LIFT-OFF TECHNOLOGY FOR THICK METALLIC MICROSTRUCTURES

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Abstract

This paper deals with a method enabling the preparation of thick metallic microstructures on metal substrates. Such metallic microstructures can be used as a resolution samples to characterize various microanalysis techniques, such as X-ray fluorescence (XRF) or X-ray photoelectron spectroscopy (XPS). Moreover, the patterned samples could be used as anodes to characterize focusing properties of X-ray tubes for micro CT systems. Considering that the standard lift-off technique is designated for structures with the thickness of several hundred nanometers at most, we had to modify lift-off technique to be possible to use it for preparation of very thick metal layers (several microns) with spatial resolution of a few microns. The mask with the desired pattern for UV exposure was prepared by e-beam lithography. SU-8 photoresist was used for a lift-off because of its aspect ratio ability, process purity and high resistance to heating. We used a thin layer of PMMA under the SU-8 masking layer to guarantee the photoresist would lift-off correctly. Thick aluminum layer was deposited by thermal evaporation. The dependence of metal layer thickness as a function of required exposed line width was determined. The final lift-off process was carried out in acetone ultrasonic bath. Generally, this technology can be used for the evaporate deposition of various materials with several microns thick layer in micron resolution.

Keywords: Lift-off technique, SU-8 photoresist, e-beam lithography, thick layer evaporation

1. INTRODUCTION

There are several techniques that can be used for metal structures fabrication. They can be divided to subtractive methods and additive methods [1]. Among subtractive methods we count all the etching techniques (wet and dry). Wet methods are suitable only for tasks where very high resolution and anisotropy are not required. However, it can be used for etching of very thick layers thus for preparation of very thick metallic structures. Dry etching techniques give much better resolution, and perfect anisotropy. However, it has high requirements for masking materials if we want to prepare very thick/deep structures. The other disadvantage is that almost all metals are dry etched by chlorine based compounds which can cause the contamination of substrate [2]. Amongst the additive technique are for example electroplating and lift-off [1]. Electroplating fulfils almost all requirements, however it can be hard to protect the complex shape substrate from contamination by chemical bath. Lift-off resolution limit is given by the thickness of the metal structure we want to prepare. Nevertheless, it is the cleanest process compared with all the processes mentioned above. The high purity is essential for any spectroscopy (XRF, XPS etc.) application, or if the sample is used under high vacuum conditions [3].

2. LIFT OFF TECHNIQUE

The lift-off technique is an additive method for the preparation of planar microstructures (the material does not have to be necessarily metal). It uses sacrificial layer of resist in which the desired pattern is prepared. The pattern is usually exposed by some lithography technique. It is desirable that exposed edges would be concavely shaped to prevent their covering during the material deposition (**Figure 1** on the left) [4]. If the UV lithography is used for preparing pattern, almost all photoresists behave by such a way when they are slightly overexposed. Single layer process is usually used, however for photoresists that are poorly dissolvable it is necessary to use a solvable under-layer (as in the case of SU-8) [5, 6]. Because of UV lithography resolution limitation, e-beam lithography can be used for achieving higher resolution. It is more difficult to achieve concavely shaped edges, but it is possible, and it is given by primary electron energies of the e-beam system and resist combination [7]. Two layer of resist are often used for achieving suitable shape of edges (**Figure 1** on the right). The resist combination is selected by such a way, that bottom resist layer is developed faster than the top one. It is possible to use the same type of resist with different molecular weight or to use a special LOR (lift-off resist) as the bottom layer in order to achieve this effect [8]. Lift-off technique is originally used for preparing very thin structure (several hundreds of nanometers at most). Sputtering or evaporation is usually used for the coating material. Evaporation is recommended to prevent covering the pattern edges in resist by the coating material [9]. The using of evaporation is necessary to prepare very thick structures, as intended in our case.

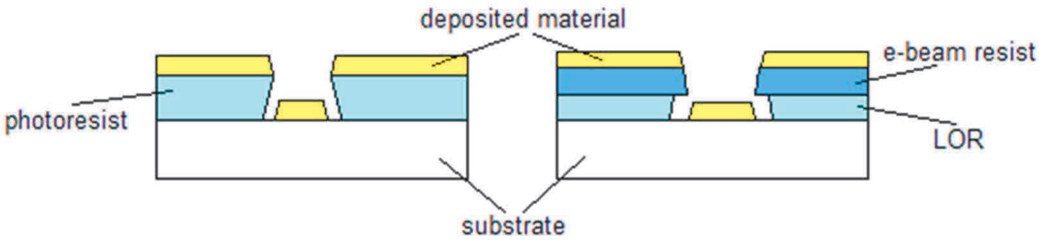

Figure 1 Lift-off technique after metal deposition. Single layer process (left), bilayer process (right)

3. SAMPLE PREPARATION

Typical lift-off technique described above had to be adjusted, particularly because of atypical substrate and desired microstructures (resolution and thickness). Technological steps of the whole process are shown in **Figure 2**.

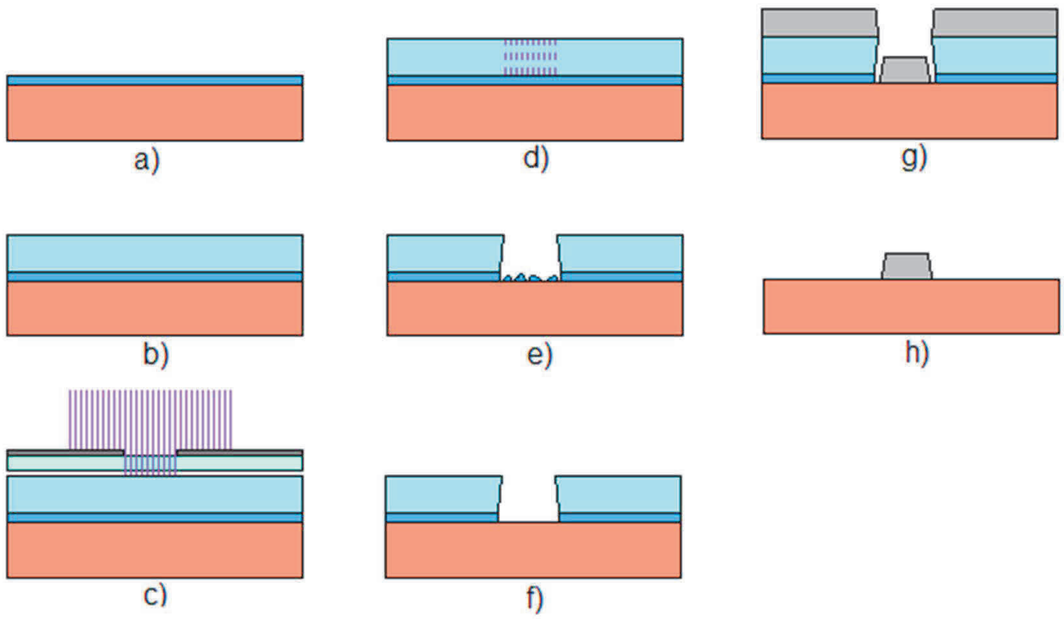

Figure 2 Adjusted lift-off process used for thick metallic microstructures preparation. a) PMMA coating and baking, b) SU-8 coating and soft baking, c) UV exposure through the photomask, d) post exposure baking, e) development, f) plasma cleaning, g) metal deposition, h) lift-off process.

3.1. Substrate preparation

The substrate was disk 15 mm in diameter and 3 mm thick made from copper due to its thermal and mechanical properties required for application. The surface of the substrate had to be diamond milled to provide the best surface quality (roughness of 10 nm RMS) which is required to achieve the high resolution and the high quality of microstructure edges.

Thin layer of PMMA (200 nm) was used as an under-layer to perform the lift-off instead of recommended OmniCoat for SU-8 photoresist. It did not meet our requirements for the purity of the process, also the temperature of 200 °C for baking the layer did not benefit to copper surface. The PMMA layer was baked on hot plate for 10 min at 130 °C (**Figure 2a**)).

SU-8 photoresist was coated directly on PMMA layer (thickness of 13-14 µm). It was soft baked on hot plate for 3.5 min at 100°C (**Figure 2b**)).

3.2. UV-exposure and development process

The mask for UV lithography was prepared by the way of e-beam lithography and reactive ion etching. The pattern containing several lines with various widths (range 5 - 100 µm) was exposed by e-beam system Raith EBPG5000+ ES. The masked layer (molybdenum) was etched over PMMA mask in Oxford Instruments PlasmaPro®System 100/133 by the mixture of SF_6 and Ar.

The UV exposure was carried out on SUSS MicroTec MA6/BA6 system (**Figure 2c**)). The post exposure bake was done on hot plate at 100 °C for 4.5 min (**Figure 2d**)). Standard mr-dev 600 developer by Microchem was used for development process (spraying for 30 s then rinsing with isopropyl alcohol and drying with nitrogen), see **Figure 2e**).

The developer for SU-8 partially dissolves the layer of PMMA. However, to guarantee the copper surface would be perfectly clean, the sample was subsequently treated by argon plasma to clean the PMMA resist residue completely (**Figure 2f**)).

3.3. Layer deposition and lift-off

The desired metal for final application was aluminum and it was thermally evaporated on the substrate surface. The layer deposition was performed by Edwards coater A306 system. The layer deposition was proceeded in several steps to prevent overheating of the sample and the melting down of structures.

Coated samples were put into acetone bath and left there for 48 hours. Then the sample was put into the clean acetone ultrasonic bath to remove possible residues of metal adhered to the sample. Finally it was dried out by nitrogen.

4. RESULTS

During the aluminum deposition we observed the strong dependency of aluminum thickness as a function of exposed line width (**Figure 3**).

As you can see, the increasing of deposition time does not help increasing the thickness of metal much for low width lines. However, in time it would cause complete covering of exposed structure thus the lift-off could not be performed correctly. We tried to deposit several materials (Ti, SiO_2, Si_3N_4) and we observed similar dependency.

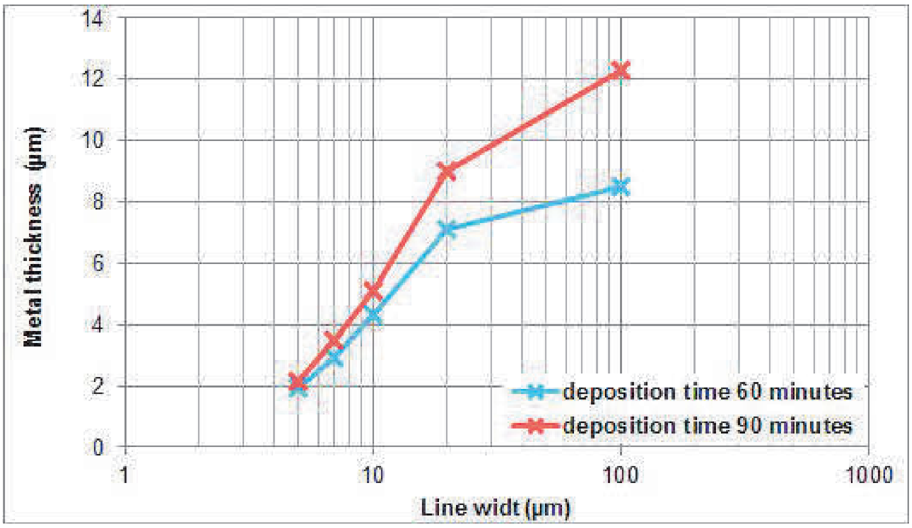

Figure 3 The thickness of aluminum layer as a function of line width for two deposition times

The final sample is shown in **Figure 4** along with detailed image from scanning electron microscope.

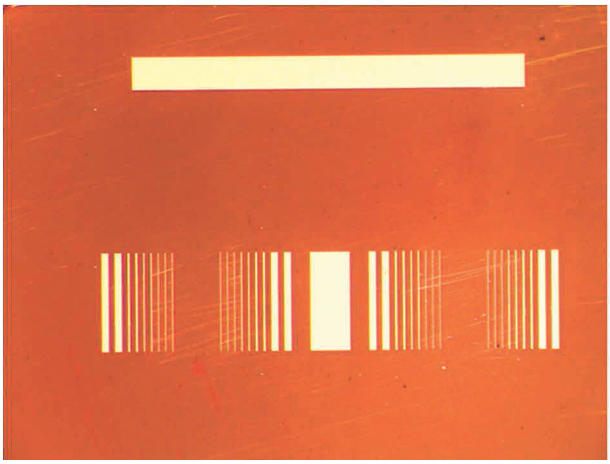
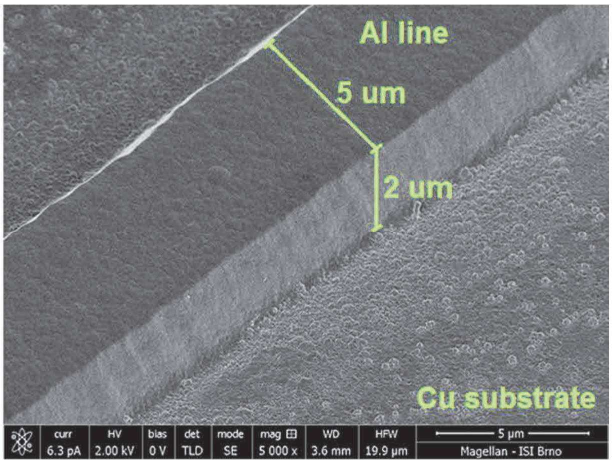

Figure 4 Copper substrate with aluminum microstructure (left), detailed SEM image of one line (right)

5. CONCLUSION

We adjusted the lift-off process for using with SU-8 photoresist and PMMA resist as an under-layer. It is primarily intended for several microns thick metallic microstructure. It was also shown, that there is the limitation of thermally evaporated material thickness related to the line width of exposed pattern. The process guarantees high level purity of resulted microstructures. It can be used with various combinations of substrate material and metallic microstructure material when proper plasma is used to clean developed structures.

ACKNOWLEDGEMENTS

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