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The transient sputtering yield change of an amorphous Si layer by low energy O_2^+ and Ar^+ ion bombardment

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Abstract

The sputtering yield change of an amorphous Si layer on Si(100) was measured quantitatively for 0.5 keV O_2^+ and Ar^+ ion bombardment with in suit MEIS. In the case of 0.5 keV O_2^+ ion bombardment, at the initial stage of sputtering before surface oxidation, the sputtering yield of Si was 1.4 (Si atoms/O_2^+) and then decreased down to 0.06 at the ion dose of 3×10^{16} O_2^+/cm^2. In the case of 0.5 keV Ar^+ ion bombardment, the sputtering yield of Si for the surface normal incidence was 0.56 at the ion dose of 2.5×10^{15} Ar^+/cm^2, and rapidly saturated to 1.2 at dose of 7.5×10^{15} Ar^+/cm^2. For the incidence angle of 80° from surface normal, the sputtering yield of Si was saturated to about 1.4 at the initial stage of sputtering. The surface transient effects, caused by change in sputtering yield at the initial stage of sputtering can be negligible when 0.5 keV Ar^+ ion at extremely grazing angle was used for sputter depth profiling.

Keywords : depth profiling, sputtering, transient effect

1. Introduction

With the rapid scale reduction of semiconductor devices, nm scale characterization of ultra thin films and dopant distribution becomes more critical. 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]. However, the depth resolution of conventional SIMS and AES using keV ion beam sputtering is not good enough for shallow junctions. Recently a low energy primary ion beam has been used to improve the depth resolution and reduce the surface transient effect. The ultimate limit for the depth resolution depends on how transient width can be minimized during sputtering.

Recently even though low energy ion sputtering have been used frequently for improving depth resolution for shallow junction, the surface transient effects caused by such low energy ion sputtering were not studied so far because of the difficulties in measuring the sputtering yield changes at the initial stage of sputtering. The surface transient effects caused by change of sputtering yield at the initial stage of sputtering should be understood in order to analyze the depth profile of ultra thin films and dopant profile of ultra shallow junction. For the quantitative measurement of the sputtering yield change in the transient region, surface and subsurface analysis tools with much better depth resolution and quantification capabilities are required. MEIS has been successfully used in obtaining the surface composition and structure almost nondestructively and quantitatively with less than 1.0 nm depth resolution [2-4]. In this work, the changes of sputtering yield in amorphous Si layers after 0.5 keV O_2^+ and Ar^+ ion bombardments have been studied by MEIS.

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2. Experiment

For the measurements of the Si sputtering yield, a MEIS analysis system connected with a ultrahigh vacuum chamber for ion beam sputter deposition and etching was used. A clean Si(100) surface was obtained by flashing up to 1150℃ after etching with dilute HF. For sputtering yield measurement, an amorphous layer of 12 nm of Si was grown on a clean Si(100) (1.5-3 Ωcm, p type) by 1.0 keV Ar^+ ion beam sputter deposition using a Si wafer target. For the low energy ion bombardment, 0.5 keV O_2^+ and Ar^+ ion were used. The current density of the ion beam was around 0.5 μAcm^{-2} measured by Faraday cup moved to the sample position. During the ion beam sputtering, the pressure of the etching chamber is around the 3.0×10^{-3} Pa. The MEIS analysis was done with 100 keV H^+ incident along the [111] direction and exiting along the [00-1] direction with the scattering angle of 125°. Details of the MEIS techniques and the system used in this experiment are given elsewhere [3,4].

3. Results and Discussion

For the sputtering yield measurement, the amorphous Si atoms are detected in the double alignment condition in MEIS measurement. In the double alignment analysis condition, only the amorphous Si layers are detected. Therefore using the calibrated MEIS system factor [5], the decrease of the Si peak area can be converted quantitatively into the number of sputtered Si atoms for each incident ion. The Si sputtering yield can be calculated quantitatively from the change of the Si atomic areal density and the ion dose. In order to measure the system calibration factor, Pt(111) surface peak, a 10 nm Ta_2O_5 and SiO_2 on Si(100) were used, and the areal density of Ta_2O_5 was determined with Rutherford backscattering spectroscopy and the thickness of SiO_2 with TEM.

Figure 1 shows the change of the MEIS energy spectra of the 15 nm(a) and 9 nm(b) amorphous Si layers on Si(100) with 0.5 keV Ar^+ ion bombardment for the surface normal incidence and incident angle of 80°. The Si peak width decreases with increasing the Ar^+ ion dose. It means that the total number of Si atoms in the amorphous Si layer decreased with Ar^+ ion bombardment. The Si sputtering yield can be calculated quantitatively from the change of the Si atomic areal density as function of ion dose. At ion dose of 2.5×10^{15} ions/cm^2, the sputtering yield was 0.56 atoms/ Ar ion, but it rapidly saturated to 1.2 atoms/Ar ion over ion dose of 2.5×10^{15} ions cm^{-2}. In the previous paper [6], we reported that in the case of 0.5 keV O_2^+ ion bombardment for the surface normal incidence, the sputtering yield drastically changes from 1.4 Si atoms/ O_2^+ at the initial stage of sputtering where the surface stage is still Si state, to 0.06 Si atoms/ O_2^+ in SiO_2 state at the steady state ion dose of around 3.0×10^{16} ions/cm^2. Before the Si sputtering yield reached the steady state value, the total number of Si atoms sputtered is 7.7×10^{15} Si atoms/ cm^{-2}, which corresponds to a 1.5 nm Si layer. This result shows that the depth scale in shallow junction SIMS profiling in the depth range of 10~30 nm is seriously distorted and can be corrected with the quantitative measurement of the sputtering yield change in the pre-equilibrium region.

As can be seen in Fig. 1(a), the ion beam mixing caused by implanted Ar atoms up to 3 nm is inevitable, which is not negligible in shallow junction profiling. For accurate shallow junction profiling, further reduction of the sputter damage with glancing incidence is required. Figure 1(b) shows the change of the MEIS energy spectra of the 9 nm amorphous Si layers on Si(100) with 0.5 keV Ar^+ ion bombardment for incident angle of 80° from surface normal incidence. There is no implanted Ar atom peak in MEIS spectrum compared with Fig. 2(a). It showed that the ion beam mixing effect can be negligible in sputter depth profiling.

The sputtering yield was 1.4 atoms/ Ar and saturated at the initial stage of sputtering because the ion beam mixing effect caused by implanted Ar atoms can be

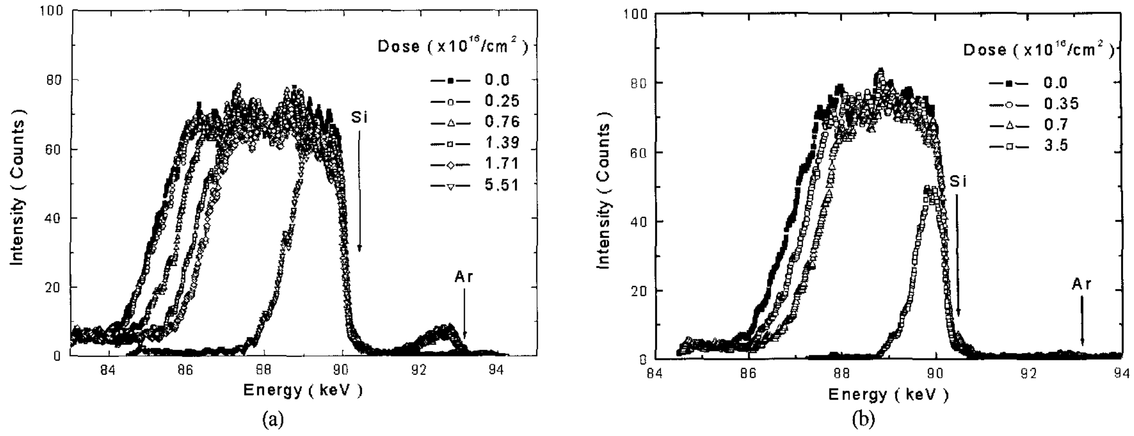

Fig. 1. MEIS spectra for an amorphous Si layer grown on Si(100) after Ar$^+$ ion bombardment at surface normal incidence (a) and grazing angle of 80o form surface normal (b). The original thickness of the amorphous layer was 12 nm (a) and 9 nm (b).

neglected. The transient Si sputtering yield changes can be negligible when 0.5 keV Ar$^+$ ion bombardment with grazing angle of 80° from surface normal incidence was used

4. Conclusions

The changes in sputtering yield on an amorphous Si layers after 0.5 keV O_2^+ and Ar$^+$ ion bombardments have been studied by MEIS. In the case of 0.5 keV O_2^+ ion bombardment, the sputtering yield of Si was 1.4 (Si atoms / O_2^+) at the initial stage of sputtering before surface oxidation, and then decreased down to 0.06 at the ion dose of 3×10^{16} O_2^+/cm^2. In the case of 0.5 keV Ar$^+$ ion bombardment, the sputtering yield of Si for the surface normal incidence was 0.56 at the ion dose of 2.5×10^{15} Ar$^+$/cm^2, and rapidly saturated to 1.2 at dose of 7.5×10^{15} Ar$^+$/cm^2. For the incidence angle of 80° from surface normal, the sputtering yield of Si was saturated to about 1.4 at the initial stage of sputtering. The transient Si sputtering yield changes can be negligible when 0.5 keV Ar$^+$ ion bombardment with glancing angle of 80° from surface normal incidence was used because the ion beam mixing effect caused by implanted Ar atoms can be neglected.

Acknowledgments

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