# High Magnetization and High Electrical Resistivity in Soft Magnetic Fe and Fe-alloy Cluster-assemblies Prepared by Impact Deposition

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Soft magnetic Fe-based nanocrystalline films have been widely obtained by either substrate heating during deposition or post-annealing at around 400-800°C to nanocrystallize amorphous alloy films. Such heat treatments are not appropriate for the magnetic devices and cluster-assembling is a promising alternative to fabricate nano-scale structure-controlled materials. In cluster-assembled films prepared by soft-landing on substrates, however, the initial cluster sizes are maintained, but their stackings are very porous. A low density Fe cluster assemblies (about 30% of the bulk) reveals large coercivity and low saturation magnetization [1]. Here, we report that high-density Fe cluster-assembled films with soft magnetic behaviors can be obtained at room temperature by impact deposition of Fe clusters.

Fe cluster-assembled films were prepared by using the plasma-gas-condensation (PGC)-type cluster beam deposition apparatus [2], which is based on plasma-glow-discharge vaporization (sputtering) and inert gas condensation techniques [3]. The apparatus is composed of the three main parts: a sputtering chamber, a cluster growth region and a deposition chamber. Using the PGC cluster beam deposition apparatus, size- monodispersed bcc Fe clusters with the mean diameter, $d$, from 7 to 15 nm and the standard deviation less than 10% of $d$ were produced. Based upon deposition experiments of total and charged Fe clusters, we roughly estimated that there are about 20% positively charged clusters, 20% negatively charged clusters and 60% neutral clusters in the Fe cluster beam. By accelerating these charged Fe clusters and depositing them with neutral clusters from the same cluster source onto a metallic sample holder which can be kept at a voltage $V_a$ up to ±25 kV in the deposition chamber ($10^{-2}$ - $10^{-1}$ Pa), high-density Fe cluster-assembled films were produced with roughly maintaining the initial cluster sizes. In this experiment, we applied negative $V_a$ from 0 to –20 kV [3].

As shown in Fig.1, the magnetic coercivity, $H_c$, rapidly decreases while the magnetization per volume, $M_s$, monotonically increases in Fe cluster assemblies with increasing in $V_a$ : $M_s$ = 1.78 T and $H_c$ < 80 A/m at $V_a$ = -20 kV. The electrical resistivity of Fe cluster assemblies, ρ, is so high as about 20 μΩm at $V_a$= 0 V owing to the very porous stacking of Fe clusters, while it is about 1 μΩm at $V_a$ = -20 kV, being one order smaller, but still one order larger than that of bulk Fe metal.

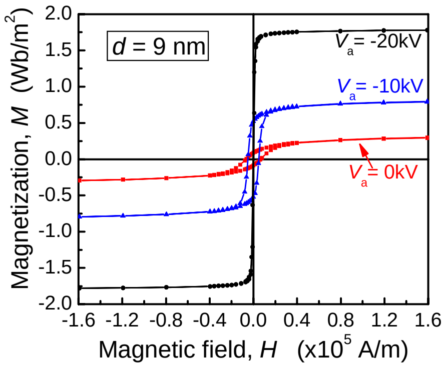


**Fig. 1. Magnetization curves of Fe cluster assembled films deposited on negatively biased substrates. *d:* the mean cluster diameter and $V_a$: the bias voltage.**

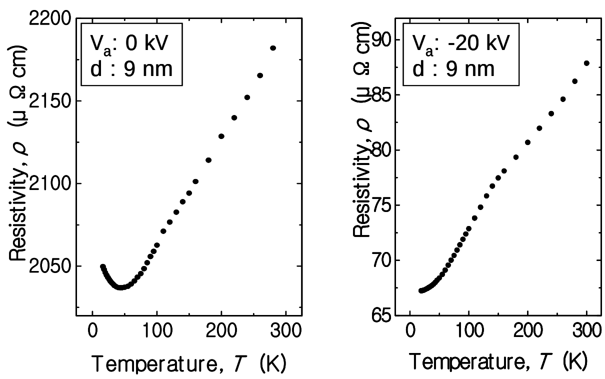


**Fig. 2. Temperature dependence of electrical resistivity of Fe cluster assembled films deposited on negatively biased substrates. *d:* the mean cluster diameter and $V_a$: the bias voltage.**

These features are much improved in Fe-Ni cluster assemblies prepared at $V_a$ = -20 kV: $M_s$ is about 2 T and ρ about 2 μΩm in Fe-rich Fe-Ni alloy cluster assemblies.

It is worth to mention the magnetic permeability at room temperature of Fe cluster assemblies in a high frequency region. As shown in Fig.3, the real part, μ’, is larger than 100 up to the frequency range of about 300 MHz.

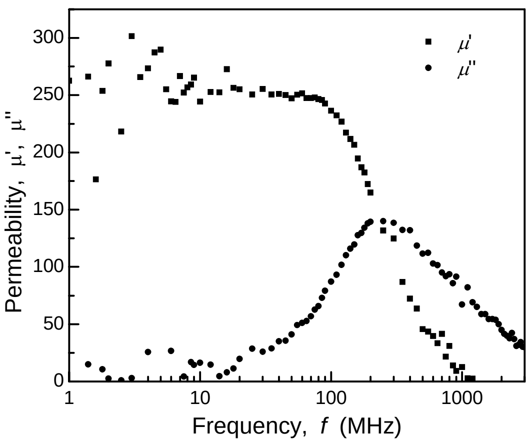


**Fig. 3. Frequency dependence of permeability. μ' is the real part and μ" the imaginary part.**

In dense Fe cluster assemblies, the exchange coupling among Fe clusters are so strong as to overcome the magnetic anisotropy of Fe clusters and their dipole-dipole interaction as discussed by Herzer [4], while the conduction electrons are scattered by the cluster interfaces, giving rise to the soft magnetic character with high magnetization and high electrical resistivity.

### References

[1] D.L.Peng, T.Hihara, K.Sumiyama and H.Morikawa, J.Appl.Phys., 92, 3075 (2002).

[2] S. Yamamuro, K. Sumiyama, M. Sakurai and K. Suzuki, *Supramol. Sci.* **5**, 239 (1998).

[3] H. Haberland, M. Karrais, and M. Mall, *Z. Phys.* **D 20**, 413 (1991)

[4] D.L.Peng, H.Yamada, T.Hihara, T.Uchida and K.Sumiyama, *Appl.Phys.Lett.* **85**, 2935 (2004).

[5] G.Herzer, IEEE Trans.Magn.,**26**, 1397 (1990).