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Research Letter

Achieving High Aspect Ratio of Track Length to Width in Molds for Discrete Track Recording Media

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Discrete track media (DTM) fabricated by nanoimprint lithography (NIL) is considered as a potential technology for future hard disk drives (HDD). In the fabrication of a master mold for NIL, patterning the resist tracks with a narrow distribution in the width is the first critical step. This paper reports the challenges involved in the fabrication of high aspect ratio discrete tracks on Polymethylmethacrylate (PMMA) resist by means of electron beam lithography. It was observed that fabrication parameters applied for successful patterning of discrete tracks in nanoscale length were not directly suitable for the patterning of discrete tracks in micron scale. Hence different approaches such as thick layer resist coating, introducing of post exposure baking process, and varying of exposure parameters were used in order to achieve uniform sharp discrete tracks in micron scale length on the resist. The optimal parameters were used to pattern 20 μm long tracks with 70 nm track pitch on the resist.

1. INTRODUCTION

In hard disk drives (HDD), achieving a high signal-to-noise ratio (SNR) without sacrificing thermal stability or writability is one of the major concerns. Recently, perpendicular recording was introduced in HDDs, because of its ability to improve SNR, thermal stability and writability as compared to the traditional longitudinal media which has gradually been phased out due to superparamagnetism. Even though perpendicular recording technology shifts the onset of superparamagnetic effect to some extent, the effect still exists and will pose a limitation to magnetic recording technology in the coming few years. Therefore, alternative technologies such as heat assisted magnetic recording (HAMR), and bit-patterned media (BPM) need to be considered. A probable intermediate step towards HAMR or BPM is discrete track media (DTM) technology [1–7].

In the conventional perpendicular recording scheme, recorded data is stored along circumferential tracks. In this scheme, the write head determines the track positions and widths. Tolerance between the write and read head locations can induce noise along the magnetically defined tracks [6]. In the case of DTM, the tracks are lithographically defined in such a way that the track widths and locations are physically fixed. Nonmagnetic region between physically defined magnetic tracks can reduce the noise during the reading process, which helps in increasing the track density [6]. To meet areal densities of 1 Tb/in^2 or higher, track densities higher than 300 ktpi are sought; however, one of the major hurdles in the introduction of discrete track recording lies in the media fabrication. Introducing DTM will require lithographic process with low cost and high throughput manufacturing capabilities. There are many state-of-the-art lithographic tools with a capability of fabrication sub 100 nm patterns. Among them, nanoimprint lithography (NIL) becomes the most promising approach with low cost and high throughput manufacturing capabilities for DTM fabrication in a large-scale area.

Previous studies presented various approaches and resist materials used for the fabrication of DTM [8–10]. Hattori et al. reported the fabrication of discrete tracks with 90 nm pitch by using ZEP520A electron beam resist and Ni and TiN hard mask layers [10]. In our study, we have investigated the fabrication of discrete track mold on resist with electron beam lithography which was designed for the target of 320 ktpi in 20 μm length. It was observed that for such high track dentist, making tracks in micron scale length with the track width in nanometer scale was one of the lithographic challenges. Those narrow width and long resist tracks require higher mechanical strength and stronger adhesion to a substrate underneath to withstand an indirect exposure by electron scattering and mechanical stress from surrounding exposed lines during the process. Similar issues were reported in simulation and experimental study from Jones and Paraszczak that narrow width of resist collapsed because of the stresses introduced by the processing conditions [11]. In our study, the lithographic challenges involved in the patterning of discrete tracks on resist with an aspect ratio of multiple of hundreds (track length/track width) and the ways to solve these problems are reported here. Resist tracks with 120 nm pitch and 20 μm length were patterned to establish the optimal process parameters and later those parameters were applied to fabricate 70 nm track pitch with 20 μm track length.

2. EXPERIMENTAL DETAILS

A thermally oxidized silicon substrate was spin coated with PMMA resist. The same substrate type was used throughout experiments, since patterning results with electron beam lithography can be changed with different types of substrate or underlayer beneath PMMA resist. More details about exposure parameters and resist coating are described in the text, as the conditions of these procedures were varied for optimization. Scanning electron microscope (SEM) and atomic force microscopy (AFM) were the main tools used for the evaluation of the fabricated patterns. TESP7 AFM probes were used throughout experiments since its maximum radius is 10 nm and tip height of 10 μm allows it to scan the bottom of resist trenches which are less than 150 nm in depth.

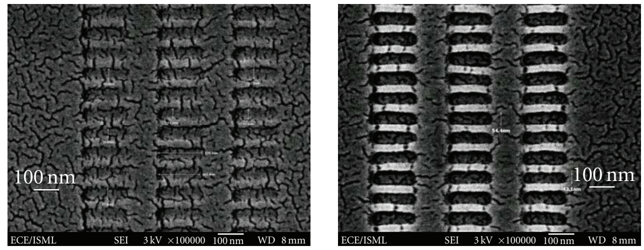
3. RESULTS AND DISCUSSION

3.1. Initial studies on sub-μm tracks

An array of tracks with 150 nm length, 40 nm width, and 40 nm spacing were patterned using PMMA resist dissolved in 2% anisole. The resist was spun at 4000 RPM for 60 seconds on the substrate and baked at 180°C for 2 minutes. Under these conditions, 55 to 60 nm thick resist was obtained after 30 seconds development time. Figure 1 shows SEM images of the developed resist patterns, showing that 40 nm line widths and spacings can be produced at exposure doses between 300 and 450 μC/cm^2 with a constant electron beam current of 100 pA. We selected the range of exposure doses between 300 and 350 μC/cm^2 for further investigation since measured line widths and spacings produced at those doses are closer to the targeted value of 40 nm compared to the doses between 400 and 450 μC/cm^2.

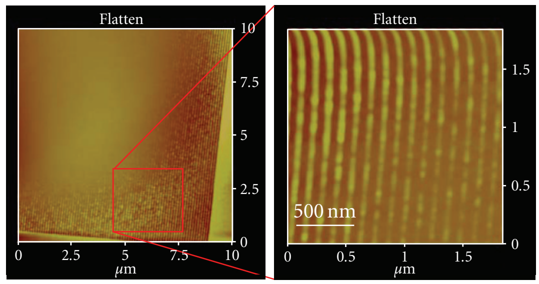
3.2. Longer track investigation

The fabrication of a master mold for DTM requires high aspect ratio tracks with good uniformity, where the uniformity is defined as the percentage of the difference between the widest line and the narrowest line over the sum of those values. For this purpose, an array of 20 μm long tracks with 120 nm track pitch (70 nm width and 50 nm spacing) was



(a) (b)

Figure 1: SEM images of developed resist patterns exposed at (a) 300 μC/cm^2 and (b) 450 μC/cm^2.

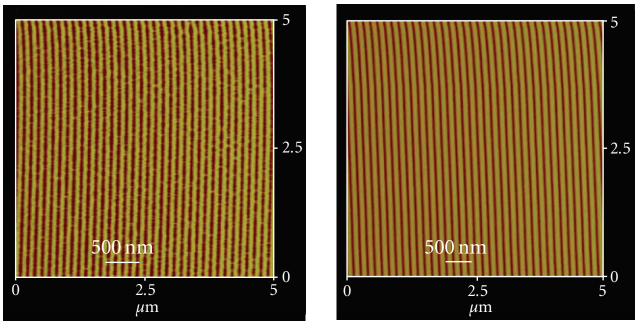


(a) (b)

Figure 2: AFM images of (a) 20 μm long-tracks with 70 nm track width and 50 nm spacing. The center of the exposed area is washed away after development. Image (b) is an enlarged area which shows that the exposed lines are broken and nonuniform. Right side figure shows a curled-shape track which is due to scanning artifact.

patterned on the PMMA resist. Parameters for resist coating, baking, and developing for 20 μm long tracks were kept the same as those described above for the fabrication of an array of tracks with 150 nm length. Figure 2 shows that the tracks were removed at the centre of the exposed area, while broken tracks of resist remained only at the edges of the array patterns. It is anticipated that etching rates are different for the edge area and the center area, since the developer solution encountered more unexposed resist bulk at four edges of the exposed area of tracks. Reducing the resist development time resulted in under developed patterns at the edges, while still giving a partial removal of the exposed resist in the centre area. These results suggest that the higher aspect ratio of the tracks leads to more difficult process control in order to achieve good intact and adhesion of those tracks to the substrate. Hence further process improvements are necessary to overcome this issue.

As a first attempt to overcome this problem, post exposure baking (PEB) process was introduced just after exposure and before resist development. PEB process was expected to harden the resist and reduce the resist sensitivity during its development. A baking temperature of 80°C was chosen which was below the glass transition temperature of PMMA. Reducing the sensitivity and hardening the resist can minimize its mechanical stress and electron scattering into unexposed resist lines from adjacent exposed lines, resulting in minimal resist deformation during its development. From AFM images, the whole exposed area is now filled with an



(a) (b)

Figure 3: AFM images of resist patterns for (a) 90 nm and (b) 120 nm of resist thickness.

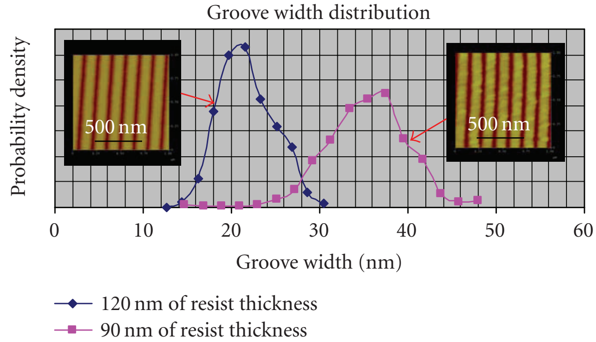


Figure 4: Groove width distributions for two different resist thicknesses.

array of 20 μm long tracks, but there is nonuniformity of resist tracks although the tracks remain present for the process with PEB. It can be concluded that the PEB process can help to improve the fabrication of long tracks but not good enough to be used for making a mold for DTM.

3.3. Effect of resist thickness and beam current

In order to see if the resist thickness plays a vital role to achieve the uniform resist tracks with high aspect ratio, two different resist thicknesses were evaluated. The first sample was spin coated with a speed of 2500 rpm and the second sample was coated twice with a speed of 4000 rpm for each resist layer. A baking at 180°C for 2 minutes was conducted for each layer to improve interfacial adhesion between them and surface uniformity. The measured resist thicknesses for the first and second samples were about 90 nm and 120 nm, respectively. In addition to the resist thickness variation, the electron beam current was reduced to 30 pA to minimize proximity effect (electron scattering on adjacent unexposed areas). The exposure dose for the two samples was increased to 600 $\mu C/cm^2$ to accommodate the increase in exposure energy requirement for thicker resists. In this study, no PEB was applied to investigate only the effect of beam current and resist thickness on tracks uniformity. As expected, both samples had uniform resist tracks intact over the whole exposed area, improved by the lower beam current (30 pA) which minimizes the proximity effect compared to previous processes in which 100 pA of beam current was applied.

Figure 3 shows AFM images of the samples scanned over 5 μm range in the centre of the processing area. The track pitch was 120 nm with 60 nm width and spacing, respectively. It can be seen from AFM images that more uniform resist tracks can be obtained on 120 nm thick resist compared with tracks on 90 nm thick resist. In order to evaluate the resist thickness effect on the uniformity of resist tracks, the widths of tracks and grooves were tabulated and the width distributions for both resist thichnesses were compared. Since the tracks and grooves have different intensity levels, simple thresholding was used to distinguish between them. Figure 4 shows groove width distributions for different resist thickness. For the sample coated with 120 nm thick resist, average widths of grooves and tracks were 22 +/− 3 nm and 122 +/− 3 nm, respectively, whilst for the sample with 90 nm of resist thickness, 35 +/− 5 nm and 109 +/− 4 nm, respectively. Although the sample with the thicker resist gave smaller variation in line widths, it was still not sufficient to achieve good signal to noise ratio as there was a ~20 nm difference between the widest and narrowest tracks. Hence further study on the optimization of electron beam energy to achieve even lower track pitch and narrower distribution of line widths was carried out for 120 nm thick resist. As a result, it was found that 600 $\mu C/cm^2$ is the optimal exposure dose for achieving long tracks of more than 20 μm with sharper edges and good uniformity.

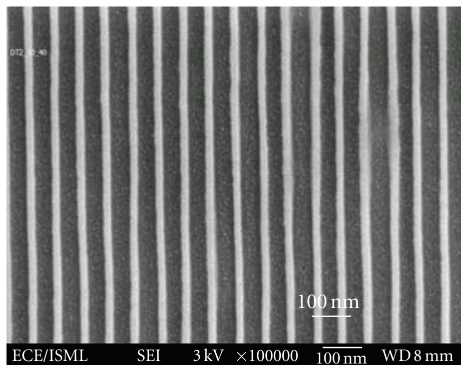


Figure 5: An SEM image of 70 nm pitch tracks.

In DTM, to be able to optimize the readback signal while reducing the noise, sharper tracks edges are needed; and from SEM images, it can be seen clearly from Figure 5 that with thicker resist, 30 pA beam current and optimal dose, it is possible to achieve sharper and uniform tracks with large aspect ratio (length/width).

4. CONCLUSION

Electron beam lithography process for making a mold for DTM was optimized by various procedures. For 55 nm thick resist, the exposure doses between 300 μC and 350 $\mu C/cm^2$ give the best result for resist tracks with 150 nm length. For the tracks in micron scale length, however, the uniformity in resist thickness was not possible using the same process parameters suggesting the weak adhesion of the resist to the sample surface. PEB was found to improve the overall resist performance to some extent that the resist tracks still remain after development. However, there is still a thickness variation in the resist by about 15 nm which is about 30% of the coated resist thickness of 55 nm. In order to overcome this issue, the electron beam current was reduced in parallel with the application of thicker resist. Resist tracks with uniform thickness and lateral dimensions were confirmed by AFM and SEM images. It is concluded that resist thickness, the optimized e-beam energy corresponding to the thicker resist, and e-beam current play a major role in obtaining long tracks with high aspect ratio.

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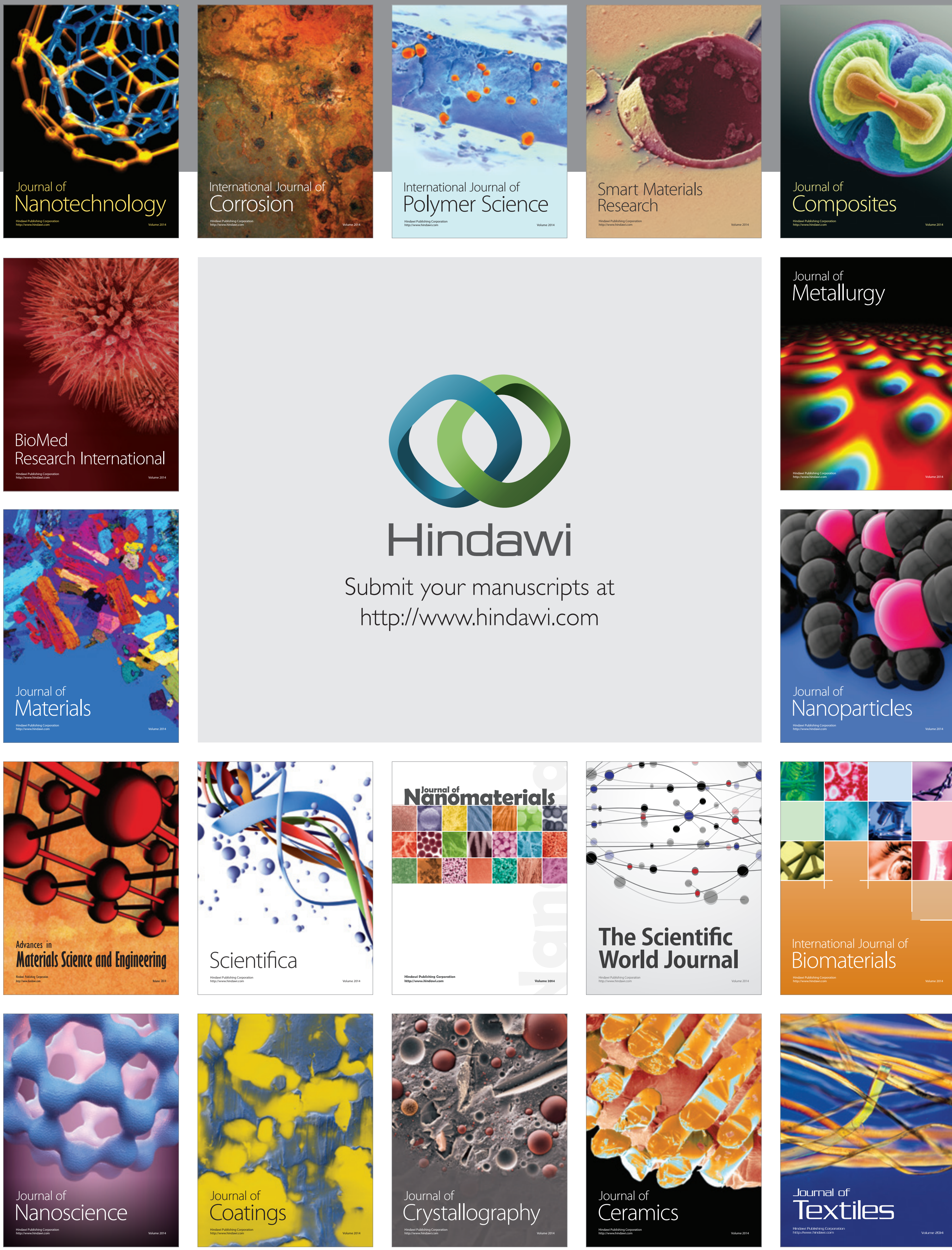

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