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High-Resolution Analytical TEM and Energy-Filtered Imaging of CoPt-Oxide Perpendicular Magnetic Recording Media

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Perpendicular magnetic media are expected to replace longitudinal hard-disk media in the near future, and to provide continued increases in areal density beyond the current maximum capacity of longitudinal media [1]. High-resolution analytical electron microscopy is required for the study of these novel thin films because they comprise nanoscale grains and grain boundaries (often ~8 nm and ~ 1 nm, respectively), and because the importance of examining the elemental distribution at near atomic level is paramount to understanding the magnetic performance.

While perpendicular media offer many advantages, quantum-mechanical exchange coupling between grains is still problematic and requires the separation of grains similar to that required in longitudinal media [2]. Energy-filtered TEM (EFTEM) imaging, which was used to examine compositional grain separation in longitudinal media [3], is capable of generating maps of the elemental distribution within the grains and the boundaries thereby depicting the extent of compositional separation. Combining EFTEM with other microanalytical techniques, such as high resolution TEM with energy-dispersive X-ray spectrometry, allows for both corroboration and easy quantification of individual grain and grain boundary areas.

For this analytical TEM study, grain separation was attempted by generating non-magnetic oxygen-rich boundaries [4, 5], either by flowing O_2 gas during deposition or by sputtering a stable oxide into the magnetic film. These CoPt-O and CoPt-oxide films were DC-magnetron sputtered at room temperature with increasing reactive O_2 or oxide content. Magnetic properties were measured using a magneto-optical polar Kerr magnetometer. Both reactive O_2 and oxide deposition methods, individually, increase grain separation and reduce intergranular exchange coupling, as shown by the hysteresis loop trends in Figures 1a and 2a. The difference between coercivity (Hc) and nucleation field (Hn) is a measure of the extent of exchange decoupling. The large increase in this loop shearing parameter as O_2 or oxide content is increased is clear evidence of a corresponding decrease in exchange coupling [6].

O/Co ratio maps, created by dividing the oxygen and cobalt core-loss intensity maps generated using EFTEM (Philips CM30 + Gatan imaging filter, 3-window elemental mapping, 30-eV slits, 4.8 mrad collection half-angle), clearly depict the oxygen distribution in these media [7]. Figures 1b and 2b show examples of O/Co ratio maps of reactive O_2 and oxide-sputtered media, respectively. Corresponding TEM micrographs show that the two processes yield dissimilar grain morphologies. With reactive O_2 sputtering (Figure 1c), the grains form undesirable clusters; oxide sputtering (Figure 2c) creates overly narrow grain boundaries. Combining these sputtering processes (Figure 3 a,b,c) yields the most beneficial magnetic and microstructural properties, as evidenced by the large difference in Hc and Hn and the wide, even grain boundaries.

While EFTEM elemental mapping depicts the overall oxygen and cobalt distributions in these media, additional high-resolution analyses were used for quantification and examination of elements that are not amenable to energy-loss techniques. Quantitative compositions measured with an energy-dispersive X-ray spectrometer (EDS) interfaced to a high-resolution TEM (Philips/FEI CM20FEG) with the nanoprobe electron beam focused to ~1.5 nm were used to compare the grain boundaries and grain interiors. Combining these and other techniques to the study of two different sputtering processes is intended to help elucidate the nature of the grain-boundary diffusing oxygen species and its role in improving magnetic exchange decoupling [8].

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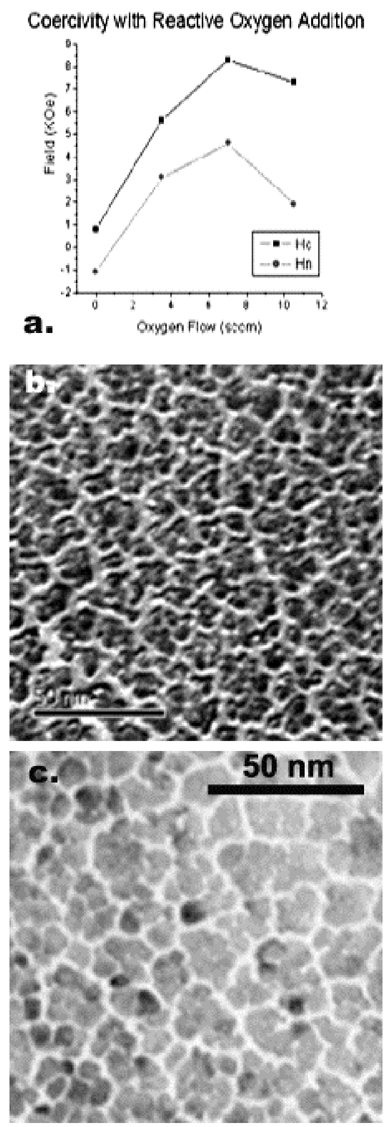

FIG. 1. (a) Graph of Hc, Hn vs. reactive oxygen content. (b) O/Co EFTEM ratio image showing oxygen-rich clustered boundaries. (c) Bright-field TEM image of the microstructure in (b).

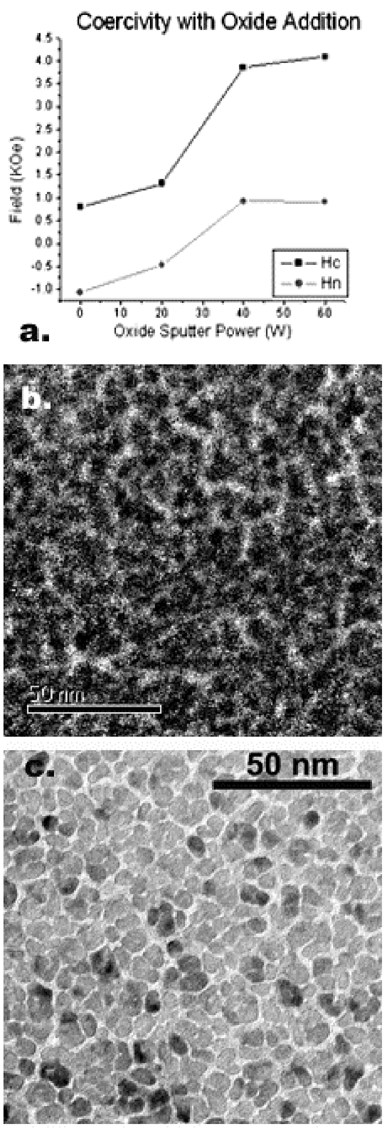

FIG. 2. (a) Graph of Hc, Hn vs. oxide content. (b) O/Co EFTEM ratio image showing incomplete oxide separation of grains. (c) Bright-field TEM image of the microstructure in (b).

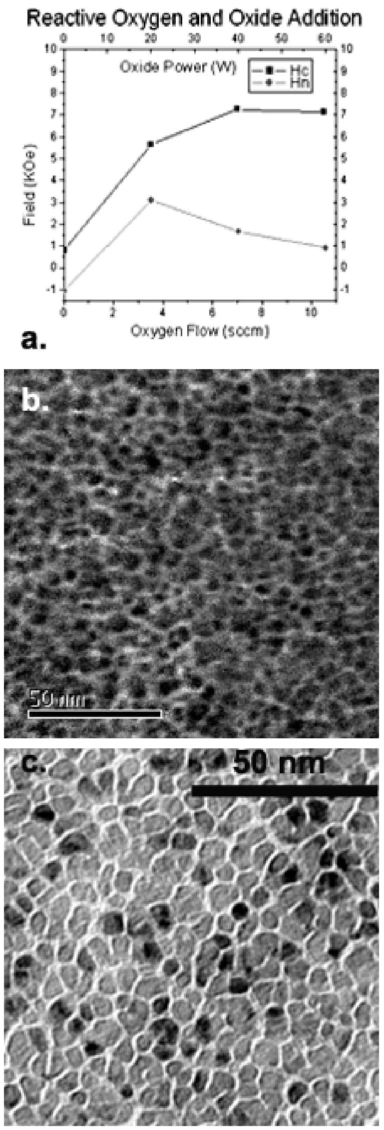

FIG. 3. (a) Graph of Hc, Hn vs. reactive oxygen and oxide content. (b) O/Co EFTEM ratio image showing successful grain isolation. (c) Bright-field TEM image of the microstructure in (b).