3-Dimensionals Lithography Techniques for Air Bearing Surface Patterning in Hard-Disk Drive Reading/Writing Head Manufacturing

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Abstract

The aerodynamic Micro-Electro Mechanical System (MEMS) patterns such as Air Bearing Surface (ABS) in the read/write head of a hard disk drive can be formed by using lithography technique. The important element is the lithography mask set. In one set of masks consists of (1) Binary Intensity Mask with Single Layer Reticle (BIM-SLR), (2) Binary Intensity Mask with Multi Layer Reticle (BIM-MLR), (3) Multi Exposure Binary Intensity Mask with Multi Layer Reticle (ME-BIM-MLR), (4) Gray Scale Lithography mask (GSL-mask) (5) Multi Film Thickness mask (MFT-mask) and (6) Vary Dose MFT-mask (VD-MFT-mask). It is found that the most cost and time effective mask type is VD-MFT-mask. As long as the number of lithography masks is less than 5, then the time required to fabricate VD-MFT-mask is still less than the time required to fabricate GSL-mask. Therefore this paper report the application of VD-MFT-mask for patterning ABS in order to reduce cost and process time instead of increasing the number of process tools such that the throughput is increased. This will essentially reduce the total process cost for the future process.

Keywords: Air Bearing Surface, Grayscale Lithography, Multi Film Thickness Mask, 3-D lithography

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Introduction

Binary Intensity Masks or BIMs are used for patterning of the ABS side of the read/write heads. In general, the ABS side contains 4 to 5 height levels. This is time-consuming and costly when employing BIMs for lithography processes and later etching processes. The reasons being there are several photoresist coating process and etching process steps. The way to speed up the process is to increase the number of process lines, which are very expensive. This paper reports 6 different mask making techniques and associated costs for ABS formation. Those techniques are (1) Binary Intensity Mask with Single Layer Reticle (BIM-SLR), (2) Binary Intensity Mask with Multi Layer Reticle (BIM-MLR), (3) Multi-Exposure with Binary Intensity Mask with Multi Layer Reticle (ME-BIM-MLR), (4) Grayscale Lithography Mask (GSL-Mask), (5) Multi-Film Thickness Mask (MFT-Mask) and (6) Vary-Dose-MFT-Mask (VD-MFT-Mask). The comparison is useful for choosing the most economical mask making methods for future hard disk Air Bearing Surface formation.

A. Read/Write Head Structures

The principle of the read/write head of the Hard-Disk Drive (HDD) is to transfer data from and to the media using magnetic field induction. The read/write head comprises 2 main features. The first feature is to read and write data from media and the other feature is to fly over spinning media. In order to fly over the media, the read/write head surface facing the media or Air Bearing Surface (ABS) needs to have special patterns, as illustrated in Figure 1. The patterns should be such that right positive and negative pressures on different positions on the ABS so it read/write head does not touch the media. The patterns are formed by several sequential lithography and etching steps.

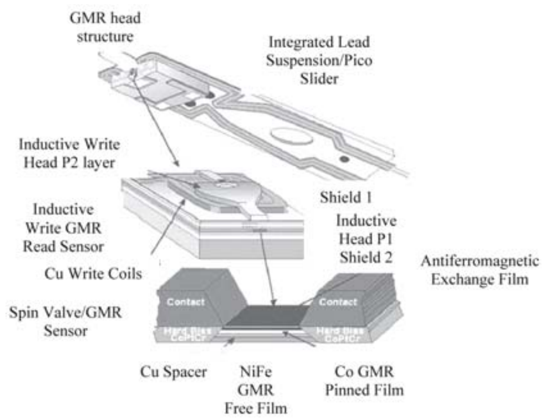

Figure 1. Read/write head of Hard Disk Drive.

B. Photomask

A photomask is a device used to transfer designed patterns onto the silicon substrate in semiconductors processing. The photomask is made of quartz glass, which is deposited by two thin-film layers of 74-nm-thick Chromium film and 26-nm-thick Chromium oxide. The role of the Chromium layer is to block the UV light while the layer of Chromium oxide works as an anti-reflection layer as shown in Figure 2. In general, there are two types of the photomasks depending on the light transparency; (1) Binary Intensity Mask (BIM), which allows equal intensity of the UV light to get through wherever no Chromium existing on the mask and (2) Gray Scale Lithography mask (GSL mask) through which varying intensity of the UV light passes through depending on the patterns on the photomask.

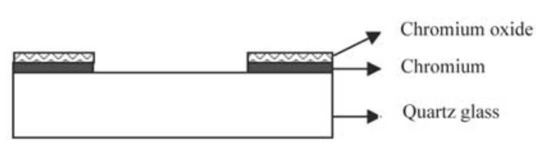

Figure 2. A cross-section of a photolithography mask

Structure formation

C. 3-D microstructure forming using Binary Intensity Mask

Binary Intensity Mask (BIM) is commonly found in two-dimensional (2-D) patterning for Integrated Circuit (IC). UV light passes through the BIM in the transparent areas (no Chromium film) while, in the opaque areas (Chromium film is present), the UV light cannot pass through (Benjamin, 2005). If a positive photoresist film (PPF) is deposited on a Si wafer, then the UV light that gets through the mask will expose on the PPF and renders the polarization of the PPF. The exposed PPF is then dissolved in a developer and the unexposed PPF is left intact.

After the lithography step is finished, the etching step is then performed. In the etching step, the remaining PPF is to protect the wafer or the top film from being etched away. The positive image is then transferred from the remaining PPF onto the underneath wafer. One of advantages of the BIM is that the processing is straightforward. However, in order to form 3-D patterns on the wafer, the wafer has to go through more than one cycle of the lithography and etching steps as shown in Figure 3 and Figure 4. Therefore, it is expensive and time-consuming. Normally, the difference pattern can generate on the same mask plate called Multi-Layer Reticle, (MLR) which can save the mask blank cost than Single Layer Reticle (SLR).

Due to high precision and accuracy of the exposure tool stage, 3-D microstructures could be patterned using the BIM in a single cycle of the lithography and etching steps with an additional technique. The technique use MLR to expose by changing the UV light intensity after moving the stage to a new position until all positions are completed. The exposed wafer is then developed and etched in a single step to form a 3-D vertical sidewall, slope profile microstructure as shown in Figure 5. This kind of technique called Multi-Exposure MLR and normally it's often use BIM for master pattern so this technique called ME-BIM-MLR (Jantawong et al., 2007).

D. 3-D microstructure forming using Gray-scale Lithography mask

Gray-scale lithography mask (GSL mask) is commonly used to form 3-D microstructures in MEMS. The GSL mask filters certain energy and intensity of the UV light that goes through it before exposing on the underneath wafer (Brian, 2004). Patterns on the GSL mask comprise varying sizes of opaque areas or pixels (with the Chrome layer on glass) separated by varying transparent areas or pitches (without the Chrome layer on glass). The patterns act like slits, which cause light diffraction and alter the light energy. Therefore, different locations on the PPF receive different UV light energy. The chosen PPF should be of low contrast to capture slight change in UV light energy. After developing, the PPF will become a 3-D microstructure and, after etching, the 3-D microstructure is then transferred onto the wafer as shown in Figure 6. A constraint of the pattern on the GSL mask, which is pitch and pixel, must be smaller than the resolution of the lithography tool (Waits et al., 2003). The relation of the smallest pixel and pitch sizes and the lithography tool resolution is shown in eq. (1) while the resolution of the lithography tool is related to the wavelength of the UV light and Numerical Aperture (NA) of the lens system as written in eq. (2). The percentage of light transparency ($\%T$) can be calculated from the known pitch and pixel areas as shown in eq. (3) (Waits et al., 2003).

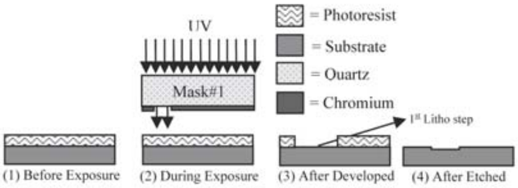

Figure 3. A formation of 3-D microstructures using a BIM with conventional multiple cycles of the lithography and etching steps (layer1).

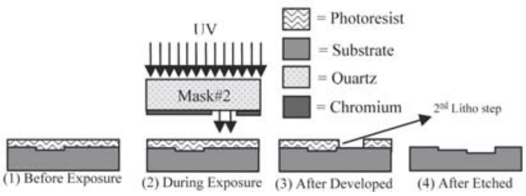

Figure 4. A formation of 3-D microstructures using a BIM with conventional multiple cycles of the lithography and etching steps (layer2).

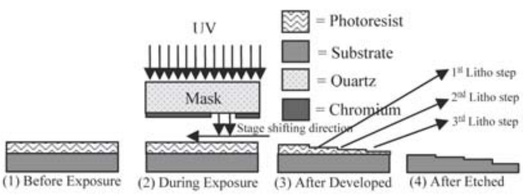

Figure 5. A fabrication of a 3-D microstructure using the BIM with multiple UV light exposures and a single-etching process step.

D. 3-D microstructure forming using Gray-scale Lithography mask

Gray-scale lithography mask (GSL mask) is commonly used to form 3-D microstructures in MEMS. The GSL mask filters certain energy and intensity of the UV light that goes through it before exposing on the underneath wafer (Brian, 2004). Patterns on the GSL mask comprise varying sizes of opaque areas or pixels (with the Chrome layer on glass) separated by varying transparent areas or pitches (without the Chrome layer on glass). The patterns act like slits, which cause light diffraction and alter the light energy. Therefore, different locations on the PPF receive different UV light energy. The chosen PPF should be of low contrast to capture slight change in UV light energy. After developing, the PPF will become a 3-D microstructure and, after etching, the 3-D microstructure is then transferred onto the wafer as shown in Figure 6. A constraint of the pattern on the GSL mask, which is pitch and pixel, must be smaller than the resolution of the lithography tool (Waits et al., 2003). The relation of the smallest pixel and pitch sizes and the lithography tool resolution is shown in eq. (1) while the resolution of the lithography tool is related to the wavelength of the UV light and Numerical Aperture (*NA*) of the lens system as written in eq. (2). The percentage of light transparency (*%T*) can be calculated from the known pitch and pixel areas as shown in eq. (3) (Waits et al., 2003).

$$W_{\min} = P - \sqrt{\frac{P_c^{\,2}}{2}} \qquad (1)$$

$$P_c = K\frac{\lambda}{NA} \qquad (2)$$

$$\%T = 1 - \frac{A_{Pixel}}{A_{Pitch}} \times 100 \qquad (3)$$

Where W_{min} is the smallest pixel width.

P is the pitch size.

P_c is the resolution of the lithography tool.

K is a constant.

l is the wavelength of the UV light.

NA is Numerical Aperture of the lens

$\%T$ is the percentage of light transparency.

A_{Pixel} is the pixel areas.

A_{Pitch} is the pitch areas.

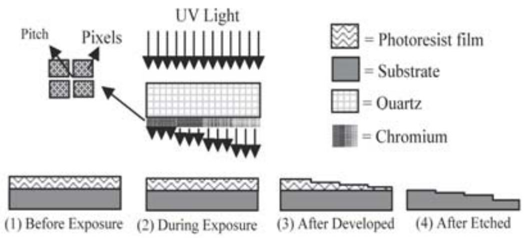

Figure 6. A formation of 3-D microstructures using the GSL mask.

E. 3-D microstructure forming using Multi-Film Thickness mask

The purpose of the Multi-Film Thickness mask (MFT mask) is to combine advantages of low cost of the BIM and a straightforward process (one-cycle lithography and etching steps) of the GSL mask. In this section, the concept of the MFT mask is described. The key idea behind the MFT mask is that when the thickness of the opaque medium changes, the transparency of the opaque medium will also change (Atthi et al., 2007). In this case, the opaque medium thickness is the Chrome layer thickness on quartz glass in which use as a lithography mask. When the thickness of the Chrome film varies on different areas of the mask, varied energy of the UV light then gets through respective areas. The thinner the Chrome film, the higher light energy goes through. This results in a 3-D microstructure on the PPF after a single exposure/developing. Moreover, the patterns on the mask do not need to be smaller than the resolution of the lithography tool. However, the 3-D microstructures formed by the MFT mask are subsets of those formed by the GSL mask in which the MFT mask can only produce vertical sidewall, slope profiles while the GSL mask can produce curvature profiles.

When using the MFT mask in a lithography step, the intensity and energy of the UV light getting through the mask increases as the thickness of the Chrome film gets thinner. Therefore, the PPF under thinner Chrome film receives higher light intensity and energy. After developing, a 3-D structure is then formed on the PPF as shown in Figure 7.

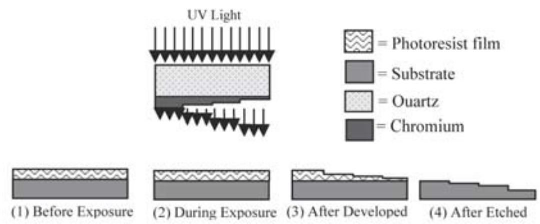

Figure 7. A formation of 3-D microstructures using the MFT mask.

After fabricating the MFT mask, the light transmission is measured through the mask. The calculation of the light transmission is in accordance with eq. (4) (Atthi et al., 2007).

$$\%T = \frac{I}{I_0} \times 100 \qquad (4)$$

Where $\%T$ is the percentage of light transparency.

I is the intensity of the light transmitted through the medium.

I_0 is the intensity of the light incident on the medium.

The relation between light absorption (A) and light transmission ($\%T$) is shown in eq. (5). The light intensity transmitted through a medium depends on the thickness of the medium through which the light passes through and also on the intensity of the incident light. The relation between them is written in eq. (6) (Atthi et al., 2007).

$$A = -\log(\%T) = -\log(\frac{I_x}{I_0}) \qquad (5)$$

$$I_x = I_0 e^{-(\frac{\mu}{\rho})x} \qquad (6)$$

Where A is the light absorption.

$\%T$ is the percentage of light transparency.

I_x is the transmitted light intensity through a medium with thickness, x.

I_0 is the intensity of the light incident on the medium.

is coefficient of the light intensity absorption.

ρ is medium density.

x is thickness of the medium.

However, difference film thickness on MFT-Mask can generate by varying exposure dose directly on mask or called Vary-Dose MFT-Mask (VD-MFT-Mask). This technique also create Multi-Film thickness on mask but its advantage is to reduce many lithography steps on mask. The 3-D image of the PPF after developed is taken using Confocal Coherence Interferometer (CCI) as shown in Figure 8.

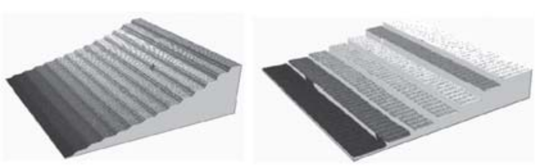

Figure 8. The 3-D image from CCI of the 3-D staircase microstructure forming by the GSL-mask and MFT-mask.

Cost and Time comparation

Regarding the most advanced lithography tool, the EUVL, 5 height stepped ABS, the cost of the process is proportional to the number of masking steps. The exception is GSL-Mask and VD-MFT-mask. The cost of the process the ABS using the 2 techniques remains the same regardless of number of height steps, VD-MFT-mask being the cheaper technique. Since both techniques require only one lithography and one etching step. However if only one step height is required on the ABS, the GSL-mask technique will become the most expensive due to highest cost of photomask making compared to the other photomasks. In term of total photomask making and process time, all except GSL-mask and VD-MFT-mask are proportional to the number of height steps since the 2 techniques only go through one photo and one etching step. However the making of GSL-mask requires 12.03 hours less than the VD-MFT-mask. Considering both photomask and wafer cost, photomask and wafer fabrication time of VD-MFT-Mask compare with the other techniques is the most attractive technique of all as shown in Tables 1 and 2, respectively.

Table 1. Photomask and wafer patterning cost comparison of 6 different mask techniques.

Mask type	Mask cost per wafer ($/wafer)					Wafer cost ($/wafer)				
	1L	2L	3L	4L	5L	1L	2L	3L	4L	5L
BIM-SLR	2.0	4.0	6.1	8.1	10.1	363.2	426.5	489.7	552.9	616.2
BIM-MLR	2.0	2.0	2.0	2.0	2.0	363.2	426.5	489.7	552.9	616.2
ME-BIM-MLR	2.0	2.0	2.0	2.0	2.0	363.2	381.8	400.4	418.9	437.5
GSL-Mask	2.6	2.6	2.6	2.6	2.6	363.2	363.2	363.2	363.2	363.2
MFT-Mask	2.0	2.1	2.1	2.1	2.1	363.2	363.2	363.2	363.2	363.2
VD-MFT-Mask	2.0	2.0	2.0	2.0	2.0	363.2	363.2	363.2	363.2	363.2

Table 2.. Photomask and wafer processing time comparison of 6 different mask techniques.

Mask type	Mask processing time (hrs/mask)					Wafer processing time (hrs/wafer)				
	1L	2L	3L	4L	5L	1L	2L	3L	4L	5L
BIM-SLR	12.96	25.91	38.87	51.83	64.78	0.11	0.23	0.34	0.46	0.57
BIM-MLR	12.96	12.96	12.96	12.96	12.96	0.11	0.23	0.34	0.46	0.57
ME-BIM-MLR	12.96	25.91	38.87	51.83	64.78	0.11	0.12	0.13	0.14	0.15
GSL-Mask	12.03	12.03	12.03	12.03	12.03	0.11	0.11	0.11	0.11	0.11
MFT-Mask	12.96	15.1	17.24	19.38	21.52	0.11	0.11	0.11	0.11	0.11
VD-MFT-Mask	12.96	12.96	12.96	12.96	12.96	0.11	0.11	0.11	0.11	0.11

Conclusion

Formation of the ABS surface on the read/write head can be done using different mask types. Those mask types are (1) BIM-SLR, (2) BIM-MLR, (3) ME-BIM-MLR, (4) GSL-mask, (5) MFT-mask, and (6) VD-MFT-mask. With respect to cost and time required assuming the most advanced (and the most expensive) lithography tool (EUVL), it is found that GSL-Mask is not suitable for making one height step ABS due to high cost of mask making. But Considering both time and cost, VD-MFT-Mask is the most attractive technique of all.

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