Study of wafer drying techniques for predeposition cleaning of silicon substrate surface

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In the new ultra-large-scale integration (ULSI) era, surface preparation techniques that avoid surface contamination and that generate very clean wafer surfaces have become of critical importance. Surface impurities are especially detrimental if present on substrate surface and the silicon (Si) bare surface is highly reactive and susceptible to impurity adsorption.

We are required to perform rinsing and drying processes right after the HF dipping; they are extremely critical steps because the clean surface can be recontaminated easily if not processed properly [1]. Rinsing in deionized (DI) water removes species that are weakly bound to the surface and can even etch the surface [2]. At the end of the water rinsing, the wafers are dried by blowing nitrogen (N_2) or by spin drying. The spin drying process is a conventionally used method [3], comprising of a 160 s DI water spin-rinse at 1000 revolutions per minute (rpm) and a 240 s spin-dry in N_2 at 2000 rpm. We have introduced a simple blow drying method which blows N_2 gas manually on the wafer with a gun. Although numerous papers have reported on the surface cleaning, there are few reports on the impact of the drying step. In this study, we evaluate and compare the cleaning efficiencies of blow drying and spin drying techniques.

All the processes were performed inside a class 100 cleanroom. The p-type (100) Si substrates with resistivity of 0.5–20 Ω-cm, were RCA cleaned and HF dipped for 20–30 s in 10:1 aqueous solutions and then rinsed in DI water. After drying by blowing N_2 manually or by using a spin dryer, the wafer was loaded into the Load Lock Chamber of the chemical vapor deposition reactor within 10 s. The base pressure of the cleaning and deposition chamber was about 1–2 $\times$ 10^{-8} Torr. The wafers were then heated up to 600 °C or 660 °C in H_2 flow with a pressure of 1 mTorr and a flow rate of 20 sccm. *In-situ* predeposition cleaning was performed by using an electron cyclotron resonance (ECR) H_2 plasma and deposition was achieved by flowing silane (SiH_4).

The evaluation of the drying processes was done by depositing epitaxial films on the substrate surface and then performing material characterizations; cross-sectional transmission electron microscopy (TEM) for observing the epitaxial layer and the epilayer/substrate interface and secondary ion mass spectroscopy (SIMS) for detecting surface carbon and oxygen. We investigated the possible relationship of the surface carbon and oxygen species with the structural quality of the deposited epitaxial layer.

In order to investigate the effect of drying techniques on the surface cleaning efficiency, we have characterized the Si thin films, rinsed in DI water, dried and then *in-situ* cleaned at 600 °C. Fig. 1a shows a TEM image of the Si epilayer and the interface cleaned with spin drying, revealing that the thickness of the interface ranges from 100 to 150 Å and defects are found to be generated from some part of the epilayer/substrate interfaces (not shown here). Fig. 1b shows a typical TEM image of the Si epilayer and the interface cleaned with blow drying, revealing that the epitaxial layer is almost defect free and the thickness of the interface is about 15 Å. Since the thickness of the epilayer/substrate interface is inversely proportional to the degree of crystalline perfection, we have thus revealed that the structural quality of the epilayer/substrate interface cleaned with blow drying is higher than that with spin drying. Fig. 2 shows the interfacial oxygen and carbon concentration based on SIMS data, revealing that the blow dried sample has a lower interfacial oxygen concentration and a higher interfacial carbon concentration than the spin

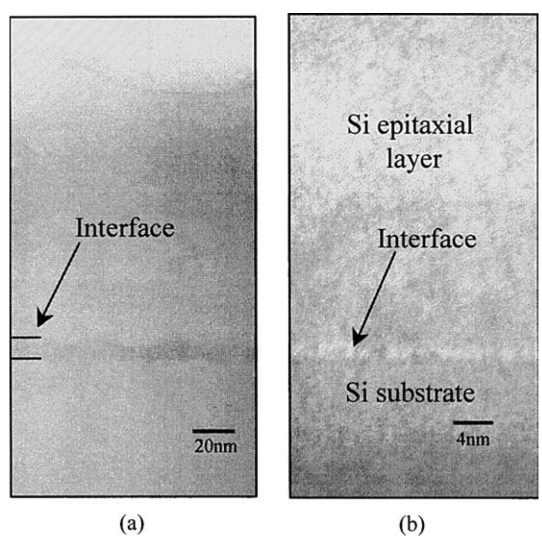

Figure 1 Cross-sectional TEM images of the epilayer/substrate interfaces (a) with spin drying and (b) with blow drying. The wafers were rinsed in DI water and *in-situ* cleaned at 600 °C.

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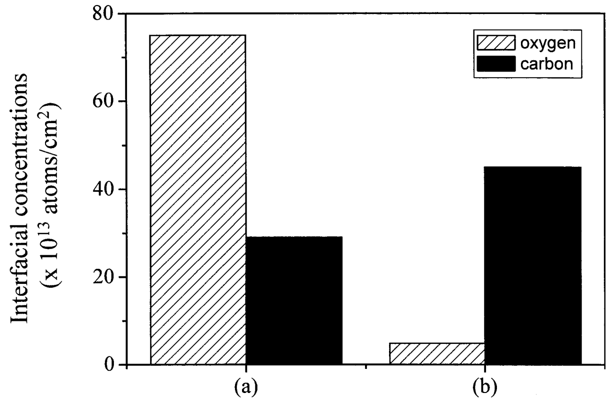

Figure 2 Column bar graph representing the oxygen and carbon concentration of the epilayer/substrate interfaces, based on SIMS data, (a) with spin drying and (b) with blow drying. The wafers were rinsed in DI water and *in-situ* cleaned at 600 °C.

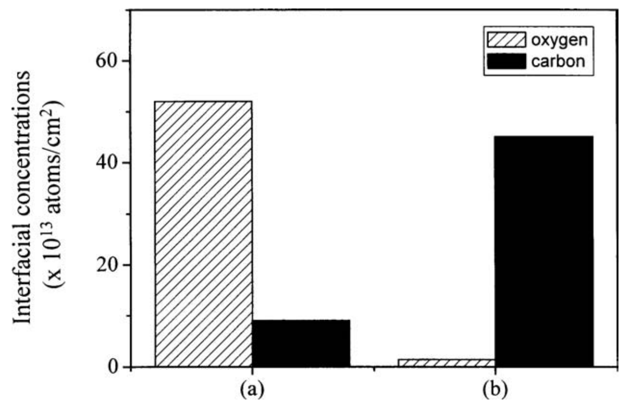

Figure 4 Column bar graph representing the oxygen and carbon concentration of the epilayer/substrate interfaces, based on SIMS data, (a) without and (b) with blow drying. The Si films are deposited at 660 °C without rinsing and an *in-situ* cleaning.

dried sample. Based on the above experiments, we see that the blow drying technique is more efficient than the spin drying technique in removing surface oxygen. Further systematic study is necessary in order to reveal the effects of surface carbon species.

In order to investigate the effect of the blow drying process, we have investigated Si films, deposited at 660 °C, without water rinsing and an *in-situ* cleaning process. Fig. 3a and b show TEM images of the Si epilayer and the interface with and without blow drying, revealing that the thicknesses of the epilayer/substrate interface, respectively, are about 80–90 Å and 10–20 Å. The structural quality of the epilayer/substrate interface is improved by blow drying. Fig. 4 shows the interfacial oxygen and carbon concentration based on SIMS data, revealing that the blow dried sample has a lower interfacial oxygen concentration and a higher interfacial carbon concentration. The SIMS analysis indicates that the interfacial oxygen concentration changes from 5.2×10^{14} atoms cm^{-2} to 1.4×10^{13} atoms cm^{-2} on blow drying. Since there was no *in-situ* cleaning step and thus no ion bombardment and mechanical damage, we surmise that the thicker interface results from the surface oxygen. Further study is necessary to reveal the detailed mechanism for the generation of oxygen-induced defects.

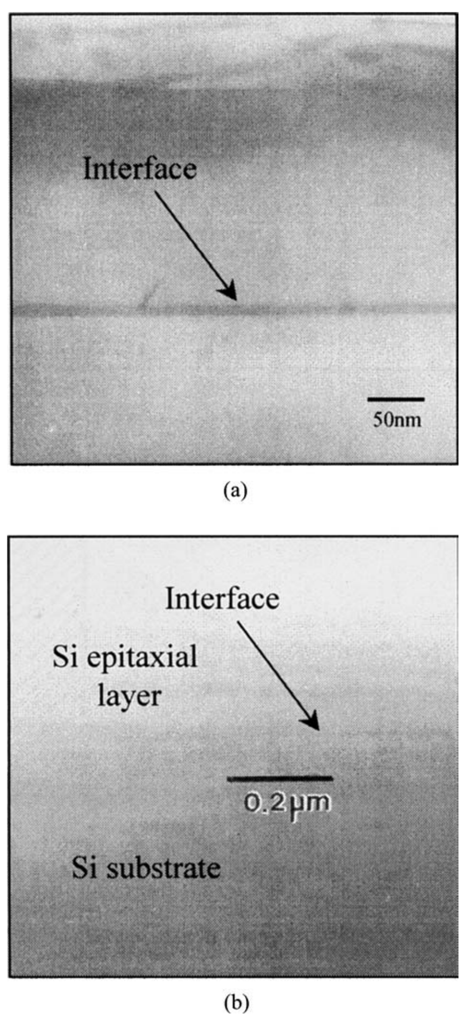

Figure 3 Cross-sectional TEM images of the epilayer/substrate interfaces (a) without and (b) with blow drying. The Si films are deposited at 660 °C without rinsing and an *in-situ* cleaning.

In summary, we have investigated the effect of the drying technique on the structural quality of Si thin films and on the oxygen and carbon concentration of the Si surface. We evaluated the structural quality by observing the grown epilayer and the epilayer/substrate interface. We revealed that the blow drying technique is more effective than the conventional spin drying technique in reducing the oxygen interfacial concentration and is a simple route to improving the structural quality of Si films and interfaces.

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