# High-accuracy measurements of sputtering and swelling of implanted layer with atomic force microscope

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Silicon dioxide is a very important material for practical applications. It is used for masking a silicon wafer during ion modification of its undersurface layer. Therefore it is necessary to correctly control parameters of silicon dioxide. Atomic force microscope (AFM) allows one to obtain the three-dimensional surface image of a nonconductive sample with angstrom scale resolution. We have developed the AFM methods for observation of the $SiO_2$ sputtering and swelling after implantation by different ions.

Two basic processes can influence the geometrical sizes of a sample during implantation. Firstly, the implantation ions sputter the atoms of target from the surface layer. Secondly, these ions create defects and, as a result, change the target density and the sample surface layer swells. At large doses of radiation, the quantity of the defects formed in a sample becomes constant because a part of defects begins to recombine with each other. It is possible to assume that the change of the sample geometrical sizes depends on the speed of target sputtering and on speeds of creation and recombination of defects. Thus, the study of the change of the sample geometrical sizes depending on the ion nature enables one to find the sputtering ratio and the defect recombination coefficient for different combinations ion - target.

In this work we used $SiO_2$ films with thickness from 340 to 380 nm formed on crystalline Si substrate as initial samples. Such $SiO_2$-Si samples were masked by the special photoresist film before implantation. The periodic stripe structure consisting of holes 2.3 μm wide and 500 μm long were formed with photolithography techniques in this film. This mask was used in order to protect certain areas of $SiO_2$, when others were implanted through the windows in the photoresist film. $Fe^+$, $Ar^+$, $C^+$ and $O^+$ ions with energy of 25 and 40 KeV and doses from $10^{14}$ to $10^{17}$ ion/cm$^2$ were used to form the periodic radiation-damaged regions in $SiO_2$. After implantation the photoresist film was removed by dissolution in NaOH. On the basis of different width of masked and nonmasked areas it is easy to distinguish the implanted and nonimplanted regions.

The measurements were carried out with a Solver-P4-18RM scanning probe microscope made by Russian firm NT-MDT. The microscope functioned in contact and noncontact mode in air. The typical AFM images of $SiO_2$ after implantation of ions are shown in Fig.1. On the basis of AFM image of such samples the change of geometrical parameters after implantation can be measured with large accuracy. Due to the AFM image being three-dimensional, it is possible to determine the difference of heights in implanted and nonimplanted areas with very high accuracy and averaged on the whole image [1]. The data obtained for various ions are shown in Table 1. The precision of such measurements was about 0.5 nm.

With the help of the program DYNA [2], modified by us, we have tried to estimate the defect recombination coefficient depending on the dose and energy of radiation for oxygen ions. We have assumed that the sputtering ratio should not strongly depend on the radiation dose and have simulated implantation the process with DYNA. Unfortunately we could not correctly estimate the change of the target density during irradiation and consequently could obtain only qualitative coincidence between the computer simulated and experimental results.

[1] Bukharaev A.A., Nurgazizov N.I., Mozhanova A.A., Ovchinnikov D.V., Russian Microelectronics 28 (1999) 330.

[2] Konoplev V.M., Radiat. Eff. Lett. 87 (1986) 207.