# TEM Studies on CoCrPtO-Based Perpendicular Magnetic Recording Media for Grain Size Distribution Analysis

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## ABSTRACT

High resolution transmission electron microscope (TEM) images were obtained of several CoCrPtO perpendicular magnetic recording medium samples with differing ruthenium interlayer thicknesses. Direct measurements on these images facilitated an analysis of the grain size distribution. The results confirmed the existence of a relationship between the interlayer thickness and the grain size of the magnetic layer. As the interlayer thickness increases, the grains grow larger until they reach a certain maximum diameter at which point they undergo a division into several subgrains preventing further increase in the average grain size. This mechanism clearly limits the upper bound of the grain size and alters the grain size distribution in favor of the smaller grains. Bright field and high resolution TEM images of the nanostructured samples have been presented along with the grain size distributions obtained.

***Keywords***: perpendicular magnetic recording media, interlayer, TEM, grain size distribution, nanostructure

## 1 INTRODUCTION

Analysis of the nanostructure of magnetic alloy layers used in recording media has become increasingly important as the data storage density (DSD) of magnetic hard disks has become larger. DSD has been growing exponentially since the production of the first magnetic recording medium in 1956 [1]. This trend is expected to continue in the future as the demand for even higher DSDs is anticipated.

The DSD of these large-area multilayered thin film devices is determined by the bit size area [2]. Bits are written on and read from a ~15 nm thick magnetic polycrystalline thin film. Decreasing the grain size in the magnetic layer (ML) helps improve the signal to noise ratio during readback since the noise is due to irregularities in the ML structure along the boundaries between bits [3]. The grain size in state-of-the-art devices is below 10 nm and will further decrease in media of higher DSD. Commercialized in year 2006 [4], perpendicular magnetic recording (PMR) media are expected to dominate the hard disk market soon since their theoretical data storage density limit is considerably higher than the other hard disk technologies available. In the laboratory version, a data storage density of about 300 Gb/in$^2$ has been demonstrated [4], while the state-of-the-art commercial hard disk has a storage density of 130 Gb/in$^2$ [4].

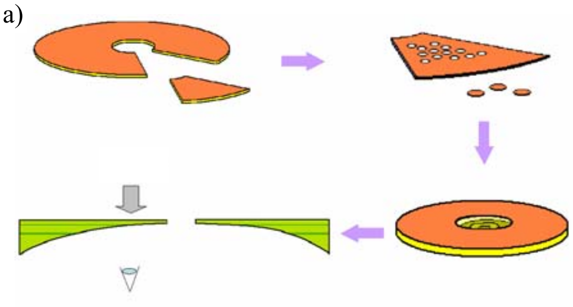
Transmission electron microscope (TEM) is an irreplaceable tool for studies on the nanosized crystallites in multilayered structures of nanometric thicknesses, as it is the only device which can facilitate observation of the interfaces and atomic structures at subnanometric scales [5]. This work focuses on the TEM study of the grain and grain boundary texture of the CoCrPtO MLs in the multilayered structure of PMR media. The magnetically hard CoCrPtO film is protected by a ~5 nm thick diamond-like carbon overcoat. The ML is composed of CoCrPtO columnar nanocrystals with the HCP structure. The [0001] direction of the crystallites is perpendicular to the surface of the disk [6], and the grains are separated by Cr-rich non-magnetic boundaries [3]. The ML is deposited on top of a Ru alloy interlayer (IL). The alloying elements in the IL are utilized to reduce the lattice mismatch between the IL and ML [7]. Since the nucleation and growth of the ML take place on the IL, the nanostructure of the latter is important in determination of the grain structure in the ML in terms of crystallographic orientation and grain size. In this paper, the relationship between the grain size in the ML and the thickness of the IL has been studied.

## 2 TEM CHARACTERIZATION

Three PMR hard disks, produced in similar conditions and of similar compositional and multilayer specifications, but different in IL thickness, were received from Komag Inc. [8]. Samples were cut from different areas of each disk, which were prepared for both cross-sectional and plan-view observations. In order to prepare a plan-view TEM sample, standard size disks (3mm in diameter) are punched out of the hard disk after initial grinding and polishing. After further polishing to a thickness of <100 μm, each disk is then dimple ground to obtain a thickness of <20 μm where it is then ion milled to obtain an electron transparent area adjacent to a hole near the center of the specimen. To prepare a cross-sectional TEM sample, two slabs are cut out of the hard disk sample. These are then formed into a sandwich structure with the multilayers facing each other. After inserting this structure into a metallic support tube of brass with a diameter of 3mm, different disks are cut out and then ground, polished, dimple ground, and ion milled similar to plan-view sample preparation. The different procedures are presented schematically in Figure 1a and Figure 1b, respectively.

The samples were characterized using a Philips CM20 TEM. High resolution (HR) and bright field (BF) TEM images were obtained for each sample. The multilayer structure of the disks was studied by cross-sectional observations, which also afforded the direct measurement of the IL thickness, while the plan-view samples facilitated grain structure observations and grain size measurements. The obtained data help understanding of the interrelation between these two important parameters. The view obtained of this relationship is preliminary as it is based on three IL thickness values only.

a)



b)

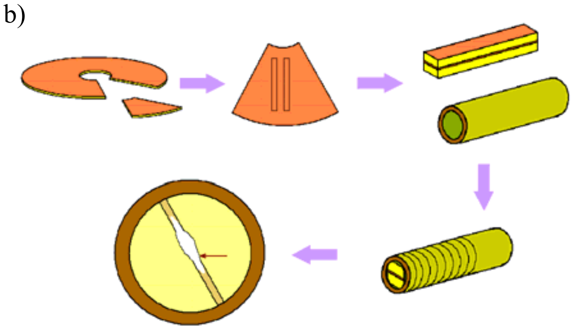


Figure 1: TEM sample preparation procedure utilized for plan-view (a) and cross-sectional (b) observations.

The grain size data were collected from 250 randomly selected grains on the plan-view HR images taken from different samples. The lengths of perpendicular long and short diameters of each grain were recorded and averaged in order to calculate the average grain size and its standard deviation in the media.

## 3 RESULTS AND DISCUSSION

The BF TEM micrograph of a plan-view sample is given in Figure 2, which illustrates the grain structure of the ML for a sample with IL thickness of 26nm. It is desirable to have MLs of uniform grain size in PMR media, as it improves the signal to noise ratio as well as the thermal stability of the medium [1]. In all of the samples analyzed the average grain size is in 6-8 nm range and having standard deviation of 1.4-1.7 nm, the grain size distributions are narrow. The exact values for the average grain sizes and standard deviations are shown in Table 1. The grain size distribution curves obtained for the three sample categories are given in cumulative percentage distribution plots in Figure 3. All of the resulted distributions can be fit by a Gaussian expression. This result differs from the previous reports that have classified the grain size distributions in the ML of PMR recording media as log-normal [9-11]. The reasons for this difference are unknown at present.

The average ML grain sizes of the samples were plotted against their respective IL thickness. The obtained diagram, demonstrated in Figure 4, includes only three experimental points as the samples studied belonged to three categories of constant interlayer thicknesses. However, each point in Figure 4 is related to the accumulated average of 250 grain size measurements for each sample, based on which a relationship between the IL thickness and average grain size in ML can be deduced.

Figure 5 shows a cross-sectional HR TEM image of sample B. Similar images obtained for all of the sample categories facilitated study of the multilayered structure of the samples and IL thickness measurements.

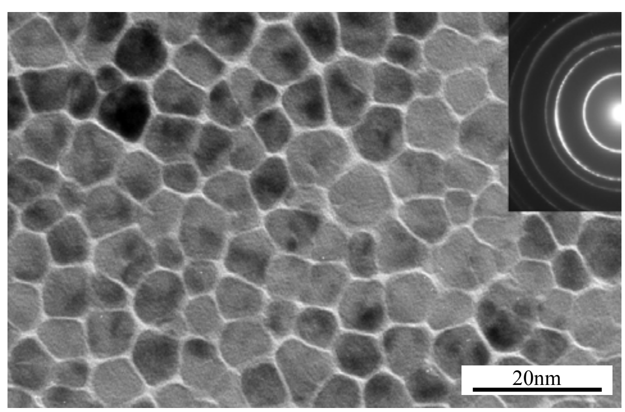



Figure 2: Plan-view BF TEM image of CoCrPtO PMR media with selected area electron diffraction pattern from sample A

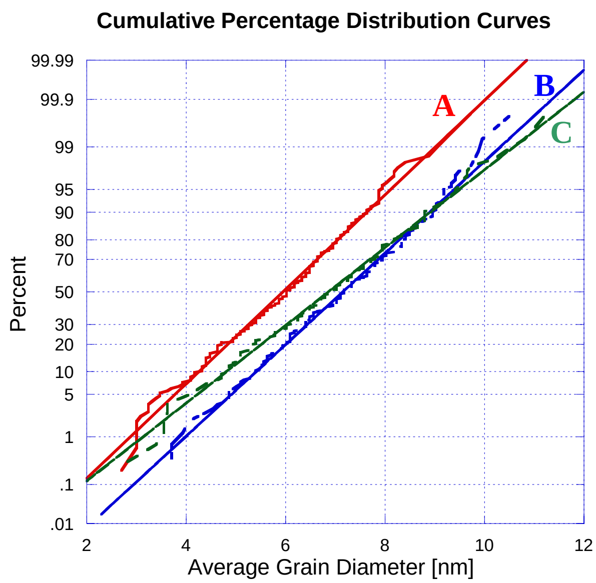



Figure 3: Grain size distributions of the three analyzed samples with normal Gaussian fit lines.

| Sample | A | B | C |
|---|---|---|---|
| IL Thickness [nm] | 14 | 26 | 38 |
| Average Grain Size [nm] | 6.4 | 7.7 | 7.4 |
| Standard Deviation [nm] | 1.4 | 1.5 | 1.7 |

Table 1: Characteristics and grain size distribution analysis results for samples characterized.

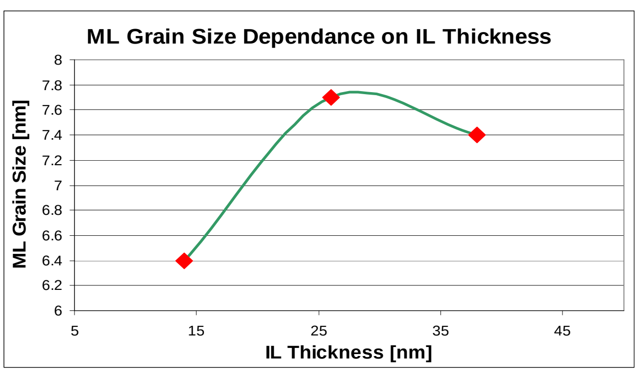



Figure 4: Diagram illustrating dependence of average grain size in ML on IL thickness.

The dark layer observed in Figure 5 is an amorphous tantalum seed layer (SL) on which the ruthenium IL is nucleated and grown by sputtering [6]. During the deposition of the IL, HCP ruthenium crystallites nucleate on the SL and grow perpendicular to the surface of the substrate. The favorable crystallographic growth orientation is [0001] and grains of this orientation dominate the growing interface [12]. As the growth continues, the grains of unfavorable orientations are eliminated while the grains of the favorable orientation gradually dominate the growing interface. This causes the total number of the grains observable at the surface to decrease, which, effectively, increases the average grain size. Hence, it is expected to have larger grains with their (0001) surface parallel to the disk surface as the thickness of the IL increases. In a subsequent step, the Co-based alloy is sputtered on to the ruthenium interlayer to form the ML. Being of HCP structure of close lattice parameters to the IL, the ML adopts the crystallographic orientations of the IL grains. As a result, the average grain size in the ML is expected to be larger in the samples of thicker IL. A suggested relationship between the thickness of the IL and grain size of the ML is illustrated schematically in Figure 6.

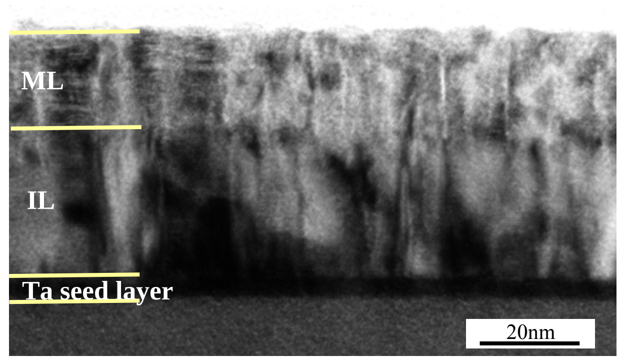



Figure 5: HR TEM image showing IL and ML grain structure in cross section of a CoCrPtO PMR medium sample with measured IL thickness of 32nm.

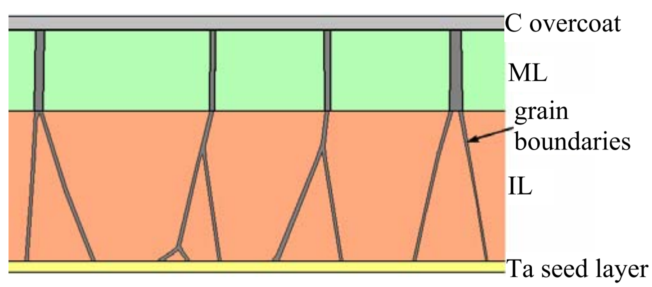



Figure 6: Schematic cross-sectional diagram presenting the suggested relationship between the grain boundaries in IL and ML, which implies that larger ML grains are expected in samples of thicker IL.

According to Table 1, sample B is of thicker IL and larger average grain size than sample A, as predicted by the above described model. However, as the size of a grain in the ML reaches a certain limit, it multiplies into subgrains forming a cluster of neighboring subgrains of parallel crystallographic orientations. Such clusters were observed in plan-view TEM images of sample C, while not detected on those of sample A. Figure 7 (which is at higher magnification than Figure 2) shows a HR TEM image of a plan-view sample with IL thickness of 38nm (sample C). In this image, the large grains indicated are showing the grain division process described. Due to this effect, the average grain size no longer increases with an increasing IL thickness. As shown in Figure 4 samples B and C have nearly the same average grain sizes, which indicates the effect of the grain division mechanism described. This effect is also evident from the diagram in Figure 3 where the sample with the thickest IL (sample C) shows a wider grain size distribution indicated by a smaller slope of the fitted line. The smaller slope is caused by an increase in the percentage of smaller grains resulted from grain divisions.

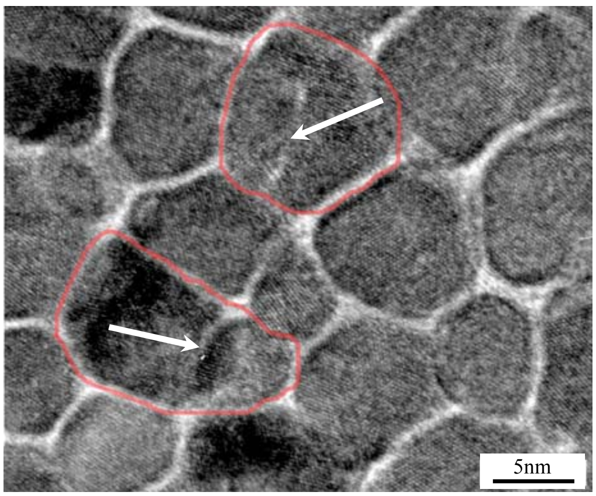



Figure 7: HR TEM image of plan-view obtained from sample C. Arrows indicate grain boundaries formed in the grain division process.

## 4 CONCLUSIONS

Plan-view and cross-sectional BF and HR TEM images were used for nanostructural studies on three CoCrPtO-based PMR samples different in their IL thicknesses. The cross-sectional images facilitated the direct measurements of the IL thicknesses, while the plan-view images were utilized for ML grain size analyses. The average ML grain sizes and grain size distributions of the samples were analyzed by statistical methods, and it was concluded that the ML grain size distribution follows a normal Gaussian distribution in the samples analyzed. It was also established that the IL thickness affects the average ML grain size. The obtained results were explained based on the involvement of two different mechanisms in the determination of the ML grain size: its dependence on the IL thickness which results in larger grains as the IL thickness increases and the subsequent subdivision of the larger ML grains, which enforces an upper bound for the ML average grain size and increases the population of the small grains in samples of thicker IL. As a narrow ML grain size distribution is desirable in the PMR media, further study of the two mechanisms described is suggested.

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