

Fabrication and Recording of Bit Patterned Media Prepared by Rotary Stage Electron Beam Lithography

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ABSTRACT

Bit patterned media (BPM) is a promising technology for magnetic recording at densities beyond 1 Tbit/in². To be viable, bit patterns must be reliably fabricated over large areas with few defects. One potential route is to employ nanoimprint lithography and direct media etching using templates generated by electron beam mastering tools. In this work, we experimentally demonstrate the merits of rotary stage electron beam mastering and the effects of direct pattern transfer on BPM arrays patterned into 2.5" disks at a density of 366 Gbit/in². The fully circumferential staggered BPM and integrated servo arrays were patterned into CoCrPt media with 42nm down track pitch and 42-84nm cross-track pitch using rotary stage electron beam lithography, liftoff, reactive ion etching, and ion milling processes. Pattern quality is verified via contact recording methods. These results and advanced patterning and etching techniques for 4Tbit/in² BPM will be discussed in detail.

Keywords: bit patterned media, electron beam lithography, ion milling, magnetic recording

1 INTRODUCTION

As the areal density of hard disk drives (HDD) approaches 1 Tbit/in², a number of recording limitations are encountered, particularly with the continuous granular coupled, or CGC, perpendicular magnetic recording (PMR) media used today [1]. Achieving higher densities will require a new recording paradigm. One promising approach is to replace continuous thin-film PMR media with bit patterned media (BPM) that consists of physically patterned magnetic islands, where each island represents an individual bit of data [1-6]. Such an approach is attractive because it lowers the magnetic noise generated at the transitions between data bits without requiring many changes to the magnetic recording heads that read and write data. However BPM does present a number of fabrication challenges. Above 1 Tbit/in², feature sizes begin to scale below 10nm in size, making lithography and etching difficult. Furthermore, BPM places stringent tolerances on defect densities and island distributions, requiring physical

deviations to have $\sigma = 5-10\%$ or better [1-6]. Despite the challenges, many believe that BPM can be commercially viable by employing high throughput nanoimprint lithography using quartz molds generated by highly accurate rotary stage electron beam lithography and guided self-assembly processes [2-6].

In this work, we demonstrate the merits of rotary stage electron beam lithography and we study the subsequent effects of direct pattern transfer on magnetic bits etched into CoCrPt CGC PMR media at densities up to 366 Gbit/in². Pattern fidelity is verified through physical analysis and magnetic recording. Moving forward, the limitations of such techniques will be addressed and new techniques will be discussed for achieving densities as high as 4 Tbit/in² using nanoparticle guided self-assembly for pattern generation and advanced methanol based RIE processes for media etching.

2 EXPERIMENTAL PROCEDURES

The BPM described in this work is fabricated on a 2.5" disk platform according to the layout of Figure 1. Each disk contains fully circumferential staggered bit patterns with 42nm down track pitch and 42-84nm cross-track pitch, as well as fully integrated IMES servo patterns composed of a preamble, gray code, ABCD burst patterns, and a postamble, all set to a constant angular track pitch of 126nm [7]. Together, the bit and servo patterns make up a single 150 μ m wide circular data band (centered at a 21mm radius) containing 256 data sectors designed for spin stand testing.

2.1 Bit Patterned Media Fabrication

The BPM disks are fabricated according to the process flow of Figure 2 using commercially available CoCrPt CGC PMR media. For etching purposes, Al, C, and SiN_x mask layers are sputter deposited onto the media to produce the structure: Glass Disk/Underlayers/Ru(20nm)/CoCrPt+Oxide(10-11nm)/CoCrPt(5-7nm)/DLC(1.5-3nm)/Al(3nm)/C(20nm)/SiN_x(5nm), where underlayers refers to a stack of proprietary magnetic and non-magnetic seed layers, where CoCrPt refers to a proprietary media alloy, and where DLC refers to diamond-like carbon. Following deposition, the

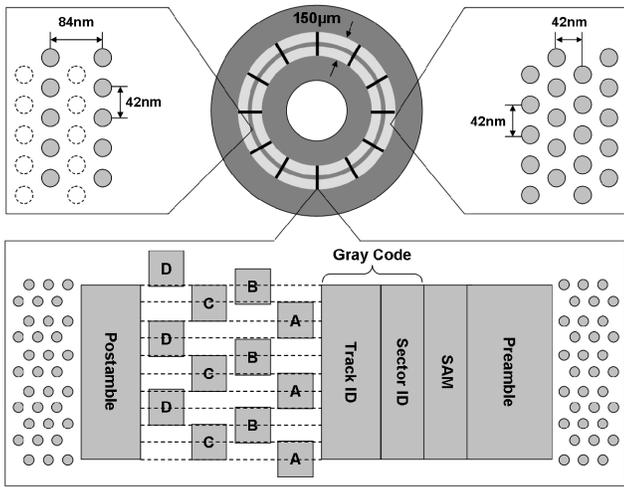


Figure 1: Schematic diagram of the BPM layout.

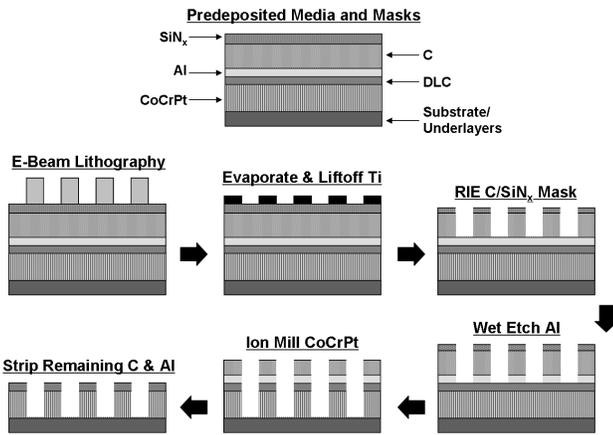


Figure 2: Schematic diagram of the BPM process flow.

BPM layout of Figure 1 is generated in 50nm thick ZEP-520A positive tone resist using an EBR-401 rotary stage electron beam lithography system developed by Pioneer Corporation [7]. During exposure, the disk rotates at a constant line velocity of 0.475m/s under a 100kV electron beam generating 15nA of current. After development, the positive tone of the resist results in a series of holes and trenches representing the bit and servo patterns respectively, as shown in Figure 3(a). To reverse the pattern for direct etching, 2.5-3nm of Ti is electron beam evaporated and lifted off with an acetone ultrasonic wash, replacing the positive tone holes and trenches with a negative pattern of Ti islands. Consequently, the Ti can be used as a mask to transfer the bit and servo patterns into the underlying SiN_x and C mask layers using CF₄/CHF₃ and O₂/Ar based reactive ion etching (RIE) processes respectively, where the Ti acts as mask for the 5nm SiN_x, the SiN_x acts as a mask for the 20nm C, and the 3nm Al layer acts as an etch stop. Following definition of the C/SiN_x, the now oxidized Al layer is removed using a wet etch solution of Clariant AZ400K developer and de-ionized

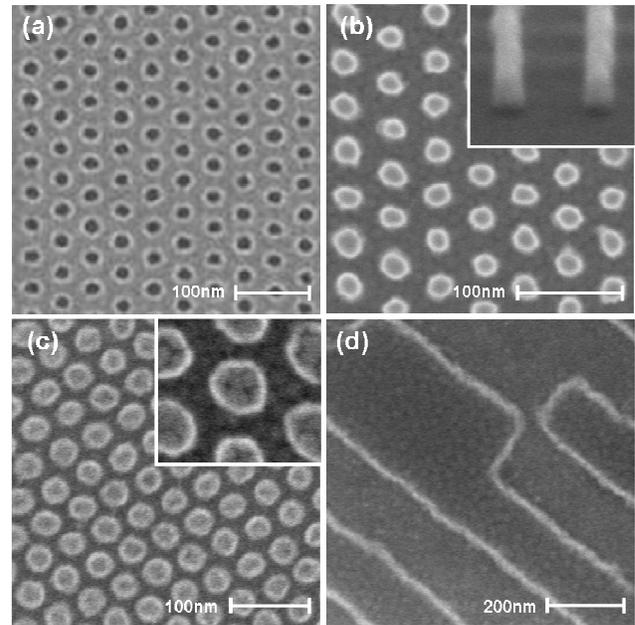


Figure 3: Scanning electron microscope images of (a) Al/C/SiN_x patterned islands, (b)-(c) ion milled bit patterns, and (d) ion milled servo gray code patterns.

(DI) water, resulting in the patterned Al/C/SiN_x structure (note that the Ti has most likely been consumed during RIE) depicted in Figure 3(b) [8-9]. With the slow etching AlO_x removed, the DLC and CoCrPt media layers are etched using a 400V Ar ion beam at an angle of 20°. To finish the media for testing, the remaining C mask (note that the SiN_x will have been consumed during ion milling) is stripped from the sample using the same O₂/Ar RIE process described above, where again, the 3nm Al layer remaining on top of the bits serves as an etch stop, protecting the DLC from etching. After RIE, the remaining Al is removed in the same AZ400K/DI solution detailed above, with the addition of a polyvinyl alcohol (PVA) foam scrub. The end result is the relatively clean undamaged media surface depicted in Figures 3(c)-(d).

2.2 Magnetic Recording

Magnetic recording tests were performed on a commercial spin stand as well as a custom built contact recording tester. Prior to testing, the media was sent to Showa Denko K.K. for post processing that includes lubrication and burnishing. After glide testing and qualification, the media is ready for testing on a spin stand.

The spin stand, built and operated by Xyratex Ltd., is designed to fly commercial magnetic recording heads at heights of 8nm or less on disks rotating at 5400-7200rpm. In this study, magnetic recording heads with magnetic write widths (MWW) of 120nm and magnetic read widths (MRW) of 82nm were used to write and read data on the circumferential BPM patterns with readback sampling rates up to 2.5G/sec. In contrast the contact recording tester uses

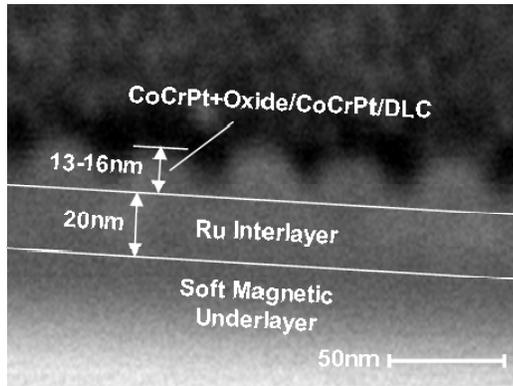


Figure 4: Cross-section SEM image of 42nm pitch bit patterns etched into CoCrPt PMR media.

a piezo controlled stage to scan a commercial recording head in contact with the media for writing and reading at step sizes as small as 1nm [10]. The heads used for contact recording have MWW of 85-95nm and MRW of 65-75nm.

3 RESULTS AND DISCUSSION

3.1 Physical Analysis & Discussion

Figure 3 provides a direct comparison of the BPM patterns as they progress through the various fabrication steps, starting with the electron beam lithography pattern of Figure 3(a). Within the 42nm pitch pattern, individual bits have very accurate placement, given that the EBR-401 system is capable of minimizing downtrack and crosstrack bit placement errors to 1.8nm and 2.8nm 3σ respectively [7]. The system accomplishes such tasks by correcting for rotational error, including repetitive and non-repetitive runout, using a series of sensors with 0.1-0.2nm positioning accuracy. However, the bits do demonstrate significant variation in size, with diameters ranging from 13-17nm, as illustrated in Figure 3(a). The variation is most likely caused by local resist variations, as well as limitations met in pushing the resolution limits of the ZEP-520A.

As the process progresses through pattern reversal and RIE, pattern fidelity remains mostly unchanged; although, the bits do appear to become somewhat irregular and larger in size, increasing in diameter to 18-22nm. Figure 3(b) depicts an image representative of the C/SiN_x mask structure. The irregularity appears to be a result of the liftoff process and the lack of a descum step prior to the Ti evaporation. The appearance of previously undetectable line edge roughness on the servo patterns further supports this hypothesis. On the other hand, the 5nm average increase in bit diameter is most likely due to less than ideal directionality during RIE. Nonetheless, the size distribution of the bits remains unchanged at ~4nm. Figures 3(c) and 4 depict the bit patterns after ion milling and mask removal. The CoCrPt media was etched to a depth of 13-16nm, stopping at or in the Ru interlayer with minimal redposition

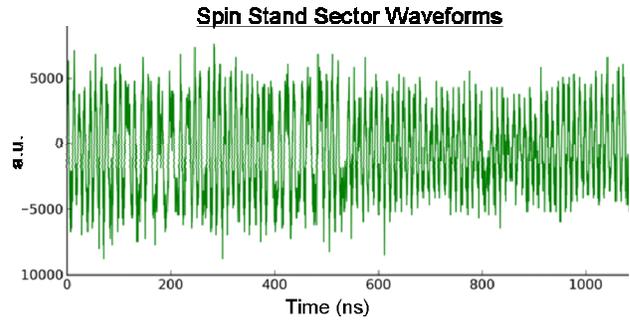


Figure 5: Spin stand readback waveforms.

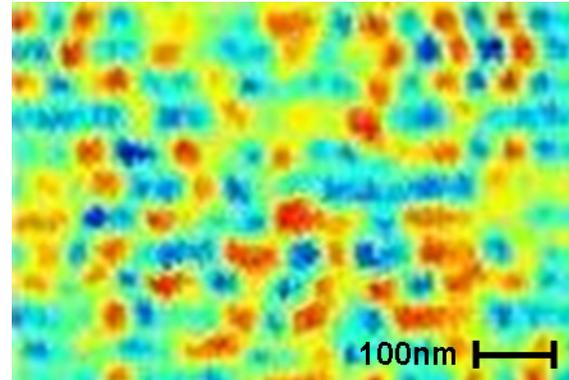


Figure 6: Contact recording readback colormap of 42nm pitch recorded bit patterns.

and sidewall angles of $\sim 70^\circ$. After milling, the bit size distribution still remains unchanged at ~4nm, even though the overall diameter has now increased to 28-32nm, or 10nm on average. The source of the increase can be determined by taking into account the mask structure and milling conditions. The C/SiN_x mask structure was chosen for its high chemical selectivity in RIE processes and its high physical selectivity in ion milling, where etch rates of C relative to Co based alloys can be as low as 1:4. Given an incident ion beam angle of 20° , an overall Al/C/SiN_x mask height of 28nm, and the resistance of the mask structure to faceting, a 10nm increase in diameter is almost exactly as expected. In addition, some of the bit irregularity and line edge roughness appears to have been removed, suggesting the ion mill can help to smooth sharp edges generated during previous processing steps.

3.2 Magnetic Recording Analysis

Physical analysis of the patterned bits and servo in Figure 3 suggest minimal media damage has occurred as a result of fabrication, but magnetic testing is necessary to confirm pattern fidelity. Figure 5 depicts a spin stand readback waveform obtained from a patterned data track at a flyheight of ~8nm. Given the sensitivity of the head to small defects on the media surface, the readback waveform confirms the disk is flyable and that the fabrication process

has not damaged the media surface. However, as flying continued, the head became unstable, ultimately leading to a crash on the disk. The instability is most likely a result of variation in flyheight caused by the fact that the media was not backfilled and planarized prior to testing [2-5].

After the head crash, remaining tests were performed via contact recording. Figure 6 depicts a two-dimensional readback map of a 42nm pitch bit array. The pattern was obtained by DC saturating an entire region of the media and incrementally reversing the patterned bits with the head, using write currents of 10-12mA. Readback was performed in steps of 4nm. The result is a series of clear, sharp 42nm pitch red-blue transitions that demonstrate the ability to write and read the BPM arrays, thus verifying a high fidelity pattern. Continued recording tests and magneto-optic kerr effect, or MOKE, measurements confirm very little change in the magnetic properties between the continuous unpatterned regions of the media and the BPM arrays, providing further evidence that the fabrication process results in minimal damage to the magnetic media.

3.3 Processes for Densities up to 4Tbit/in²

Rotary stage electron beam lithography is a promising technology for use in nanoimprint master templating. However, at ultra-high densities above 1 Tbit/in², it would take weeks to write a single 2.5-3.5in master template with an electron beam. Thus, many believe that electron beam writing must be coupled with self-assembled nanostructures [2-6]. Currently, researchers are exploring the use of block copolymers (BCP) for this task., where sparse electron beam patterns are written as guides to control self-assembly [3,6]. By writing only sparse guide patterns, electron beam writing time becomes drastically reduced. BCPs have also demonstrated the ability to heal or ignore defects in the electron beam pattern [3,6]. However, at very high densities, BCPs become difficult to control. In addition, the guide patterns can only be written at pitches a few times greater than the BCP pitch before defects start to occur. An alternative is to use self-assembled nanoparticle arrays for pattern generation and masking. Nanoparticles can be highly monodispersed for sizes down to only a few nanometers. If guided properly, they can produce long range order using very sparse guides and still have the same defect healing properties demonstrated by BCPs. Figure 7(a) shows an example of preliminary work in which 11-12nm FeO_x nanoparticles, representing a density of 4.1Tbit/in², are guided on a C surface using hydrogen silsesquioxane posts as anchor points. The corresponding Fourier transform image of Figure 7(b) confirms that very good ordering is achieved for guide pitches of 7X relative the nanoparticle pitch. With more work, long range ordering may be achievable at guide pitches above 10X.

Regardless of how pattern generation is achieved, the pattern must be transferred into the PMR media. At densities well beyond 1 Tbit/in², feature sizes approach the sub-10nm regime, presenting a number of challenges for

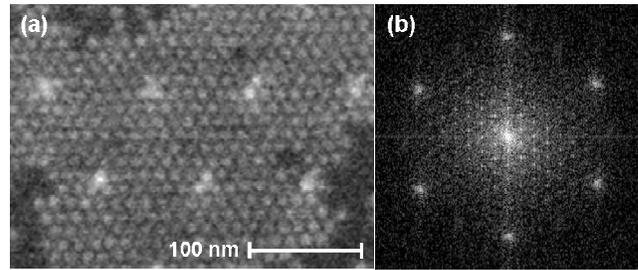


Figure 7: (a) SEM image of the guiding and self-assembly of nanoparticles on HSQ posts and (b) the corresponding Fourier transform of the ordered nanoparticle arrays.

direct media etching using conventional Ar ion milling. Instead, advanced RIE processes will be needed to meet the challenge. As such, we are currently exploring the use of a methanol based inductively coupled plasma RIE process for direct pattern transfer of sub-10nm features into Co, Fe, and Ni based BPM alloys [11]. Such techniques will be critical in providing a viable BPM product.

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