Studies of the reactivity of water and atomic hydrogen on Si surfaces prepared by the UHV and wet process

The surface condition of single crystal Si prepared in an ultrahigh vacuum (UHV) has been investigated after the surface processes with several analyzing devices. With a non-contact atomic force microscopies (nc-AFM), a scanning auger microscopy (AES) and a measurement of surface wettability we argued the Si surfaces from the view of physics and chemistry. Particularly, Si surfaces under the process of fabricating devices were focused, aiming at the discussion of the standard way of the surface cleaning and the evaluation method of the clean Si surfaces to advance fine semiconductor devices.

With the AES measurements, three types of surfaces prepared in UHV, which was the clean, the H- terminated and the oxidized surfaces, were analyzed just after cleaning in UHV, after placed into nitrogen gas atmosphere and after dropping pure water. At the same time the wettability of Si surfaces were argued by measuring water contact angles (WCA) measurement. As a result, peaks of C and O were detected after dropping water. From the intensity of them, the H-terminated surfaces were the most chemically stable. Besides, the H-terminated surfaces were the most hydrophobic, but the clean and the oxidized surfaces showed the super hydrohilicity, regarded as the density of silanol groups on surfaces. Then, we tried to measure the WCAs on super hydrophilic surfaces by calculating the intervals of the interference fringes appeared along the edge of water.

For the Si surfaces prepared the standard of preparing semiconductor surfaces were discussed by chasing the surface condition and change under the device processing environment. Moreover, with the originally improved nc-AFM which was controllable in the gas condition, the fine structural of the Si surfaces after dropping water and the structural changes before and after irradiating atomic hydrogen (H) were observed. H irradiation on Si surfaces were examined in high H_2 gas pressure, and after that in-situ observations of the changes of a fine structure were challenged.

Si surfaces terminated with H or silanol groups were not contaminated, even though water were dropped. On the other hands, it was revealed that the contamination and the oxidation intensively proceeded because of an existence of active dangling bonds on clean surfaces. And, as to effects of the atomic H irradiation, it was observed that the difference of the etching process and rate between Si (001) and (111) surfaces. After the atomic H irradiation, it was observed that many etch pits were formed and they became deeper and larger on Si (001) surfaces. On the other hand, there was no etch pits formation on Si (111) surfaces, and surfaces became flatter by the atomic H irradiation. In addition, it was revealed that the etching rate was changed by the H_2 gas condition and the temperature of Si substrate.

As for the report of the observation of the Si surface and the adsorption and reaction of atomic H, almost all experiments had been carried out under the UHV until now.

However, I realized observation in environment near the surface treatment stage of the real semiconductor manufacturing process by this study and was able to analyze nano scale observation of the Si surface structure there and the process of the surface reaction. It is in this way thought that a clue to apply a soft Si etching effect of H to semiconductor minute processing was provided.

Keywords: silicon surface, nc-AFM, wettability, atomic hydrogen