Breaking the Limits: Combination of Electron Beam Lithography and NanoImprint Lithography for Production of Next Generation Magnetic Media and Optical Media

Babak Heidari, Marc Beck
Obducat AB, Box 580, 20125 Malmö, Sweden.
E-mail: babak.heidari@obducat.com

ABSTRACT

The increased requirement e.g. resolution in multimedia displays creates the need for more storage capacity in both optical discs as well as hard drives. Blu-Ray-ROM and particularly future optical media formats require the employment of new lithography technologies. Today's magnetic media technology is facing difficulties to continue to higher surface densities and larger capacities due to the superparamagnetic limit. By using isolated magnetic domains to store the data, making it possible to get beyond 500 Gbits/in^2 densities. The approach we describe uses a unique direct-write electron beam lithography system for lithography on a rotating substrate and creates a patterned master disc, which can be used as a mold in replication of final disks by imprint lithography. The imprint process replicates the original pattern with an exceptionally fast turn around time, making mass production of optical and magnetic media possible. However, realization of these new technologies offers challenges in implementation.

Keyword list: Nano Lithography, Nano Imprint lithography, Electron-beam, Hard disk, Optical disk, Pattern media, DTR, BPM

INTRODUCTION

Optical disk media:

The new optical disk format, Blu-Ray is the 3rd generation optical disk with capacity of 25GB. There are already now work being performed to develop future formats such as Super-RENS (Super-Resolution Near Field Structure, Jooho Kim et al., Samsung) to enable higher storage capacities. The minimum structure size in the BD format is less than 150 nm and for following generations of high-density optical disks this value will become significantly smaller, which represents a challenge with laser based lithography. Optical disk tests are already being conducted with structures as small as down to 30 nm using electron beam lithography.

Magnetic disk media

At present magnetic recording is the most economical way storing large amount of data with fast access time. During 20-year period, Hard Drive Disk (HDD) unit prices have reduced from $2000 for a 10MB HDD to $100 for today's 300GB drive. The hard drive industry has been using longitudinal recording and perpendicular recording successfully until today. The polycrystalline nature of the magnetic medium sets a limit for the maximum storage density of the written information. At the very high densities, above 500 Gigabits per square inch, the small dimension of the grains (around 10nm) is not sufficient to stabilize the magnetization direction over long time period due to issues such as thermal stability. A way to circumvent this upcoming limitation is to use patterned media, where discrete track recording (DTR) and bit-patterned media (BPM) are the most promising technologies. Patterning magnetic media, in combination with other techniques, is expected to extend the data densities up to 50 Tb/in^2 (Mark H. Kryder, DSSC, Carnegie Mellon University). Toshiba Corporation recently announced a prototype hard disk drive (HDD) that uses Discrete Track Recording (DTR) technology, which enabled a capacity of a record-breaking 120 gigabytes (GB) on a single 1.8-inch disk. Toshiba plan to release product to the market with DTR at the end of 2009.

Superparamagnetic limit

The first advantage of patterned media is that data densities can be increased beyond the superparamagnetic limit. Ordinary thin-film media consist of small, single domain magnetic grains, which are exchange-decoupled from one

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another. The magnetic axes of these grains are randomly distributed. For a good signal-to-noise ratio (SNR) in a written bit, each bit must contain a number of grains. To increase storage densities, bit sizes (and there fore grain sizes) must be reduced to much less than 10 nm in diameter. However, the grain size cannot be reduced arbitrarily, because, as the grain volume decreases, thermal effect becomes significant. When the magnetic grains are decreased in size, the magnetisation directions of the grains can reverse spontaneously. This leads to loss of recorded data.

MANUFACTURING TECHNOLOGY

The manufacturing approach makes use of two lithography technologies. First, an Electron Beam Recorder (EBR) is used to define the pattern on a master disc and second, this master is used as a stamp for replication on the final media disk substrate using nano-imprint lithography technique.

A new electron beam lithography system has been developed having a rotating spindle on a linear slider that moves the substrate in radial direction. The software and encoders allow data conversion to be performed on-the-fly while the pattern is written, thereby eliminating conversion time losses and memory requirement known from conventional vector scan e-beam systems.

The process used for replication of both optical and magnetic media disks via nanoimprinting is based on a two-step imprint process comprising the generation of an intermediate polymer stamp (IPS^{R}) and a simultaneous thermal and UV imprint process (STU^{R}). Both imprint tool and process are capable for high volume manufacturing and the combination of EBR-mastering with NIL enables high volume manufacturing with 600 HDD disk/hour per lithography system.

Electron beam Recorder, EBR

The EBR electron beam recorder is based on a thermal field emission cathode with high current stability and brightness. It operates as a paraxial Gaussian beam system at an acceleration voltage of 50 kV. The lithography of pattern structures is derived from the combination of disk rotation, translation, high speed sub-field deflection, and beam blanking. A schematic drawing is shown in figure 1.

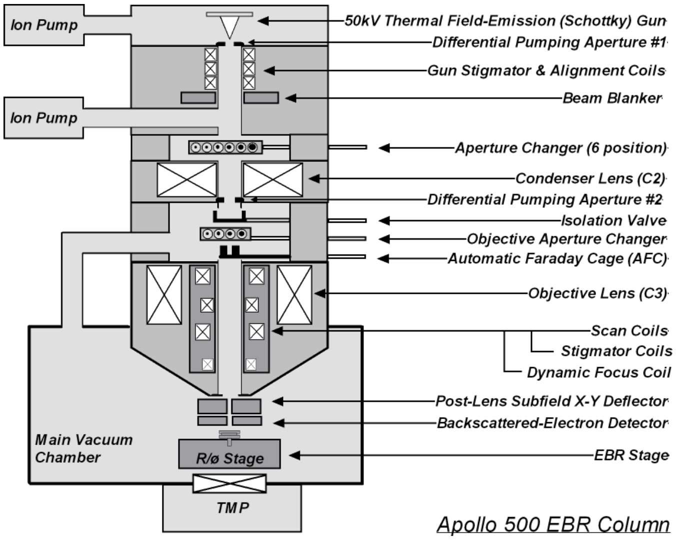


Fig.1: The drawing shows the EBR column design.

The electron beam column was designed mainly for high-resolution, high-speed beam blanking, high-speed beam deflection and long-term stability. A thermal field type emitter (TFE) was used to obtain high-intensity and stable electron beam. The beam energy of 50 keV was selected to decrease influence of the back scattering. To ensure the beam stability, the control system of the electron beam column was feedback coupled for stable and accurate control. The high-speed beam blanker and a stigmator installed above the beam blanker were adopted to write precise pits without shape-distortion caused by beam blanking. The rise and fall times of beam blanking were measured to less than 5 ns. In addition, a high-speed sub-beam deflector was added with resolution of 1 nm for improved definition positioning of servo patterns. A dynamic focus system was adopted to realize stable recording through the exposure area of the substrate. It consists of a height sensor and focusing lens in the electron beam column. The height sensor measures the fluctuation of the substrate height and the focal distance of the objective lens is controlled in accordance with the height information.

The substrate is attached to the turntable directly and the rotation imbalance could be minimized. A laser interferometer and a rotation laser encoder were installed to ensure the substrate positioning accuracy in nanometer level while the stage is rotate and move in radial direction. In addition, an active vibration isolation system was adapted to sustain the work chamber. The vibration of the work chamber was controlled against the undesirable disturbance.

The system is controlled by software that was developed in order to generate the pattern for both magnetic and optical medium writing. The patterns is calculated on fly during the exposure to minimize the memory requirements and total exposure time. The software addresses accuracy of 1 nm in both down track and cross track direction. The writing strategy for optical disk is fast exposure speed but the writing strategy for HDD application is accuracy that is way the HDD pattern is written in lower speed to maintain the requirement accuracy.

As an evaluation method of the recording stability, we fabricated a nickel stamp and measured the uniformity of pattern by AFM and FIB analyses. A summary of the track pitch accuracy on the Blu-Ray nickel stamp is shown in figure 3. In HDD application the structures are measured in several ways to determine the accuracy and resolution. A summary of those kind of measurement is shown in table 1.

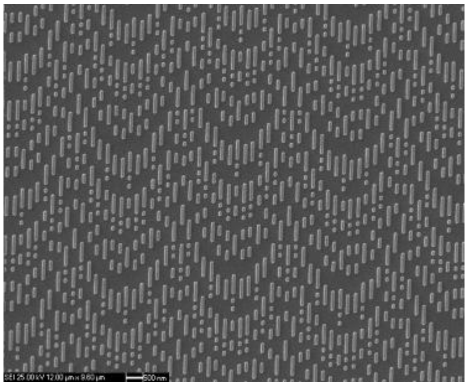


Fig.2: SEM picture shows the Blu-ray master disc made by EBR. The line width is 150 nm

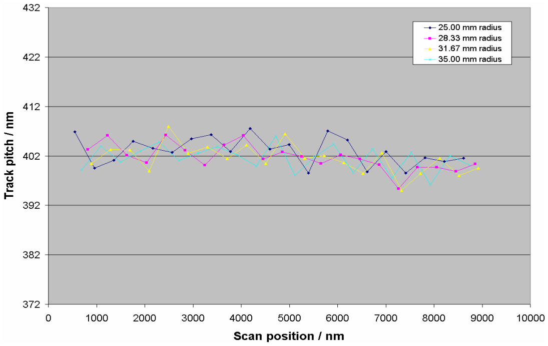


Fig.3: The graph shows the track pitch analyses made on an optical disk master made by the EBR and it shows that the track pitch variation is less than 6nm.

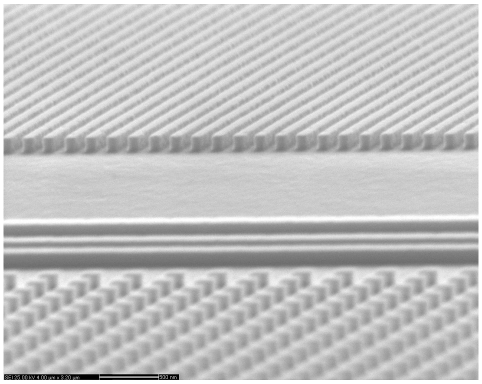


Fig.6: SEM images of the DTR structure in Nickel stamp.

Exposure accuracy	3sigma [nm]
Track LER 3s (x50k)	3,25
Preamble LER 3s (x50k)	4,48
Pitch distribution cross track direction 3s	5,56
Pitch distribution down track direction 3s	4,09
Line width distribution cross track direction 3s	2,75
Line width distribution down track direction 3s	2,74

Table.1: A summary of AFM and SEM measurement and data analyses shows accuracy on a HDD nickel stamp

In these experiments, silicon substrates were used in recording process, which was coated with the resist (ZEP-520A, Nippon ZEON Co., Ltd.). The recording parameters were chosen dependent on speed or resolution requirements. The neam current were chosen in the range of 0,9 nA to 20 nA. Constant Linear Velocity (CLV) writing strategy was used in both optical and HDD disks to ensure the dose uniformity. The exposed substrates were developed and a sputtered with a metal seed-layer as a conductor for subsequent Nickel electroplating process. All measurements were made on the Nickel stamps made according to the described process. The nickel stamps had a total thickness of 300 microns.

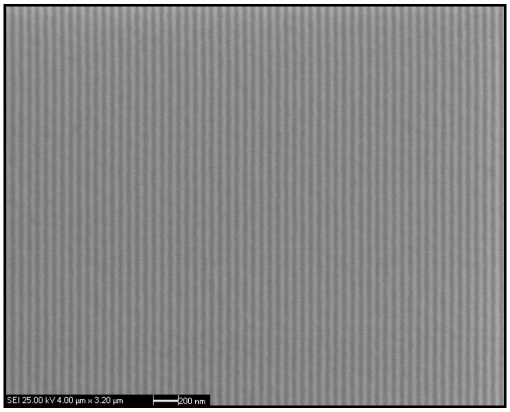
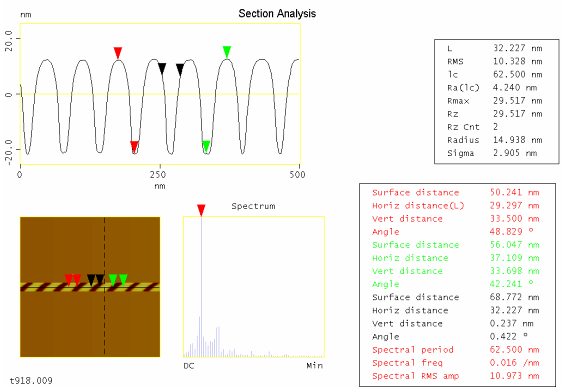


Fig.5: SEM image of the stamp showing the 60nm pitch



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L          32.227 nm
RMS        10.328 nm
lc         62.500 nm
Ra(lc)     4.240 nm
Rmax       29.517 nm
Rz         29.517 nm
Rz Cnt     2
Radius     14.938 nm
Sigma      2.905 nm
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Surface distance      50.241 nm
Horiz distance(L)     29.297 nm
Vert distance         33.500 nm
Angle                 48.829 °
Surface distance      56.047 nm
Horiz distance        37.109 nm
Vert distance         33.698 nm
Angle                 42.241 °
Surface distance      68.772 nm
Horiz distance        32.227 nm
Vert distance         0.237 nm
Angle                 0.422 °
Spectral period       62.500 nm
Spectral freq         0.016 /nm
Spectral RMS amp      10.973 nm
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Fig.4: AFM scan showing lines with 60 nm pitch and height of the pattern are 33,5 nm.

NanoImprint Lithography, NIL

Thermal Nanoimprint Lithography (Kuwabara et al.: U.S. Patent 5 259 926 , 1993), (S.Y. Chou et al. Applied Physics Letters 67, 1995, 3114) and UV Nanoimprint Lithography (M. Colburn el al. SPIE, 3676 (1999) 379-389) were introduced as process technologies in many applications.

Thermal NIL is a widely distributed method to transfer a mold pattern to a polymer layer. The polymers used in the process are mostly thermoplastic materials of different composition, molecular weight, and a variety of glass transition temperatures. Some of the most common thermoplastic polymers are polyacrylate-based materials and their derivatives. Many other thermoplastic materials are available and one may choose the material fitting best to the process and its final application.

Imprinting in thermoplastic polymers require heating to above Tg to print and cooling to lower temperature than Tg to fix the pattern. One can eliminate the cooling phase from a thermal imprint process by using a photo curable polymer. The polymers with photo initiated curing have major advantages compared to thermosetting polymers since the curing process is start when it exposed to UV-light. An ideal imprint pre-polymer being less sensitive for particle adsorption forms a solid film after spin coating and evaporation of the solvent in a soft bake process. It has a low glass transition temperature and can be cross-linked fast after UV-exposure.

STU®-Process

The Simultaneous Thermal and UV process, STU® (M. Beck el al. *50th EIPBN* (2006) 167) has all the benefits of a pure UV process and allows the user to select spin-coatable pre-polymers that are in a dry state after the soft bake.

The used pre-polymers have thermoplastic properties. Ideally they have a very low glass transition temperature and can be printed at temperatures ranging from room temperature up to 100 ºC. The pre-polymers have a sufficient number of reactive sites that can be activated for cross-linking by UV radiation. The cross-linking reaction takes place during a post-exposure bake that is executed at the same temperature as the other process steps. A typical process flow comprises the following steps and is illustrated in figure 7.

1.) Preparation of substrate by cleaning process
2.) Coating of cross-linkable pre-polymer layer on substrate
3.) Soft bake
4.) Temperature conditioning of stamp and substrate
5.) Imprint (pressure phase)
6.) UV-exposure
7.) Curing phase

8.) Pressure release
9.) Stamp/substrate separation
10.) Ashing of residual layer with O_2-plasma (typically 5-15 nm)
11.) Pattern transfer (user specific)

Steps 5-9 are executed at constant temperature thereby eliminating the risk for pattern distortion known from hot embossing processes due to the presence of a heating and cooling phase.

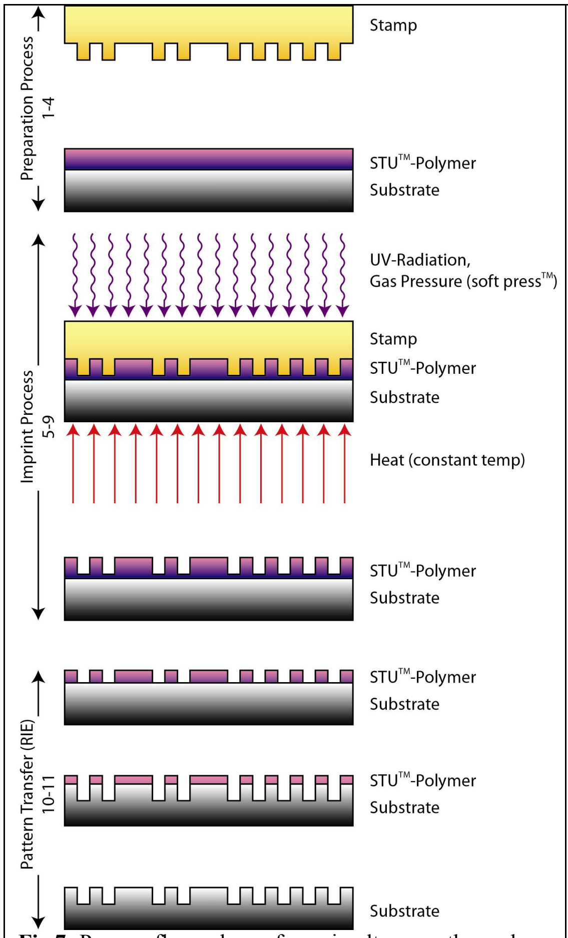
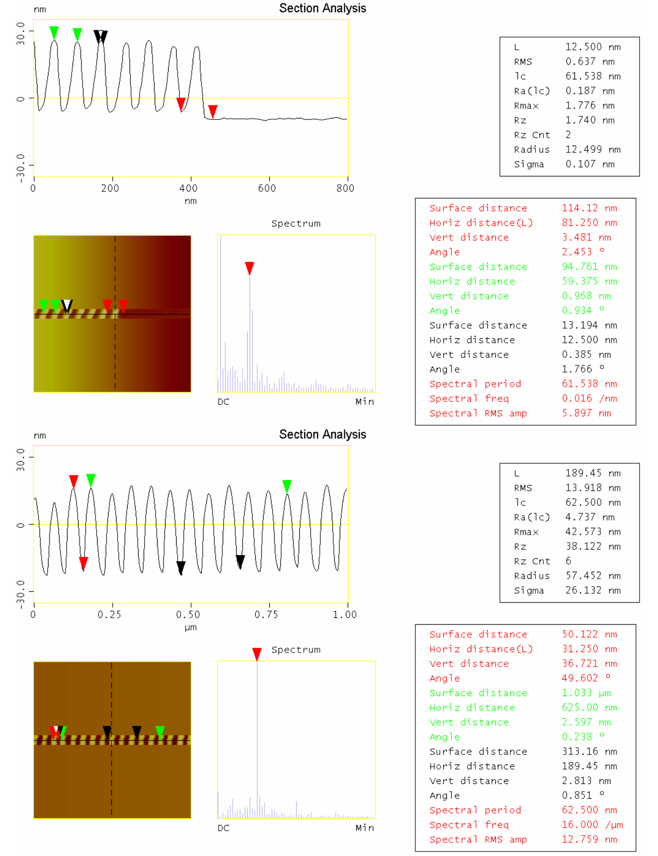


Fig.7: Process flow scheme for a simultaneous thermal and UV nanoimprint lithography process (STU®-NIL).



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L          12.500 nm
RMS        0.637 nm
lc         61.538 nm
Ra(lc)     0.187 nm
Rmax       1.776 nm
Rz         1.740 nm
Rz Cnt     2
Radius     12.499 nm
Sigma      0.107 nm
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Surface distance       114.12 nm
Horiz distance(L)      81.250 nm
Vert distance          3.481 nm
Angle                  2.453 °
Surface distance       94.761 nm
Horiz distance         59.375 nm
Vert distance          0.968 nm
Angle                  0.934 °
Surface distance       13.194 nm
Horiz distance         12.500 nm
Vert distance          0.385 nm
Angle                  1.766 °
Spectral period        61.538 nm
Spectral freq          0.016 /nm
Spectral RMS amp       5.897 nm
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L          189.45 nm
RMS        13.918 nm
lc         62.500 nm
Ra(lc)     4.737 nm
Rmax       42.573 nm
Rz         38.122 nm
Rz Cnt     6
Radius     57.452 nm
Sigma      26.132 nm
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Surface distance       50.122 nm
Horiz distance(L)      31.250 nm
Vert distance          36.721 nm
Angle                  49.602 °
Surface distance       1.033 µm
Horiz distance         625.00 nm
Vert distance          2.597 nm
Angle                  0.238 °
Surface distance       313.16 nm
Horiz distance         189.45 nm
Vert distance          2.813 nm
Angle                  0.851 °
Spectral period        62.500 nm
Spectral freq          16.000 /µm
Spectral RMS amp       12.759 nm
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Fig.8: AFM cross-section analysis of the residual layer thickness (left) and imprint uniformity (right). The residual layer thickness was measured to 3,6 nm ± 2,1 nm and the FFT spectrum plot revealing a sharp peak at a spectral period of 62,5 nm.

An example for a STU® imprint obtained on a 2,5-inch HDD substrate is given in figure 8. The two AFM-images show the data track with 30 nm half-pitch. The upper image shows a residual layer analysis scan obtained after scribing the imprinted substrate with tweezers followed by measurement of the step height. The residual layer analysis for this pattern gave 3,6 ± 2,1 nm on the entire pattern area. The lower image shows a non-scribed area with an FFT spectrum plot revealing a sharp peak at a period of 62,5 nm. The mean imprint depth is 37 nm.

CONCLUSION

Nano Imprint Lithography promise of simpler tool sets and effective sub-100 nm patterning is being realised today. Independent from the limiting effects of UV-lithography (diffraction, etc.), the ability to replicate sub-100 nm features with low-cost tool set opens new device-making opportunities, not only in storage media, but also in MEMs, biodevices, optical components and semiconductors.