Advanced Techniques for Sub-100 nm Resolution Lithography and Molecular Electronics

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ION PROJECTION LITHOGRAPHY FOR NANO PATTERNING

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ABSTRACT

As a result of continuous improvement of the resist process, the experimental ion projector in the Fraunhofer Institute in Berlin (manufactured by Ion Microfabrication Systems, IMS, Vienna) has been able to print 75 nm lines and spaces into180 nm thick standard DUV resist UV II HS without pattern collapse. A new wafer flow process for more reliable open stencil mask making was developed by IMS –Chips, Stuttgart (Germany), based on SOI wafers. Resistless direct surface modification by He and Xe ions has been tested on metallic and magnetic films in the Berlin projector. This method opens up a new possibility for the production of patterned media for future magnetic storage disks.

INTRODUCTION

In the European MEDEA Project for the development of ion projection lithography (IPL) for next generation lithography (NGL) the Fraunhofer Institute ISiT has taken the part of resist process development. Standard deep UV chemically amplified resists have been found very useful also for ion irradiation and the latest results are reported in the following.

However, in special cases the contact of a resist with the surface to be structured is not wanted. This situation may arise, because of chemical reactions with the resist (high temperature super-conductors) or the fear of topography change and residues after resist removal (thin magnetic films for storage media). Ions have the unique feature that they can directly modify a surface without the need for a resist. Compared to electrons of the same energy, ions deposit their energy in a shorter range near the surface because they do not penetrate as much. Since direct ion processing takes place in vacuum, it can be useful for all substrates which cannot be exposed to air for example in the case of an intermediate step in in-situ processing.

In order to demonstrate this technology of direct ion processing, tests have been performed in the Berlin ion projector to structure metallic and magnetic films. For the production of magnetic nano dots other techniques are competing like optical interference lithography [1,2], e-beam lithography [3], and nano imprint lithography [4,5]. All of these methods use some kind of resist process which is not desirable to keep the topography of a surface unchanged. This is extremely important for magnetic disks with a surface roughness of a few nanometers.

EXPERIMENTAL

Exposures have been performed with the ion projector IPLM-02 at the Fraunhofer Institute in Berlin [6]. H^+ or He^+ ions pass an open stencil mask at a beam energy of 3.5 keV and are accelerated behind the mask to 75 keV(see Fig. 1). Mask features are projected with 8.7 times demagnification via the ion optical lens system onto the wafer. The original duoplasmatron ion source has been exchanged with a multicusp ion source developed at the Lawrence Berkeley Laboratory with reduced energy spread of appr. 2 eV [7]. This reduces chromatic aberration of

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the lens system and allows the printing of 50 nm isolated lines [8]. Nested lines and spaces of this size have been difficult to print because of pattern collapse and needed further development of the resist process.

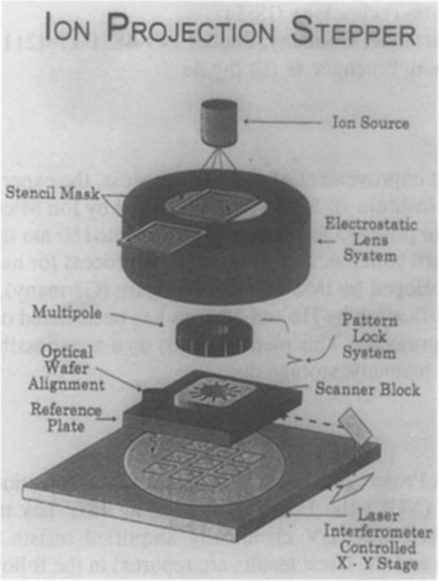

Figure 1: Principle set-up of the ion projector

SOI WAFER FLOW MASK PROCESS

Normally the production process of an open stencil mask starts with e-beam writing on the already thinned 2-3 µm thick Si mask membrane. The membrane handling is not compatible with standard wafer processing equipment. Therefore, a new process has been developed by IMS-Chips, Stuttgart and Infineon, Dresden, which employs e-beam writing of the mask features and etching on the full wafer. An SOI-wafer (Silicon On Insulator) is used with the embedded oxide layer serving as etch stop [9].The single process steps are demonstrated in Fig. 2. Trench etching of the stencil pattern is performed in a STS (Surface Technology Systems) plasma etcher. A retrograde profile of the stencils which avoids scattering of ions on the sidewalls is created by using the gas chopping etch technique, which is a controlled balance between sidewall passivation and in depth etching.

The membrane etching is also performed by a dry etch process up to a preliminary Si membrane thickness of 25 µm with final thinning in a tetramethylammoniumhydroxide (TMAH) solution. During this step the sensitive structures on the frontside of the wafer are protected by a water soluble wax.

In order to avoid ion implantation of the Si stencils during ion bombardment in the exposure process, which leads to swelling and deformation, a carbon protective layer is finally coated onto the finished mask. For this purpose a novel method of forming very low stress

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carbon layers based on direct RF sputter coating with nitrogen added to the argon sputter gas has been developed [10].

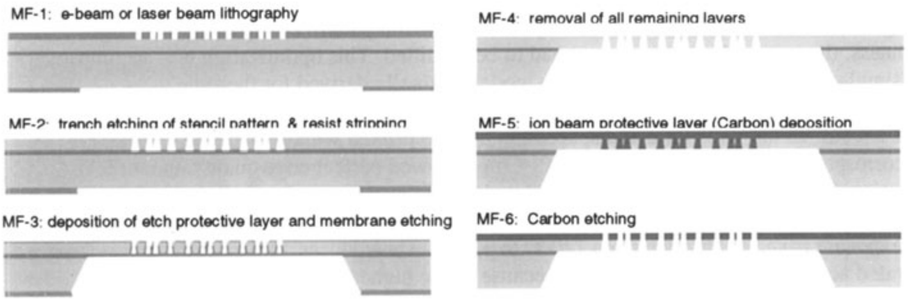
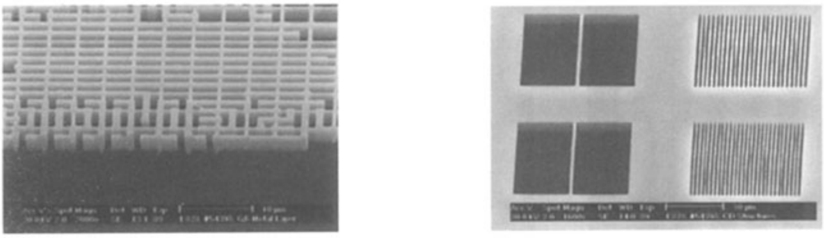


Figure 2 : SOI wafer-flow stencil mask fabrication process developed at IMS-Chips, Stuttgart.



gate forrest metal layer with 400nm support grid

350nm - 400nm isolated lines and lines & spaces

Figure 3 : Details of open stencil mask fabricated with the SOI wafer flow process

Figure 3 shows details of a finished mask with 350 – 400 nm isolated lines as well as lines and spaces, etched uniformly into a 3µm thick membrane. Even 100 nm isolated lines and 200 nm lines and spaces have been demonstrated so that after 4 times demagnification, the reduction factor planned for the production tool, sub-50 nm structures are achievable on the wafer.

RESIST PROCESS DEVELOPMENT

Resist exposures have been performed by ISiT in the Berlin IPLM-02 projector.The best results were obtained so far with the standard DUV chemically amplified resist UV II HS from Shipley. The sensitivity of this resist for 75 keV H^+ ion exposure is 1x 10^{12} ions/cm², which corresponds to 0.15 µC/cm² [11].

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The resist shows a contrast number higher than 10 and a dose gap between positive and negative development of nearly two orders of magnitude.

The standard resist treatment of UV II HS resist is optimized for optical exposure (smoothing of standing waves) of quarter micron features in 600 nm thick resist. In order to use its high resolution capability under ion exposure and avoid pattern collapse and line edge roughness, the standard resist treatment had to be modified. This optimization was accompanied by a simulation of the resist process with a model originally derived for the simulation of APEX-E resist [12].

As a result 75 nm wide lines and spaces can now be printed without pattern collapse (Fig. 4). The corresponding mask fabricated by IMS-Chips showed perfect edge quality under SEM inspection. The UV II HS resist has been diluted so that a smaller resist thickness of 180 nm could be obtained. The resist has also been made less sensitive (0.46 μC/cm²) by lowering the post exposure bake temperature from 140°C to 125°C. This reduces movement of the radiation generated acid and improves resolution. Because of the higher dose it also reduces edge roughness.

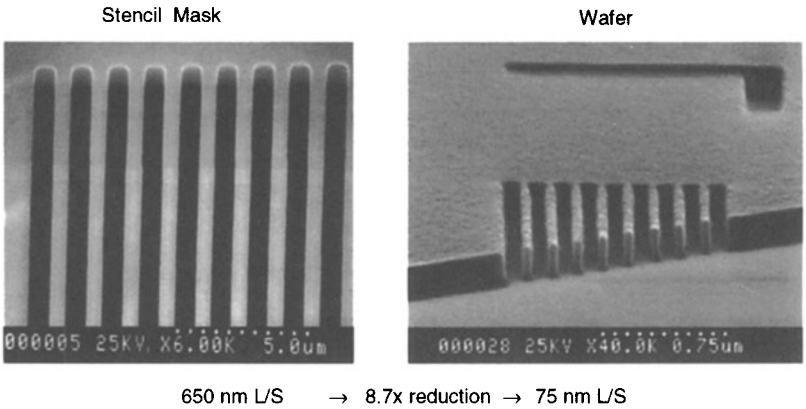

Figure 4: Ion projection exposure (Fraunhofer- ISiT) in 180 nm thick Shipley DUV resist UV II HS with 75 keV He^+ ions, dose : 0.46 μC/cm², Stencil mask fabricated by IMS-Chips, Stuttgart.

No proximity effect is visible at the line ends in figure 4 even though the resist has been removed by a second exposure of equal dose in the front part of the picture to allow SEM side view.

The high sensitivity of chemically amplified resists is a concern because statistical fluctuations in the ion beam can create line edge roughness. It is difficult to extract numerical data characterizing roughness from lines less than 100 nm wide by SEM inspection. Therefore, the printing of dot matrices has been investigated for this purpose. With decreasing dose statistical fluctuations translate into missing dots which can easily be counted. In figure 5 an evaluation of the printing probability against ion dose is plotted [13]. As expected the curve follows a Poisson distribution . A number of 115 ions is needed to create a 50% defect probability. A number of 220 ions per 90 nm dot corresponds to a dose of 0.46 μC/cm², which is the dose used in figure 4. This confirms that in the resolution range around 90 nm this dose is sufficient for delineation. Going to smaller features the dose per pixel has to be kept constant, which means that the dose has to be increased accordingly.

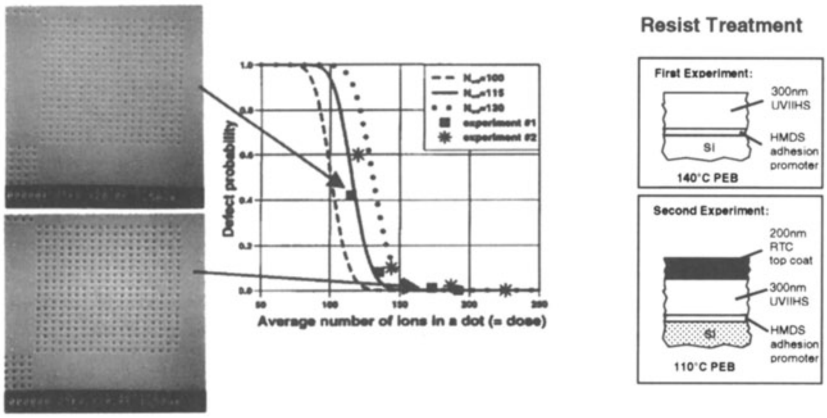

Figure 5: IPL exposure dose versus defect probability of printed dot matrices for two resist treatments.

IPL MILLING WITH Xe $^+$ IONS

Ions have the property of direct surface modification, and if the ion beam is structured like in ion projection a whole surface area can be treated in parallel. In this way a pattern can be transferred into a sample in an easy one step process without using a resist. In order to test this technique the light ions normally used in the multicusp ion source have been replaced by the heavier Xe species without any change in emission stability or uniformity.

First milling tests performed in a 35 nm thick Au film with a dose of $2x10^{15}$ Xe^+/cm^2 at 75 keV resulted in a milling depth of 8 nm as demonstrated by white light interferometry (Fig. 6).

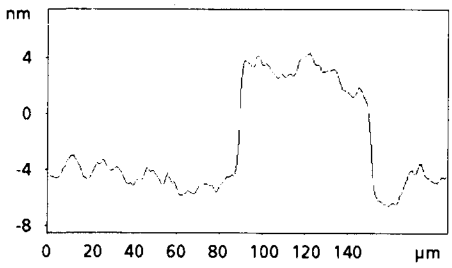

Figure 6: Surface depth profile of an Au film patterned by Xe ion milling .

A high resolution pattern contained narrowest lines with a line width down to 130nm (Fig.7) [14]. The apparent roughness of the gold film seems to be due to its grain structure. This encouraging result shows the promises of structured ion milling of magnetoresistive materials for sensor applications.

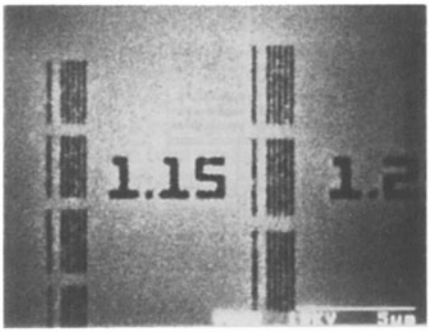

Figure 7: Xe^+ ion milling with IPL in polycrystalline Au film .
Smallest line width: 130 nm.

IPL PATTERNING OF MAGNETIC FILMS WITH He^+ IONS

The increase of storage density of magnetic disks of 100% per year is gained by a continuous shrinkage of the size of the magnetic bit cell. This process comes to an end, when the superparamagnetic limit is reached and the magnetic bits start to flip at room temperature. The superparamagnetic limit is related to the volume of a bit cell. One concept to overcome the situation is to go to prepatterned media, with bit cells separated by nonmagnetic or magnetically altered material so that the interaction of bits is prevented. We started experiments with IPL which has the ability of direct surface structuring without the need for a resist , an advantage compared to competing technologies.

Samples of chemically ordered FePt magnetic films have been supplied by Bruce Terris of the IBM, Almaden Research Center. The film preparation has been described previously in reference [15]. Under ion bombardment these layers change their magnetic properties. Experiments at Almaden with a mask in direct contact with Co/Pt multilayer magnetic films had demonstrated that a dose of 10^{16} N^+ ions /cm² was necessary to switch the magnetization direction [16]. This is a factor of 10^4 more compared to resist exposure. Therefore, in the exposure experiment in the IPLM-02 System in Berlin the He^+ ion intensity has been increased by a factor of 10. The discharge current in the multicusp source rose from 0.6 to 6 A. A mask with an arrangement of dots has been demagnified 8.7 times and projected onto the sample. Exposure time was 1000 s.

Irradiated samples with a dose of 10^{16} He^+ / cm² have been investigated at IBM with atomic force and magnetic force microscopy. Figure 8 shows a picture taken in magnetic force mode with 340 nm wide magnetic features[14]. With a new mask having smaller holes the ion projector should be able to print dots in the 50 nm range. This corresponds to a storage density of 64 Gbits/ in², assuming equal dots and spaces. The arrangement of dots in the mask, which is written by e-beam can be done with rotational symmetry. In this way the technique of rotating disk drives can survive, which is not possible with rectangular dot arrangements created by laser interferometry.

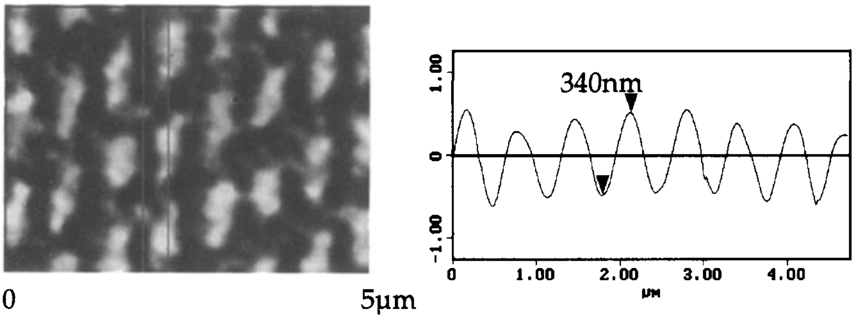

Figure 8: Magnetic force image of a FePt film showing magnetic dots structured, by resistless IPL with 10^{16} He^{+}/ cm^2 at 75 keV; The averaged intensity profile demonstrates a dot size of 340 nm.

Investigations with atomic force microscopy have shown that the topography change due to the IPL process is in the range of 2 nm. This confirms that IPL is very suitable for this application.

CONCLUSION

With the development of resistless ion nano structuring a second application field for ion projection lithography has been opened up.The method is specially suited for defect sensitive in – situ processing. This is very suitable for the fabrication of nano dots for magnetic storage devices. Improvements in ion source current density and in the sensitivity of magnetic films against ion exposure are under way to make this technique economical.

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REFERENCES

1. E.H. Anderson, C.M. Horwitz, H.I. Smith, Appl. Phys. Lett. **43**, 874 (1983)

2. C.O. Bolzler, Ch.T. Harris, S. Rabe, D.D. Rathman, H.I. Smith, J. Vac. Sci. Techn. B **12**, 629 (1994)

3. P.R. Krauss, S.Y. Chou, J. Vac .Sci. Techn. B **13**, 2850 (1995); R.M.H. New, R.F.W. Pease, R.L. White, J. Vac. Sci. Techn. B **13**,1089 (1995)

4. L. Kong, L. Zhuang, S.Y. Chou, IEEE Transactions on Magnetics **33**, 3019 (1997)

5. W. Wu, B. Cui, X. Sun, W.Zhang, L. Zhuang, L. Kong, S.Y. Chou, J. Vac. Sci. Techn. B **16** (6), 3825 (1998)

6. L.-M. Buchmann, U. Schnakenberg, M. Torkler, H. Löschner, G. Stengl, W.Fallmann, G. Stangl, E. Cekan, J. of Microelectromechanical Systems. Vol.**1**(3),116 (1992)

7. Y. Lee, R.A. Gough, K.N. Leung, J. Vujic, M.D. Williams, N. Zahir, W. Fallmann, M. Torkler, W.H. Bruenger, J. Vac. Sci. Techn. B **16** (6) , 3367 (1998)

8. W.H. Bruenger, M. Torkler, K.N. Leung, Y. Lee, M.D. Williams, H. Loeschner, G. Stengl, W. Fallmann, F. Paschke, G. Stangl, I.W. Rangelow, P. Hudek, Microelectronic Engineering **46**, 477 (1999)

9. F. Letzkus, J. Butschke, B. Höfflinger, M. Irmscher, C. Reuter, R. Springer, A. Ehrmann J. Manthuni, MNE-99, Microelectronic Engineering, in press

10. P. Hudek, P. Hrkut, M. Drzik, I. Kostic, M. Belov, J. Torres, J. Wasson, J.C. Wolfe, A. Degen, I.W. Rangelow, J. Voight, J. Butschke, F. Letzkus, R. Springer, A. Ehrmann, R. Kaesmaier, K. Kragler,J. Mathuni, H. Loeschner, EIPBN-99, J. Vac. Sci. Techn. Nov/ Dec (1999) in press

11. W.H. Bruenger, H. Buschbeck, E. Cekan, S. Eder, T.H. Fedynyshyn, W.G. Hertlein, P. Hudek,I. Kostic,H. Loeschner, I.W. Rangelow, M. Torkler, Microelectronic Engineering **41/42**, 237, (1998)

12. W. Henke , M. Torkler , EIPBN-99, J. Vac. Sci. Techn., Nov/ Dec (1999) in press

13. W.H. Bruenger, M. Torkler, M. Weiss, H. Loeschner, K.N. Leung, Y. Lee, P. Hudek, I. W. Rangelow, G. Stangl, W. Fallmann, EIPBN-99, J. Vac. Sci. Techn., Nov/ Dec (1999) in press

14. W.H. Bruenger, M. Torkler, B.D. Terris, H. Rothuizen, P. Vettiger, G. Stangl, W. Fallmann, MNE-99, Microelectronic Engineering, in press

15. B.D. Terris, L. Folks, D. Weller, J.E.E. Baglin, J. Appl. Phys., to be published

16. B.D. Terris, L. Folks, D. Weller, J.E.E. Baglin, A.J. Kellock, H. Rothuizen, P. Vettiger, Appl. Phys. Lett. **75**, 403 (1999)