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Writing and reading perpendicular magnetic recording media patterned by a focused ion beam

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We have written and read bit patterns on arrays of square islands cut with a focused ion beam into granular perpendicular magnetic recording media. Using a static write–read tester, we have written square-wave bit patterns on arrays of islands with sizes between 60 and 230 nm, matching the recording linear density to the pattern period. These measurements reveal the onset of single-domain behavior for islands smaller than 130 nm, in agreement with magnetic force microscope images. The recording performance of patterned regions is systematically compared to that of unpatterned regions. © *2001 American Institute of Physics.* [DOI: 10.1063/1.1347390]

Patterned media are one of many schemes proposed to overcome the thermal stability problem that arises in the traditional scaling approach to achieving higher areal density using conventional recording media.[1–5] Here signal to noise is maintained while increasing bit density by reducing the grain size and keeping the number of grains (several hundred) per bit constant. However, in this approach, the grains will ultimately become small enough to be thermally unstable and undergo spontaneous reversals of their magnetization direction. This effect can be alleviated by patterning the media into single domain bits that have enhanced thermal stability due to the increased magnetic switching volume. In addition to this thermal stability advantage, patterning the media may also effectively reduce transition noise that in conventional media arises from the many grains per bit.[6] In this letter, we report the results of systematic write and read experiments on media patterned at densities as high as 100 Gb/in.^{2} and compare the recording performance with that of the unpatterned regions.

Perpendicular granular $Co_{70}Cr_{18}Pt_{12}$ recording media have been patterned using a focused Ga^+-ion beam to cut ~20 nm wide trenches into the ~20 nm thick media to form arrays of uniformly sized square islands. The island edge length varies from 60 (100 Gbit/in.^{2}) to 230 nm (10 Gbit/in.^{2}) and the patterned areas are between $2.5\,\mu m \times 3.2\,\mu m$ and $2.5\,\mu m \times 10\,\mu m$, respectively. Details of the fabrication process are published elsewhere.[7] Figure 1 shows atomic force microscope (AFM) and magnetic force microscope (MFM) images of typical islands with sizes of (a) 230 nm and (b) 80 nm. The corresponding period p is (a) ~250 nm and (b) 100 nm. The MFM images were obtained after an ac-demagnetization process, in which a perpendicular field was applied to the sample and decreased from 20 kOe to 100 Oe in 1% steps, with reversal of the field direction at each step. While the larger islands clearly show a multidomain contrast, the smaller islands are either uniformly bright or dark, indicating that they contain a single magnetic domain. This single-domain behavior of islands is observed for $p < 130\,\text{nm}$[7] and is found when the intergranular exchange interaction is sufficiently strong to couple all the grains in the island. MFM measurements also reveal that the small islands have a coercivity that is about half of that in the unpatterned regions.[8]

To evaluate the recording properties of magnetic media without the need for flying a write/read head, static write read testers have been previously used, both on continuous films[9,10] as well as on well-separated patterned islands.[11] This tester consists of a conventional magnetic recording head, mounted on a flexible stainless-steel suspension, placed in contact with the sample. The sample is raster scanned with respect to the head with a positioning accuracy

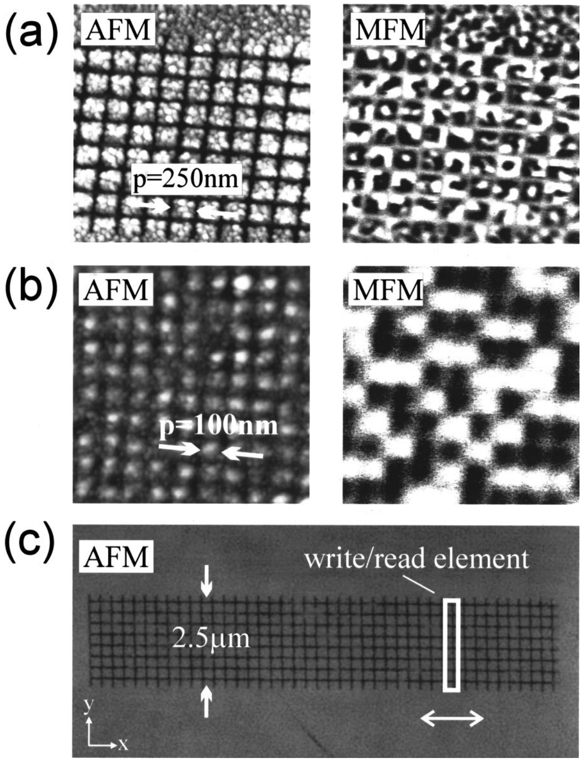

FIG. 1. (a) AFM/MFM image of granular perpendicular CoPtCr recording media, patterned at a period (a) $p \sim 250$ nm and (b) $p = 100$ nm. (c) AFM image of the entire array patterned with $p \sim 250$ nm. The write/read element of the static write read tester and the scan direction are schematically shown.

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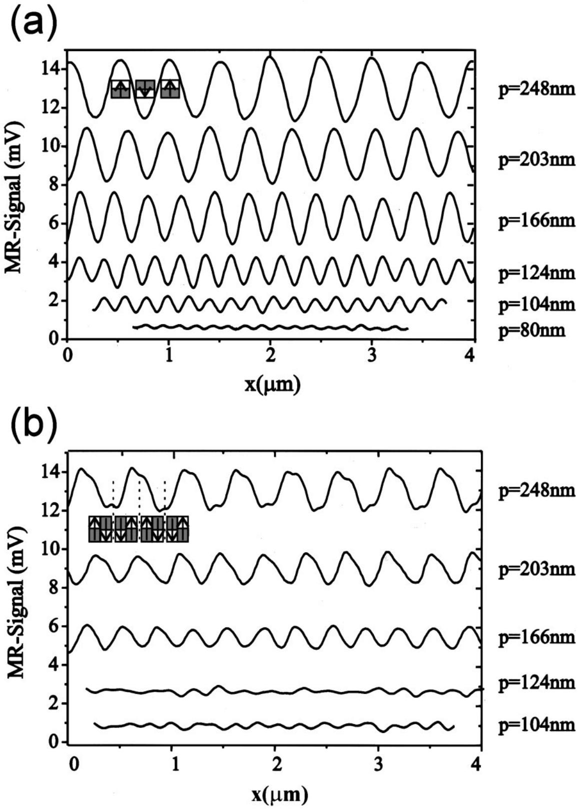

FIG. 2. (a) Readback signal for island arrays of different period p. Here the bits are written in phase; i.e., adjacent island rows are magnetized in opposite directions (inset). (b) The readback signal for the same arrays but when the square wave is written 90° out of phase with the islands.

of <2 nm. The recording head includes a write coil with a 2.4 μm wide write pole and a 2.2 μm wide magnetoresistive read element having a gap of ~ 250 nm.

Figure 1(c) shows schematically how the write/read element of a conventional head is scanned back and forth on the sample for an array of $p \sim 250$ nm. Since the width of the write/read element nearly matches the width of the patterned areas (2.5 μm), entire columns of single islands are simultaneously magnetized and read back. Skew and tilt angles are minimized using additional lithographical markers on the sample. To precisely adjust the $x-y$ position of the write/read element above the sample a constant write current is applied (dc erase) while the head is scanned across the sample at various y positions. The readback amplitude has a maximum when the head is positioned exactly above the pattern.

Using this procedure to align the head, well-defined square wave bit patterns can be written in the patterned areas. It is also necessary to optimize the write current to match the coercivity for each island size. Using write currents that are too high causes erasure effects, since the magnetic field emanating from the back, or trailing, edge of the write pole becomes large enough to magnetize the media and thus erase previously written transitions.

Two types of square-wave patterns were written and the corresponding readback wave forms are shown in Fig. 2. The readback signal from the first, referred to as in-phase writing, is shown in Fig. 2(a). Here, adjacent columns are magnetized in opposite directions by reversing the head field as the head passes over the trenches, so that the transitions between up and down bits occur at the trenches between the islands. As one can see in Fig. 2(a), the readback amplitude decreases with island size, but even the very smallest islands clearly exhibit a periodic signal.

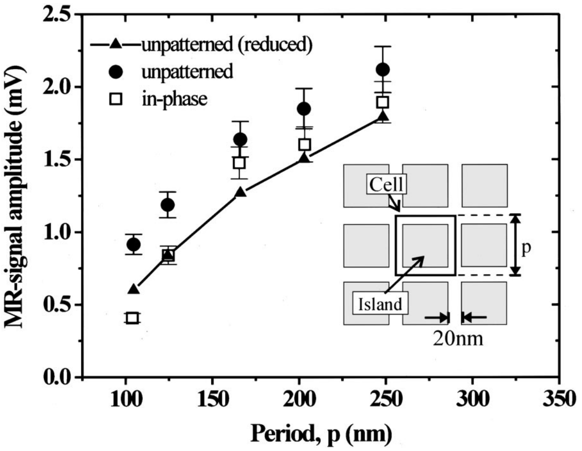

FIG. 3. Average signal amplitude for in-phase written bits (open squares) and for bits written in the unpatterned regions at linear densities that match the corresponding period p (closed circles). The inset shows the definition of the island area and the cell area. The triangles represent the signal for the unpatterned region, multiplied with the corresponding ratio of island area to cell area.

Figure 3 shows the average readback amplitude for the in-phase writing versus the trench period p (open squares). For comparison, bit patterns were also written in unpatterned regions at the identical linear densities $1/p$ and the corresponding signal amplitudes are shown as well (closed circles). The reduction in signal amplitude in the unpatterned media with decreasing p reflects the roll-off curve of the head–media combination.[12] In the patterned areas, the absence of material in the trenches areas results in a slightly reduced readback amplitude compared to that of the unpatterned areas. To illustrate this, the inset in Fig. 3 schematically shows a part of the patterned area. The bit cell has an area of p^2 and scaling the readback amplitude for the unpatterned case with the ratio of remaining island area/cell area $=(p-20\,\mathrm{nm})^2/p^2$ leads to the expected reduced signal amplitude (triangles). As one can see, these scaled amplitude values agree well with the measured in-phase amplitudes.

In addition to writing square waves in phase with the patterned islands, it is also possible to write squares waves out of phase with the islands. Figure 2(b) shows readback signals for square-wave bit patterns that have been written 90° out of phase. In this case the write field is modulated to produce peak write fields when the head is over a trench, in an attempt to write bit transitions in the center of the islands. Note that the readback signal from the largest islands shows a slight dip in amplitude at the peaks, indicative of the magnetic material removed from the trench located at the center of the island. While a pronounced readback amplitude remains for the larger islands, the signal for the smaller single-domain islands ($p<130$ nm) almost vanishes completely. This is a result of the fact that bit transitions, i.e., domain walls, cannot be placed in the islands and thus each island will have a 0.5 probability of being either magnetized up or down. Hence, on average the total magnetization of a single

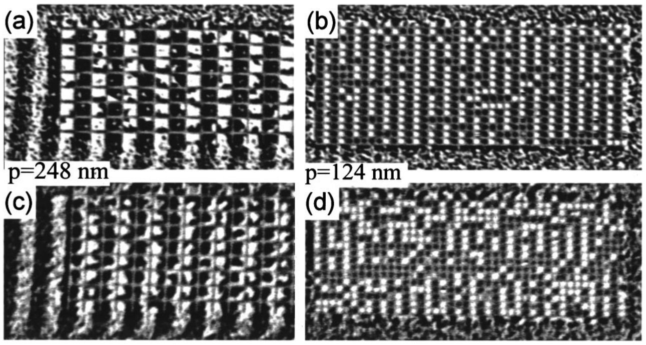

FIG. 4. MFM images of arrays of written islands. Panels (a) and (b) have a period of 248 nm, and (c) and (d) a period of 124 nm. The islands shown in (a) and (c) were written with the write head in phase, while those in (b) and (d) were written out of phase with the islands.

column of islands and therefore the readback signal equal roughly zero.

This transition to vanishing readback signal for the single domain islands when the write head is not properly positioned can also be seen in MFM images of the written bit patterns. Shown in Fig. 4 are MFM images of the $p = 248$ and $p = 124$ nm islands written both ''in phase'' [Figs. 4(a) and 4(b)] and ''out of phase'' [Figs. 4(c) and 4(d)]. For the $p = 248$ nm islands, a clear pattern of alternating black and white columns is seen. In Fig. 4(c), a trench is seen in the center of the bits, corresponding to the dip in the readback signal in Fig. 2(b), and reversed domains are seen in the islands. In contrast, for the $p = 124$ nm islands, Fig. 4(b) shows columns of alternating contrast, although a number of islands are clearly incorrectly written, possibly due to the switching field distribution of the islands.[8] However, in Fig. 4(d), each column consists of roughly an equal number of black and white islands, a result of reversing the write field out of phase with the island position. As discussed above, since domain walls cannot be placed in these small islands, the island will switch with a roughly 0.5 probability resulting in no readback amplitude.

In summary, we have demonstrated the writing and reading on perpendicular recording media patterned to areal densities of 100 Gbit/in.^{2}. We have found that readback amplitudes depend strongly on the write phase, vanishing for writing out of phase on the single-domain islands. Furthermore, we found evidence that the reduction of the readback signal for in-phase writing is mainly due to the reduction of magnetic material associated with patterning. Future work will focus on transition position jitter and signal to noise ratio measurements, as well as thermal stability measurements of patterned island arrays.

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