AFM investigation of thin post-baked photoresistive films for microsystem technology application

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In this paper we discuss the application of photoresist films as the sacrificial layers for „bridge“ working elements in microsystem technology. Different regimes and conditions of post-baking and plasma chemical etching processes for forming sacrificial layers with the precise thickness and roughness were investigated. The photoresist surface morphology was observed with help of atomic force and scanning electron microscopy.

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1. Introduction

Development of manufacturing process of micro-electro-mechanical systems (MEMS) devices with so-called „bridge“ working element to be elastically deformed during operation is of great interest because it can be used for various microsystems. This element (membrane) consists of two metallic layers with total thickness of less than 1 μm. The first metal film is usually deposited by vacuum evaporation and the second (much thicker) by galvanic deposition. The ordinary technology used for manufacturing of „bridge“ structures is based on the use of sacrificial layers of various materials to be removed after formation of metallic membrane. In is clear that in this case mechanical characteristics and operational capability of the membrane very strong depend on sacrificial layer morphology. It was shown [1] that the optimal working characteristics of the membrane can be reached when underside roughness of the first metal layer does not exceed 4 nm.

Several types of materials have been tested for formation of sacrificial layers. Some of them like polyimide films require too high polymerization and high removal temperature (above 350°C) [2,3] and this can cause generation of sufficient mechanical stress in thick metal membrane after cooling. Therefore the use of photoresistive materials as the sacrificial layers is more attracrive for application in industrial manufacturing of „bridge“ working elements in MEMS.

However the use of spinning technology for the photoresistive coating can not provide precisely required thickness of a sacrificial layer. Therefore soft plasma etching of photoresistive layers has been often used to adjust thickness.

The main aim of this paper is to study the influence of the regimes and conditions of post-baking and plasma chemical etching processes on surface roughness of the photoresistive coatings used as sacrificial layers in manufacturing of „bridge“ MEMS structures.

2. Experimental

Two positive photoresists, PhP 91-20 and PhP 4-04B, prepared on the basis of phenolformaldehyde resin, have been chosen because they have been widely used in microelectronics and readily available. Photoresist processing on silicon wafers for this work included a spin-coating of about 1100–1300 nm thick layer. A soft-bake of 90°C for 6 min was used after the spin-coating process, prior to exposure. The wafers were then developed and post-baked (or hard-baked) at different temperatures as listed in Table 1.

The wafers were then treated with the use of commercial installation for photoresist plasma etching (type 08 100T-004) equipped with parallel-plate reactor. The RF (radio frequency) generator (5.24 MHz) was connected to the top stationary electrode, the bottom was grounded. Both electrodes were cooled with water. The dry oxygen was introduced into the reactor only. The total pressure in the reactor was 50 Pa. The etching time varied from 10 to 75 s.

The surface roughness of photoresist layers before and after plasma etching was investigated by AFM (atomic force microscopy) (Solver P 47-Pro, NT-MDT Co., Russia) and SEM (scanning electron microscopy) (JSM-6060 JEOL, Japan).

3. Results and discussion

The results obtained showed that post-baking process patameters did not display significant changes of the photoresist morphology. The roughness of untreated photoresist surface was less than 3 nm (Table 2).

Table 1. Conditions of the post-baking processes

Post-baking process	The first step	The second step	The third step
	Temperature, time		
I	90°C, 30 min	–	–
II	90°C, 30 min	120°C, 30 min	–
III	90°C, 30 min	120°C, 30 min	145°C, 20 min

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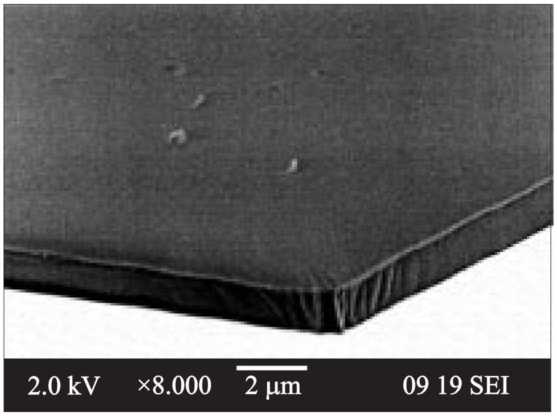

Figure 1. SEM image of PhP 91-20 photoresist patterns after post-baking process III.

It is very propably, that the mechanical stresses appeared in thick photoresist films after post-baking (PB) under highest temperature tested. This is confirmed by the appearance on the SEM images of both photoresists post-baked under condition III (Table 1) of the strias in relief, which were observed on the corners and the sides of photoresist patterns (Fig. 1). Thus post-baking regimes with lower temperatures were chosen for next sets of experiments.

Table 2. Average roughness of photoresists film surfaces obtained after post-baking processes carried out under different conditions (Table 1)

Post-baking process	Average roughness, nm	
	PhP 4-04B	PhP 91-20
I	0.96	1.13
II	0.96	1.14
III	1.13	1.22

It was found that the average roughness of untreated polymer surface was less than 3 nm, however it was negligible changed after post-baking processes performed under conditions I and II.

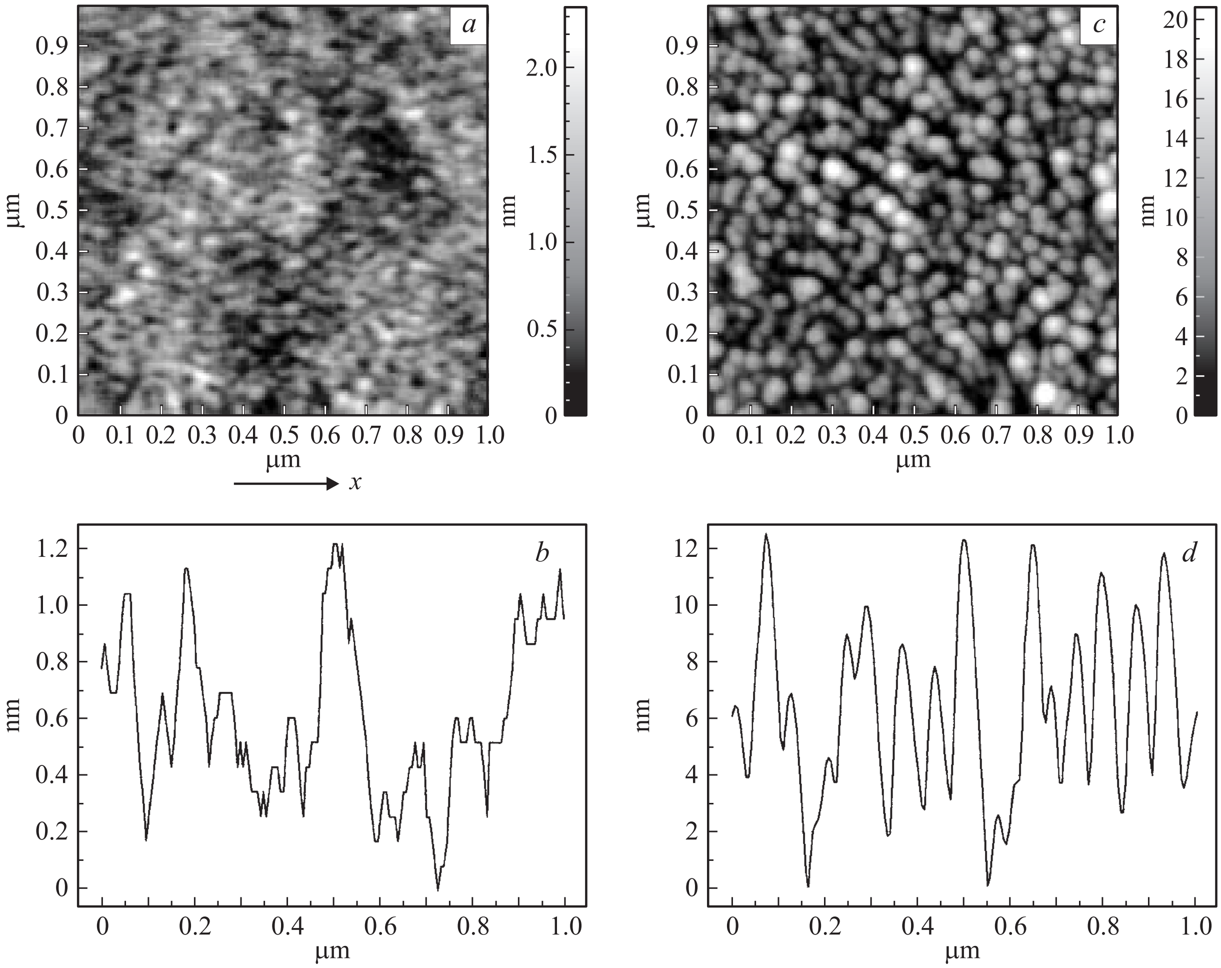

Figure 2. AFM images of surfaces and profiles of the center of the scan in x direction of untreated (a, b) and after 60 s etching (c, d) PhP 91-20 photoresist.

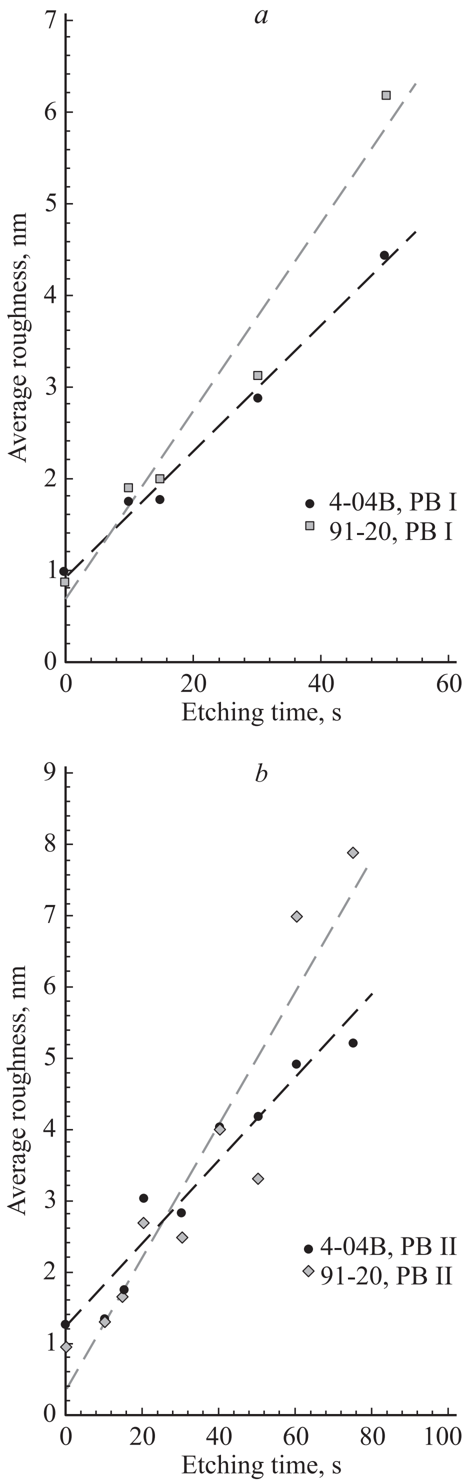

Figure 3. The trends in variaton of surface roughness of photoresistive layers with etching time for photoresists post-baked under process I (*a*) and process II (*b*).

Plasma etching of photoresistive layers caused sufficient increase in roughness of a sacrificial layer. AFM images of untreated and etched photoresist surfaces are presented in Fig. 2. Appearance of grains with the shape close to a sphere was found in all cases. The average diameter of the spheres monotonically increased in the range 10−50 nm with the etching time varied in the interval 10−75 s.

The trend in variation of surface roughness with etching time is shown in Fig. 3. The average surface roughness of PhP 91-20 photoresist is increased with the etching time more significant than for PhP 4-04B. The most probably, this is related with the some differences in polymeric compositions of two photoresists studied. We suppose that the PhP 91-20 photoresist contains a grate deal of solvent.

It was also found that the average surface roughness for identical plasma chemical etching parameters is larger for both photoresists post-baked under condition I than under condition II. Taking this into account two steps post-baking process during 30 min under 90 and 120°C (condition II) can be recommended for industrial application of both photoresists studied. As to etching time, the results of investigation obtained allow us to recommend the duration of plasma etching for both post-baking process regimes to be in the range 30−40 s to provide photoresist surface roughness not higher than 4 nm.

4. Conclusion

In this work we discuss the possibility to use photoresistive layers as sacrificial ones for manufacturing of „bridge“ structures in different MEMS devices. The influence of post-baking regimes and plasma chemical processes parameters on the photoresist layers morphology was studied by the AFM and SEM techniques.

It was found that the photoresist patterns began disfigure after post-baking procedure if the process temperature does not exceed 145°C for investigated photoresists materials. It was proposed to use plasma chemical etching process for precise adjustung of photoresist thickness for formation of a sacrificial layer of required height.

It was shown that proper choose of conditions of post-baking (Table 1, condition II) and parameters of plasma etching process allows to form sacrificial layers with average roughness not exceeding 4 nm.

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