High-density Optical Disk Mastering Using Electron Beam Lithography with Modified LIGA Demolding Mechanism

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ABSTRACT

In this study, optical disk mastering using electron beam lithography is presented. The process parameters of the electron beam mastering such as beam current, constant linear stage velocity, developing time, and focus distance were discussed in this research. In these experiments, it was also found that focus distance is an important parameter to fabricate nano-linewidth. The resist with nano-pattern was transferred into metal Ni-Co (Nickle-Cobalt) mold by electroplating. The technique of Ni-Co electroplating process with hardness larger than Hardness of Vicker (Hv) 650 was developed. Then, with the Ni-Co mold, LIGA process was applied to produce high-density optical disk. The Ni-Co mold was served as master for hot embossing process to replicate the nano-pattern onto PMMA sheet. Since the feature size is down to nano-meter range, the study presents an innovative demolding mechanism to demold the master from the PMMA sheet without damaging the nano-meter patterns. In the study, a spiral nano-groove with 110nm in linewidth and 80nm in depth has been successfully fabricated about 50Gbytes storage capacity.

Keywords: mastering, high-density, electron beam, Ni-Co , lithography

1 INTRODUCTION

As the capacity of an optical disk increased from CD 650Mbytes to DVD 4.7Gbytes, the minimum linewidth on optical disk has been reduced from 830nm to 400nm. According to the developing trend, the capacity of the next generation optical disk will be over 15Gbytes in 2005, and the minimum linewidth will relatively reduce to 190nm or less. It is well known that the spot size of a conventional laser beam can be expressed as $K\lambda/NA$, where λ is the wavelength of a laser beam, NA is the numerical aperture of an objective lens and K is a constant related to the photoresist and process. Thus, two major approaches of laser optical system can be taken to reduce the spot size. One is using a shorter wavelength laser, and the other is using an objective lens with a larger NA value. Therefore, the conventional laser beam mastering will meet its resolution limitation and will be difficult to satisfy the requirement of the next generation optical disk.

The electron beam mastering aren't restricted by the optical diffraction limit because it uses a high-energy electron beam with the characteristic of a short material wavelength and an electron beam column to replace a laser and an objective lens respectively. Besides, many investigations [1,2] have successfully demonstrated fabrication of nano-structure and nano-device using the electron beam. There was also an investigation in developing and improving an electron beam mastering machine for fabrication of high-density disk [2]. On the other hand, process using newly developed photoresist to increase the resolution with smaller linewidth was conducted, with which higher capacity of disk was made [3].

However, the critical issue of electron beam lithography is its throughput, which prevents this technique from the mainstream of VLSI manufacturing [4]. $40Gb/in^2$ was fabricate by [5, 6] using direct writing method, with which mass production could not be achieved. In addition, an electron beam mastering system integrated with SEM to on-line inspect process was reported [7]. David and Hambach tried to use method of defocus to control linewidth from 100nm to several micro-meters, but the precision is only about 300 nm [8].

This study presents a modified LIGA process to fabricate high-density optical disk. The process includes electron beam lithography, Ni-Co electroplating with high hardness and hot embossing with novel demolding mechanism. The approach is a considerably less expensive option than synchrotron radiation exposure of thick photoresist. To enhance the throughput and keep the production costs as low as possible, a modified LIGA process was applied to replicate the nano-pattern on PMMA-based. The electroplated Ni-Co mold was served as master for hot embossing molding process to transfer the nano-patterns onto PMMA sheet. Since pattern feature size is down to nano-meter range, demolding technique is one of the key factors to the hot embossing process. The study also presents an innovative demolding mechanism to demold the master from the PMMA sheet without damaging the nano-pattern. Besides, in this research the process parameters of the electron beam mastering such as beam current, constant linear stage velocity, developing time, and focus distance were discussed in depth.

2 PROCESS PROCEDURE

2.1 Experimental Set-Up

In this research, the electron beam mastering system EBR-200 from Obducat Inc. is used to expose and define the pattern of resist film. The setup of EBR-200 system is shown in Fig. 1. It was composed of an electron beam column with an acceleration voltage of 40kV (max), an air spindle motor with vacuum seat and a translation stage constructed in a vacuum chamber. The electron beam column, which was composed of a lanthanium hexaboride cathode (LaB6), three pieces of electron lenses, two apertures, blanking plates and stigmator, was used to produce the focused electron beam onto the surface of the substrate. During the experimental process, the air spindle motor and the translation stage were synchronously controlled to keep the focal spot of the electron beam moving with relative to resist film at constant linear stage velocity. The encoded data was transferred to the resist film by controlling blanking plates to deflect the electron beam.

2.2 Electron Beam Lithography

The electron beam mastering process introduced here was schematically shown in Fig. 2. A silicon wafer with a thickness of 525 μm and a diameter of 100mm was used as substrate. Its resistivity is less than 0.01 Ω-cm to prevent the charge up effect. Positive electron beam resist, ZEP520A, was spun on the substrate. In order to improve the adhesion between the resist and the substrate, the specimen was pre-baked for 3 minutes at 160 °C on a hot plate. After that, resist film was exposed by the electron beam and developed by a high resolution developer, ZED-N50, at 23 °C. Later, the developed pattern was inspected by using atomic force microscope (AFM).

2.3 High-hardness Electroplating Process

After the resist pattern was successfully transferred by electron beam on silicon wafer, metal Ni-Co electroplating technique was applied to transfer the resist pattern into Ni-Co mold. The metallization process includes the following steps, first, silicon substrate was cleaned by RCA process (see Fig. 2(a)). Then electron beam resist was spun on the substrate by spin coating and pre-baked at 160 °C for 3 minutes (Fig. 2(b)), followed by electron beam exposure (Fig. 2(c)) and developing process (Fig. 2(d)). Then Ni thin film was sputtered on the resist template surface served as seed layer (Fig. 2(e)). Then Ni-Co electroplating technique was used to form the Ni-Co mold with 1 mm in thickness, followed by chemical mechanic polishing (CMP) process to reduce the total thickness variation of Ni-Co mold after electroplating process (Fig. 2(f)). The ingredient and condition of Ni-Co electroplating bath were listed in Table 1. The hardness of the Ni-Co mold over Hv 650 can be obtained and its residual stress after electroplating process was below 1.5 kg/mm^2. The resist template could be transferred into Ni-Co mold for subsequent mass production. Then silicon wafer was removed from the Ni-Co mold by KOH wet etch (Fig. 2(g)), and resist was stripped off (Fig. 2(h)). Finally, with the metal mold, hot embossing process was used to replicate the pattern (Fig. 2(i)).

3 RESULTS AND DISCUSSIONS

For ZEP520A resist lithography process, the ranges of the process parameters used here are that I is from 200 to 400nA, linear stage velocity is from 50 to 100cm/s, focus distance is from 16.85 to 16.95mm, developing time is from 3 to 5min. Fig. 3(a) and (b) show the pit linewidth for CD (650 Mbytes) and DVD (4.7 Gbytes) by AFM, 630 nm and 400 nm, respectively. As the capacity of optical disk increases, the capacity of the next generation optical disk will be over 15 Gbytes in 2005. The minimum pit linewidth will relatively reduce to less than 220nm. The preliminary result by AFM measurement was shown in Fig. 3(c) and (d) for HD-DVD and UDD, 215 nm and 100 nm, respectively. Later, the resist template pattern was metalized and transferred into Ni-Co mold by electroplating process. To avoid damage the metal mold, silicon substrate was removed from the Ni-Co mold by KOH wet etch. Finally, hot embossing process was used to replicate the pattern. In the study, Ni-Co electroplating process was developed. The Ni-Co mold hardness over Hv 650 could be obtained and its residual stress after electroplating process was below 1.5 kg/mm^2. Thus the resist mold could be accurately transferred into Ni-Co mold. The Ni-Co mold has the duplicability of resist patterns and has potential for mass production as show in Fig. 4. With the Ni-Co mold, hot embossing process to fabricate PMMA-based patterns was tested. The experiment parameters include hot embossing time, applied loading force, and hot embossing temperature. Due to the nano-meter structure, demolding is one of the key factors to the LIGA process. To demold the PMMA sheet from the Ni-Co mold without damaging the nanometer structure, an innovative demolding mechanism was explored. Prior to demolding, high pressure nitrogen gas was purged slowly into the vacuum hot embossing chamber (Fig. 5). When purged N_2 pressure level of 2 kg/cm^2 (196 KN/m^2) was achieved, it will result in uniform pressure distribution on the interface between Ni-Co mold and PMMA sheet. Thus, demolding process could be successful finished. Various PMMA in thickness under different temperature condition was conducted to realize its shrinkage effect. The result shows that its shrinkage of PMMA is a function of hot embossing temperature (Fig. 6). The percentage of shrinkage will become less obvious with decreasing in thickness of PMMA sheet. In the study, a spiral nano-groove with 110nm linewidth and 80nm depth have been successfully demonstrated for 50 Gbytes storage capacity. A top and a cross-sectional views of the nano-groove patterns by AFM were shown in Fig. 7.

4 CONCLUSION

The process parameters of the electron beam mastering such as beam current, constant linear stage velocity, developing time, and focus distance were discussed in this research. From the experimental results, the fabricated linewidth proportionally increases with increasing in beam current and developing time, but decreases with increasing in linear stage velocity. Besides, modified LIGA process was applied. It consists of electron beam lithography, extra-hard Ni-Co electroplating process (as a metal mold) and chemical mechanic polishing (CMP) process to produce a metal mold of the optical disk, with which hot embossing process onto PMMA sheet was conducted. The study also presents an innovative demolding mechanism to demold the master from the PMMA sheet without damaging the nanometer patterns. In the study, a spiral nano-groove with 110nm linewidth and 80nm depth has been successfully fabricated for 50Gbytes storage capacity.

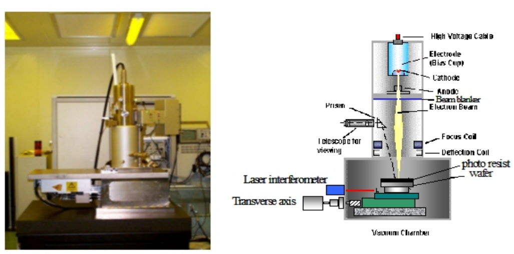


Fig. 1 The outline of the electron beam mastering machine EBR-200

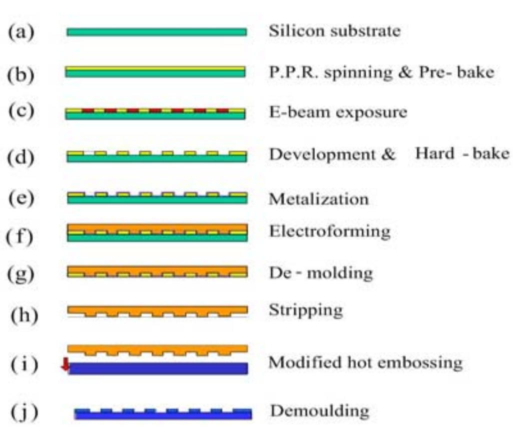
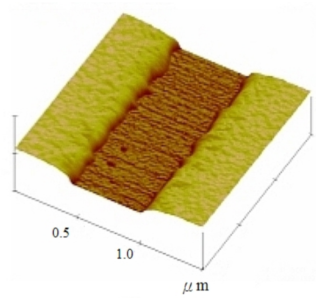
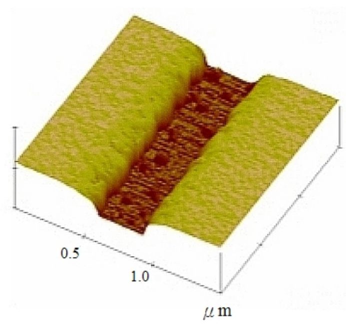


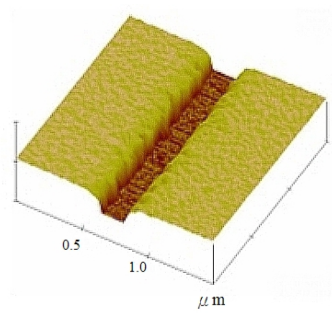
Fig. 2 Schematical flow chart of electron beam mastering process



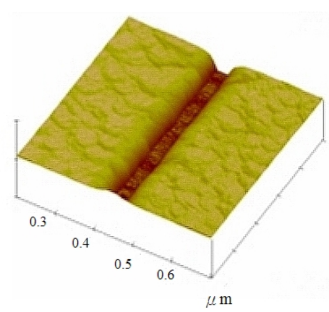
(a) CD:630nm in linewidth



(b) DVD:400nm in linewidth



(c) HD-DVD:215nm in linewidth



(d) UDD:100nm in linewidth

Fig. 3 Critical dimension of linewidth on optical disk by AFM

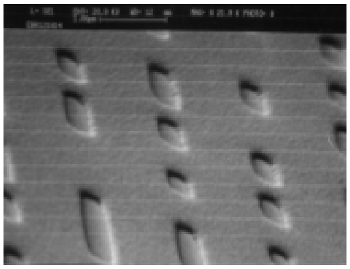


Fig. 4 Ni-Co mold by electroplating process

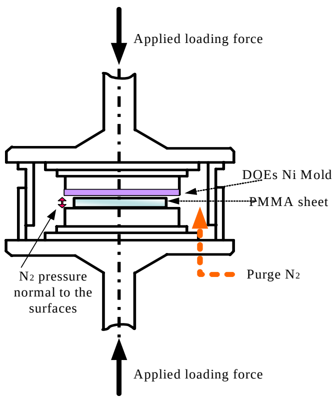


Fig. 5 Schematic illustration of demoulding mechanism for hot embossing process

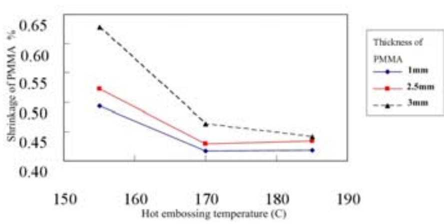


Fig. 6 Shrinkage of PMMA as a function of hot embossing temperature

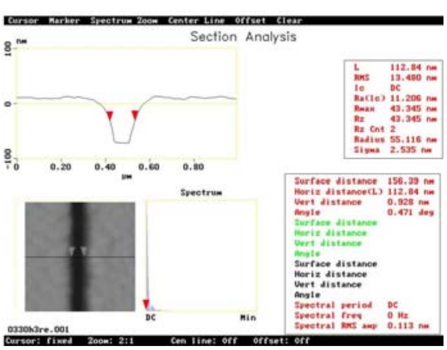


Fig. 7 Measurement of linewidth by AFM(b) A top and cross-sectional AFM image of a nano-groove on PMMA

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