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Profiling of nanostructures by scratching probe nanolithography and plasma chemical etching

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Abstract. This work presents the results of the experimental investigations of nanostructure profiling using scratching probe nanolithography and plasma chemical etching. It is shown, that combination of these methods allows us to profile the silicon surface with height from approximately 7,8 to 38 nm and diameter from 670 to 123 nm.

1. Introduction

Reducing the size of the elements of integrated circuits (IC) is one of the main tasks of micro- and nanoelectronics [1-5]. The modern level of technology requires the formation of the elements with size below 100 nm. The photolithography cannot be used for creation of such structures due to its resolution limit. Therefore, there is a need to develop new techniques for production of IC elements on a nanometer scale [5, 6]. Scratching probe nanolithography of atomic force microscopy (AFM) is one of the promising methods on this way [7]. The method is a mechanical modification of the photoresist surface using a probe tip [8-18]. After the structures profiling is done, plasma-chemical etching of the substrate can be carried out [13, 14]. The photoresist layer plays the role of a mask.

The aim of this work is investigation of profiling of nanostructures using scratching probe nanolithography and plasma-chemical etching.

2. Experiment details

The diagram of nanostructures formation on the Si surface is shown in Figure 1. A positive photoresist FP-383 mixed with a diluent RPF-383 in the ratio 1:14 was used as an experimental sample. This solution was applied to the silicon substrate by centrifugation at a rotational speed of 5500 rpm (Fig. 1a). Then the sample was dried at 90°C for 2 minutes. The film thickness was 20±2 nm.

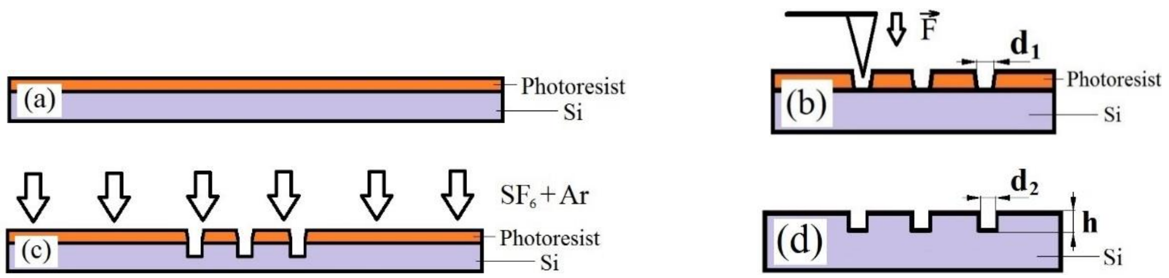

Figure 1. Diagram of nanostructure formation on Si: (a) deposition of photoresist; nanostructures formation: (b) on photoresist by scratching probe nanolithography; (c) on Si surface by plasma-chemical etching; (d) on Si substrate after photoresist removing.

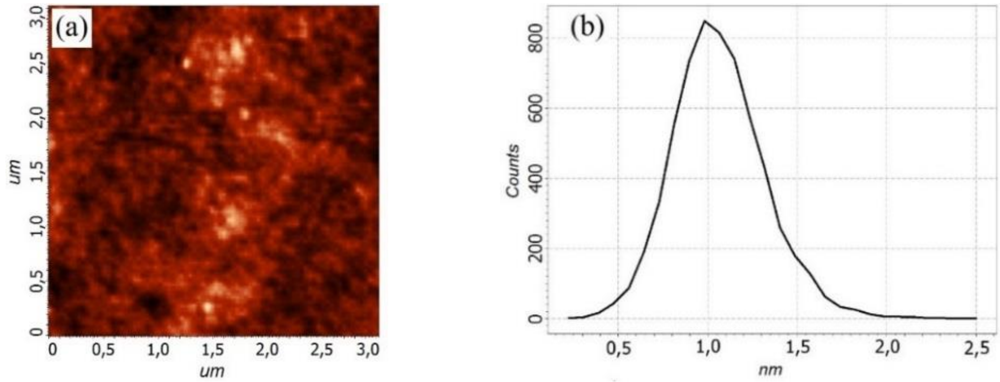

Figure 2. Photoresist surface morphology: (a) AFM image; (b) roughness histogram.

Scratching probe nanolithography was carried out at the Ntegra probe nanolaboratory (NT-MDT, Russia) in contact mode AFM using a cantilever NSG-11. As a result, arrays 3×3 μm^2 of profiled nanoscale structures with diameters d_1 from 60±4 nm to 436±27 nm were formed in different regions of the photoresist surface at F = 3 μN (Fig. 1b).

For experimental studies of plasma interaction with Si under inductively coupled plasma, a cylindrical flow-through plasma chemical reactor was used. The pressure of a mixture of plasma-forming gas was 2 Pa. Plasma etching of the samples was carried out in STE ICPe68 (SemiTEq JSC, Russia). Nanostructures were formed in combined gas discharge plasma with following parameters: power source inductively coupled plasma W_{ICP}=300 W; power capacitive plasma source W_{RIE}=35 W; bias voltage U_{bias} = 73 V. For etching, a working mixture of gases Ar:SF_6 in the ratio of 10:1 was used; etching time was about 1 min at 23°C (Fig. 1c). After that photoresist residues were removed in dimethylformamide (Fig. 1d). AFM images of nanostructures were obtained in semicontact mode to define diameters d_2 and height h (Fig. 1d). Images were analysed using Image Analysis 2.0 software.

3. Results and discussion

The surface was analyzed before scratching probe process using AFM (Fig. 2a) and it was shown that surface roughness was 0.97±0.61 nm (Fig. 2b). This implies that the photoresist film can be used for scratching probe nanolithography.

It is important that the height (Fig. 1b) of the formed nanostructures on the photoresist surface must be equal to photoresist thickness. Therefore, after formation of the profiled nanostructures on the photoresist surface the AFM images were obtained to examine the nanostructure height (Fig. 3a). It is shown that structures height 20±2 nm (Fig. 3b) is equal to the thickness of the photoresist film.

After scratching probe nanolithography, plasma chemical etching and photoresist removing, AFM images of nanostructures on Si surface were obtained to examine their heights and diameters (Fig. 4).

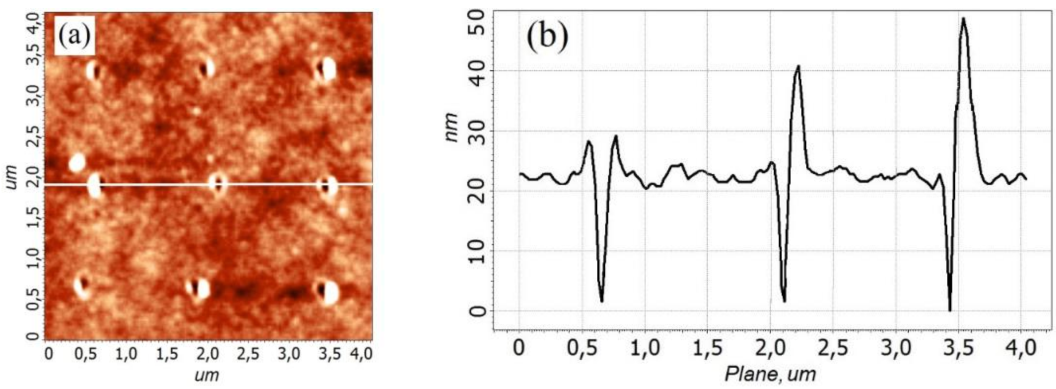

Figure 3. Profiled nanostructures formed on photoresist surface using scratching probe nanolithography: (a) AFM image; (b) profile along white line on (a).

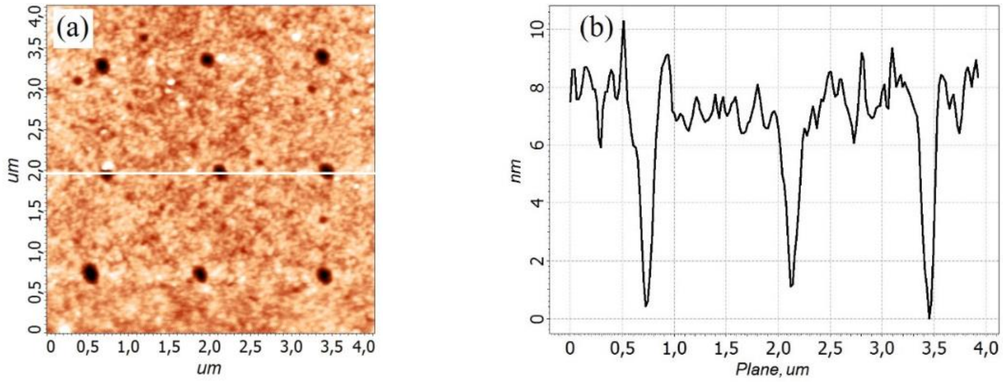

Figure 4. Profiled nanoscale structures on Si surface after plasma-chemical etching and photoresist removing: (a) AFM image; (b) profile along white line on (a).

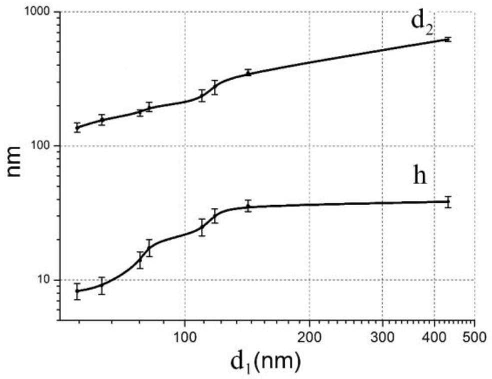

Figure 5. Dependence of the diameter d_1 of nanostructures at the photoresist surface on the height h and diameter d_2 of nanostructures at Si surface.

Dependence of the height h of nanostructures and the diameter d_2 on the diameter d_1 were plotted (Fig. 5). It is shown that increase of d_1 from 68±3 to 428±48 nm leads to increase of h from 8±1 to 38±5 nm and increase of the diameter d_2 from 123±17 to 672±48 nm.

4. Conclusion

In summary, we have investigated regimes of profiling of nanostructures using scratching probe nanolithography and plasma chemical etching. It has been shown that the combination of these methods allows profiling the silicon surface with height h from approximately 7.8 to 38 nm and diameter d_2 from 670 to 123 nm. The results can be used in the micro- and nanoelectronics elements manufacturing using probe nanotechnology.

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