E-BEAM NANO-PATTERNING FOR ELECTROFORMING REPLICATION

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Abstract:

This contribution deals with nano-patterning by the way of electron beam lithography with satisfying requirements for electroforming replication of desired patterns. Electron beam lithography can be used for creating nano graphics (images, text etc.) due to its very high resolution and precision. However, patterns created by electron beam lithography cannot be applied for mass production directly because of resist material soft nature (usually a polymer material). Because of that, hard printing plate must be produced. Nickel plate prepared by electroforming is one of the ways to accomplish that. Prior to the production of nickel plate by electroforming, the surface of polymer material has to be covered by a sufficiently thick layer of metal. This procedure can lead to a partial destruction of the motif (completely covered by metal) thus the decreasing of nano graphics resolution. In this paper several nano graphics (images and text with various resolutions) are prepared in positive resist PMMA (thickness of 2000 nm) by e-beam lithography. Chemical developer (pentyl acetate) was used for wet developing of prepared patterns. The sputtering of silver (100 nm) was carried out to achieve sufficient thickness of conductive layer for electroforming. Electron scanning microscope was used for evaluation, which one of the images and texts are still recognizable.

Key words:

Electron beam lithography, nano graphics, polymethyl methacrylate, metal sputtering, electroforming.

INTRODUCTION

E-beam lithography is commonly used method for micro and nano patterning in various field of application (optics, MEMS, microelectronic components etc.) [1]. Also it can be used for creating nano graphics as a security feature. The advantages of e-beam lithography are achievable resolution, precision and direct writing without any masks required. However it has two main disadvantages regarding to nano graphics. These are low throughput in high resolution patterning and because of that it cannot be used for mass production. The second problem is that the master itself cannot be used as printing plate due to the resist material soft nature (usually a polymer material).

Hard printing plate must be produced to achieve high throughput. Electroforming is one of the methods that can be used. Hard plate prepared by electroforming is usually made of nickel. The main advantages of this kind of replication is low cost and high accurate copying (with right settings of parameter such as composition of electrolytic solution, current value etc.) [2]. Nevertheless, master for electroforming replication have to be conductive to perform electroforming. Resists for e-beam lithography are non-conductive, and because of that the master has to be sufficiently metalized. This step has the significant impact to the high resolution structures prepared by e-beam lithography. This paper deals with the resolution of nano-graphics and nano-texts which are still recognizable after metallization.

1. RESOLUTION IN NANO-PATTERNING REPLICATION BY ELECTROFORMING

The resolution of patterns prepared by electroforming is determined by lithography process, metallization and electroforming process. Below, it will be discussed resolution regarding to master preparation for electroforming process – lithography process and metallization. Electroforming process is described briefly because it is not the subject of this paper.

1.1 E-beam lithography resolution

Resolution in e-beam lithography is determined by these parameters:

- Electron energy,
- Resist material,
- Chemical developing process.

Electron energy is based on e-beam system used for lithography process. In this case we are using 100 keV system Vistec EBPG5000+ ES. High primary electron energy can guarantee high resolution in principle [3]. Considering the resist material, it depends on the composition of resist, its thickness, deposition technique and baking method. Finally, the resolution is determined by chemical developer, developing time, temperature and the way of developing.

Most of these parameters can be summarize into theoretical resolution expressed by modulation transfer function (MTF) which is Fourier transformation of PSF function that describes proximity effect [4]:

$$M = \frac{1}{1+\eta}\left[\exp\left(-\frac{\pi^2\alpha^2}{p^2}\right) + \eta \cdot \exp\left(-\frac{\pi^2\beta^2}{p^2}\right)\right], \qquad (1)$$

where α – coefficient characterizing electrons forward scattering, β – coefficient characterizing backscattered electrons range, η – coefficient characterizing ratio between backscattered electrons energy to primary electrons energy, p – pitch of close exposures (lines period). On **Fig. 1** is the MTF as function of lines period for two thicknesses of resist layer (Polymethyl methacrylate - PMMA). Coefficients α, β, η were obtained by approximations of Monte Carlo simulations (MCS) in software TRACER by GenISys.

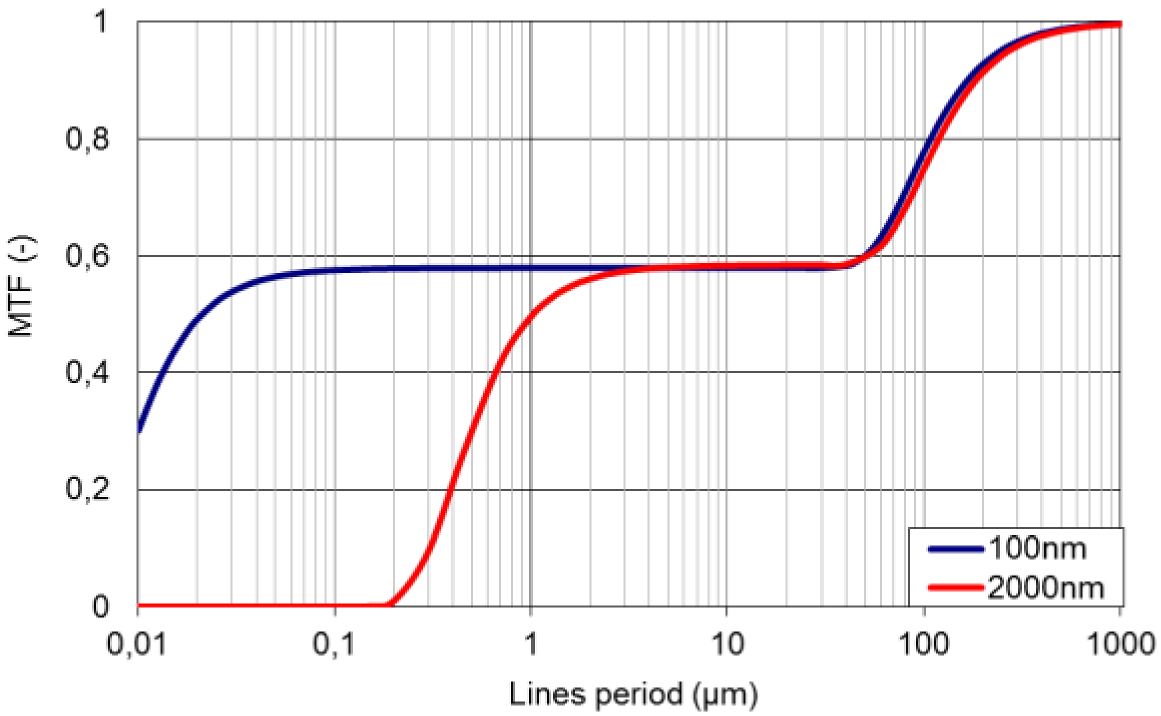

Fig. 1 MTF as a function of lines period for 100 keV primary electron energy for two resist thickness of 100 and 2000 nm resist PMMA on silicon substrate.

Basically, it expresses the difference of energy deposited between exposed and unexposed areas. It is sufficient if the MTF value is higher than 0.5. It is clear that the thinner layer is capable of higher resolution. Advantage of the nano graphics is that they are usually generated in the upper part of resist layer.

1.2 Resolution of metalized master for electroforming process

Electroforming is capable of replicate nanoscale structures (such these prepared by e-beam lithography) with high accuracy [5]. However, non-conductive materials have to be coated with metal, and this procedure distorts the resolution and the shape of prepared structures. To achieving good conductivity, relatively thick metal layer is necessary (approximately 100 nm). It also depends on metallization technique and metal itself. Two most available techniques are vacuum evaporation and magnetron sputtering. Considering the requirements for electroforming magnetron sputtering has two major advantages over vacuum evaporation. It creates smaller grains of metal and the metal film is more homogeneous, but unfortunately it is not very directional [6].

From conductivity point of view, the best option is to use silver. Also it has very good compatibility with our electroforming process (compatibility with electrolytic solution). Unfortunately the growth of silver film on surface leads to creating grain in size of more than 10 nm (in comparison with chromium or tungsten) [7].

2. SAMPLES PREPARATION

Two types of patterns were prepared for this experiment - nano images and nano text (**Fig. 2**). Nano images were prepared in three sizes of 100, 200 and 500 px and nano texts in fonts 72, 48, 28, 20, 14 and 12 pt (both in bitmap format). Pixel size of input bitmap was 10, 5 and 1nm.

Fig. 2 Input nano image and nano text.

Exposure was carried out on PMMA resist with thickness of 2000 nm. Such a thick layer was used because nano patterns are usually used with various kinds of micro and nano elements with diverse function. If the thinner resist layer would be used, possible resolution would be higher (as was shown on **Fig. 1**). However, other elements function (combined with nano graphics) would be very limited in that case. Non-alcoholic based chemical developer (pentyl acetate) was used for developing of patterns.

Two different layers were used for metallization of prepared master. One sample was sputtered by 100 nm thick layer of silver. This was the sample for determination of maximum resolution with respect to requirements for preparation of master for electroforming. Second one was coated (also by sputtering) with 10 nm of chromium. This one was the reference sample just to show what resolution is achievable if the pattern is not destroyed by 100 nm of silver.

3. RESULTS

All samples were evaluated by scanning electron microscope and it was determined which size of nano images and nano texts are still recognizable. Nevertheless, this task could be subjective thus two sets of results were chosen. One which was without question sufficient for electroforming and it was not very damaged. The second was still recognizable but it was damaged by the way which could not guarantee successful creation of nickel replica by electroforming.

3.1 Maximum resolution of metalized master for electroforming

The smallest nano image which reaches requirements for electroforming was 2000 nm large (**Fig. 3**). Image which was still comparable with design but it would be not reproducible by electroforming was even 1000 nm large (**Fig. 4**).

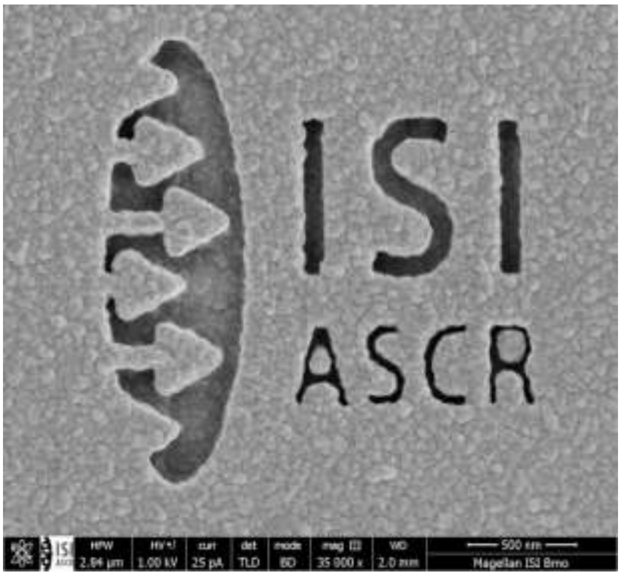

Fig. 3 Nano image, input 500 px - 5 nm/px.

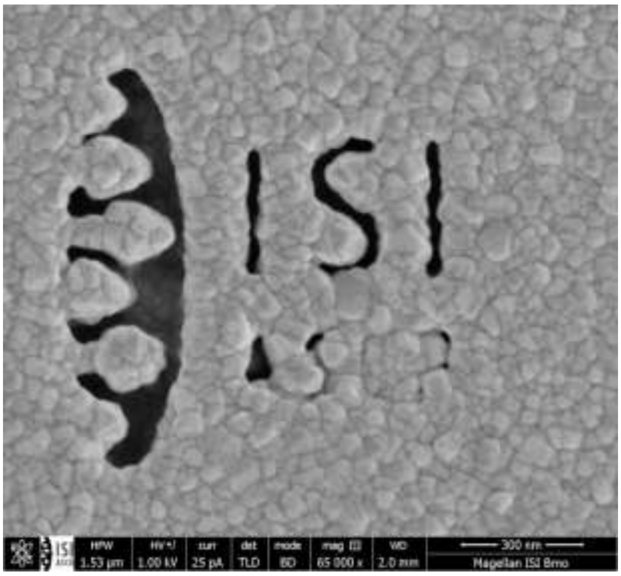

Fig. 4 Nano image, input 200 px – 5 nm/px.

The smallest text which should be possible to replicate by electroforming had letters 425 nm high with the line width of approximately 20 nm (**Fig. 5**). Nano text which was the smallest one still readable was about 300 nm high with the line width of approximately 10 nm (**Fig. 6**).

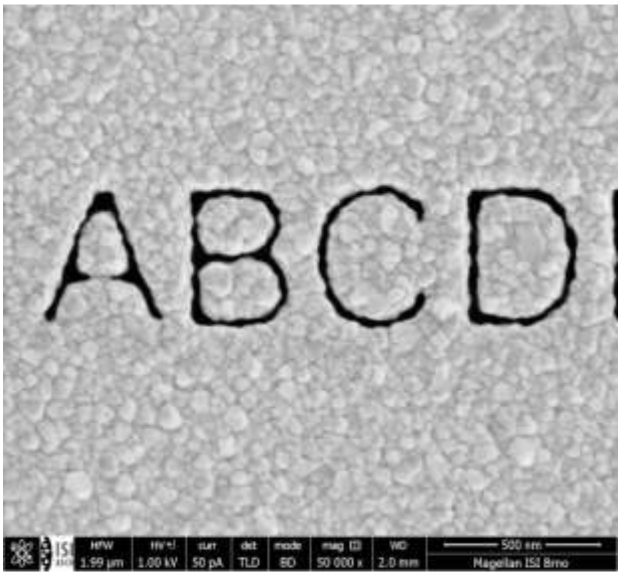

Fig. 5 Nano text, input font 48 pt - 10 nm/px.

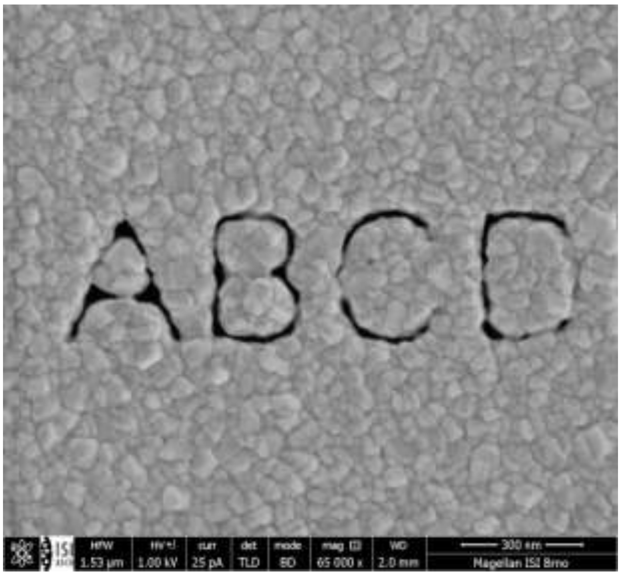

Fig. 6 Nano text, input font 72 pt - 5 nm/px.

3.2 Maximum possible resolution of nano graphics

As expected, when patterns are not covered with relatively thick layer of metal (in this case 100 nm of silver) it is possible to reach higher resolution. On **Fig. 7** is shown the smallest nano image which was still recognizable (950 nm large). By circumstance it is the one shown on **Fig. 4**. The smallest nano text was 125 nm high with the line width of 10 nm.

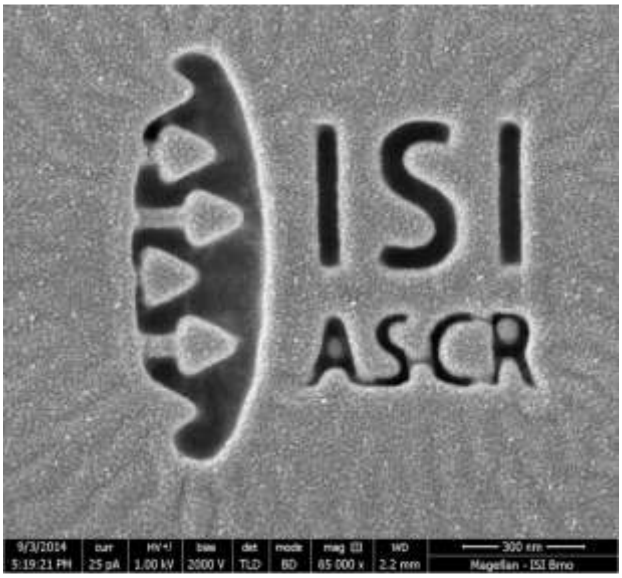

Fig. 7 Nano image, input 200 px – 5 nm/px.

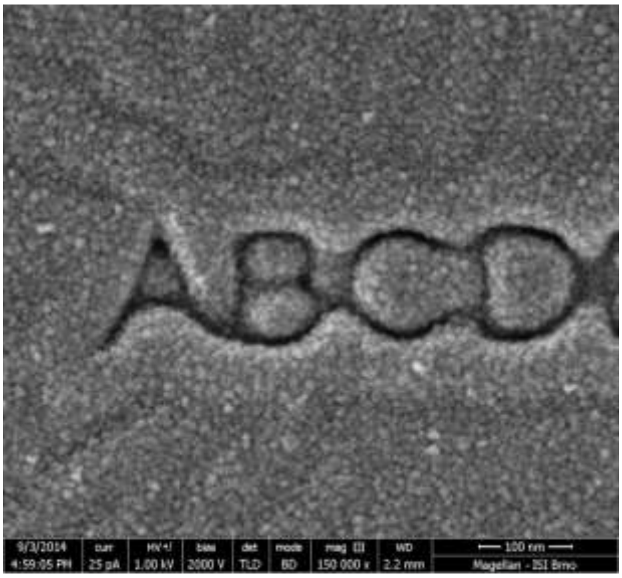

Fig. 8 Nano text, input font 28 pt - 5 nm/px.

CONCLUSION

We successfully prepared nano graphics (nano images and nano texts) with respect on requirements of electroforming replication. The results concerned to nano text are clear but the results concerning nano images can be related to the specific nano image which was used in this work (shape of image was chosen with respect to its complexity of exposure - unexposed isolated arrows on exposed ellipse). For other simpler nano image it would be possible to achieve higher resolution. It is also clear that electroforming replication requirements in current condition (thick layer of silver) does not allow using full capability of e-beam nano patterning. Maybe using of another metallization process and even another metal could guarantee achieving higher resolution.

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