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Effect of surface carbon and oxygen on the structural quality of silicon homoepitaxial films

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In recent years, surface preparation techniques that avoid surface contamination and generate very clean wafer surfaces have become of critical importance to achieve high-quality epitaxy. Numerous methods such as argon (Ar) ion sputtering [1], Ar/hydrogen (H_2) ion sputtering [2], and H_2 plasma cleaning [3, 4] have been investigated.

Although Ar or Ar/hydrogen plasma sputtering is an effective cleaning technique, the substrate can be damaged during plasma exposure by Ar ion bombardment. H_2 is the lightest element and thus severe substrate damage during ion bombardment will be minimized, so the removal of surface contaminants has become the main issue for efficient surface cleaning using the H_2 plasma cleaning.

Although there are some reports on the effect of substrate defects on the structural properties of subsequently grown films, there are few reports on the effect of surface contaminants on the structural quality of the films. In this paper, cross-sectional transmission electron microscope (TEM) images are used to reveal the structural quality of the Si epitaxial film deposited on the Si substrate which is *in situ* cleaned by electron cyclotron resonance (ECR) hydrogen plasma. The individual effects of the surface oxygen and the surface carbon on the structural quality of the Si epitaxial layer is investigated. In this study carbon and oxygen are taken into account as contaminants, since other contaminants can be suppressed to negligible levels through careful wafer handling and an established cleaning method [5].

Substrates were 10 cm in diameter, czochralski-grown, *p*-type ⟨100⟩ silicon with 0.5–20 Ω-cm resistivity. The wafers were RCA cleaned by immersing in baths of $NH_4OH/H_2O_2/H_2O$ and $HCl/H_2O_2/H_2O$ and then by rinsing in DI (deionized) water [6]. They were HF dipped for 20–30 s in 10:1 aqueous solutions and rinsed in DI (deionized) water and then dried by blowing nitrogen on them. *In situ* predeposition wafer cleaning was performed by using ECR hydrogen plasma. The ECR was operated at the 2.45 GHz S-band microwave frequency. Depositions were done by flowing 10 standard cubic centimeters per minute SiH_4 without carrier gases, immediately after the plasma was extinguished. Cross-sectional transmission electron microscopy (XTEM) (Jeol 200CX) was used to observe the epitaxial layer and the epilayer/substrate interface. Secondary ion mass spectrometry (SIMS) (Perkin Elmer 6600) was used to determine the concentration of the oxygen and carbon. The raw data were transformed to the processed data (atoms/cm^3) and the areal density (atoms/cm^2) of carbon and oxygen by integrating the areas under the interfacial peaks in SIMS depth profiles.

In order to reveal the effect of surface carbon on the crystallinity of the resulting silicon epitaxial layer, samples that have the same interfacial oxygen concentration but different interfacial carbon concentrations were selected. As shown in Table I, samples A and B have the same interfacial oxygen concentration of 1×10^{15} cm^{-2} and interfacial carbon concentrations of samples A and B of about 1.1×10^{14} and 1.5×10^{13} cm^{-2}, respectively. Fig. 1 shows typical XTEM images, revealing that both samples A and B show stacking faults originating from the epilayer/substrate interface. Even when the interfacial carbon concentration is 4.5×10^{14} cm^{-2}, an almost defect-free epitaxial layer is obtained at a reduced interfacial oxygen concentration of 4.8×10^{13} cm^{-2} (not shown here). The crystallinity of the silicon epitaxial layer is not improved by reducing the carbon interfacial concentration.

In order to reveal the effect of surface oxygen on the crystallinity of the resulting silicon epitaxial layer, samples that have the same interfacial carbon concentration but different oxygen concentrations were chosen. As shown in Table I, samples C and D have interfacial carbon concentrations of about 1.4×10^{13} cm^{-2} and the interfacial oxygen concentrations of samples C and D are about 7.8×10^{14} and 1.8×10^{15}, respectively.

TABLE I Summary of interfacial oxygen and carbon concentrations measured by SIMS

	Carbon (cm^{-2})	Oxygen (cm^{-2})
Sample A	1.1×10^{14}	1.0×10^{15}
Sample B	1.5×10^{13}	1.0×10^{15}
Sample C	1.4×10^{13}	7.8×10^{14}
Sample D	1.4×10^{13}	1.8×10^{15}

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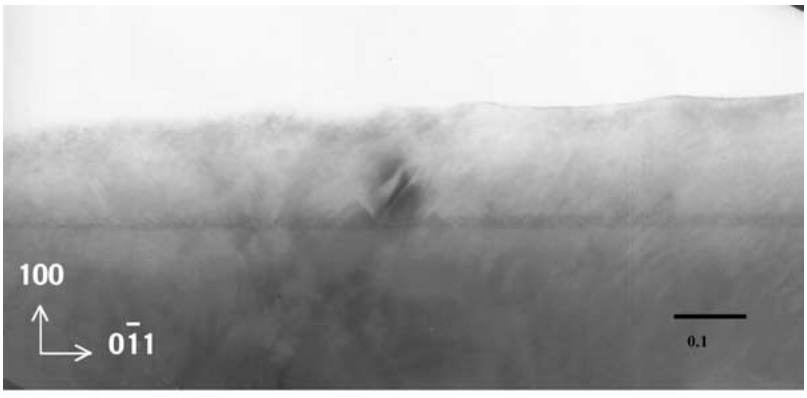
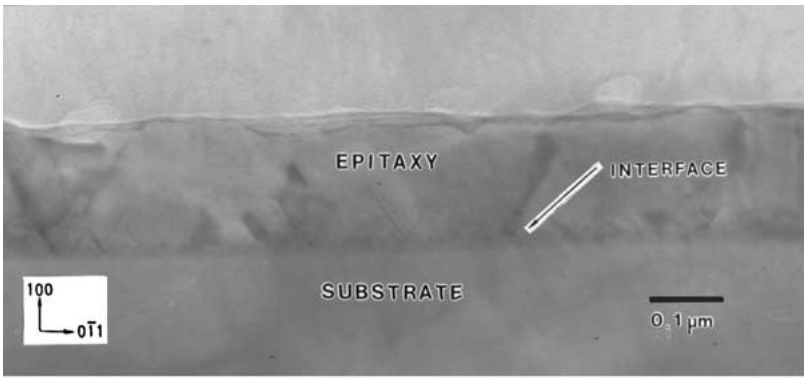


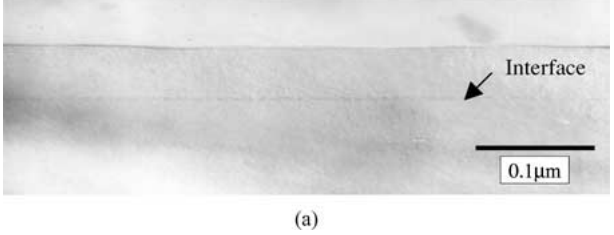
(a)



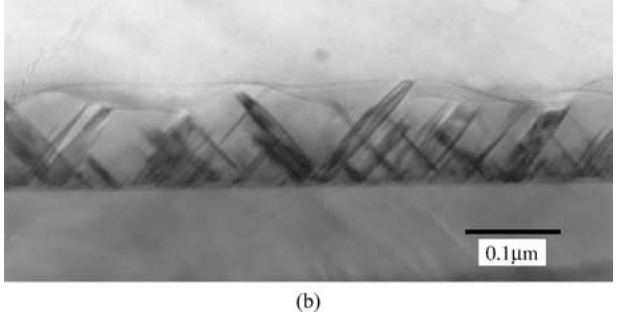
(b)

Figure 1 XTEM image of samples with different interfacial carbon concentrations, revealing that the crystallinity of silicon epitaxial layer is not improved by reducing the carbon interfacial concentration. The interfacial carbon concentrations are (a) 1.1×10^{14} and (b) 1.5×10^{13}, respectively.

Fig. 2 shows typical XTEM images of samples C and D, revealing that the crystallinity of silicon epitaxial layer is degraded by increasing the oxygen interfacial concentration.



(a)



(b)

Figure 2 XTEM image of samples with different interfacial oxygen concentrations, revealing that the crystallinity of silicon epitaxial layer is degraded by increasing the oxygen interfacial concentration. The interfacial oxygen concentrations are (a) 7.8×10^{14} and (b) 1.8×10^{15} cm^{-2}, respectively.

Further systematic study is necessary to reveal the defect generation mechanism related to the role of oxygen and carbon species. In addition, the combined effect of oxygen and carbon needs to be investigated.

In summary, the effect of surface oxygen and carbon species on the structural qualities of the grown silicon epitaxial films when the Si surface is cleaned using ECR H_2 palsma has been investigated. In order to determine the individual effect of oxygen and carbon, the oxygen concentration at fixed carbon concentration was varied and vice versa. The crystallinity of the epitaixal layer does not decrease with increasing interfacial carbon concentration. Defects are generated by increasing the surface oxygen content and the crystallinity of the film decreases with increasing interfacial oxygen concentration.

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