LIFT-OFF TECHNIQUE USING DIFFERENT E-BEAM WRITERS

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Abstract

This paper deals with lift-off technique performed by the way of electron beam lithography. Lift-off is a technique mainly used for preparation of metallic patterns and unlike etching it is an additive technique using a sacrificial material – e.g. e-beam resist PMMA. In this paper we discussed technique of preparation of lift-off mask on two different e-beam writing systems. The first system was BS600 – e-beam writer with rectangular variable shaped beam working with 15keV. The second system was Vistec EBPG5000+ HR – e-beam writer with Gaussian shape beam working with 50 keV and 100 keV. The PMMA resist single layer and bi-layer was used for the lift-off mask preparation. As a material for creation of metallic pattern, magnetron sputtered chromium was used. Atomic force microscope, scanning electron microscope and contact profilometer were used to measure and evaluate the results of this process.

Keywords: Lift-Off, electron beam lithography, e-beam writers with shaped and Gaussian beam

1. INTRODUCTION

The lift-off process is one of the methods for creating metal patterns on a substrate. The nanometer scale metal patterns are produced mostly by electron beam lithography using positive resist, usually in multilayers [1]. By electron beam lithography, we are capable to create patterns up to 100 nm size but the clear undercut profile is needed. The achievable resolution of created structures is affected by many conditions during process – e.g. temperature of developer but mainly thickness of the resist. Better resolution can be obtained with the thicker resists [2, 3]. In this study lift-off single resist layer and bilayer process on two e-beam writers is compared.

2. LIFT-OFF TECHNIQUE

Lift-off is a method for metal patterning and unlike etching it is an additive technique using a sacrificial material – in this case, positive resist PMMA (polymethyl methacrylate). Lift-off can be carried out by using of single resist layer (Fig. 1) or by using of double resist layer (Fig. 2). A bilayer process requires two resist layers with different molecular weight or special resist which is not affected by exposing of electrons. The bottom layer is developed faster and it results in the formation of undercut structure [4].

![Fig. 1 Lift-off process with single resist layer: a) deposition of resist; b) exposure and developing; c) sputtering of metal; d) lift-off process; e) mechanical cleaning](image1)

![Fig. 2 Lift-off process with two resist layers: a) deposition of two resist layers; b) exposure; c) developing; d) sputtering of metal; e) lift-off process](image2)
3. SAMPLE PREPARATION

Samples were prepared under the same conditions for both e-beam writers. Layers were spin-coated on silicon wafers for both processes (single and bilayer). Chromium was used for creation of metallic patterns.

3.1. Single resist layer process

Positive resist PMMA was used as the sacrificial layer for the single layer resist process. Prepared layers had molecular weight of 350k and it was 9 % wt solution in anisole [5]. Silicon wafers with the resist were baked on hot plate for 9 minutes at 150 ºC. The thickness of the resist layer for Vistec e-beam writer was 460 nm. After the baking process the exposition was done with the dose of 400 µC·cm². Isopropyl alcohol based developer was used for chemical developing. Developing time was approximately 8 minutes. The thickness of the resist layer for BS600 e-beam writer was 475 nm. After the baking process the exposition was done with the doses of 20, 40 and 80 µC·cm². As a developer, n-amyl acetate was used (time – 4 minutes). Resist residues on developed areas were removed in oxygen plasma [6]. Then approximately 50 nm of chromium was sputtered on the silicon wafers. Afterwards the lift-off process was carried out by using of dichloromethane which dissolves the sacrificial layer of PMMA in a few seconds. Finally, the samples were cleaned in ultrasonic cleaner, where the undesirable metal around the patterns was removed. During the dissolution, it is important that the sample remains wet until it is fully cleaned. The residues of the chromium can therefore stick to the silicon wafers or even somewhere else in the pattern which can cause problems with evaluation. You can see these chromium residues on Fig. 3.

![Fig. 3 Chromium residues in the pattern – a) macro view; b) detail of the pattern.](image)

3.2. Bilayer process

Positive resist PMMA was used for both layers in the bilayer process. The bottom layer had molecular weight of 350k and it was 9 % wt solution in anisole, the top layer had molecular weight of 950k and it was 6 % wt solution in anisole [5]. At first the bottom layer was baked on the hot plate for 9 minutes at 150 ºC, then at 100, 125, 150 ºC for 10 minutes each step. Afterwards the top layer of the resist was deposited and baked on the hot plate at 100, 125, 150, 160 ºC for 10 minutes each step [7]. The bottom layer was 450 nm thick and both layers together were 866 nm thick for exposition on Vistec. The bottom layer's thickness was 484 nm and both layers were 821 nm thick for exposition on BS600. The exposition on both e-beam writers was done the same as described above. In both cases (single layer, bilayer process) the same developer was used. The exposition from Vistec e-beam writer took 15 minutes to develop and the exposition from BS600 took 11 minutes. After the plasma etching, approximately 100 nm of chromium was sputtered on the wafers. Then the lift-off process and the final cleaning were done.
4. RESULTS

All the expositions consisted of 5x5 mm cross grating with the period 50 µm, lines from 0.1 – 2 µm with step 100 nm and gratings with period 200, 400, 600, 800, 1000, 1600, 2000, 3000, 4000 nm. The exact dimensions of structures were measured by scanning electron microscope after the lift-off process.

4.1. Vistec EBPG5000+ HR – e-beam writer

In the bilayer resist process, too much of sputtered chromium was used. Due to this during lift-off process the residues of the metal sticked to the pattern and contaminated lines and gratings. Gratings with periods smaller than 600 nm were ruined. The difference between the 200 nm and 600 nm gratings is visible on the Fig. 4.

With the single resist process we achieved better results with the gratings – starting with 400 nm period grating. Smaller periods than 400 nm were ruined or covered by chromium residues (similar to Fig. 4 a)). The first visible line in this process was 100 nm wide in design and the actual dimension measured by SEM was 164.5 nm.

4.2. BS600 – e-beam writer

On the e-beam writer BS600 three doses were tested. In the single layer resist process the only dose that remained on the silicon wafer after the lift-off was the 80 µC·cm². The rest of exposed area was washed away during the cleaning process in ultrasonic cleaner. We had to deal with a similar problem in the bilayer resist process, when the lower doses were ruined. These problems are probably caused by short developing time of the exposition. Gratings with smaller period than 1000 nm were ruined in the single layer resist process. The same problems occurred in the bilayer resist process for grating with period smaller than 1600 nm. We also measured the dimensions of single lines on both expositions. The first line that is visible in the single layer process is 300 nm wide and in the bilayer process it is the narrowest – 100 nm wide. Measured dimensions are in both cases larger than design although greater difference occurs in the bilayer process. The difference is visible on Fig. 5.
4.3. Comparison

Achievable resolution of both e-beam writers was compared on single lines and gratings in previous results. The exposed 100 nm wide line from rectangular variable shaped beam on 15 keV has width of 240.4 nm and from Gaussian shaped beam on 100 keV has width of 164.5 nm. The first grating that was not ruined on Vistec exposition was with 400 nm period and on BS600 exposition it was grating with 1000 nm period. Also the curvature of the corners was measured as shown on Fig. 6 by inscribing a circle into the corner of the cross grating. A lot smaller magnification was used for measuring the curvature from BS600 e-beam writer than for Vistec e-beam writer.

Fig. 5  a) 100 nm wide line performed by the bilayer process; b) 300 nm line performed by the single resist layer process

Fig. 6  a) curvature of the cross grating performed on BS600; b) curvature of the cross grating performed on Vistec
5. CONCLUSION

We performed the lift-off process on two different e-beam writers – one with Gaussian shaped beam and the second one with rectangular variable shaped beam. The best results are achievable on Vistec e-beam writer with Gaussian shaped beam on 100 keV. We tested the same structures in the single layer resist process and in the bilayer resist process. Actual structure dimensions were measured by scanning electron microscope and it was compared with the design.

ACKNOWLEDGEMENTS

This work was partially supported by the EC and MEYS CR (project No. CZ.1.05/2.1.00/01.0017 ALISI, project No. CZ.1.07/2.3.00/20.0103 OPVK), the TACR project No. TE 01020233 and by the institutional support RVO: 68081731.

LITERATURE


