*Phys. Low-Dim. Struct.*, **3/4**(*2001*)*pp.97–102*

# AFM Investigation of Radiation Damage Distribution in Implanted Silicon Oxide

N.I.Nurgazizov, A.A.Bukharaev, A.V.Sugonyako, and V.A.Zhykharev

*Kazan Physical Technical Institute of RAS*
*10/7 Sibirsky tract, Kazan 420029, Russia*

(*Received 26 February 2001, accepted for publication 1 March 2001*)

Wet etching of the local implanted silicon dioxide layer on silicon substrate was studied *in-situ* by atomic force microscopy (AFM). A good agreement between the computer simulated ion distribution and the experimental depth profile of the enhancement ratio of the etching rate shows that this AFM method of investigation of implanted samples allows to correctly estimate the thickness of implanted surface layer.

## 1. Introduction

Silicon dioxide $SiO_2$ is a very important material for practical application and ion implantation is widely used for modification of its undersurface layer. The etching rate of $SiO_2$ is known to be enhanced by ion implantation [1]. This effect can be connected with radiation defects induced by ion bombardment in the implanted layer.

The atomic force microscope (AFM) allows ones to obtain the three-dimensional surface image with nanometer-scale resolution in liquid. We have developed the AFM methods for *in-situ* observation of the $SiO_2$ etching in the HF aqueous solution. This allows us to study $SiO_2$ wet etching kinetics, to measure the absolute etching rate for implanted $(R_i)$ and non-implanted $(R_0)$ $SiO_2$ surface layer and to determine the depth profile of the etching rate [2].

This work is devoted to the AFM investigation of the radiation-induced dissolution and comparison of the experimental depth profiles of the etching rate with computer simulated depth profiles of radiation defects induced by ion bombardment in $SiO_2$.

## 2. Experimental

The $SiO_2$ films with thickness from 340 to 380 nm formed on a crystalline Si substrate were used as initial samples. These $SiO_2$-Si samples were masked by

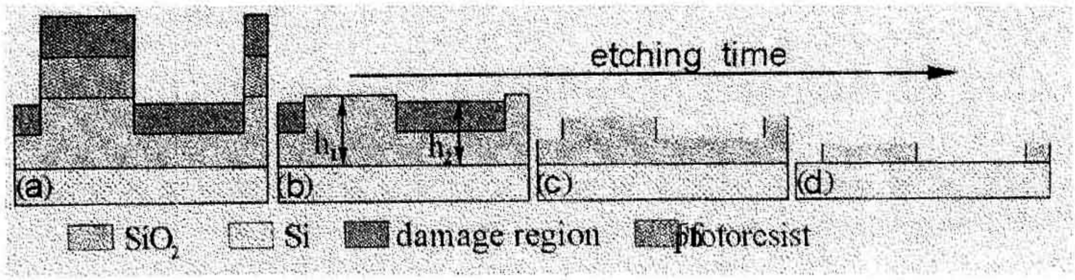

**Figure 1.** Sample scheme: (a) initial state after implantation; (b)–(d) transformation during etching in the AFM liquid cell.

a special photoresist film before implantation. In such a film, a periodic stripe structure consisting of holes with 2.3 $\mu$m width and 500 $\mu$m length was formed with photolithography techniques. This mask was used in order to protect some areas of $SiO_2$ when other areas were implanted through the windows in the photoresist film. $Ar^+$ and $C^+$ ions with the energy of 25 and 40 KeV and doses from $10^{14}$ to $10^{16}$ ion/cm$^2$ were used to form the periodic radiation-damaged regions in $SiO_2$. The cross-section scheme of the initial implanted sample is presented in Fig.1(a). After implantation, the photoresist film was removed by dissolution in NaOH. Figs. 1(b)–(d) show the schemes of the different states of the sample during etching in the AFM liquid cell.

Weak HF aqueous solutions with the volume concentration of HF from 0.25 to 1 % were used for chemical etching. It is essential for our experiments that the Si substrate does not dissolve in such solutions. The measurements were carried out with a Solver-P4-18RM scanning probe microscope made by the Russian firm Nanotechnology-MDT. Description of the home-made liquid cells used in this work and of the respective one-scan method of AFM *in-situ* etching measurements were published in Ref. [2].

Usage of the indicated type of samples allows one to measure the height $\Delta h = h_1 - h_2$ of the step between implanted and non-implanted areas during etching. Figs.1(b)–(d) show the scheme of the sample transformation during liquid chemical etching in the HF aqueous solution. The implanted range is etched faster than non-implanted ranges due to radiation-induced damages and the crystalline Si substrate is not etched in HF at all. It is very important that at the final stage of etching (Fig.1(d)), after chemically removing $SiO_2$ under implanted range completely, we can determine the absolute etching rate of non-implanted $SiO_2$. In this case, $\Delta h = h_1(t)$ was measured as a step height between Si and non-implanted $SiO_2$. This dependence allows us to determine $h_1(t)$ for the complete etching process by extrapolation and to reconstruct the $h_2(t)$ curve

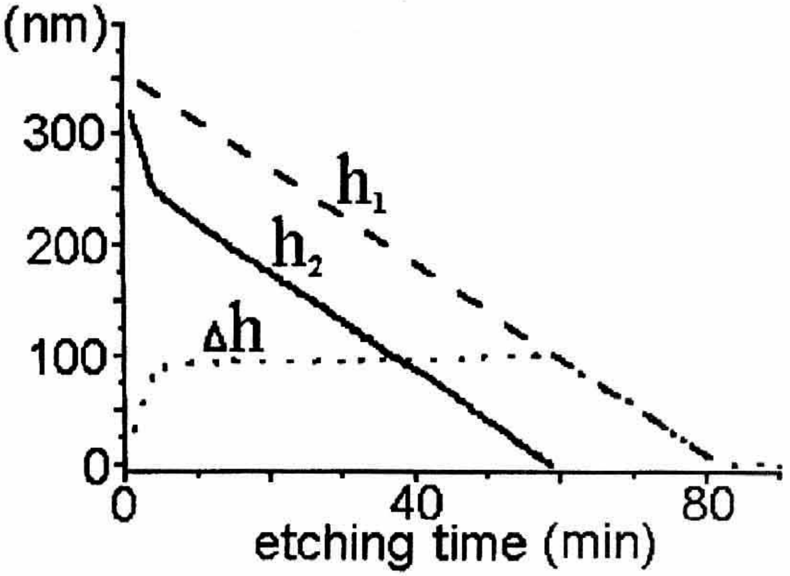

**Figure 2.** Experimental curves reflecting *in-situ* the wet etching process on the surface of periodically implanted $SiO_2$-Si sample.

(Fig.1(d)). Fig.2 shows $h_1(t)$, $h_2(t)$ and $\Delta h(t)$ curves.

## 3. Results and Discussion

Real-time monitoring of wet etching allows us to determine with good accuracy the experimental depth profile of the enhancement ratio of the etching rate $(R_i/R_0)$ on the basis of $\Delta h(t)$ curves. The corresponding experimental curves $(R_i/R_0)$ for 25 and 40 KeV $Ar^+$ implantation are presented in Figs. 3 and 4. According to the known mechanism of the radiation-induced etching, these curves allow one to estimate the depth of the radiation-damaged region induced by ion implantation.

The mechanism of the radiation induced enhanced etching is poorly understood. That is why the experimentally obtained depth profile of the etching rate was compared with the computer-calculated distribution of the penetration profile of embedded Ar ions (Fig. 3) and vacancies formed by $Ar^+$ implantation (Fig. 4). The SRIM and DYNA programs were used for computer calculations [3, 4]. The DYNA program, in addition to the SRIM program, takes into account the change in the element composition of the surface layer during ion implantation. Moreover, the DYNA program allows one to consider the sputtering of the target more correctly.

Rather good agreement between the DYNA-simulated Ar ion distribution

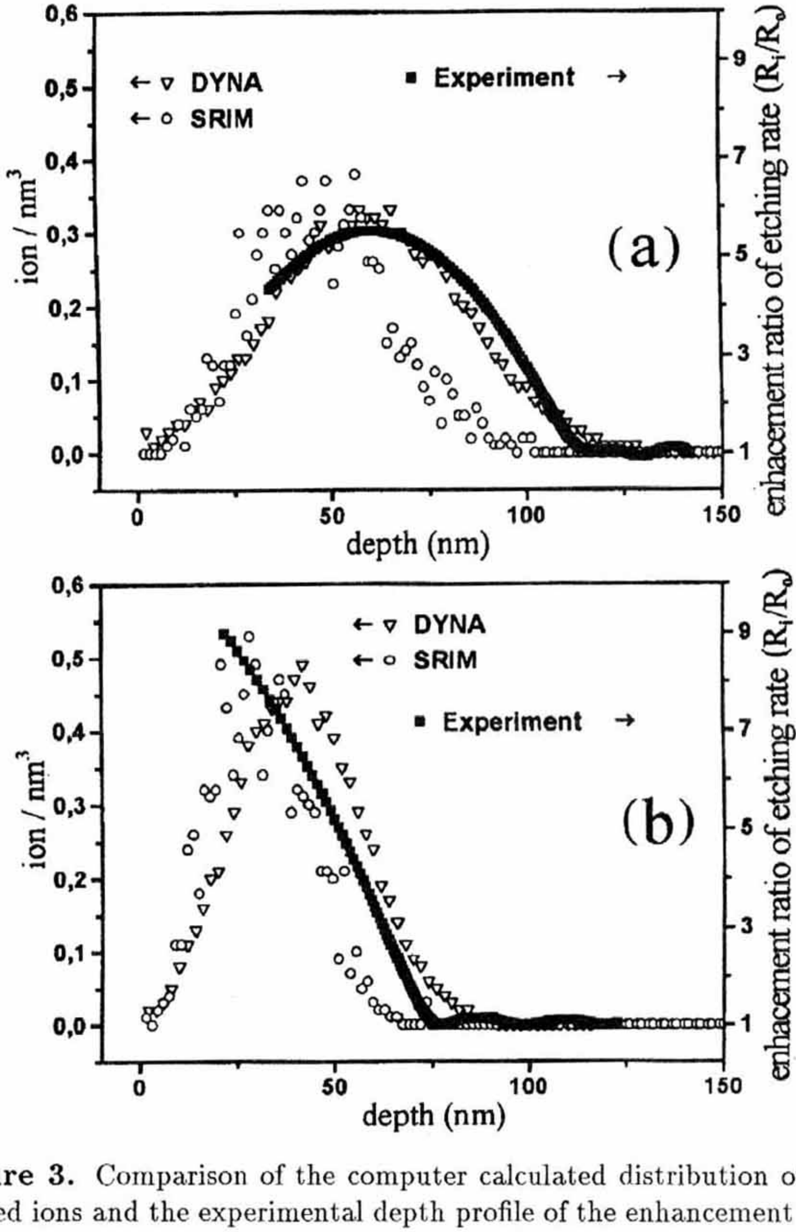

**Figure 3.** Comparison of the computer calculated distribution of embedded ions and the experimental depth profile of the enhancement ratio of the etching rate for $SiO_2$ implanted by $Ar^+$ ions with (a) 40 keV and (b) 25 keV energy.

and experimental etching data shows that this AFM method of investigation of implanted $SiO_2$ allows us to at least correctly estimate the thickness of the implanted surface layer. For example, the depths of the implanted $SiO_2$ layer measured by this method were 75 and 120 nm under implantation with $Ar^+$ ions

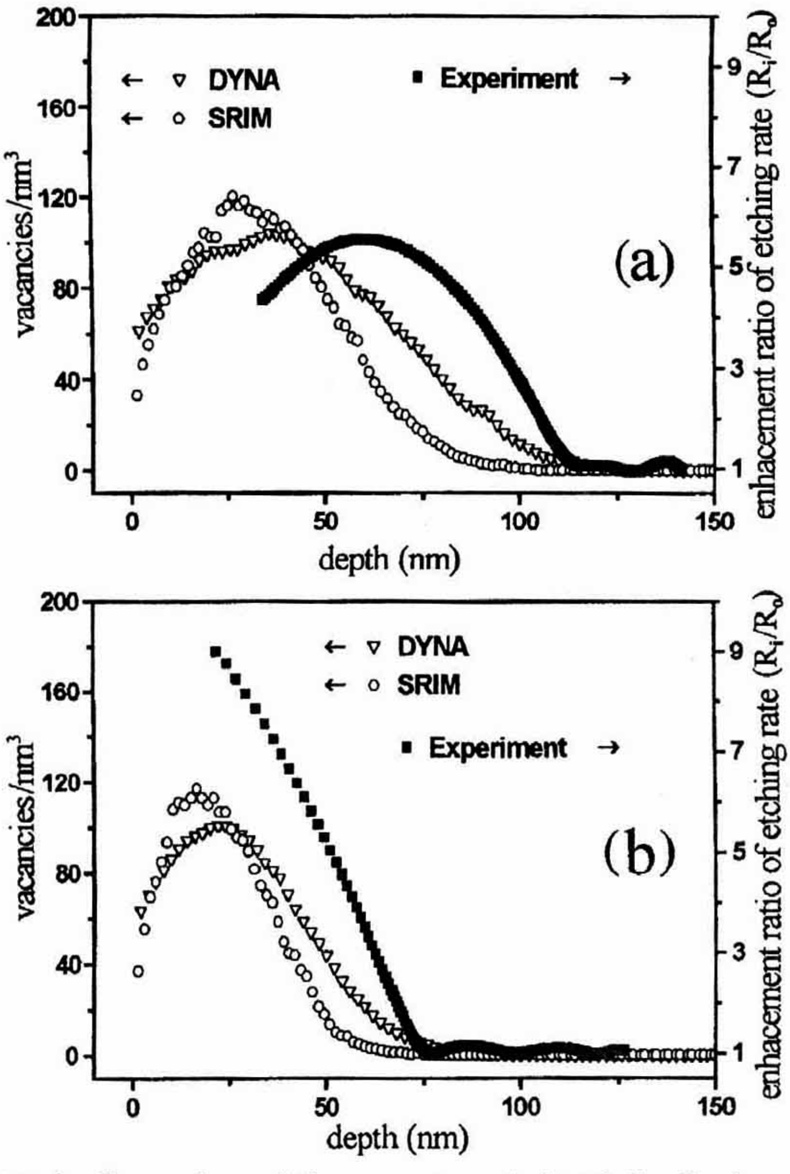

**Figure 4.** Comparison of the computer calculated distribution of vacancies and the experimental depth profile of the enhancement ratio of the etching rate for $SiO_2$ implanted by $Ar^+$ ions with (a) 40 keV and (b) 25 keV energy.

with the energy of 25 and 40 KeV, respectively. Comparison of the experimental and calculated data revealed that it is not evident whether the effect of radiation induced etching is only related to the radiation defects (vacancies) and additional investigations in this direction are necessary to understand the nature of this phenomenon.

## 4. Conclusions

The developed AFM method for *in-situ* investigation of the wet etching of implanted silicon dioxide allows one to estimate the thickness of the implanted surface layer with good accuracy.

## Acknowledgements

This work was supported by the Russian Foundation of Basic Research (Grants 98-03-32753 and 00-15-97410), the Ministry of Industry and Science of the Russian Federation (Grant 02.04.3.1.40.∋.22) and by the NIOKR Foundation of the Tatarstan Republic (Grant 14-01). The authors thank the collaborators of the Radiation Physics Laboratory of the Kazan Physical Technical Institute for the help in the sample implantation.

## References

[1] G.W.Arnold, Radiat. Eff., 65 (1982) 17.

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

[3] J.F.Ziegler, J.P.Biersack and U.Littmark, *The Stopping and Range of Ions in Solids*, Pergamon Press. New York, 1996.

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