Planar patterned media fabricated by ion irradiation into $CrPt_3$ ordered alloy films

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Planar patterned media using $CrPt_3$ ordered alloy films were fabricated by Ar^+ or Kr^+ ion irradiation through nanoimprinted or electron beam lithography made masks. $CrPt_3$ ordered alloy film on fused quartz substrate exhibits a large perpendicular anisotropy of 5×10^6 erg/cc and a large coercivity of 12 kOe, and we found that its magnetic order (magnetization) was completely suppressed by a quite low Ar^+ or Kr^+ ion dose of about $1-2\times10^{14}$ ions/cm^2. Magnetic force microscope image of the ion-beam patterned $CrPt_3$ with a bit size of 90×90 nm showed clear magnetic contrast in nonirradiated regions, while no magnetic contrast in irradiated regions. The read-back waveform taken from an ion-beam patterned $CrPt_3$ disk with 600 nm patterning pitch showed sharp signal transition between irradiated and nonirradiated regions, which indicates the possibility of high-density planar patterned media using $CrPt_3$ ordered alloy. © *2009 American Institute of Physics*. [DOI: 10.1063/1.3072024]

Bit patterned media have attracted considerable interest as future high-density magnetic recording media since they provide a promising technology to postpone the problem of superparamagnetic limit, i.e., thermal instability of the recorded bits in the media. One of the problems for the practical use of the bit patterned media is topography of discrete magnetic bits defined by lithographical fabrication because the rough surface of the disk disturbs stable flying of the hard disk drive (HDD) head. Ion beam irradiation has been proposed as a new approach to pattern magnetic materials locally without etching magnetic materials, i.e., without altering the surface topography,[1,2] and ion irradiation into Co/Pt (Refs. 1–4) and Co/Pd (Refs. 5 and 6) multilayers (MLs) has been reported for the local modification of their perpendicular anisotropies. However, in the Co/Pt and Co/Pd MLs patterned by ion irradiation, the adjacent magnetic bits are not magnetically isolated due to the exchange coupling through in-plane magnetized spacing, which will limit the ultimate density of the media.

In this paper, we report the ion-beam patterned medium using phase change of a $CrPt_3$ alloy film from ordered to disordered structure. The $CrPt_3$ shows ferrimagnetism when it has an ordered $L1_2$ phase, while paramagnetism when disordered fcc phase, and the ferrimagnetism of $CrPt_3$ can be destroyed by quite low dose of ion irradiation due to the phase change from ordered $L1_2$ to disordered phases. In the previous study, 700 keV N^+ ion irradiation was used to transform the ordered $L1_2$ $CrPt_3$ into disordered phase;[7] however such high-energy and low-mass ion irradiation is not practical for fabrication of patterned media due to the deep ion penetration depth ($\sim$500 nm).[8] In this study, we describe the heavy ion irradiation into $CrPt_3$, such as Kr^+ or Ar^+, and report quite low ion dose about 10^{14} ions/cm^2 is sufficient to suppress the magnetization of $CrPt_3$. Moreover, we first present read-back signals from bit patterned $CrPt_3$ disk fabricated by nanoimprint patterning and ion irradiation, and show that this pattered medium can be a candidate for future ultrahigh-density bit patterned media.

$L1_2$ phase $CrPt_3$ films were obtained by postannealing of Cr/Pt MLs or Cr-Pt alloy films. The $[Cr(0.4\ nm)/Pt(1.5-1.7\ nm)]_{10}$ MLs were prepared by alternating sputtering of Cr and Pt, and the $Cr_{25}Pt_{75}$ (15 nm) alloy film was prepared by co-sputtering of Cr and Pt. We used fused quartz or thermally oxidized (500 nm SiO_2) silicon as a substrate. Two types of annealing methods were used in this study: annealing in vacuum at a temperature of 850 °C for 15 min or rapid thermal annealing (RTA) in N_2 atmosphere at temperatures of 950–1000 °C for 30 s. 30 keV Kr^+ or 14 keV Ar^+ ions were irradiated onto $L1_2$ phase $CrPt_3$ to suppress its magnetic order. For the patterning of the $CrPt_3$ films, we used electron beam lithographed ZEP520A resist or nanoimprinted PMMA resist before the uniform ion irradiation onto $CrPt_3$ films. The film structure was characterized by x-ray diffraction with Cu $K\alpha$ radiation. Magnetic properties were measured by using alternating gradient-field magnetometer (AGM) and torque magnetometer. The surface

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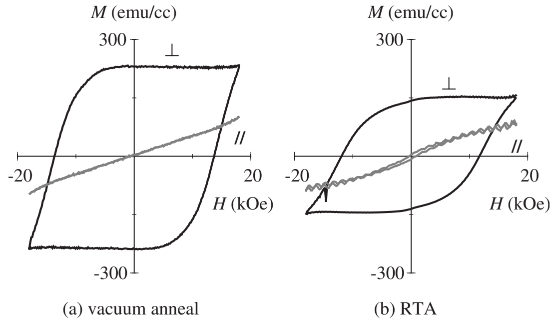

FIG. 1. *M-H* loops of (a) $CrPt_3$ (20 nm) on SiO_2 substrate obtained by vacuum annealing at 850 °C and (b) $CrPt_3$ (15 nm) on SiO_2 by rapid thermal annealing (RTA) at 1000 °C. The symbols ∥ and ⊥ represent the loops measured applying a magnetic field along in-plane and out-of-plane directions, respectively.

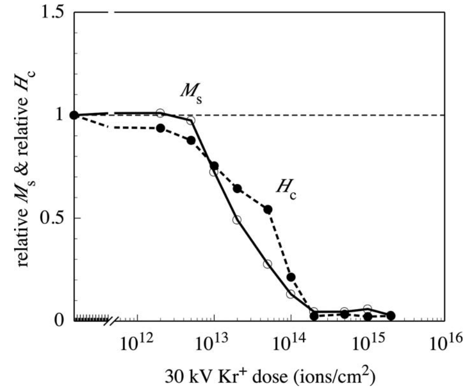

FIG. 2. Dependence of saturation magnetization M_s and coercivity H_c (relative values) of irradiated $CrPt_3$ (20 nm) on 30 kV Kr^+ dose intensity.

topography and magnetic domain structure were studied by atomic force microscopy (AFM) and magnetic force microscopy (MFM), respectively. The read-back signal from an ion-beam patterned $CrPt_3$ disk was obtained by HDD spin stand with a 200 nm core width spin valve head.

Figure 1 shows *M-H* loops of $CrPt_3$ alloy films obtained by vacuum annealing at 850 °C and RTA at 1000 °C. Both films were prepared on fused quartz (SiO_2) substrates and exhibited large coercivity of about 12 kOe. The large coercivity of $CrPt_3$ alloy films results from a strain-induced uniaxial anisotropy, and the strain is considered to originate from the difference of the thermal expansion coefficient between the $CrPt_3$ and substrate.[9] The $CrPt_3$ films studied here have total thicknesses of 15–20 nm so that larger perpendicular anisotropy K_u than that of the previous report (total thickness 60 nm)[9] was obtained. The K_u of $CrPt_3$ (20 nm) on SiO_2 substrate is estimated to be 5×10^6 erg/cc from torque measurements. The magnetization of $CrPt_3$ at 18 kOe is about 250 emu/cc and 150 emu/cc for the samples prepared by vacuum annealing and RTA, respectively. We consider some reasons why smaller magnetization of the RTA made $CrPt_3$ than that of vacuum-annealed $CrPt_3$ is observed: slight difference of the composition between vacuum-annealed and RTA samples, low chemical ordering of $L1_2$ phase in RTA made $CrPt_3$ compared to vacuum annealed one, and larger saturation field of RTA made $CrPt_3$ than that of the vacuum annealed one. In this study, RTA was used for the fabrication of an ion-beam patterned $CrPt_3$ disk for read-write experiments, and vacuum annealing was used for the other experiments. RTA has a great advantage to make a perpendicular recording medium having $L1_2$ $CrPt_3$ layer since it can control the interdiffusion between $CrPt_3$ recording layer and soft under layer (SUL). We have confirmed that the interdiffusion between $CrPt_3$ layer and CoZrNb SUL after RTA was perfectly prevented by inserting a SiO_2 (20 nm) intermediate layer.

Figure 2 shows the dependence of saturation magnetization M_s and coercivity H_c of irradiated $CrPt_3$ on 30 kV Kr^+ dose intensity. Samples were vacuum annealed $CrPt_3$ (20 nm) films on thermally oxidized Si substrate. The M_s and H_c before ion irradiation were estimated to be 250 emu/cc and 8 kOe, respectively, under a maximum applied field of 18 kOe. The M_s and H_c, which are normalized as those before irradiation to be 1, roughly kept their original values up to ion dose of 5×10^{12} ions/cm^2, and decreased when the ion dose exceeded 5×10^{12} ions/cm^2. They became almost 0 at ion dose of 2×10^{14} ions/cm^2. This ion dose of Kr^+ 2×10^{14} ions/cm^2 is much lower than that of the previous report using 700 keV N^+ ions.[7] AFM measurements show that such a low ion dose of 2×10^{14} ions/cm^2 has no influence on the surface topology and the film thickness just as the previous report on 22 keV Ga^+ ion irradiation into Co/Pd MLs.[10] When 14 keV Ar^+ ions are used, almost the same ion dose as Kr^+ ions is confirmed to be sufficient to suppress the magnetization of $CrPt_3$; the minimum ion dose to suppress the magnetization of $CrPt_3$ was 1×10^{14} ions/cm^2 for the 14 keV Ar^+ irradiation. The suppression of magnetization (loss of the magnetic order) of the $CrPt_3$ film is attributed to the transformation of the structure from $L1_2$ phase to disordered fcc phase by the ion irradiation, which was confirmed by x-ray diffraction (XRD) analysis (not shown in this paper). Moreover, the in-plane and out-of-plane lattice spacings of $CrPt_3$ obtained by XRD profiles remained unchanged after the Kr^+ irradiation of 2×10^{14} ions/cm^2, which means Kr^+ irradiation does not affect the lattice distortion contributing to the large uniaxial anisotropy of $CrPt_3$.

Figure 3 shows the MFM image of patterned $CrPt_3$ with

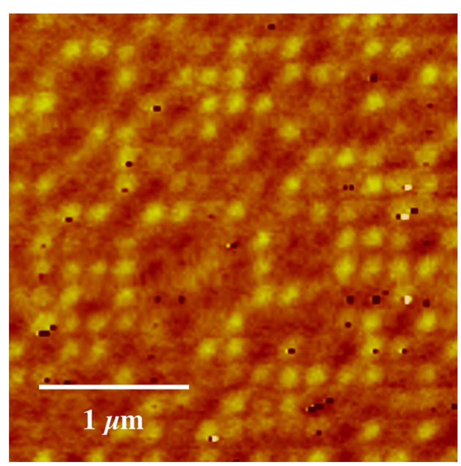

FIG. 3. (Color online) MFM image of ion-beam patterned $CrPt_3$ with square bit size of 90×90 nm^2 separated by the spacing of 90 nm fabricated by 30 keV Kr^+ irradiation of 2×10^{14} ions/cm^2 through the EB lithography made ZEP resist mask.

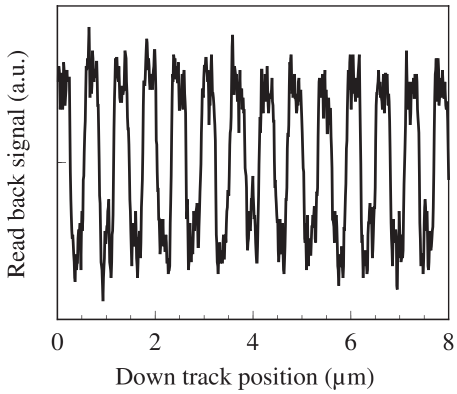

FIG. 4. Read back waveform taken from an ion-beam patterned $CrPt_3$ disk with 600 nm patterning pitch. The magnetization in nonirradiated regions was saturated by a field of 20 kOe.

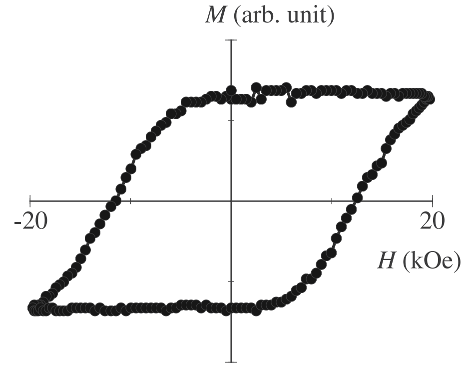

FIG. 5. *M-H* loop taken from the ion-beam patterned $CrPt_3$ disk with 600 nm patterning pitch.

square bit size of 90×90 nm separated by spacing of 90 nm, i.e., patterning pitch of 180 nm, fabricated by ZEP resist patterning followed by 30 keV Kr^+ irradiation of 2×10^{14} ions/cm^2. Even in the sub-100 nm bit size, clear magnetic contrast is seen in the image. Bright and dark contrasts come from the nonirradiated bit where $CrPt_3$ remains $L1_2$ phase and exhibits ferrimagnetism. No magnetic field was applied after the heat treatment for ordering the $L1_2$ phase, thus observed magnetic contrasts in nonirradiated bits reflect an initial demagnetized domain structure of the $CrPt_3$ film. On the other hand, no magnetic contrast is seen in the irradiated area (spacing), which indicates the magnetization of $CrPt_3$ is suppressed locally by ion irradiation. In the case of Co/Pd patterned by the local ion irradiation, there exists exchange coupling between the bits via in-plane magnetized spacing,[6] while, for the ion-beam patterned $CrPt_3$, irradiated spacing becomes nonmagnetic, thus the adjacent magnetic bits are magnetically isolated. This is the reason why the clear magnetic contrast is seen even in sub-100 nm bit size as shown in Fig. 3.

Figure 4 shows the read-back waveform taken from the ion-beam patterned $CrPt_3$ disk with 600 nm patterning pitch: 300 nm width lines arranged along radial direction with a space of 300 nm. The disk sample was fabricated as follows. First the film construction of SiO_2(2 nm)/$Cr_{25}Pt_{75}$(15 nm)/SiO_2 disk was prepared by magnetron sputtering, and then RTA was carried out for ordering the $CrPt_3$ layer. The patterned $CrPt_3$ disk was obtained by nanoimprint patterning followed by 14 keV Ar^+ ion irradiation of 1×10^{14} ions/cm^2 through the SiO_2 (2 nm) capping layer. After removing the resist, the disk was coated with a carbon overcoat and a lubricant film. The area irradiated with Ar^+ of 1×10^{14} ions/cm^2 has no magnetization, while the magnetization in the nonirradiated area was saturated by an initial magnetic field of 20 kOe. Clear read-back signals from the spin valve head having a core width of 200 nm indicate a successive fabrication of the $CrPt_3$ planar patterned medium. The signal to noise ratio is estimated to be 10.6 dB. Furthermore, sharp signal transition between irradiated and nonirradiated regions was confirmed. The signal transition width is estimated to be 40–50 nm, which is considered to be comparable to the read gap of the spin valve head. The head slider flew on the patterned disk stably, and thus the surface of the $CrPt_3$ patterned medium was sufficiently smooth without any treatment after removing the masks. The *M-H* loop taken from the ion-beam patterned $CrPt_3$ disk is shown in Fig. 5. The coercivity of patterned $CrPt_3$ is about 12 kOe, which is almost the same as that of unpatterned $CrPt_3$ as shown in Fig. 1. For the ion-beam patterned Co/Pd MLs, the coercivity was significantly reduced by ion-beam patterning since the nonirradiated bits are exchange coupled via irradiated (in-plane magnetized) spacing.[6] The reduction in the coercivity after the patterning was not seen for the ion-beam patterned $CrPt_3$ disk; this is probably attributed that the irradiated region (spacing) becomes nonmagnetic, and well magnetically isolates the adjacent magnetic bits (un-irradiated regions). These results suggest the possibility of high-density planar bit patterned media by using $CrPt_3$ ordered alloy films.

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[1]C. Chappert, H. Bernas, J. Ferré, V. Kottler, J.-P. Jamet, Y. Chen, E. Cambril, T. Devolder, F. Rousseaux, V. Mathet, and H. Launois, Science **280**, 1919 (1998).
[2]B. D. Terris, L. Folks, D. Weller, J. E. E. Baglin, J. Kellock, H. Rothuizen, and P. Vettiger, Appl. Phys. Lett. **75**, 403 (1999).
[3]J. Ferré, C. Chappert, H. Bernas, J.-P. Jamet, P. Meyer, O. Kaitasov, S. Lemerle, V. Mathet, F. Rousseaux, and H. Launois, J. Magn. Magn. Mater. **198–199**, 191 (1999).
[4]R. Hyndman, P. Warin, J. Gierak, J. Ferré, J. N. Chapman, J. P. Jamet, V. Mathet, and C. Chappert, J. Appl. Phys. **90**, 3843 (2001).
[5]E. Suharyadi, S. Natsume, T. Kato, S. Tsunashima, and S. Iwata, IEEE Trans. Magn. **41**, 3595 (2005).
[6]E. Suharyadi, T. Kato, S. Tsunashima, and S. Iwata, IEEE Trans. Magn. **42**, 2972 (2006).
[7]O. Hellwig, D. Weller, A. J. Kellock, J. E. E. Baglin, and E. E. Fullerton, Appl. Phys. Lett. **79**, 1151 (2001).
[8]J. Fassbender, D. Ravelosona, and Y. Samson, J. Phys. D **37**, R179 (2004).
[9]T. Kato, H. Ito, K. Sugihara, S. Tsunashima, and S. Iwata, J. Magn. Magn. Mater. **272–276**, 778 (2004).
[10]E. Suharyadi, S. Natsume, T. Kato, S. Tsunashima, and S. Iwata, Trans. Magn. Soc. Jpn. **5**, 125 (2005).