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


Department of Materials Science and Engineering, and Department of Applied Chemistry, Nagoya Institute of Technology, Nagoya 466-8555, Japan

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 (spattering) 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, \(\rho\), is so high as about 20 \(\mu\) \(\Omega\) m at \(V_a = 0\) V owing to the very porous stacking of Fe clusters, while it is about 1 \(\mu\) \(\Omega\) m at \(V_a = -20\) kV, being one order smaller, but still one order larger than that of bulk Fe metal.

These features are much improved in Fe-Ni cluster assemblies prepared at \(V_a = -20\) kV: \(M_s\) is about 2 T and \(\rho\) about 2 \(\mu\) \(\Omega\) m 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, \(\mu'\), is larger than 100 up to the frequency range of about 300 MHz.
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


Fig. 3. Frequency dependence of permeability. $\mu'$ is the real part and $\mu''$ the imaginary part.