Atomic Structure Imaging of Co Clusters in Co-C Granular Thin Films by High-Resolution Transmission Electron Microscopy

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Granular magnetic thin films, consisting of ferromagnetic metal nanoparticles embedded in a non-magnetic medium, have been actively studied in the last two decades due to their novel magnetic and magnetotransport properties. Recently, some of the authors have reported novel temperature-dependent magnetotransport phenomena in Co-dilute Co-C granular thin films produced by sputtering [1]. A large negative magnetoresistance of 27.6% was obtained at 2 K under a magnetic field of 90 kOe. In order to elucidate atomic structures of the aforementioned Co-C thin films, we used aberration (C_s) corrected transmission electron microscopy (TEM) and electron diffraction [2].

Cross-sectional TEM samples of Co-C films sputtered onto Si(001) substrates were prepared by a tripod polishing technique in combination with Ar ion milling. HRTEM and STEM images were obtained by using an FEI TITAN80-300 (S)TEM operated at 300 kV with a C_s-corrector for the objective lens.

Figure 1(a) is a cross-sectional BF-STEM image of the Co-C granular thin film, showing densely distributed nanometer-sized particles with dark contrasts throughout the 90-nm-thick Co-C layer. On the other hand, in the HAADF-STEM image shown in Fig.1(b), Co nanoparticles are imaged as bright contrasts due to Z contrast.

Figure 2(a) shows an HRTEM image and the corresponding selected area electron diffraction (SAED) pattern of the Co-C layer. A few nanometer-sized crystalline clusters, where lattice fringes are clearly seen, are distributed in an a-C matrix; while the SAED pattern shows only halo rings arising from a-C. The lattice fringes shown here indicate that these Co particles, 1~3 nm in diameter, possess the face centered cubic (fcc) structure with a random orientation. The presence of the fcc-Co, instead of the equilibrium hexagonal closed-packed (hcp) phase, is due to the size effect. Figures 2(b) and 2(c) show typical examples of high magnification images of [100]- and [110]-oriented Co particles, respectively. The C_s was adjusted to 8.7 μm and therefore the atomic structure of clusters can be clearly imaged at a defocus value close to the just focus condition. In Figs. 2(b) and 2(c), atomic positions appear as dark contrasts, which are in good agreement with those calculated. Thus C_s-corrected HRTEM unambiguously revealed the formation of densely distributed crystalline Co nanoparticles 1~3 nm in diameter, which is responsible for the magnetotransport properties of the Co-dilute Co-C granular films.

References

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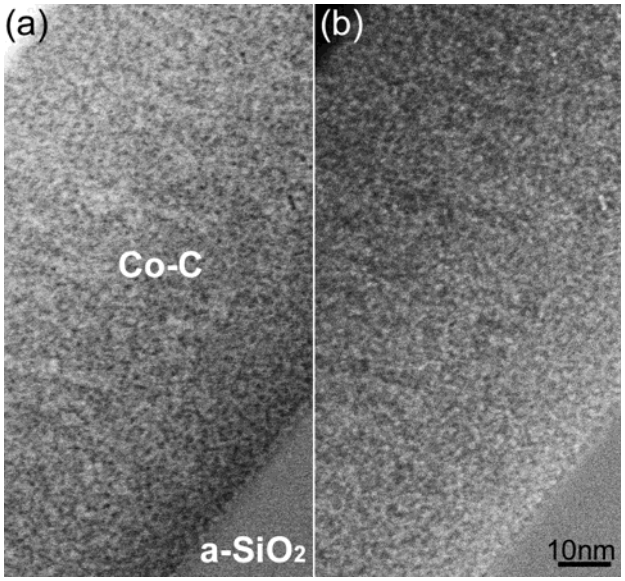

FIG. 1. A pair of (a) BF-STEM and (b) HAADF-STEM images of a cross section of the Co-C granular thin film. For the HAADF-STEM imaging, a beam convergence of 10 mrad and a detector inner angle of 60 mrad were used.

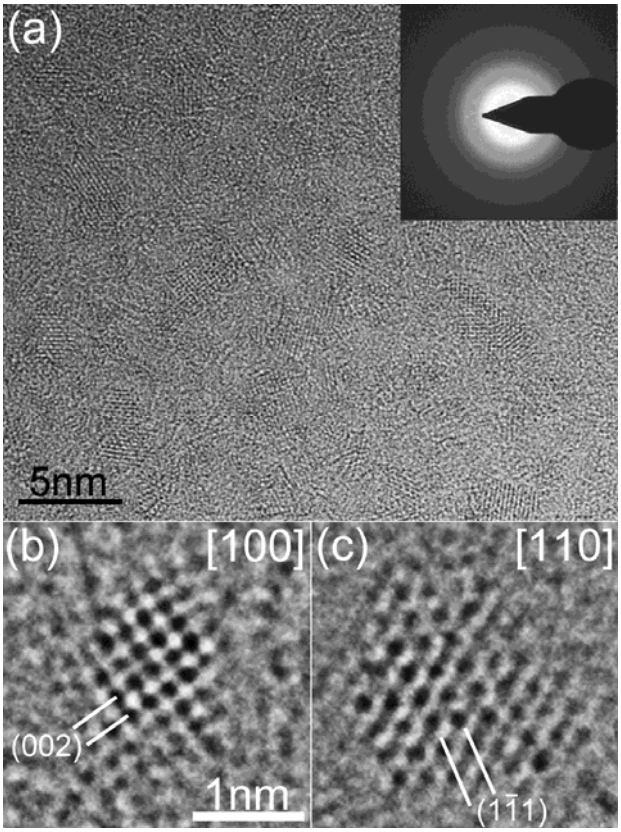

FIG. 2. (a) Cs-corrected HRTEM image and the corresponding SAED pattern of the cross section of