Effect of *in-situ* cleaning temperature on the structural quality of homoepitaxial film on Si substrate

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In order to obtain a high-quality epitaxial layer with low temperature processing, the *in-situ* plasma cleaning method has been developed [1, 2]. For low temperature *in-situ* cleaning, various gases such as argon (Ar) [3], Ar/hydrogen (H_2) [4], and H_2 [5] have been investigated. Since H_2 is the lightest among them and is able to react chemically with surface contaminants, severe substrate damage can be avoided by employing H_2 plasma.

Although we have previously reported on the effect of *in-situ* H_2 cleaning and growth temperature on the silicon (Si) homoepitaxial growth [6], the cleaning and the deposition have been performed at the same temperature. In this paper, in order to study the effect of cleaning temperature only, we deposited the films at 600 °C, while performing the *in-situ* plasma cleaning in the range of 25–600 °C.

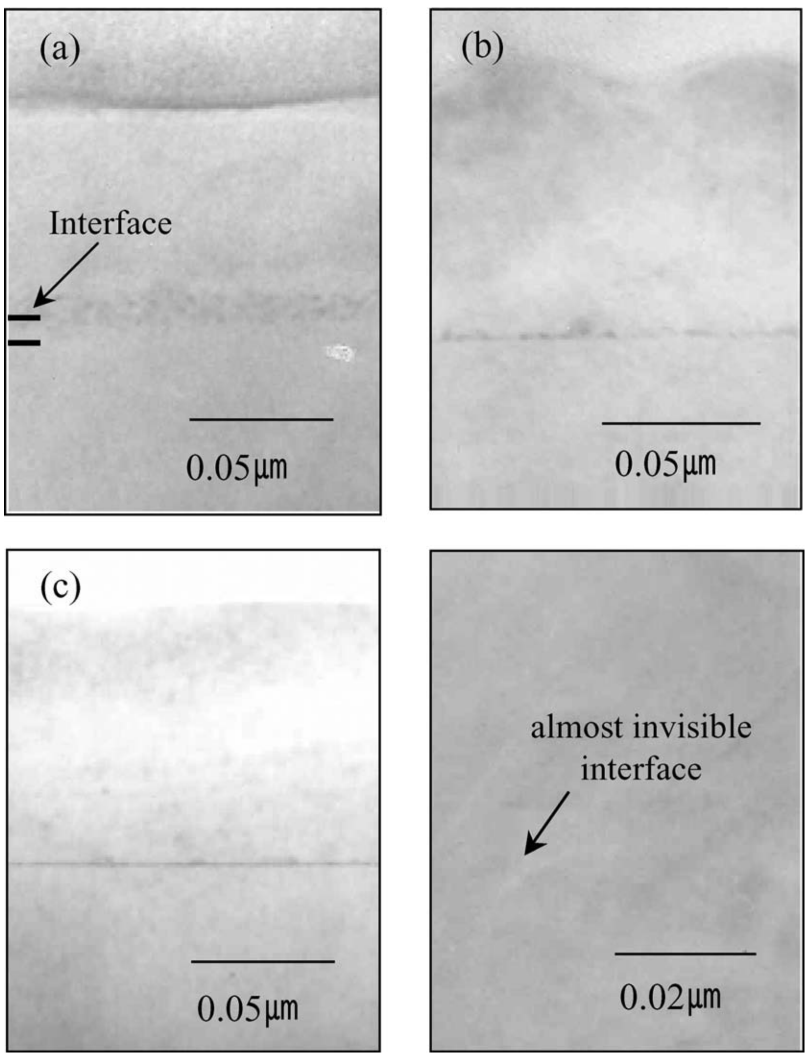

Figure 1 Cross-sectional TEM image of silicon epilayer and the interface, *in-situ* cleaned with a microwave power of 300 W, a DC bias of 10 V, and a pressure of 1 mTorr. *In-situ* cleaning temperature is: (a) 25, (b) 280, (c) 480, and (b) 600 °C. High-quality epitaxial layers are produced regardless of *in-situ* cleaning temperature.

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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 deionized (DI) water. After using a spin-dryer to effect drying, 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.

Since electron cyclotron plasma (ECR) H_2 plasma delivers a higher density of light H_2 ions to the wafer, we performed the *in-situ* predepositon wafer cleaning using ECR H_2 plasma with a 2.45 GHz S-band microwave frequency, expecting highly efficient surface cleaning with minimal substrate damage. With a microwave power of 300 W, a DC bias of 10 V, and a pressure of 1 mTorr, we varied the cleaning temperature in the range of 25–600 °C. Subsequently we deposited the silicon epitaxial layer at 600 °C, by flowing 10 sccm of SiH_4 without carrier gases. When the *in-situ* cleaning was done at 25 °C, for example, it took about 7 min to heat up to the deposition temperature of 600 °C.

In order to evaluate the crystallinity of the deposited films, we measured the ratio of the channeling yield of the films to the random yield (λ_{min}) by Rutherford backscattering spectroscopy. The measurement shows that the λ_{min} of the films *in-situ* cleaned at 25 and 600 °C, respectively, are 5 and 3%. We therefore surmise that epitaxial layers were produced.

Fig. 1 is the cross-sectional transmission electron microscopy (TEM). Images show the epitaxial layer and the epi/substrate interface *in-situ* cleaned at temperatures of 25, 280, 480, and 600 °C. It is noteworthy that almost defect-free epitaxial layers are deposited, regardless of cleaning temperature. Since the thickness of the epilayer/substrate interface is inversely proportional to the degree of crystalline perfection, we have measured the interfacial thickness from the TEM images in Fig. 1, revealing that the interfacial thicknesses at cleaning temperatures of 25, 280, 480, and 600 °C, respectively, are 80, 20, 15, and <10 Å (Fig. 2).

Fig. 3 shows the interfacial oxygen and carbon concentration at cleaning temperatures of 25 and 600 °C, based on secondary ion mass spectroscopy (SIMS) data. Regarding the interfacial carbon concentration, the integrated doses were about 1.4×10^{13} cm^{-2} and about 4.5×10^{14} cm^{-2}, respectively, at cleaning temperatures of 25 and 600 °C. Regarding the interfacial oxygen concentration, the integrated doses were about 7.8×10^{14} cm^{-2} and about 4.8×10^{13} cm^{-2}, respectively, at cleaning temperatures of 25 and 600 °C. Although the interfacial carbon concentration is relatively high, the interfacial oxygen concentration after *in-situ* cleaning at 600 °C is significantly reduced. Since we surmise that the interfacial oxygen is responsible for defects in the epitaxial layer and the epi/substrate interface [2], the SIMS data agree with the TEM images. Further systematic study is necessary to reveal the detailed mechanism of defect generation.

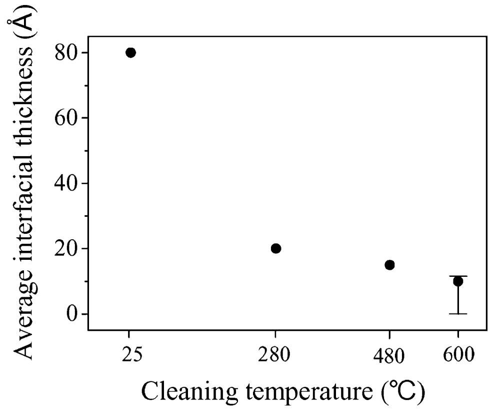

Figure 2 Variation of average thickness of the epilayer/substrate interfaces with varying *in-situ* cleaning temperature.

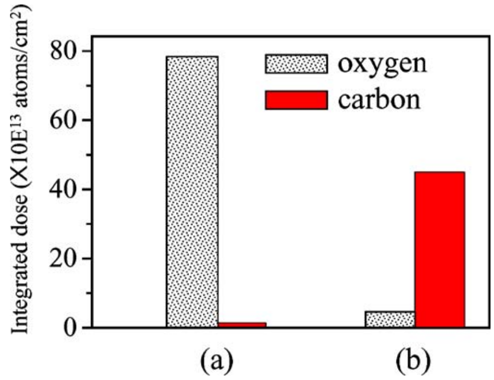

Figure 3 Column bar graph showing the effect of *in-situ* cleaning temperature on the interfacial oxygen and carbon concentration. *In-situ* cleaning temperatures are: (a) 25 and (d) 600 °C.

In summary, we have applied *in-situ* cleaning using ECR hydrogen plasma, demonstrating the growth of an almost defect-free epitaxial layer at cleaning temperatures in the range of 25–600 °C. Cross-sectional TEM images indicate that the epilayer/substrate interfacial thickness decreases slightly with increasing cleaning temperature. SIMS data reveals that the epilayer/substrate interface *in-situ* cleaned at 600 °C has a lower oxygen concentration than that at 25 °C.

Acknowledgment
This work was supported by grant no. R05-2001-000-00843-0 from the Basic Research Program of the Korea Science & Engineering Foundation.

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Received 7 November 2003
and accepted 3 June 2004