The inset of Fig. 4 shows the annealing temperature ($T_{an}$) dependence of the room-temperature $H_c$, where $t_{an}$ was fixed as 1 h. As one can see in the inset, for $T_{an} < 500$ °C, $H_c$ did not exhibit obvious change. When $T_{an}$ becomes higher than 500 °C, $H_c$ first increases rapidly as $T_{an}$ increases from 500 to 700 °C, and then decreases dramatically with further increasing $T_{an}$. A peak value of $H_c \approx 14$ kOe appears at 700 °C. The similar result was also observed in Fe–Pt nanoparticle assemblies by chemical synthesis, probably resulting from excessive interparticle exchange coupling due to particle–particle coalescence. As shown in Fig. 4, on the other hand, $H_c$ value abruptly reached about 9 kOe after first 10 min annealing, and then increases gradually as $t_{an}$ increases. This result also suggests that in the fcc disordered Fe–Pt clusters formed in the present vapor phase, Fe and Pt atoms have a homogeneous distribution so that the transformation towards a fct ordered phase occurred in such a short time, leading to a large $H_c$.

Typical hysteresis loops for the Fe$_{49}$Pt$_{51}$ alloy cluster-assembled film with a thickness of 50 nm annealed at 600 °C for 2 h, in directions both parallel and perpendicular to the film, are shown in Fig. 5. It is seen that for both directions, the loops show the same coercivity and almost the same shape, namely the same magnetic anisotropy.

In summary, we have employed a plasma-gas-condensation technique to produce nearly size-monodisperse disordered Fe–Pt alloy clusters which have the fcc structure in the composition range of 39–70 at. % Fe. It was observed that the composition of the clusters can be controlled easily by changing the relative power of the two targets and the Ar gas flow rate. The experimental results also show that the Fe and Pt atoms are distributed homogeneously in the obtained alloy clusters which have a narrow distribution of the chemical composition. The optimal magnetic hardening or the chemical ordered fct FePt clusters can be achieved at proper annealing temperature and short annealing time.

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