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CoPtCr:C nanocomposite films for high density recording

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We report results on the magnetic properties of nanocomposite films of the form $(\text{Co}_{86}\text{Cr}_{14})_x\text{Pt}_{1-x}:\text{C}$, which were prepared by magnetron sputtering and subsequent annealing. X-ray diffraction shows that these films consist of CoPtCr grains with the face-centered-tetragonal structure embedded in an amorphous C matrix. Magnetic properties such as coercivity (H_c), remanence ratio (S), and coercive squareness (S^*) are strongly dependent on the Pt and C composition and annealing temperatures. Compared with previously reported CoPt:C films with an equiatomic Co and Pt ratio, lower exchange coupling and higher S and S^* at the same C concentration were obtained. H_c values ranging from 2 to 10 kOe and S close to 1 were achieved for film thicknesses down to 10 nm. These features make CoPtCr:C nanocomposite films very attractive for next-generation high-density recording. © 2001 American Institute of Physics. [DOI: 10.1063/1.1331643]

High anisotropy materials with magnetically isolated grains below 10 nm are required to retain adequate signal-to-noise ratio and thermal stability for future high density recording media (>100 Gb/in²).¹ Most recently, nanocomposite films with L1₀ structured CoPt and FePt nanoparticles imbedded in nonmagnetic matrix have received considerable attention.^{2,3} These films possess high magnetocrystalline anisotropy ($K_u > 3 \times 10^7$ erg/cm³), from which high coercivity ($H_c \geq 5$ kOe) and thermal stability ($K_u V/k_B T \geq 60$, where V is the grain volume) can be obtained.² At the same time, the matrix materials isolate the magnetic grains and restrict the growth of grains. As a result, small intergranular interactions and grain sizes are obtained. Results on nanocomposite films such as CoPt:ZrO_x,⁴ CoPt:C,² CoPt:B,⁵ CoPt:Ag,³ and FePt:SiO₂, (Ref. 6) have been reported. Grain sizes below 5 nm have been achieved in FePt:B₂O₃ films.⁷ Recording performance also has been studied.⁴ However, a high concentration of nonmagnetic matrix material could deteriorate magnetic and recording properties, which will be discussed below. On the other hand, it is well-known that in conventional Co alloy media, Cr rich regions forming at grain boundaries are found to reduce exchange coupling, resulting in lower media noise.⁸ Therefore it might be expected that similar segregation mechanism would work in Cr-doped fct CoPt films. In this study, $(\text{Co}_{86}\text{Cr}_{14})_x\text{Pt}_{1-x}:\text{C}$ nanocomposite films were prepared and studied. Cr was introduced to suppress intergranular interactions so that lower C concentration might be needed to decouple grains. Compared with previously studied CoPt:C films,² these films have improved magnetic properties as measured by δM , S , and S^* .

$(\text{Co}_{86}\text{Cr}_{14})_x\text{Pt}_{1-x}/\text{C}$ multilayers were prepared by magnetron sputtering onto Si(100) substrates. The base pressure was less than 3×10^{-7} Torr and the working Ar pressure was 3 mTorr. The Pt atomic composition was varied from 30 to 45; C concentration was varied from 0% to 50% volume fraction. Film thickness ranged from 10 to 20 nm. All the films were annealed at 600, 650, and 700 °C, respectively, for half an hour to produce the CoPtCr:C nanocomposite. The structural properties were characterized by x-ray diffraction. Magnetic properties were measured by alternating-gradient-force and superconducting quantum interference device (SQUID) magnetometers. All the coercivities measured are in-plane unless otherwise specified.

All as-deposited films show that the magnetic alloy has a disordered face-centered-cubic (fcc) structure with (111) texture. Small-angle x-ray diffraction reveals a multilayer structure for these films. After annealing, the films undergo a phase transition from disordered fcc to ordered fct, with the C matrix being amorphous, which is similar to the behavior of previously studied CoPt:C films.² However, there is a significant difference between the x-ray diffraction pattern of CoPtCr:C and CoPt:C films. All CoPtCr:C films show (111) texture, while for CoPt:C films, CoPt grains are randomly orientated. Figure 1(a) shows the x-ray diffraction (XRD) pattern for a 20 nm $(\text{Co}_{86}\text{Cr}_{14})_{60}\text{Pt}_{40}$ film without C matrix and annealed at 650 °C. Only the (111) and (222) peaks are visible. On the contrary, from the inset of Fig. 1(a) we see that all peaks show up in the XRD pattern of the CoPt film prepared under the same conditions. When C matrix is present, as can be seen from Fig. 1(b), the XRD peak intensity drops dramatically accompanying the broadening of the peaks. (111) texture is present for all C concentrations.

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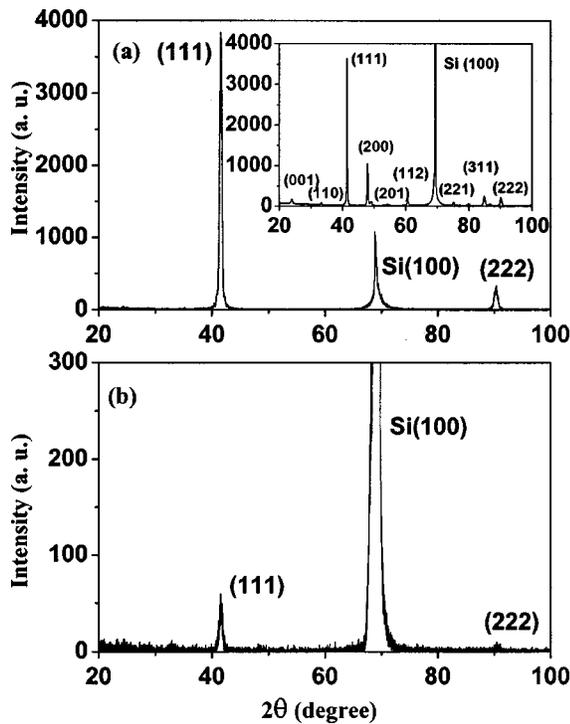


FIG. 1. XRD pattern of (a) a 20 nm thick $(\text{Co}_{86}\text{Cr}_{14})_{60}\text{Pt}_{40}$ film, (inset) a 20 nm $\text{Co}_{50}\text{Pt}_{50}$ film and (b) a 20 nm CoCrPt:C with 40 vol % C annealed at 650 °C for 30 min.

CoPtCr grain size calculated from Scherrer's formula ranges from 10 to 20 nm, and decreases rapidly with increasing C concentration. Transmission electron microscopy (TEM) plan view of a typical sample with 40 vol % C annealed at 650 °C is shown in Fig. 2. The average grain size is about 7 to 8 nm, with some grains agglomerated.

All as-deposited films are magnetically soft, with coercivities less than 50 Oe. H_c of the annealed films is strongly dependent on Pt and C compositions and annealing temperatures. Figure 3 shows the coercivity of $(\text{Co}_{86}\text{Cr}_{14})_{60}\text{Pt}_{40}:\text{C}$, with a thickness of 15 nm, C concentration ranging from 0 to 50 vol %, and annealing temperatures at 600, 650, and 700 °C, respectively. At fixed annealing temperature, coercivity first increases slightly when 10% C matrix is added.

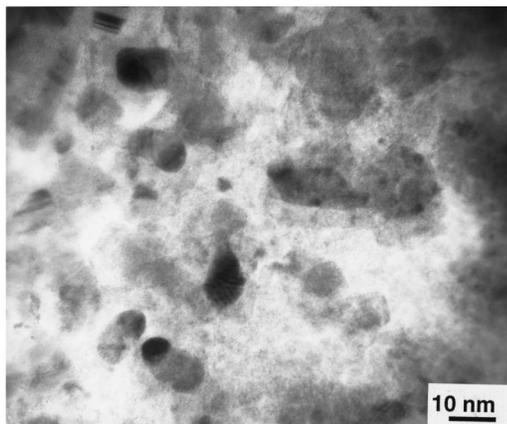


FIG. 2. TEM plan view of a 20 nm thick $(\text{Co}_{86}\text{Cr}_{14})_{60}\text{Pt}_{40}:\text{C}$, with 40 vol % C annealed at 650 °C.

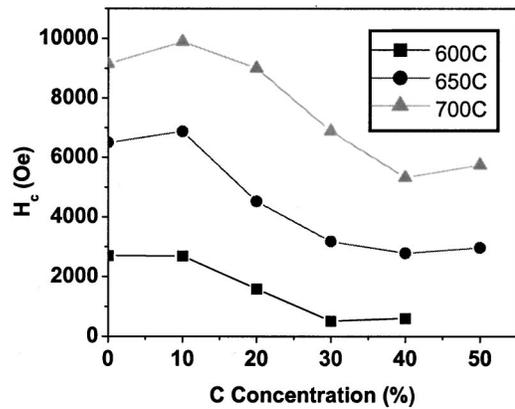


FIG. 3. H_c as a function of C concentration for 15 nm $(\text{Co}_{86}\text{Cr}_{14})_{60}\text{Pt}_{40}:\text{C}$ annealed at 600, 650, and 700 °C, respectively.

This may be due to the addition of C, which isolates the grains, reducing exchange coupling. The addition of C may also increase pinning sites. Further increase of C concentration results in the rapid decrease of H_c . The most probable explanation may be that the presence of C hinders the formation of the ordered fct phase, thus decreasing anisotropy. Excessive C also tends to suppress the growth of magnetic grains.

It is seen clearly that coercivity increases dramatically with annealing temperature. For the three curves shown in Fig. 3, the peak values of H_c at around 10% C concentration increase from 2700 to 6900 to 10 000 Oe for annealing temperatures at 600, 650, and 700 °C, respectively. This is closely related to the formation of the $L1_0$ phase. Ristau *et al.* found that there is a direct relationship between H_c and volume fraction of the ordered phase, therefore annealing temperatures.⁹ This seems to be also true for both CoPt:C and CoPtCr:C nanocomposite films.

Pt composition also plays a crucial role in determining the coercivity. As shown in Fig. 4, when Pt composition increases from 30% to 40%, H_c generally increases. H_c decreases when Pt reaches 45%. For pure CoPt , anisotropy and coercivity usually reach maxima near the equiatomic compo-

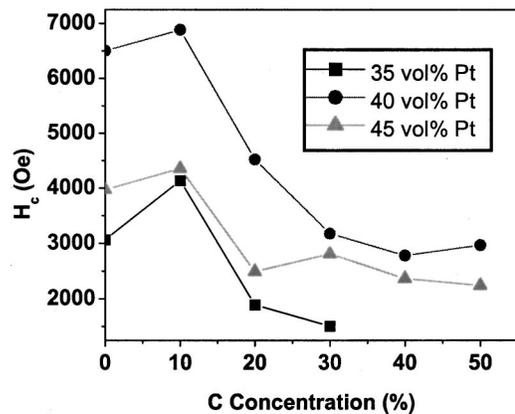


FIG. 4. H_c as a function of C concentration for 15 nm $(\text{Co}_{86}\text{Cr}_{14})_{1-x}\text{Pt}_x:\text{C}$ annealed at 650 °C, and $x = 35, 40,$ and 45 , respectively.

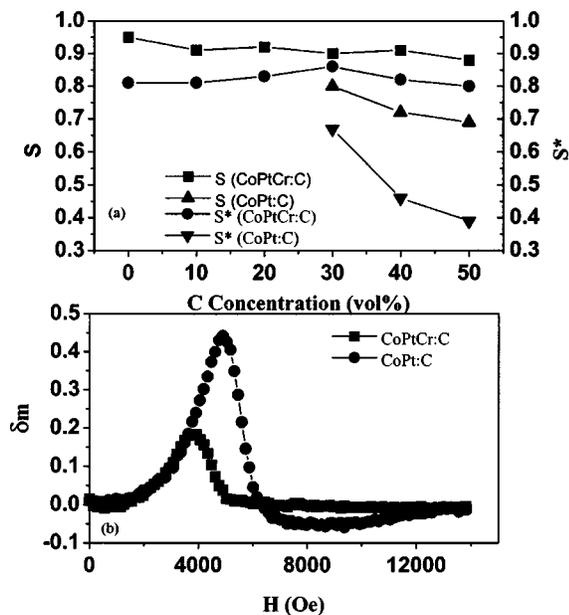


FIG. 5. (a) S and S^* of CoPtCr:C and CoPtCr prepared at the same annealing conditions at various C concentrations. (b) δm plot for a typical CoPtCr:C sample and a CoPt:C sample, with 10% C concentration.

sition. The fact that the coercivity of CoPtCr:C films reaches its maximum at $\sim 40\%$ Pt seems to indicate that part of Co is alloyed with Cr.

In this study, Cr was introduced originally to further reduce the intergranular interactions. Other effects of Cr doping on magnetic properties are also discovered. Figure 5 compares the remanence ratio S , coercive squareness S^* , and δm of CoPt:C and CoPtCr:C films prepared at similar conditions. δm is defined as $m_d - (1 - 2m_r)$, where m_d and m_r are reduced dc remanence and isothermal remanence, respectively.¹⁰ δm is a qualitative measurement of the intergranular interactions. It is seen from Fig. 5(a) that: (a) For CoPtCr:C films, S and S^* remain largely unchanged for C concentrations varying between 0 and 50%, while for CoPt:C films, S and S^* decrease with C concentration rapidly. (b) S and S^* of CoPtCr:C films are significantly higher than that of CoPt:C at the same C concentrations. An increase in S^* is also reported in CoCr/Pt multilayer films without significant effect in the signal-to-noise ratio.¹¹ It is likely that the higher S comes from some in-plane texture, and the higher S^* may come from more uniform grain size distribution than previously reported CoPt:C films. Further study is ongoing to clarify the role of Cr in improving S and S^* . For application purposes, high S is desired to give adequate signal output without sacrificing resolution as thickness goes down; a reasonably high S^* is desired for signal output, writability, and narrow transitions, provided that the grains are exchange decoupled.¹²

The δm peak values generally decrease with increasing C concentrations, which is to be expected, since more C

isolates grains better. It is observed that δm peak values are lower for CoPtCr:C films than for CoPt:C films with the same C concentration. Figure 5(b) shows δm curves for a typical CoPtCr:C sample and a CoPt:C sample prepared under similar conditions. The C concentration is 10% in both cases. The peak value for CoPtCr:C film is close to +0.2, which is much lower than that of CoPt:C. This result means that with the addition of Cr, less C is able to decouple the grains. From the TEM image, we can see that some grains look agglomerated. However, δM measurements indicate very weak exchange coupling. This suggests that some Cr may go into grain boundaries and make grains magnetically decoupled. As mentioned above, higher C concentration could deteriorate magnetic and recording properties. Previous studies on CoPt:C show that H_c and S decrease rapidly with increasing C concentration. On the other hand, higher C concentration leads to fewer magnetic grains per unit volume, which eventually could result in higher dc noise. Therefore CoPtCr:C films may be superior to CoPt:C in the sense that they show much lower interactions at low C concentration, where the magnetic properties are also optimal.

In summary, we have prepared CoPtCr:C nanocomposite films with high anisotropy and magnetic properties which can be tailored to fit the requirements of magnetic recording media. Compared with CoPt:C films, higher remanence ratio and coercive squareness are produced. Furthermore, a much lower exchange coupling is found in CoPtCr:C films than in CoPt:C films at the same C concentrations. These improved features make CoPtCr:C very attractive for next-generation high-density recording.

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