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Atomic Order Flattening of Hydrogen-Terminated Si(110) substrate For Next Generation ULSI Devices

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1. Introduction

Recently, there is a possibility to increase current drive capability of MOSFETs by changing the silicon surface. Especially, Si(110) is reported as compared with the conventional Si(100) that hole mobility improves 2.4 times[1]. This is not only effective to the area reduction in a CMOS circuit, but the application to RF analog circuits using highly efficient pMOS is also expected[2]. On the other hand, interface roughness of the silicon surface and a gate insulation films affect the carrier mobility of the MOSFETs. Carrier mobility lowering and degradation of electrical breakdown or TDDB characteristics by the increase in the interface roughness are also known [3][4]. Moreover, the influence of roughness is so large when a gate insulator film becomes thinner. It is always important to realize an atomic order flatten surface, when any silicon surface are employed. Although flattening on the Si surface has much reports about Si(100) and Si(111), there are few reports about Si(110). We tried atomic flattening and hydrogen-terminate of (110)Si using the radical oxidation and the wet chemical processing.

2. Experiment

Degreasing and RCA cleaning was carried out to Cz –just(110) n-type-Si wafers (8-12 Ω cm), and various treatments of flattening were performed. AFM and FTIR-ATR are employed for evaluations of the surface micro-roughness and the hydrogen-terminate, respectively. Furthermore, the atomic order flattening and the hydrogen-terminate evaluation were measured by STM.

3. Result and Discussion

Surface morphology of the Si(110) surface after RCA cleaning is shown in Fig.1. In addition to micro-roughness, the lines like trough to the <110> directions are obtained. Trough lines are generated by the anisotropic etching on the Si surface by OH^- ions at the time of SC1 processing of RCA cleaning, and it suggests that lines are sequence of (111) micro-facets. In order to obtain the surface flatness in atomic level, it is necessary to reduce micro-roughness and trough lines.

At first in order to reduce micro-roughness, the Si(110) surface after RCA cleaning was treated by radical, wet(1000 ℃) and dry(1000 ℃) oxidations. The AFM pictures after removing the silicon oxide film is shown in Fig.2. The radical oxidation was carried on condition that the following. The silicon oxide thickness is 5nm. The microwave excited high density plasma oxidation system utilize low ion bombardment energy of less than 7eV as well low electron temperature below 1.0eV[5]. In addition, HF/HCl=1/19 solution was used for silicon oxide removing in order to prevent Si surface etching by OH^- ions. In dry oxidation, the micro-roughness increase. To the contrary, the radical and the wet oxidation have an effect in roughness reduction. Furthermore, by the radical oxidation, the micro-roughness disappeared remarkably.

Next, reduction of trough lines was tried. 5steps cleaning process was considered in order to lower OH^- ion concentration. 5steps cleaning is characterized by to perform all processes at room temperature and not using alkali treatment. It was already checked that the cleaning performance against metals, organic materials and particles of 5steps cleaning is as well as or better than that of RCA cleaning [6]. The process comparison with RCA cleaning is shown in Table I. Hydrogen addition UPW (H_2-UPW) used for further reduction of OH^- ions. The AFM picture after 5steps cleaning is shown in Fig.3. It turns out that lines have disappeared completely. Furthermore, the effect of using H_2-UPW is described. In the last step of 5steps cleaning, surface roughness at the time of using the UPW is shown in Fig.4 instead of the H_2-UPW. It become clear that surface roughness is increasing at using the UPW. The FTIR-ATR results of the H_2-UPW and the UPW treatment to Si surface is shown in Fig. 5. As compared with the case of the UPW, surface hydrogen terminates was strengthened by adding Megasonic to the H_2-UPW. Hydrogen radical was generated and OH*attack was suppressed effectively and it can achieve to reduce the trough lines.

Radical oxidation was performed after 5step cleaning, and the silicon oxide was removed with the HF/HCl. Then, the STM observation result is shown in Fig.6. Although the (111) micro-facet was seen, however large terrace structure by which the terminus was carried out by silicon mono-hydride has been confirmed. The roughness of the depth direction is an equivalent for four atoms in the screen range. From now on, it is due to be adapted for a device in this technology.

3. Conclusions

Flattening and hydrogen-terminate of Si(110) was carried out. In addition to micro-roughness, the trough lines to the <110> direction was observed after RCA cleaning. Radical oxidation was effective in micro-roughness reduction. And the dissolution of trough lines found that it was effective to use 5steps cleaning with H_2-UPW instead of RCA cleaning. From the STM observation result, large terrace structure was seen and the terminus of silicon mono-hydride has been confirmed. These flattened process of Si(110) surface is essential to next generation devices.

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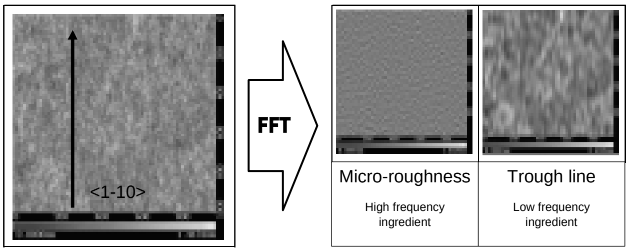

Fig.1 Surface morphologies after RCA cleaning.

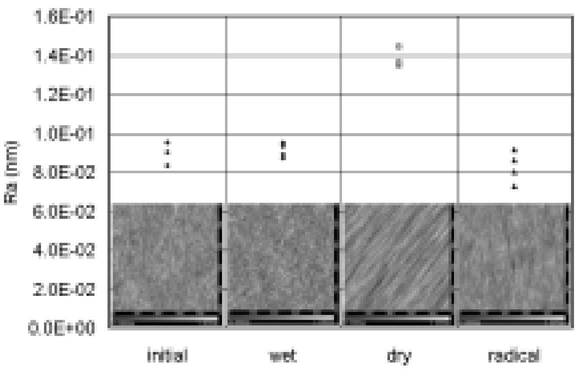

Fig. 2 Si surface roughness after SiO_2 removing.

Table I procedure of RCA and 5steps cleaning

RCA cleaning	5steps cleaning
H_2SO_4/H_2O_2	1st step O_3-UPW
UPW rinse	2nd step FPM(HF/H_2O_2) / surfactant +Megasonic
DHF	3rd step O_3-UPW + Megasonic
UPW rinse	4th step DHF
SC1 $NH_4OH/H_2O_2/H2O$	5th step H_2-UPW + Megasonic
UPW rinse	
Hot-UPW	All processes are carried out at room temperature.
UPW rinse	
DHF	
UPW rinse	
SC2 $HCl/H_2O_2/H2O$	
UPW rinse	
DHF	
UPW rinse	

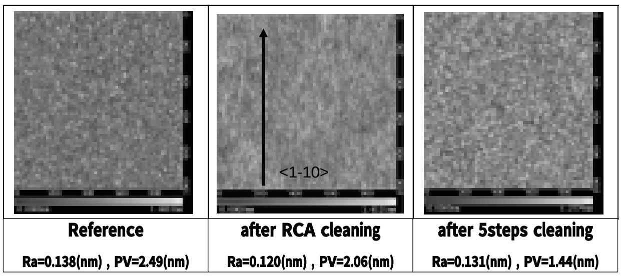

Fig. 3 Dependence of surface morphology on cleaning method.

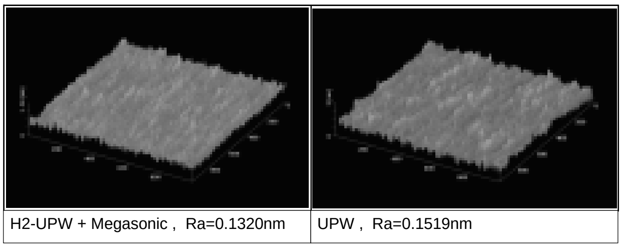

Fig. 4 Dependence of surface morphology on rinse water at 5steps cleaning.

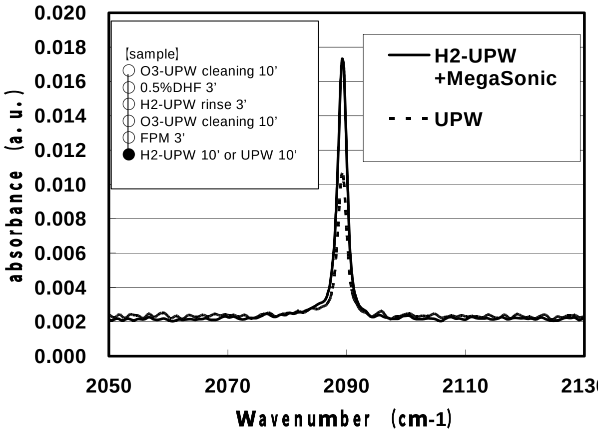

Fig. 5 Dependence of Si-H terminate strength on rinse water at 5steps cleaning.

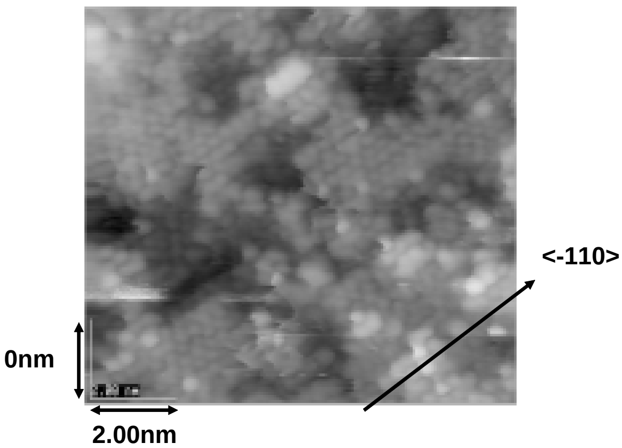

Fig. 6 STM image after H2-UPW +Megasonic treatment and O* oxidation. From the interval of brightness points, it can check that the terminus of the surface is carried out by silicon mono-hydride.