Technical Report

Damage distribution in Si surface by 0.5keV Ar^+ ion bombardment.

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The damage distributions in Si(100) surface after 0.5 keV Ar^- ion bombardment were studied using MEIS and Molecular Dynamic simulation. The primary Ar^+ ion beam direction was varied from surface normal to glancing angle. The MEIS results show that the damage thickness in 0.5 keV Ar ion bombardment is reduced from 5.1nm at surface normal incidence to 0.5 nm at the incident angle of 80°. Molecular Dynamics simulation reproduced the damage distribution quantitatively.

1. Introduction

Sputter depth profiling by secondary ion mass spectrometry (SIMS) and Auger electron spectroscopy (AES) have been widely used in semiconductor industries due to its high sensitivity and depth resolution [1]. As the device size scales down to sub nm ranges, the use of low energy primary ions with grazing incident angles has became popular for obtaining the shallow junction depth profiling [2,3]. Recently a low energy primary ion beam has been used in order to minimize the surface damage since the ultimate limit for the depth resolution depends on how damage can be minimized.

Even though low energy ion bombardments have been used frequently for the shallow junction depth profiling, the damage distribution caused by such low energy ions was not measured quantitatively so far because of the difficulties in measuring the damage. However, the damage effect by low energy ion bombardment is crucial in obtaining the ultra shallow junction depth profiling. To minimize both the damage effects and in-depth distribution of the primary ion by low energy ion sputtering is one of key factors to obtain a good depth resolution. The MEIS is an appropriate apparatus for the measurement of damage distribution and in-depth distribution of the primary ion after low energy Ar^+ ion sputtering because it can probe the surface composition and structure almost nondestructively and quantitatively with less than 1.0nm depth resolution [4,5].

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In this work, the damage distribution in Si surface and depth distribution of implanted Ar atoms after 0.5 keV Ar^+ ion bombardments for sputtering has been studied by MEIS and Molecular dynamics (MD) simulation.

2. Experiment

Details of MEIS system at the Korea Research Institute of Standard and Science have been described in detail elsewhere [4]. For the MEIS analyses, 100 keV, 10 nA H^+ ion beams were used and the energy of the scattered H^+ ions were analyzed by a toroidal electrostatic energy analyzer with a two-dimensional position sensitive detector. The base pressure of the MEIS chamber was 5.0×10^{-10} Torr. The operating pressure was 5.0×10^{-9} Torr during the MEIS analyses. Si(100) (1.5-3 Ωcm, p type) samples were rinsed with methanol and mounted in the MEIS analysis chamber without further treatments. The Ar^+ ion incident angle was 0°, 45°, 60° and 80° from surface normal. After enough Ar^+ ion bombardment to reach the steady state of the damage distribution, MEIS spectra were taken in the double alignment condition with the channeling and blocking along the [111] and [00-1]axial direction corresponding to the scattering angles of 125.3° for both of them.

3. Results and discussion

The MEIS spectra taken from a clean Si(100) surface after 0.5 keV Ar^+ ion bombardment with saturation ion dose are shown in Fig. 1. Here the surface peak obtained from clean Si(100) is shown for comparison. As the incidence angle changes from 80° to the surface normal, the peak widths showing the damage depth became wider as shown

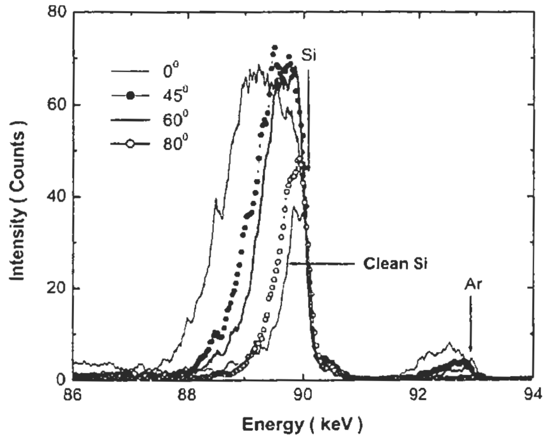

Fig. 1. MEIS spectra measured for the scattering angle of 125.3° after 0.5 keV Ar^+ ion bombardment on Si(100).

in Fig. 1.

It showed that the surface layers become amorphous and the amorphous surface layers get thicker as the incidence angle vary from glancing angle to surface normal. The in-depth concentration distribution of implanted Ar atoms can be seen in Fig. 1 (right hand side peak). The electronic energy loss factor estimated from the experimental condition is about 3.1 nm/1000 eV. Therefore the damage distribution and the in-depth profile of the implanted Ar atoms after ion bombardment can be estimated directly using the electronic energy loss. The damage depth was about 5.1 nm at surface normal incidence, 3.5nm at the incidence angle of 45 °, 2.7nm at the incidence angle of 45 ° and 0.5

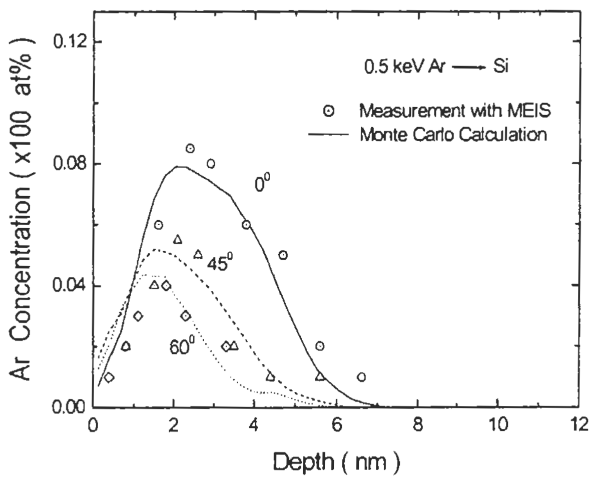

Fig. 2. In-depth composition of the implanted Ar atoms in Si(100) after 0.5 keV Ar^+ ion bombardment on Si(100).

nm at the glancing angle of 80°. It showed that the damage thickness could be drastically reduced to a few layer by using 0.5 keV primary ions at the glancing angle of 80°. The damage thickness is closely related to the in-depth distribution of primary ion beam for sputtering. Fig. 2 shows the concentration distributions of implanted Ar atoms after 0.5 keV Ar^+ ion bombardments, which were obtained from the analysis of MEIS spectra and Mote Carlo simulation [6]. The maximum concentration of implanted Ar atoms is about 8 at % at the depth of about 2 nm for surface normal incidence, but was not detected at the incident angle of 80°. It showed that the primary ion effects for sputter depth profiles can be minimized by using low energy at the incident angle of 80°. Details about the in depth distribution of implanted Ar atoms can be seen elsewhere [6].

In order to understand the damage distribution in Si(100), MD simulation carried out. MD simulation gives us a fairly good picture of how the damage develops by low energy ion sputtering. MD simulations have been carried out using SPUT93 version [7]. The Tersoff potential [8] was employed for the interaction between Si and Si atoms and the Ziegler-Biersak-Littmark (ZBL) potential [9] for the interaction between Ar and Si atoms. MD results are illustrated in Fig. 3 for a 0.5 keV Ar^+ ion bombarded into Si(100) at the incident angle of 0° and 80° from surface normal. The Si(100) substrate has a dimension $15a_0 \times 15a_0 \times 15a_0$ (a_0 is lattice distance). Here the snapshots of atom positions are shown at various instants of time. As can be seen in Fig. 3, the damaged layers are saturated after 1.5 ps elapsed. The damages take place in 3 nm at the incident angle of 0° and in about 0.5 nm at the incident angle of 80°. It clearly showed that the damage depth could be minimized down to 0.5 nm for the incident angle of 80°, which is in quite good agreement with MEIS results. The reduction of the damaged layer by the low energy ion bombardment with the grazing incident angle plays an important role in depth profiling of ultra shallow junction.

4. Conclusion

MEIS analysis allows us to obtain the damage distribution and the in-depth concentration distribution of the implanted Ar atoms in Si(100) surface after 0.5keV Ar^+ ion bombardment for sputter depth profiling. The damage thickness is about 5.1 nm at surface normal incidence and about 0.5 nm at the incident angle of 80°. The maximum atomic concentration of implanted Ar atoms after 0.5 keV ion bombardments is about 8.0 at % at the

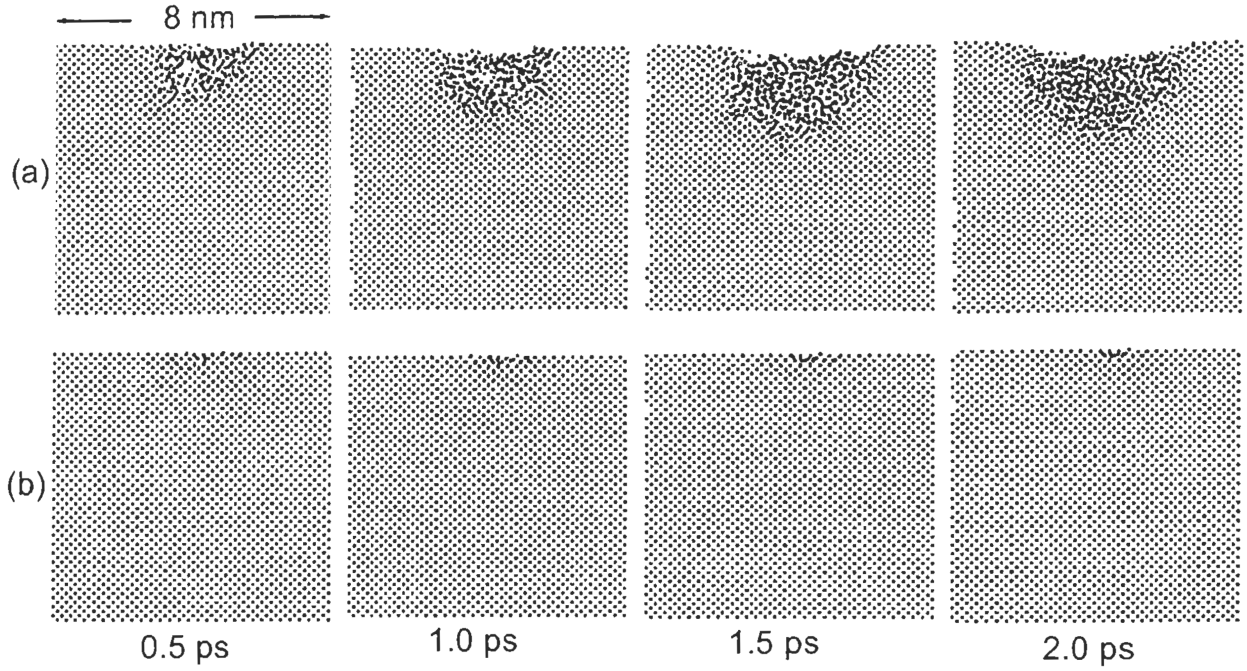

Fig 3. The snapshot of atom positions viewed along the (010) direction, at several instants of time after 0.5 keV Ar^+ ion bombarded into Si(100) substrate. The incident angles were 0^o (a) and 80^o (b) from the surface normal respectively.

depth of 2.0 nm for surface normal incidence and the in-depth Ar distribution cannot be observable at the incident angle of 80^o. Molecular Dynamic simulation reproduced the damage in Si(100) quantitatively.

Acknowledgments

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References

[1] S. Hofmann, J. Vac. Sci. Technol. A**9**, 146 (1991).
[2] Z. X. Jiang , P.F.A Alkemade, Surf. Interface Anal. 27, 125 (1999).
[3] M.G. Dosett, T.J. Ormsby, G.A. Cooke, D.P. Chu, J. Vac. Sci. Technol. B 16, 302 (1998).
[4] J.C. Lee, C.S. Chung, H.J. Kang, Y.P. Kim,H.K. Kim, D.W. Moon, J. Vac. Sci. Technol. A**13**, 1325 (1995).
[5] D. H. Oh, H. J. Kang, K. H. Chae, C. N. Whang, B. V. King, D. J. O'Conor, D. W. Moon, Surf. Sci. 477, L289 (2001).
[6] D. W. Oh, S. K. Oh, H. J. Kang, H. I. Lee, D. W. Moon, Nucl. Instr. and Meth. B 190, 598 (2002).
[7] N. Winograd and B. J. Garrison, "Ion Spectroscopies for Surface Analysis" Eds, A.W. Czanderna and David M. Hercules(Plenum Press, NY, 1991) P. 45.
[8] J. Tersoff, Phys. Rev. B38, 9902 (1988).
[9] J. F. Ziegler, J. P. Biersack, U. Littmark, in The Stopping and Ranges of Ion in Solid, (Pergamon, New York, 1985).