AFM investigations of the nanoscale roughness of polymer replicas on glass substrates

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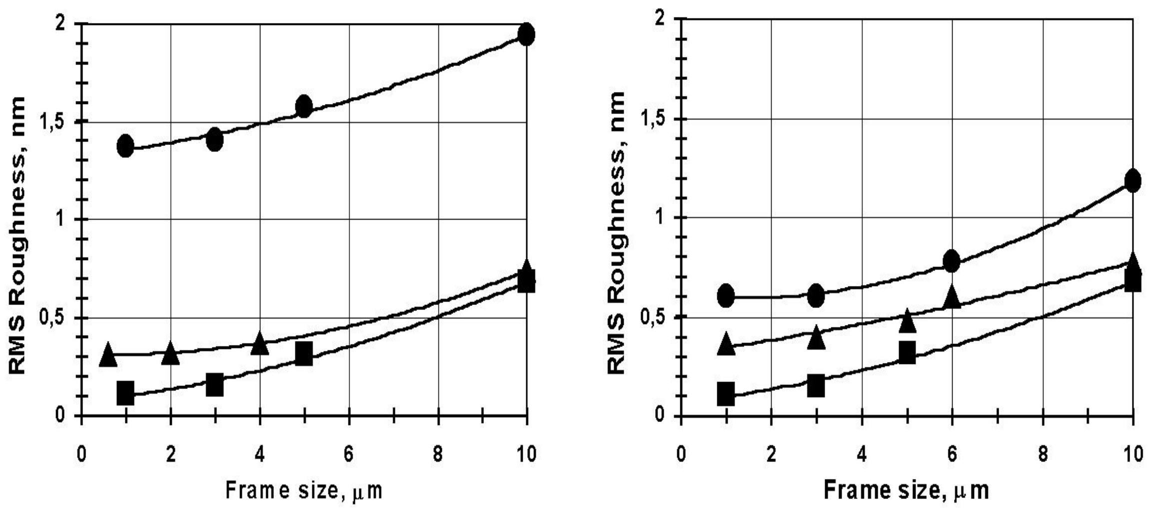
The polymer materials are widely used in replication technologies. Recently different methods such as polymer imprinting, casting, hot embossing, injection molding were successfully used for polymer replication of the different surface structures with nanometer scale elements [1-4]. However, most investigations are connected only with resolution studies and directed at fabrication of sub-micron elements with a high aspect ratio. The quality of a polymer replica surface on sub-nanometer scales was not investigated. The present work is devoted to SPM investigation of the polymer films surfaces on glass substrates to be used in X-ray mirror fabrication.

Thin films on the base of acryl anaerobic adhesives and photopolymer compounds were investigated as possible replicate layers. Deep polished silicon wafers (thickness is 0.5 mm) and zerodur substrates (thickness is 5 mm) were used as the etalon surfaces for the replicas preparation. A possibility of smoothing the roughness of different glass substrates (rms roughness about 1.5 and 0.7 nm measured by x-ray reflection methods) was investigated.

The polymer replicas were prepared in the following way. Thin layers of liquid prepolymer were spread evenly on a glass substrate surface. Afterwards, etalon plates and the glass substrate were pressed together. Liquid polymer remaining on the edges of samples was removed to protecting of the replica surface. The polymerization process was carried out in the absence of air or under light illumination in free state without any external pressure. As a result, thin polymer layers of near 5 μm thickness were formed between the two surfaces. Etalon plates were separated from polymer layer by flexural deformation for silicon plates and under thermoelastic stress in the etalon sample – glass substrate system for zerodur substrates.

A scanning atomic force microscope “Solver P-47” designed by NT-MDT company (Zelenograd, Russia) was used for the surface roughness investigation. A set of frames of the same sizes was taken from different areas of the sample surface. The root-mean-square roughness σ was calculated as the average value for the set of AFM frames of certain scales. Our AFM measurements and other authors’ investigations showed that practically all surfaces have a multiscale relief structure. The main component of this structure is the low scale (Gauss) roughness. But there are a lot of various large-scale features increasing the root-mean-square roughness in the large AFM frames. Thus, as a result of AFM measurements we formed the scale dependences of the σ value on the frame size, which characterized surface roughness at different scales.

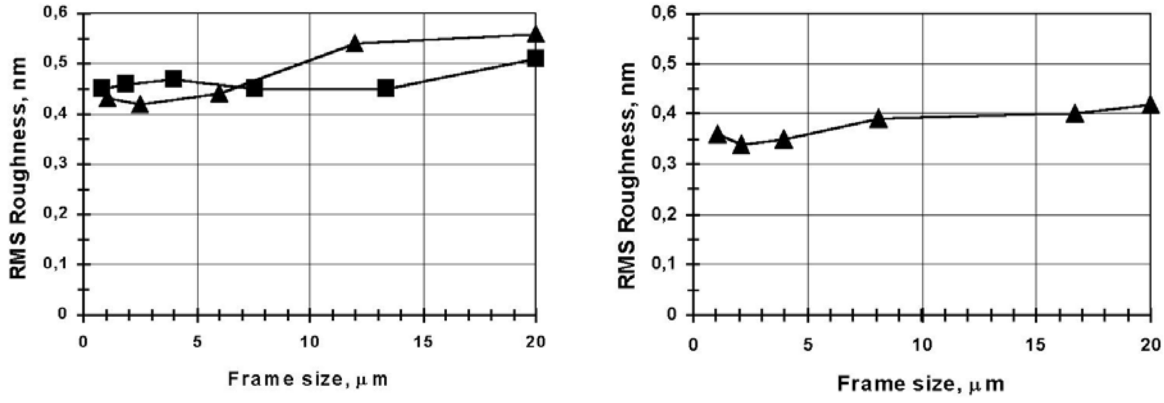
Polymer smoothing of glass substrates of two types with thicknesses 3 and 4 mm and with different values of surface roughness were investigated in our experiments. The results of comparative AFM surface roughness measurements for silicon, glass and polymer film are shown in Fig. 1. The 3 mm thick glass substrate had surface roughness in the range 1.3 – 1.9 nm depending on the frame size. As is clearly seen in Fig. 1a, the polymer film surface roughness is less than that of the glass surface. The differences in the roughness for the polymer layer and the silicon surface are only about 0.2 nm on the 1-5 μm^2 square. The AFM measurement results for the polymer replicas on the 4 mm thick glass substrate are shown in Fig.1b. In this case, the glass surface roughness was in the range 0.6-1.2 nm. The differences in the roughness for the polymer layer and the initial silicon surface are about 0.25 nm on the square of 1-5 μm^2. Thus the AFM measurements show that polymer layers replicate the surface of etalon samples quite well.



(a) (b)

Fig.1. The results of polymer smoothing of glass substrates. (a) – AFM measurements results for 3 mm thick glass substrate with high surface roughness. (b) – AFM data for 4 mm tick substrate with low surface roughness. The rms roughness scale dependence of the polymer replicas surface is indicated by triangular points ▲. Two curves (indicated as square points ■ and circle points ●) show the rms roughness scale dependences for silicon and glass substrate surfaces, respectively.

Similar replicate experiments were carried out for zerodur etalon substrates with the x-ray measured surface roughness of about 0.4 nm. The results of AFM measurements for these etalon substrates are shown in Fig. 2a. As seen in Fig 2a, the zerodur and its corresponding polymer replica surface roughness values practically do not depend on the frame sizes and have a good coincidence. Similar results were observed for polymer replicas prepared from highly polished Si substrates. As shown in Fig. 2b, in this case the polymer replica surface roughness is about 0.4 nm and does not practically depend on the frame sizes in the range of 10 μm.



(a) (b)

Fig. 2. The AFM measured rms roughness scale dependences. (a) – The rms roughness scale dependences of the polymer replica surface (indicated by triangular points ▲) and etalon zerodur substrate (indicated as square points ■). (b) - The rms roughness scale dependences of the polymer replica surface prepared from highly polished Si substrate.

The multilayer Mo-Si x-ray mirrors were fabricated on combined glass-polymer substrates by vacuum magnetron deposition. For comparison, similar mirrors were fabricated on etalon Si substrates in the same experimental conditions. The x-ray angle and spectrum dependences of either mirror were measured by reflectometer designed in IPM RAS on the base of RSM-500 spectrometer. It was shown that the half- width and peak values of the reflectivity spectral dependences for mirrors on the combined glass-polymer substrates practically coincided with the same values for mirrors on the Si substrates.

In conclusion, the AFM investigations of the polymer replicas surface showed that the acryl composites layers successfully replicated the supersmooth etalon samples surfaces. As was shown in direct x-ray measurements, the mirrors grown on the combined polymer-glass substrates have practically the same characteristics as the mirrors on etalon Si wafers. So, combined polymer-glass substrates can be used as low-cost substrates for x-ray mirrors production.

The authors are thankful to A.V.Birjukov, S.A.Treskov, L.A.Suslov, M.V.Zuev and N.A.Korotkova for assistance in this work. This work was supported by the Russian Foundation for Basic Research (grant № 00-02-16444).

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